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PREFACE

This study plan summarizes and extends the discussion of Study Plan 8.3.1.4.2.1 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.

Sections 1, 4, and 5 of this plan were written by Frances R. Singer, and sections 2 and 3 by S.T. Harding, W.D. Mooney, P.H. Nelson, H.W. Oliver, Z.E. Peterman, and R.P. Snyder. R.W. Spengler was the primary reviewer. D.L. Schleicher and W.R. Keefer assisted in writing and reviewing the plan.

ABSTRACT

Repository design and long-term performance are critically dependent on hydrological, geochemical, and thermal/mechanical parameters present throughout the Yucca Mountain geological environment. These parameters, in turn, are a function of the distribution of rock units (lithostratigraphic, thermal/mechanical units), and the physical, chemical and structural variability within these units. Therefore, a very clear understanding of the vertical and lateral distribution of stratigraphic units is essential for development of a three-dimensional geological model which will supply the framework for most other site characterization and performance assessment studies, as well as design criteria for the engineered barriers.

Data obtained in Study 8.3.1.4.2.1 will directly address the vertical and lateral distribution of stratigraphic units including, but not limited to, subunits within the Paintbrush Tuff, tuffaceous beds of the Calico Hills, Crater Flat Tuff, and possibly older volcanic units within the repository site area at Yucca Mountain. To adequately characterize the distribution of these units, collection and integration of a wide variety of geological, geophysical and geochemical data are planned. Activities proposed in Study 8.3.1.4.2.1 include geologic mapping, geophysical surveys, borehole studies, and numerous tests and analyses of drill core and surface samples in order to calibrate subsurface geophysical studies and non-cored boreholes where intact samples are unavailable. Specific study goals are to determine a large number of primary stratigraphic and lithologic parameters and their variations within and surrounding the potential repository site. Ultimately, data will allow identification and location of interunit flow contacts and unit thickness, as well as identifying three-dimensional variations in such intraunit properties as primary welding, crystallization, mineralogical and volcanoclastic characteristics, diagenic alteration, acoustical, density, magnetic and electrical properties, and geochemical and isotopic compositions. In addition to activities within Study 8.3.1.4.2.1, data and interpretations from concurrent investigations of hydrologic, geochemical and thermal/mechanical properties will be utilized to better understand the permeability, mineralogy, petrology, volcanology and alteration of the volcanoclastic deposits, which will, in turn, provide optimum stratigraphic information as it relates to these other characterization studies and, ultimately, to design and performance assessment parameters of the repository.

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TABLES

CHARACTERIZATION OF THE VERTICAL AND LATERAL DISTRIBUTION OF STRATIGRAPHIC UNITS WITHIN THE SITE AREA

Study 8.3.1.4.2.1 consists of five activities:

- 8.3.1.4.2.1.1: Surface and subsurface stratigraphic studies of the host rock and surrounding units
- 8.3.1.4.2.1.2: Surface-based geophysical studies
- 8.3.1.4.2.1.3: Borehole geophysical studies
- 8.3.1.4.2.1.4: Petrophysical properties testing
- 8.3.1.4.2.1.5: Magnetic properties and stratigraphic correlations

The SCP includes a sixth activity -- 8.3.1.4.2.1.6, Integration of geophysical activities -- in this study. The same activity, however, is also treated as a separate activity (8.3.1.4.1.2, SCP, p. 4-26, 27) which is designed to provide a focal point for the integration of all geophysical site characterization activities. Inasmuch as several other studies acquire and utilize geophysical data (e.g., Study 8.3.1.17.4.3, Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane), the integration of all such geophysical activities is not considered to be an appropriate element for inclusion in the present study. Note that a comprehensive summary of geophysical activities related to the Yucca Mountain site characterization program has been published by Oliver, et al, (1990).

Study 8.3.1.4.2.1 is part of the Rock Characteristics Program (8.3.1.4), and is included in Investigation 8.3.1.4.2, Geologic framework of the Yucca Mountain site.

1. PURPOSE AND OBJECTIVE OF STUDY

The primary objective of Study 8.3.1.4.2.1 is to determine the geometry of rock units present within the Yucca Mountain area (fig. 1.1-1) and to establish the spatial variability of pertinent rock parameters within individual stratigraphic units . The distribution and nature of rock units within and surrounding the Yucca Mountain site form the basis upon which repository design and long-term performance is based. Therefore, most site characterization and performance assessment studies will rely heavily on an accurate geological framework provided, in large part, by the stratigraphic information obtained in this study. The integrated geological, geophysical, and petrophysical activities proposed in this study will establish a comprehensive database on the three-dimensional distribution of lithostratigraphic subunits, providing a basis for rock correlation throughout the area.

Equally important is the determination of the spatial variations in primary and secondary rock parameters within individual subunits (e.g., volcaniclastic facies, degree of compaction and welding, lithophysae development, devitrification, diagenetic alteration). Quantification of these parameters will allow geotechnical classification of rock units into correlatable hydrogeologic and thermal/mechanical units and thus help provide the means of establishing physical models of the thermal/mechanical behaviors of rock masses, sorption/retardation capacities and hydrological pathways used in assessing repository performance (Programs 8.3.1.15, 8.3.1.3, and 8.3.1.2, respectively). Data from this study will be combined with structural information (Study 8.3.1.4.2.2) to form the basis for an integrated three-dimensional geological model (Study 8.3.1.4.2.3), as well as three-dimensional models of the rock characteristics at the repository site (Investigation 8.3.1.4.3). Objectives specific to each activity within this study are discussed in sections 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6, respectively.

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

Determination of the geometry and spatial variability of rock units underlying Yucca Mountain requires characterization of a large number of physical and chemical parameters observed within surface exposures and subsurface drill cores. Primary features of tuffaceous rocks which will aid in characterization and correlation of units include the type and nature of geological contacts; flow thicknesses; internal volcanological structures; grainsize distributions and textures; distribution and type of lithic fragments; phenocryst content, mineralogy and chemical composition: bulk chemistry and isotopic compositions; primary cooling features including degree of compaction, welding, devitrification, and degree of development of lithophysal zones and secondary mineralization/alteration. Rock units present within the unsaturated zone and upper parts of the saturated zone (i.e., members within the Paintbrush Tuff, tuffaceous beds of Calico Hills, and Crater Flat Tuff) will be emphasized, however older volcanic units and volcanogenic sediments as well as Paleozoic sediments lower in the saturated zone may also become important. Geologic mapping and sampling of surface outcrops and trenches, plus logging and sampling of cored drill holes will provide the samples from which these data will be obtained (Activity 8.3.1.4.2.1.1). Data obtained in this activity will be complimented by geologic mapping and testing in the exploratory shaft and drifts (Activity 8.3.1.4.2.2.4). In addition, surface-based potential-field geophysical surveys (Activity 8.3.1.4.2.1.2) and down-hole geophysical studies (Activity 8.3.1.4.2.1.3) will provide important data for correlation of stratigraphic units and extrapolation of rock characteristics across areas where subsurface samples are unaccessible or where core samples are unavailable from boreholes. In order to utilize geophysical data most efficiently, petrophysical properties will be tested (Activity 8.3.1.4.2.1.4) on core samples so that geophysical interpretations will be based on the most accurate rock parameters available. In addition, magnetic susceptibility and orientation of remnant magnetic directions will be measured (Activity 8.3.1.4.2.1.5) to provide additional rock unit characterization parameters, structural rotation information, and a means of orienting core specimens.

Some of the data necessary to determine rock correlation and spatial variability in this study plan is similar to data being collected at Los Alamos National Laboratory (Study 8.3.1.3.2.1, Mineralogy, petrology and rock chemistry of transport pathways; Study 8.3.1.3.2.2, History of mineralogical and geochemical alteration of Yucca Mountain). Likewise, geological interpretations from this study are essential for adequate characterization of the transport pathways being investigated elsewhere. Therefore, we envision close communication and information exchange with scientists at Los Alamos in areas of potential overlap (mineralogy, petrology and diagenesis) so that data sets collected by each group are unique and complimentary.

The information obtained in this study will be used to produce a comprehensive, three-dimensional characterization of the spatial extent and variability of rock units within and around the proposed repository site. Much of the work in this study plan is directed toward identifying and predicting vertical and lateral variations in stratigraphic units and rock properties in areas of the repository block where relatively few subsurface samples will be collected. These data are critical to development of a "rock unit geometry and properties" model component (Fig. 1.1-2), which along with "fracture geometry and properties" and "fault geometry and properties" components (Study 8.3.1.4.2.2), will be used to develop an integrated three-dimensional geological model of the Yucca Mountain site (Study 8.3.1.4.2.3). A well-defined, three-dimensional stratigraphy also provides an essential geological context for concurrent mineralogical and alteration studies at LANL (Studies 8.3.1.3.2.1 and 8.3.1.3.2.2) in terms of ignimbrite eruption, deposition, cooling, devitrification and primary permeability interpretations. In addition, further hydrological, geochemical and thermal/mechanical property characterization investigations (SCP sections 8.3.1.2, 8.3.1.3, and 8.3.1.15, respectively) are strongly dependent on this geological framework in order to most accurately quantify parameters required in each of these fields, for instance, quantification of potential permeable-flow pathways, groundwater travel times, sorptive capacities of natural barriers, ambient temperature distributions, and appropriate subdivision of stratigraphy in terms of thermal and mechanical units. Results from each of these property characterization studies (geological, hydrological, geochemical and thermal/mechanical) will ultimately be integrated into a physical property model which is directly linked to repository performance assessment. In addition, rock property data determined in this study are directly applicable to development of design criteria for the underground facility, shaft and borehole seals and waste package configuration.

Previous geological and geophysical studies of the Yucca Mountain region are summarized in Chapter 1 of the SCP and a comprehensive review of geophysical activities is given by Howard, et al (1990). Although the stratigraphic, volcanological, structural, geophysical and tectonic interpretations included in these references are sufficient to provide a regional geological context into which the Yucca Mountain site can be placed, the quality of data for existing vertical and lateral distribution of stratigraphic units are inadequate to establish a three-dimensional model on a localized scale at the confidence level required by SCP guidelines. Accordingly, activities proposed in this study plan are designed to provide a wide variety of fundamental geological data which will be used to predict detailed variations in rock parameters critical to final geometric placement and design of the repository, as well as for overall performance assessment of the natural barrier. In this sense, data collected in this study will not be redundant with information provided through previous work. The studies proposed herein rely on currently available data and interpretations to provide the ranges of expected results for each of the activities, listed in sections 3.1.5, 3.2.1.5, 3.2.2.5, 3.2.3.5, 3.3.5, 3.4.5, and 3.5.5.

1.2 Rationale and justification for the information to be obtained.

Compliance with conformance and design criteria for a geologic repository, as presented in 10CFR60.122, requires specific and detailed information about the rock characteristics of the Yucca Mountain site. Design criteria for the underground facility, for seals of shafts and boreholes, and for waste packages must also be evaluated in the context of the natural rock properties of the proposed site. Assessments of whether the performance objectives and siting and design criteria can be met will therefore rely primarily on information about the stratigraphy and characteristics of the rock units occurring at the site.

The specific relationship between the data-gathering activities planned for Study 8.3.1.4.2.1 and other elements of the SCP are shown on the logic diagram in figure 1.1-2. A detailed list of the design and performance issues directly or indirectly supported by the various activities, and the characterization parameters being addressed, are given in Table 1.2-1. Uses of the information for supporting other studies in the Yucca Mountain Site Characterization Program are given in section 4.

2. RATIONALE FOR SELECTED STUDY

The activities in this study were chosen to provide essential data on the stratigraphy, rock characteristics, and emplacement history of individual units within the Paintbrush, Calico Hills, Crater Flat, and possibly older volcanic sequences for the purpose of developing quantitative three-dimensional models of rock properties within the Yucca Mountain area. The tests planned for each activity were selected as optimum means to address satisfactorily the parameters as specified in the SCP. The rationales for the selected test methods are given in the following sections; the test plans are described in section 3 of this study plan.

2.1 Activity 8.3.1.4.2.1.1 Surface and subsurface stratigraphic studies of the host rock and surrounding units.

This activity consists of the following tests:

- Surface-outcrop mapping
- Borehole drilling and coring
- Sampling, lithologic examination, and analysis of drill bit cuttings and cores
- Borehole video camera surveys and logging
- Petrographic, geochemical and isotopic studies on drill core, cuttings and outcrop samples

The above tests are designed to provide the fundamental materials (physical samples and required data, outcrop data, drill-hole logs) needed to develop stratigraphic models, lithological correlations, and spatial variability of rock characteristics from a limited number of control sites within and around the potential repository site (Table 2.1-1). These data will also provide the geological basis for interpretation of surface and borehole geophysical surveys (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3). Geophysical interpretations will then be used to predict changes in the subsurface geometry and lithological variability in areas lacking direct subsurface access. Iterative interactions between the activities in this study will ultimately provide the required three-dimensional rock unit model described above.

2.1.1 Rationale and justification for the selected tests

2.1.1.1 Surface-outcrop mapping

Detailed field investigations on surface exposures of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff provide the most reliable method of accurately determining the distribution, thicknesses, attitudes and physical characteristics of the volcaniclastic units constituting Yucca Mountain. The ability to predict the extent and variability of these units both beyond the perimeter drift and in the subsurface underlying Yucca Mountain is enhanced by outcrop mapping in the highlands surrounding the site area. This information is critical for three-dimensional visualization of the geological framework of the Yucca Mountain region and provides "ground truth" for interpretation of seismic and potential-field geophysical surveys and surface-expression ties for subsurface geological interpretations. Surface geological mapping also allows determination and visualization of larger-scale features, as well as complex field relationships in two dimensions, which are not available from (essentially linear) core samples. The larger picture obtained by detailed outcrop-scale mapping can often provide insight necessary for correctly interpreting textures and fabrics observed in core. Surface mapping will provide the most cost-effective means of collecting a wide range of stratigraphic, lithologic, volcanological, and rock property data distributed over a large region. This information is critical not only for overall objectives of determining lateral and vertical stratigraphic variations, but also, more immediately, for providing selection criteria for siting of future drill holes. Outcrop mapping performed under this activity is supportive of and complimentary to structural mapping activities designed to establish zonal features and fracture networks (Activities 8.3.1.4.2.2.1 and 8.3.1.4.2.2.2, respectively).

Primary features inherent to pyroclastic flows and bedded tuffs will be a strong focus of the field investigations and will provide data to be used for establishing such required information as a correlatable stratigraphy, the volcanology and emplacement history of ignimbritic units (for predicting lateral facies variations in individual flow units), and the geological properties critical to accurate estimation of matrix fluid flow and mechanical rock unit models. Macroscopic rock characteristics representing essential data to be collected from outcrops include, but are not limited to, the nature and attitude of geological contacts (both interflow contacts and internal cooling unit breaks); thicknesses of flows and lithostratigraphic units; internal volcanological/depositional structures; matrix and pumice-clast grainsize distributions and textures; degrees of sorting; distribution of lithic-rich zones and type of lithic fragments; phenocryst content and mineralogy; and primary cooling features including degree of compaction, welding, devitrification, and development of lithophysal horizons. Specific scientific approaches and strategies to accomplish this work are discussed in section 3.1.1. Extent of secondary mineralization and alteration of tuffaceous rocks and lithophysal horizons is also important to models for sorption/retardation of radionuclides within the natural barrier. As a consequence, types and distributions of altered rock will also be mapped in order to define the spatial relationships of alteration in host units. This aspect of work will be closely coordinated with detailed alteration studies performed at LANL (Study 8.3.1.3.2.2). In addition to examination and documentation of macroscopic features in surface exposures, qualified rock samples will be collected to further establish and/or verify the lithologic characteristics and variability of subunits through the use of petrographic, geochemical and isotopic studies (section 2.1.1.5). Samples will be collected to best represent the range of systematic variations within subunits exposed in outcrop, as well as to represent anomalous horizons or features which may provide key stratigraphic or rock property information.

2.1.1.2 Borehole drilling and coring

Although borehole drilling and coring is mentioned under this activity in the SCP, this test will be conducted primarily under a different activity specifically mandated to integrate and prioritize all surface-based activities with the objective of producing a drilling program best suited to the comprehensive needs of representativeness, efficacy concerns and budgetary constraints (Activity 8.3.1.4.1.1, Integrated drilling program). Several cored boreholes greater than 152 m (500 ft) have already been drilled in the area for geological purposes (G and UE holes, fig. 2.1-1). Core samples from these holes are currently available to this study through the YMP sample maintenance facility (SMF). Pending integration of the drilling program (Activity 8.3.1.4.1.1), three additional deep cored boreholes (G-5, -6, -7, fig. 2.1-2) have been proposed in the SCP to help resolve inferred geologic and geophysical anomalies identified through the input of previous studies. Hole G-5 will be sited along the northeast flank of Yucca Mountain to determine the structural character and facies changes in Yucca Wash and whether lithological or structural causes are responsible for the steeper gradient in the potentiometric surface north of drillhole G-1. Hole G-6 is tentatively planned to be sited along the northwest flank of Yucca Mountain in the Windy Wash area and is designed to provide representative stratigraphic data for use in correlation of units across the repository site area. Hole G-7 is tentatively located in the southern part of Yucca Mountain in order to test the hypothesis of a pre-existing paleotopographic high and its affects on the deposition of the Paintbrush Tuff, as well as providing important geological constraints on hydrogeological properties, groundwater travel times and potential flow paths to the south of the repository for saturated zone flow modeling (SCP Section 8.3.1.2.3.3). It is anticipated that boreholes G-5, G-6, and G-7 will be drilled to depths that will penetrate a representative portion of the Paleozoic rock sequence beneath the volcanic tuffs. Approximately 50 more boreholes. deeper than 152 m (500 ft) (fig 2.1-2) are planned for studies of the unsaturated and saturated zones and will provide further opportunity for stratigraphic studies through logging of borehole cuttings (section 2.1.1.3) and downhole geophysical surveys (Activity 8.3.1.4.2.1.3). Note that there is no additional discussion of this test in section 3 of this study plan for the reason stated in the opening sentence of this section.

2.1.1.3 Sampling, lithologic examination, and analysis of drill bit cuttings and cores

Drill hole core and cuttings represent the most effective and widespread means of obtaining subsurface samples underlying Yucca Mountain. Examination and analysis of these materials is essential to provide accurate estimation of the three-dimensionality of rock units and their *in situ* physical properties at depth. Cored holes are of particular interest as these materials will provide logs and samples to be used for stratigraphic correlations and lithologic/petrographic/ geochemical quantification of variable rock properties, geological control for surface-based geophysical survey interpretations (Activity 8.3.1.4.2.1.2), geological calibration for downhole geophysical surveys (Activity 8.3.1.4.2.1.3), and materials essential for petrophysical property testing (Activity 8.3.1.4.2.1.4) and magnetic/ paleomagnetic studies (Activity 8.3.1.4.2.1.5). Core from tuffaceous units will be examined and logged with regard to the same volcanological and diagenetic features observed in surface outcrops (section 2.1.1.1). Samples will be collected to best represent individual lithologic units, as well as any anomalous zones which may prove to have importance for identifying key marker horizons. Sampling strategies will consider the needs for both microscopic and geochemical characterization, as well as petrophysical testing and magnetic studies. Boreholes lacking core are much more abundant (fig. 2.1-2) and will provide additional control throughout the repository site area for determining subsurface lateral and vertical stratigraphic and lithologic variations. This information will be obtained through the use of drill bit cuttings correlated with downhole video camera logs (section 2.1.1.4) and geophysical logs (Activity 8.3.1.4.2.1.3). Systematic sampling of drill bit cuttings will be made for petrographic and geochemical analysis (section 2.1.1.5) to further clarify downhole log interpretations, and to provide data useful for rock parameter quantification.

2.1.1.4 Borehole video camera surveys and logging

Examination of drill bit cuttings alone does not provide adequate characterization of many of the parameters necessary for rock unit and parameter interpretations. Downhole imagery obtained through video camera logs will provide geometrical, morphological, textural, tonal and structural information comparable in nature and detail to observations made on recovered core. When combined with examinations of cuttings and borehole geophysical logs from correlated depths. interpretations can approach the quality and detail of cored holes with the added benefit of obtaining data from poorly consolidated, or non-welded intervals which do not yield good core recovery. Video camera logs will enable much valuable information to be collected for use in geological and stratigraphic interpretations such as accurate location and nature of contacts, key marker horizons, and lithophysal zones as well as fabric elements and textural features occurring on a scale larger than the size of individual cutting chips (approximately 1 to 10 mm) such as presence and orientation of bedding, potential porosity, pumice clast size distribution and sorting, spherulite and fiamme development, and extent of fracture and lithophysal control on secondary alteration. These types of observations are not possible from examination of drill cuttings alone, yet many are critical to identifying stratigraphic relationships and potential flow pathways. Borehole video camera logging will be coordinated with downhole fracture studies proposed in Activity 8.3.1.4.2.2.3.

2.1.1.5 Petrographic, geochemical and isotopic studies

This test provides technical support for geological interpretation of other surface mapping and subsurface logging tests described within this activity (2.1.1.1 and 2.1.1.3, respectively).

These studies are designed to provide data of particular use for identification of key marker horizons, lateral correlation of units, matrix porosity estimation, and degree and nature of diagenetic alteration. Petrographic analysis of rock samples provides a fundamental tool for characterization and correlation of tuffaceous units on the basis of microscopic properties, including such features as phenocryst content, assemblage and morphology; grain-size distribution; glass shard morphology; degree of matrix compaction, welding, and devitrification; spherulite development and composition; identification of lithic fragment types and frequency distributions; abundance of primary void space, type and degree of alteration (high-temperature vapor phase versus medium-temperature hydrothermal alteration and diagenetic effects). Although these features, along with macroscopic observations, can often be unique enough to characterize an individual rock unit or eruptive event, the recurring processes of ignimbrite eruption and deposition were sufficiently similar to produce a thick pile of morphologically similar volcaniclastic rocks at Yucca Mountain. In addition, physical characteristics of the deposits from a single eruptive event are variable depending, in large part, on transport distance from the vent, local topographic effects and dispersal agents acting during and after emplacement.

Geochemical analyses can often fingerprint unique magmatic compositions indicative of co-eruptive deposits. Trace elements and radiogenic isotopes are particularly sensitive to complex pre-eruptive geochemical histories which are often not exactly duplicated between consecutive eruptions from the same magmatic system. These types of data may prove instrumental in discriminating unique horizons within monotonous pyroclastic flows and flow sequences. However, care must be taken in the interpretation of these data since individual pyroclastic flows are vulnerable to lateral and vertical compositional variability produced by grainsize and density sorting, as well as the temporal/stratigraphic effects of evacuating compositionally-zoned magma chambers and secondary alteration effects. Analysis of individual tuff components (e.g., pumice clasts. glass shards, mineral fragments) can often elucidate some of the uncertainties in chemical correlations. Whole-rock, energy-dispersive XRF analyses for major and trace elements along with a subset of radiogenic isotopic analyses are expected to form the greatest proportion of analytical work necessary to accomplish study plan goals, however mineral separation and/or microanalysis (including SEM and electron microprobe) may prove to be important techniques for solving some of the geological objectives of this study plan (for example, occurrences of unique mineral chemistry or ash shard morphology as a means of identifying co-eruptive units). Geochronological studies will also provide an absolute time frame for quantification of pre-closure eruptive events and prediction of post-closure volcanism. These studies are essential for characterization of vertical and lateral distribution of rock units in the Yucca Mountain region, and the results and interpretations will be coordinated with the petrological investigations on the Topopah Springs Member (repository host unit) and the mineralogy of transport pathways to the accessible environment being studied at LANL (Activities 8.3.1.3.2.1.1 and 8.3.1.3.2.1.2). Chemical and radiogenic isotopic studies will also provide a means of assessing the nature and kinetics of post-emplacement elemental mobility within more-permeable flow pathways in individual ash-flow units. Chronological investigations may prove particularly useful for estimating rates of cation movement through the natural barrier system. These studies will be closely coordinated with other investigations on the mineralogy and petrology of geochemical alteration at LANL (Study 8.3.1.3.2.2).

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

2.1.2.1 Number and location

At least 10 sections (possibly as many as 20 sections) containing the Yucca Mountain and Pah Canyon members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and the Prow Pass and Bullfrog members of the Crater Flat Tuff are exposed along the north, east and south flanks of Yucca Mountain (fig. 2.1-3). All of these outcrop areas will be examined and mapped in detail in order to obtain as much information as possible from this limited number of exposures. In addition, at least 30 sections exposing the Topopah Spring member of the Paintbrush Tuff occur within and adjacent to the site area (fig. 2.1-4). All of these areas will be examined. (see also, fig. 2.1-5). But the level of mapping detail will depend on the range of the observed lithologic variability. The number of samples to be collected for further microscopic, petrographic and possible geochemical and isotopic analysis will be determined by the physical nature of the outcrops and by the degree of heterogeneity observed in each. Collection strategies at each location will attempt to obtain a suite of samples representative of each unit, incorporating, as much as possible, the internal lithologic variations observed macroscopically on the outcrop scale. Additional samples will be collected to examine special features of lithologic or volcanologic interest. Exact numbers of samples to be collected is unknown, but will probably be in the hundreds.

Seven continuously cored drill holes (fig. 2.1-1) presently exist within the site area. Pending approval through Activity 8.3.1.4.1.1, an additional three cored holes, deep enough to penetrate Paleozoic rocks (>2000 m), have been proposed (fig. 2.1-2). These additional cored holes will provide detailed subsurface data in areas where high degrees of stratigraphic uncertainty exist based on currently-available surficial geological and geophysical data (section 2.1.1.2); other cored holes may need to be proposed to further reduce three-dimensional geological uncertainties in other areas. Core from all of these holes will be used for lithologic log construction and sample characterization (see below). Approximately 50 (non-cored and partially cored) boreholes with expected depths greater than 150 m (500 ft) are being proposed (fig. 2.1-2), and cuttings and core will be sampled from all of these holes for use in constructing lithologic logs and sample characterization. The amount of detailed study any one of these shallower holes will receive is dependent on hole distribution density and total depth in relationship to the level of stratigraphic uncertainty at any single location and to the degree of lateral variability.

Drill holes containing fully qualified core will receive the greatest amount of attention for logging, sampling and further petrographic and geochemical characterization studies. These materials represent the highest quality subsurface samples available for three-dimensional geological interpretations. All core will be macroscopically studied in detail to determine characterization parameters of interest (section 2.1.1), to subdivide core into separate lithological units, and to determine the degree of vertical heterogeneity within each unit. Samples which best represent the range of macroscopic variability in each unit will be collected for petrographic characterization and possible chemical and isotopic studies. Exact numbers of samples cannot be predicted, however it is anticipated that sample distribution will average five samples per 30 m (100 ft). Non-cored holes will not receive the same degree of detail due to the uncertainty of geometric relationships of recovered cuttings. However, many of these holes may provide critical subsurface data necessary to reduce stratigraphic uncertainty in the immediate vicinity of the repository site to required levels. Cuttings will be obtained in 3 m (10 ft) intervals from all holes, and lithological logs, constructed from borehole video camera (see below) and geophysical surveys (Activity 8.3.1.4.2.1.3) correlated with cuttings, will be made for many of these holes. The exact number cannot be estimated at present, but will be determined as work proceeds.

Borehole video camera surveys in cored holes will be required to produce continuous vertical lithological data through areas of non-welded or poorly consolidated units where core recovery is poor or non-existent. This is necessary for fully quantifying these deep holes which provide the most comprehensive subsurface sampling and depth control for interpretation of stratigraphic, volcanological, and geophysical models. Video camera surveys are also necessary in non-cored boreholes so that accurate lithologic logs can be constructed. The exact number of surveys in these holes depends on decisions to be made once geological work has begun.

Samples obtained through both surface geological mapping and borehole logging will require a suite of petrographic, geochemical, and isotopic analyses for comprehensive three-dimensional rock characterization. In order to statistically demonstrate sample representativeness, much data will be collected to average potential population biases. Energy-dispersive XRF on whole-rock samples provides a rapid, economical means of generating large amounts of data which will allow definition of chemical trends and limits of variation within individual stratigraphic units. As many as several hundred samples systematically collected from outcrop, core and cuttings will be analyzed by XRF to provide the foundation for a large chemical database. Quantitative petrographic analyses will be performed on as many (possibly also several hundred)surface and subsurface samples as will be necessary to adequately quantify the range of lithological characteristics present within correlatable rock units. Additional quantitative mineralogical data (by electron microprobe) and morphological data on glass-shards and crystal-fragments (by SEM) may prove very useful as tools for stratigraphic correlation of units above and below the Topopah Springs member of the Paintbrush Tuff. The evolving database of combined stratigraphic, petrographic and XRF chemical data will be used to select representative samples for further detailed mineralogical and geochemical studies of the potential host rock (i.e., devitrified Topopah Springs member) at LANL (Study 8.3.1.3.2.1), and for geochronological studies of the volcanic section and, if necessary, further three-dimensional mineralogical, geochemical, petrological and isotopic characterization of other stratigraphic units (this study). Although one of the rock characterization parameters documented in this study will be the spatial distribution of secondary alteration, Study 8.3.1.3.2.2 by LANL will be responsible for detailed models of the geochemical effects of post-depositional elemental mobility. Towards this goal, the USGS will provide a limited number (tens of analyses) of radiogenic isotopic analyses to test the kinetic aspects of the low-temperature alteration on samples identified by LANL investigations. If these data prove important, USGS and LANL may jointly propose a detailed study of combined mineralogical, geochemical and isotopic data perhaps involving several hundreds of analyses.

2.1.2.2 Duration and timing

Surface outcrop mapping and sampling of rock units exposed on Yucca Mountain and vicinity of will be accomplished in the first few years of the study. Initial volcanological and stratigraphic interpretations of macroscopic observations and construction of lithologic sections for each individual area will proceed along with mapping. Quantitative petrographic and bulk-rock XRF chemical analyses should be available within several months of sample collection. Once obtained, these data will be included in the sample database, and used to update geological interpretations. Preliminary cross-sections and section descriptions with correlated rock units based on surface geology should be available by the end of the first year after section mapping commences. Core and cuttings from several drill holes are currently available for examination. Some of these data have already been used for preliminary interpretations, however to ensure consistent interpretations, core will be re-examined by the same personnel involved with surface mapping. Only fully-qualified subsurface samples will be studied in detail, although non-qualified materials may be used to help verify and support interpretations where qualified material is not available. Typically, two weeks are required for detailed lithostratigraphic logging (hand-specimen examination) of each 300 m (1000 ft) of core. Quantitative petrographic examination and XRF chemical analysis will require an additional three months. Timing of lithologic logging and petrographic analysis for proposed boreholes is dependent on the integrated drilling schedule, however preliminary detailed logs, along with accompanying whole-rock XRF chemical analyses, should be complete within a few months after drilling is complete. Borehole video surveys will be accomplished soon after drilling is complete, and results will be incorporated into the lithologic logs at the same time petrographic examination is in progress.

Additional analyses needed for stratigraphic correlations and three-dimensional characterization, including SEM, microprobe and isotopic analysis, will commence after initial macroscopic, petrographic and XRF results have been screened. These analyses may take additional months depending on the nature and volume of work deemed necessary. If these techniques prove to be essential to geological interpretation on a routine basis, steps will be taken to accommodate an increased sample volume in order to assure timely acquisition of data. Isotopic work on secondary alteration studies will be coordinated with initial geochemical models, established at LANL. Initial isotopic results will require 1 to 3 weeks per analysis with several samples being processes simultaneously.

Integration of surface and subsurface information will commence after sufficient data has been obtained, and preliminary three-dimensional models will be proposed perhaps within the first year. However, interpretation of lateral and vertical rock characteristics and stratigraphic correlations is expected to be an iterative process. Final results are not only dependant on the tests within this activity, but also on input from results of other activities in this study plan.

2.1.3 Constraints: Factors affecting selection of tests

The selection of the test methods and analytical approaches for this activity was unaffected by the following factors: potential impacts on the site; simulation of repository conditions; timing; scale of phenomena to be measured; and interference with other tests or the exploratory shaft. With regard to accuracy and precision of measurements and limits of analytical methods, no specific requirements are listed in the SCP. However, the selected tests will provide the generally accepted levels of accuracy in terms of stratigraphic measurements and analytical results. Utilization of cores, cuttings, and well logs from existing boreholes that penetrate, or are adjacent to, the repository block during the conduct of this activity will have no additional impact on the repository site.

2.2 Activity 8.3.1.4.2.1.2 Surface-based geophysical studies

Surface-based geophysical studies will include the following SCP test methods:

- Seismic reflection methods
- Seismic refraction methods
- Gravity and magnetic methods
- Electrical methods

These tests all require the acquisition of geophysical data and will supplement data from geologic and hydrologic investigations. They encompass a wide range of techniques designed to assist in mapping the lateral and vertical extent of the lithostratigraphic units, and, in combination with many of the tests planned for Activities 8.3.1.4.2.1.3 and 8.3.1.4.2.1.4 (this study) and with several additional geophysical surveys planned in other activities (as detailed in Table 8.3.1.4-4 of the SCP, p. 8.3.1.4-42 to 8.3.1.4-51), represent the best available geophysical methods for accomplishing this purpose. Only the specific surveys being planned for the present activity will be described below, but the integration of data from other activities will be discussed in section 3.2. It should be noted further that the fourth test listed above primarily involves the application of electrical data to interpret the lateral and vertical continuity of stratigraphic units; these data will be collected in other activities as discussed in sections 2.2.1.4 and 3.2.4.

2.2.1 Rational and justification for the selected tests

2.2.1.1 Seismic reflection surveys

Shallow, intermediate, and deep seismic reflection surveys are planned for the Yucca Mountain site characterization program. Shallow, high-resolution reflection methods, such as Mini-Sosie (Barbier, 1983), are designed primarily to study the position of marker stratigraphic horizons that are buried beneath the alluvial deposits of washes and valleys to depths of about 1 km. Such markers may show sufficient contrast in seismic velocities to assist in identifying and tracing faults in the shallow subsurface. The technique (Mini-Sosie) will be tested along some (but perhaps not all) of the geophysical traverses described in section 2.2.2 to determine its effectiveness in providing higher resolution seismic responses from shallower horizons than those responses that may be received from deeper reflection surveys. If successful, shallow reflection surveys may be conducted across other alluvial-covered areas to assist in determining stratigraphic continuity and fault displacements at shallow depths.

Intermediate reflection surveys target geologic structures lying between about 0.3 and 10 km depth. According to Oliver, et al (1990, p. 66): (1) structural features that represent the tectonic setting of Yucca Mountain are likely to be found in this depth range; (2) methods employed in intermediate reflection surveys are more specific to the site area relative to surrounding areas, and thus may be useful for assessing the relation of deeper structure to shallower, more easily recognizable features of which the effects on site performance are better understood; and (3) the clarity of interpretation that can result from intermediate-depth reflections in certain geologic settings is preferable to that typically obtained from other geophysical methods, hence may be more reliable in investigating such complex topics as the origin of Crater Flat and the conformation of the Paleozoic-Tertiary contact beneath Yucca Mountain.

Deep seismic reflection methods provide a means to explore the stratigraphy and structure to depths of about 40 km. The principal purposes of these surveys are to explore the geology of the whole crust beneath Yucca Mountain and adjacent areas, to determine the relationships among the several major fault zones and fault blocks in the region, including detachment faults and thrust faults, and to help identify and locate potentially significant seismic source zones. Deep seismic reflection profiling will be conducted along the profiles described in section 2.2.2; the resulting data will be applicable to achieving some of the objectives designated for Activity 8.3.1.17.4.3.1 (Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane).

2.2.1.2 Seismic refraction surveys

Intermediate depth refraction surveys will be used to trace velocity contrasts in the sequence of volcanic tuffs that (1) are associated with abrupt lateral changes in lithology in the subsurface, and (2) may be the result of structural displacement or alteration associated with a steep gradient in the potentiometric surface. The technique was selected because of its demonstrated success in resolving velocity contrasts, in five previous surveys across and around Yucca Mountain (see Oliver, et al, 1990, p. 51).

2.2.1.3 Gravity and magnetic surveys

Gravity surveys provide the most economical method for determining (1) the depth and general configuration of the buried pre-Tertiary bedrock surface under Yucca Mountain and adjoining basins, (2) the subsurface extent of tectonic and volcanic features, and (3) by repeated surveys, changes in ground water regime. Magnetic surveys help define volcanic units, locate concealed faults where magnetic volcanic strata have been offset, and determine the depth of the Curie temperature isotherm (Activity 8.3.1.8.5.2.1). The planned gravity and magnetic surveys employ standard techniques that are widely used in the earth sciences; there are no alternative methods that would provide the kinds and quality of information required for this test.

2.2.1.4 Electrical surveys

Electrical methods offer further means of identifying subsurface stratigraphy and structure in the site area. Shallow penetrating surveys such as electromagnetic and direct current resistivity traverses provide information on subsurface mineral alteration, degree of welding, fluid saturation, and faulting on the scale of tens of meters to a few hundred meters vertically and laterally. Deeper penetrating surveys such as magnetotellurics and telluric profiling provide information on structures and lithology at depth with resolution which decreases with depth of penetration.

The electrical geophysical data discussed above will be obtained primarily from surveys conducted in other activities (e.g., 8.3.1.17.4.3.1, Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane; 8.3.1.17.4.7.5, Evaluate surface geoelectric methods and plan potential applications of these methods within the site area), and the resulting information will be applied to the present activity. In addition, radiometric (airborne gamma-ray intensity) and remote sensing methods (thermal infrared scanner) will be evaluated in Activities 8.3.1.17.4.7.7 (Evaluate thermal infrared methods and plan potential applications of these methods within the site are) and 8.3.1.17.4.3.5 (Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures), respectively, for application to the detection of faults and fractures at the surface. Radiometric or surface temperature anomalies may be associated with radon emanation or water infiltration, respectively, along faults and fractures.

2.2.2 Rationale for the number and location of selected tests

Seismic reflection and refraction, gravity, and magnetic surveys will be conducted along five profiles (labeled 1-5 in fig. 2.2-1), selected so as to provide (1) test lines to determine the effectiveness of the geophysical methods employed, including correlations with geologic features observed in several existing boreholes; (2) the maximum amount of data bearing on the designated parameters for this activity (see sec. 3.2) relative to the level of effort being planned for this part of Study 8.3.1.4.2.1; (3) a follow-up to the recommendations of the peer panel review of previous seismic profiling in Yucca Mountain region (report to DOE, January 22, 1991); and (4) data for locating proposed borehole G-5 in the northern part of the site area. To the extent possible, the lines are located along existing roads to take advantage of the easier access afforded for the large vehicular equipment required to conduct the surveys.,

Profiles 1-4 are part of a 25 mile-long series of intersecting lines extending from near the east flank of Bare Mountain southeast across Crater Flat, including the site of borehole VH-1 (Profile 1); from central Crater Flat northeast across the crest of Yucca Mountain, including the site of borehole H-3 (Profile 2); from the west side of Yucca Mountain east-southeast to the west side of Jackass Flats, including the site of borehole UE25 p#1 (Profile 3); and from the east edge of Yucca Mountain northeast across the southeast end of Yucca Wash (Profile 4). Profile 5 extends for about 10 miles north and northeast along the east side of Yucca Mountain and northwest along Yucca Wash. These combined profiles are designed especially to provide much-needed data on the geologic relationships beneath Crater Flat and on the subsurface extent and geometry of several of the major Quaternary faults that cut Yucca Mountain (e.g., Solitario Canyon, Ghost Dance, Bow Ridge, Paintbrush Canyon, and Stagecoach Road faults), as well as to take advantage of the stratigraphic and structural information derived from studies of lithologic samples and geophysical logs in the several boreholes on or near the survey lines. Data from Profile 5 will be instrumental in selecting a location for the proposed G-5 borehole.

By conducting various kinds of surveys (i.e., seismic, gravity, magnetic) along the same traverses, it is anticipated that maximum benefit will be derived from the combined data and that direct and meaningful comparisons can be made as to the relative effectiveness of each of the methods to provide a reliable basis for interpreting subsurface structure and stratigraphy.

The number and location of geoelectric surveys are covered in study plans for other activities (e.g., 8.3.1.17.4.3.1, and those in Study 8.3.1.17.4.7).

2.2.3 Timing and duration of selected tests

The surveys discussed in sections 2.2.1 and 2.2.2 are scheduled to be completed in advance of selecting the site for borehole G-5 in the northern part of the potential repository site area. All data acquisition and interpretations will be scheduled to furnish results for the three-dimensional geologic modeling effort planned for Study 8.3.1.4.2.3. It is anticipated that the planned surveys will be completed and preliminary results processed in a 9-month period following inception.

2.2.4 Constraints: factors affecting the selection of tests

The selection of the test methods for this activity were unaffected by the following factors: potential impacts on the site; simulation of repository conditions; required accuracy and precision of measurements; limits of capability of analytical methods; timing; scale of phenomena to be measured; and interference with other tests or the exploratory study facilities.

2.3 Activity 8.3.1.4.2.1.3 Borehole geophysical surveys

2.3.1 Rationale and justification for the selected tests

This activity consists of one test method--borehole geophysical surveys and logging--that involves the interpretation of geophysical logs that will assist in stratigraphic correlations and rock property determinations. The suite of logs selected for study (table 2.3-1) has evolved from many years of usage both at Nevada Test Site and Yucca Mountain. Some of the logging tools can be used in both liquid- and air-filled boreholes; others operate in only liquid-filled holes.

Geophysical logs can be used qualitatively, and in some cases quantitatively, to determine basic rock characteristics such as lithology, bulk density, porosity, permeability, fracture zones, degree of saturation, seismic velocities, and magnetic susceptibility. As shown in table 2.3-1, certain parameters are subject to measurement by more than one kind of log. This is because no single log type, in most cases, is by itself adequate to make completely accurate determinations. A combination of different log types, on the other hand, through cross plotting and various other comparative techniques, provides a more reliable basis for making the desired calculations and interpretations. Density logs, for example, are generally considered to be the most reliable of the geophysical log suite for determining porosity, but this logging technique does not perform well in rugose boreholes. In rugose (rough-walled) holes, the gravimeter log is an alternative method to the density log, providing good interval density values. However, neither the gravimeter log nor the density log can be used to accurately estimate porosity unless the grain density, which varies significantly from one tuff unit to another, can be reliably estimated independently of logging. The sonic log can be calibrated against cores in a given borehole to provide porosity values for the stratigraphic units penetrated, and the velocities then extrapolated to nearby, non-cored boreholes, but this logging technique can be used only in liquid-filled boreholes. Although the compensated neutron log responds to water-filled porosity, it is subject to error owing to the presence of minor amounts of a few minerals with high neutron capture cross-sections. In saturated rocks, both resistivity and dielectric logs can be calibrated against core measurements to provide porosity estimates; in unsaturated rock, however, the two logs respond only to saturated pore spaces. Consequently, no single log can be used for porosity estimation in all circumstances.

The above discussion also pertains to the measurement of other parameters listed in table 2.3-1 (i.e., no single logging technique, by itself, is adequate for the intended purpose). Although all types of logs respond to variations in lithology, there will be a certain degree of uncertainty as to the true nature of these variations until close comparisons can be made between log responses and actual rock characteristics as determined through detailed study and physical properties testing of cores and cuttings. In this regard, close coordination of effort with Activities 8.3.1.4.2.1.1, 8.3.1.4.2.1.4, and 8.3.1.4.2.1.5 of this study will be required to obtain the necessary data for log calibration. For estimates of permeability, fracturing, and degree of saturation in particular, there is room for improvement in the current techniques used to determine these parameters from geophysical logs.

The neutron activation and neutron die-away (also called thermal decay time) logs have been considered as alternative means for obtaining hydrogen (hence, water) content. However, neither of these logging techniques offers any advantage over the compensated neutron log, and, in addition, both are slow to run. Nuclear magnetic resonance (NMR) offers another possible way of determining water content. One commercial version of this log type has been investigated and found to be limited because of its extreme sensitivity to borehole rugosity. Other experimental NMR tools will be tested if their characteristics appear suitable to the Yucca Mountain borehole environment.

A new pulsed-source epithermal neutron sonde has been developed by a major oil company for the purpose of determining porosity. The technique is currently being tested at NTS; if the test is successful, cosponsorship of further development should be considered by the Yucca Mountain Project.

Improved induction tools with greater accuracy for measuring resistivities greater than 100 ohm—m will be tested if they become available. The dielectric log appears promising as a means of determining water saturation; use of this log depends upon rock properties testing discussed under Section 2.4 of this study plan.

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

2.3.2.1 Number

The number of logs will vary from borehole to borehole, but in most cases a fairly complete suite of the logs listed in table 2.3-1 will be obtained. The gravimeter log, which is considered as an alternative to the density log, will not be run if a borehole is relatively smooth or if the density logging technique is improved with regard to hole rugosity to the extent that gravimetry is not needed.

2.3.2.2 Location

Because the logs are required by a variety of users, logs will be acquired in every borehole which penetrates the Topopah Springs member. At this stage of planning, fifty boreholes are planned to a depth of 500 ft or greater (fig. 2.1-2).

2.3.2.3 Duration and timing

The logging schedule is determined by the drilling schedule. Logs are normally run after total depth is reached but before the installation of casing, except for surface casing. The duration of logging will be about 24 to 48 hours. If the gravimeter is run, an additional 24 to 48 hours are required.

2.3.3 Constraints: factors affecting selection of tests

Borehole surveys do not affect other tests because no logging instruments are left in the borehole after logging is completed. There is no effect on the exploratory shaft. The logging activity uses sonic, electrical, gamma, and neutron sources of very low and non-destructive source strength which cannot affect the ability of the site to isolate waste. The choice of logging methods was affected neither by those factors nor by the need to simulate repository conditions, the accuracy and precision of other test methods, the limits and capabilities of analytical methods, nor by time constraints or issues of scale and applicability of other test methods. Information on logging in air-filled or fluid-filled boreholes, as well as the qualitative or quantitative nature of the recorded data, is given in Table 2.3-1.

2.4 Activity 8.3.1.4.2.1.4--Petrophysical properties testing

2.4.1 Rationale and justification for the selected tests and analyses

This activity involves a single test--laboratory measurements of rock properties--to provide physical property data for the interpretation of surface and borehole geophysical surveys and logs (see secs. 2.2 and 2.3). Information on such parameters as rock density, porosity, seismic velocity, and electrical resistivity, are essential for correlating and comparing values as determined from core studies and analyses with the recordings obtained by surface and borehole geophysical techniques. The ultimate use of the physical property measurements based on core analyses is to establish a petrophysical model to be used in the interpretation of a suite of well logs from the same well in which the cores were taken. An example is the determination of bulk density of core samples which can be used to confirm the interpretation of surface borehole gravity measurements. In this manner, geophysical logs can be used more confidently as quantitative tools for measuring physical properties of rocks in boreholes which were not cored.

The determination of electrical properties will receive primary emphasis in this activity because laboratory measurements hold considerable promise in providing methods to (1) derive water content from electrical resistivity and dielectric logs, and (2) demonstrate the effectiveness of resistivity and dielectric measurements in delineating zeolitic and clay-bearing rock units.

There are no alternatives to the selected methods of commonly used, standard core analyses (see secs. 3.4.1 and 3.4.2) that would provide the quality of rock property data required from this activity.

2.4.2 Rationale for selecting the number and location of selected tests and analyses

Figures 2.1-1 and 2.1-2 show the location of boreholes in and near the site area that have been, or will be, continuously cored or intermittently cored. Selected core from most, if not all, of these wells will be sampled and analyzed for purposes of this activity. The sampling program will be designed so as to represent the complete sequence of lithostratigraphic units beneath Yucca Mountain and the adjacent areas where the cored holes are located.

2.4.3 Duration and timing

Selection of petrophysical test samples in any one hole will occur after borehole geophysical logging is completed. Duration of laboratory testing for the parameters listed in section 2.4.1 will take 3-6 months. Integration of petrophysical results with geological, stratigraphic, and geophysical data from the same borehole will take place shortly after completion of these tests to provide timely information for determining lateral lithologic variability or continuity. Data will be incorporated into interpretations of surface-based geophysical models as they become available.

2.4.4 Constraints: factors affecting selection of tests and analyses

The selection of the test for this activity was unaffected by potential impacts on the site; simulation of repository conditions; required accuracy and precision, limits and capability of analytical methods; timing; scales of phenomena to be measured; and interference with other tests or the exploratory shaft. The drilling and coring operations, which may have some potential impact on the site area, are being conducted independently of the activity here being described. With regard to possible interference with tests in other studies utilizing cores, the size of the samples required for petrophysical properties testing is small and should not pose problems as to the total volume of available core material unless the core recovery is very poor.

2.5 Activity 8.3.1.4.2.1.5--Magnetic properties and stratigraphic correlations

2.5.1 Rationale for the types of tests selected

Previous studies (Rosenbaum and Snyder, 1985) have demonstrated high-amplitude systematic variations in magnetic properties with depth in ash-flow sheets at Yucca Mountain. There is a strong empirical relation between some of these variations and the locations of depositional breaks within thick ash-flow tuff cooling units. Other variations in magnetic properties have been shown to be related to the cooling history of the ash-flow sheets. Rock magnetic properties also vary as a function of the type, quantity, and grain size of the magnetic minerals. Therefore, knowledge of the changes in magnetic properties, and the relations between these changes and the depositional histories of the ash-flow sheets aid in stratigraphic correlation across the Yucca Mountain area. In addition, related paleomagnetic studies place constraints on the sense, timing, and amount of vertical-axis rotation caused by tectonic movements, and provide the only means of orienting specific core segments obtained from boreholes where cores were not oriented when the drilling took place.

The primary test selected for this activity involves the sampling, rock magnetic testing, and analysis of selected cores and outcrops of tuffaceous units that underlie Yucca Mountain and

adjacent areas. Supporting tests include: (1) petrographic analysis of selected intervals of core and outcrop to aid in identifying lithostratigraphic boundaries; (2) measurements of density variations in the rock mass to distinguish individual ash-flow sheets; (3) measurement of magnetic susceptibility on intact core to help limit the size of intervals of core selected for petrographic studies; and (4) borehole magnetic susceptibility and magnetic field logging as additional means for identifying and correlating lithostratigraphic units in the subsurface. Some of the above tests will be conducted in coordination with other activities in Study 8.3.1.4.2.1 (see secs. 2.1, 2.2, etc.), but the specific purpose may differ. F
or example, petrographic studies and bulk rock density measurements are also planned for Activities 8.3.1.4.2.1.1 and 8.3.1.4.2.1.3, respectively, but the sampling programs for these activities may not provide sufficiently detailed information through the suspected contact zones to completely satisfy the requirements of the rock magnetic studies in the present activity (see sec. 3.5.1).

Methods, procedures, and instruments for quantitatively measuring magnetic properties, as discussed in detail in section 3.5, were selected on the basis that they provide a satisfactory means for acquiring the kinds and quality of data required for the activity. Alternative methods are available but offer no advantage in cost or data quality over those selected.

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

2.5.2.1 Number and Location

The number and location of magnetic susceptibility measurements made on core are dictated by the need to define variations in susceptibility with depth. The number and location of samples taken from core for laboratory magnetic property measurements will therefore be controlled by the observed variation in the susceptibility and the position of observed depositional breaks, as well as the need to avoid disturbing core that may be needed for other studies.

The number and location of paleomagnetic sampling sites will be selected to optimally address relative rotations between major structural blocks. The sites will necessarily be limited by the locations of suitable outcrops.
The number and location of samples taken to paleomagnetically orient core segments will be controlled by the need to orient specific features as identified by other activities.

2.5.2.2 Duration and Timing

The duration and timing for this activity will be determined by the need to incorporate information from other activities (8.3.1.4.2.1.3 and 8.3.1.4.2.1.4) into this activity, the need for access to drill core, and the need to provide information to other activities (see section 4). The scheduled duration and timing are based on the anticipated complexity of magnetic property variations, the complexity of the observed pattern of differential vertical-axis rotation, and the number of core segments that need to be oriented in support of other activities. Because samples from drill core will be used for part of this activity, the drilling schedule will dictate when core samples will be available.

2.5.3 Constraints: factors affecting selection of test(s)

The choice of tests was not affected by the following factors: impacts on the site; simulation of repository conditions; required accuracy or precision; limits of analytical methods; capability of analytical methods; time constraints; scale and applicability; interference with exploratory shaft. This activity consists of (1) collection of small samples (one-inch diameter cores, at most several inches in length) from outcrops,(2) collection of similar samples from drill cores, (3) non-destructive tests on drill cores, and (4) laboratory measurements on the samples. It will therefore have no effect on the ability of the site to isolate waste, or on the construction and design of the exploratory shaft. The activity does not simulate repository conditions.

The paleomagnetic and rock magnetic studies of this activity are either the only method available to provide the needed data or are used to complement, rather than replace, other techniques. The instruments used in this activity provide the required accuracy and precision, but other instruments are available that can also provide similar levels of accuracy and precision. Hence, accuracy and precision, limits and capability of analytical methods, time constraints, and scale and applicability were not considerations in the choice of test methods.

The need to acquire samples from drill core has the potential of interfering with other tests. To minimize such interference. closely spaced susceptibility measurements will be acquired passing the recording device along the core as it is laid out at the Sample Management Facility rather than taking samples of the core itself. Samples for laboratory analysis will be acquired by drilling small (one-inch diameter) core from the larger core at the SMF.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.4.2.1.1 Surface and subsurface stratigraphic studies of the host rock and surrounding units

The objective of this activity is to determine the spatial distribution, history, and characteristics of stratigraphic units within the Paintbrush Tuff, tuffaceous beds of Calico Hills, Crater Flat Tuff, and possibly older volcanic rocks within the site area.

To achieve the above objective, the following SCP-designated characterization parameters will be studied:

- Welding and primary crystallization characteristics of lavas and ash-flow tuffs
- Petrographic characteristics
- Pumice characteristics
- Type and abundance of lithic fragments
- Characteristics of lithophysal zones
- Degree and type of alteration
- Depth, thickness, attitude. and extent of lithostratigraphic units

The four tests discussed in section 2.1 -- surface mapping, core/cutting logging, borehole video logging, and sample analysis (petrographic/chemical/isotopic) -- constitute the primary work elements necessary to quantify the rock characteristics listed above. The fifth test mentioned in the SCP and in section 2.1 consists of borehole drilling and coring. Although the rock characteristics program has the capability of suggesting drill site locations, this test is not specific to the present activity. Since future drilling will provide material and information to a number of activities described under a variety of different programs, a separate activity has been established in the SCP (8.3.1.4.1.1) to integrate and coordinate the drilling program. Therefore. further details of the drilling program will not be presented in the following discussion on test methods for the present activity. We make the assumption that fully-qualified cores and drill cuttings will be available as needed for the tests described below.

In addition to rock characterization studies proposed under the present activity, many of the general features of volcaniclastic deposits at Yucca Mountain (Table 2.1-1) will be investigated under the geochemistry program (Activity 8.3.1.3.1.1) at LANL to specifically address detailed mineralogical, chemical and petrologic variations within devitrified tuffs of the Topopah Springs member of the Paintbrush Tuff within the limits of the proposed repository drifts. The mandate of the present study plan is to provide three-dimensional rock characterization of all Tertiary volcanic units throughout the broader Yucca Mountain region, including the tuffs of the Topopah Springs Member. We anticipate close communication and cooperation with LANL scientists to produce an integrated stratigraphic/volcanologic model of these tuffs without producing directly overlapping data sets. The stratigraphic and rock characterization studies proposed under the present activity will utilize LANL mineralogical, chemical and petrological results obtained on repository host units, and integrate them into models of stratigraphic correlation, three-dimensional parameter variation and petrology for the same tuffs outside the perimeter drift.

In the following sections, separate discussions will be given for the general approach to the individual tests. Other prescribed topics-- test methods; QA requirements; required tolerance, accuracy, and precision; range of expected results; required equipment; data-reduction techniques; representativeness of results; and relations to performance goals and confidence levels--will be covered on an activity-wide basis. Because each of the planned tests is designed to provide data on more than one (in some cases, nearly all) of the designated parameters, the specific parameters being determined by a given test will not be listed separately.

3.1.1 General approach

The general objective of the tests described below is to produce a data set which adequately quantifies the lithologic characteristics (geometries, physical constituents, textures, volcanic/sedimentary structures, and chemical compositions) of volcaniclastic deposits available from surface exposures and drill holes distributed across Yucca Mountain (see fig. 2.1-5). Table 2.1-1 lists the volcaniclastic features to be measured from outcrops, drill cores/cuttings, borehole video logs and associated laboratory samples that are needed to fully describe the deposits. The levels of uncertainty needed in measuring the various parameters will range from qualitative (e.g., visual estimates of macroscopic features) through quantitative (e.g., petrographic modal analyses, chemical analyses) depending on the nature of the observed feature and the importance of the measured parameter in relation to three-dimensional stratigraphic interpretations and other repository performance issues. Initial studies will be directed at determining the relative importance of each of these parameters and degree of uncertainty needed to obtain the goals of this study plan, as well as the needs of other investigations for specific rock characteristics. Appropriate semi- and fully-quantified parameters will be incorporated into strip logs representing individual surface and drill hole sections constructed to standard scales. In this way, data from this work can be directly compared to and integrated with other structural, geophysical, hydrologic and petrophysical logs being prepared under other activities. As these data become available, evaluations and adjustments will be made concerning the level of detail for each of the measurements being made. Data for individual sections will be closely correlated with ongoing geophysical activities within this study plan and will supply critical geological control for these surveys. At the same time, variations between individual outcrop and drill hole sections will be integrated into working three-dimensional fence diagrams, cross sections, and isopach and structure contour maps which will provide further feedback to refine stratigraphic correlation models, petrologic interpretations of individual stratigraphic units and optimum accuracy of rock unit extrapolations defined by geophysical methods.

The general approach toward surface and subsurface sampling issues must recognize the physical and chemical heterogeneities inherent to pyroclastic and epiclastic deposits. Volcanologic and sedimentary processes responsible for the emplacement of deposits associated with a single eruptive event are capable of imparting a wide range of observed rock characteristics depending on a number of variable factors such as eruption and dispersion mechanics, transport distance, thickness, and cooling history. Therefore, any one stratigraphic unit may exhibit highly variable lateral and vertical properties which must be individually characterized on an appropriate scale in order to provide useful information for stratigraphic, hydrologic, and thermal/mechanical interpretations. In general, the strategy of systematically sampling outcrops and core/cuttings will involve an attempt to define some local scale at which macroscopic homogeneity is observed, after which a sample will be collected which is large enough to best represent that defined interval, given the grainsizes of individual constituents. For instance, within thick pyroclastic flows, a series of subunits (e.g., vitrophyric, lithophysal, densely-welded, partially-welded and non-welded subunits) will be identified and individually sampled for representative characterization of the parameters identified in Table 3.1-1. This bulk-sampling goal may not be attainable in excessively coarse or heterogeneous deposits (especially in core), and in these cases, individual constituents will be collected and their proportions estimated. Where thick, macroscopically homogeneous horizons are present, samples will be collected at regular intervals to document the extent of uniformity and to identify any subtle petrographic or chemical variations not obvious in hand specimen. In addition to representative bulk sample collection, sampling of individual constituents, such as pumice and lithic clasts, and other special features (e.g., distinct marker horizons) will be made. These types of samples may have unique importance in correlating stratigraphic units representing the same eruptive event over wide distances. Special attention will also be given to collection of subsurface samples from depths which correlate with any anomalous data observed in borehole video or geophysical logs. Only fully qualified surface and drill hole samples will be used for final interpretations, and these samples will be appropriately designated in maps and logs.

3.1.1.1 Surface-outcrop mapping of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff units

Field investigations utilizing fundamental geological mapping techniques, aided by interpretations from aerial photographs, will be employed to describe the geological relationships and rock parameters (Table 3.1-1) of volcaniclastic deposits exposed throughout the Yucca Mountain area. The results of this test will be a series of section descriptions and columnar sections documenting the aerial distribution and volcanological features of stratigraphic and rock units, including structural relationships (coordinated with Activity 8.3.1.4.2.2.1: Geologic mapping of zonal features in the Paintbrush Tuff). Initial reconnaissance investigations will identify areas of outcrop to be selected for detailed examination and measurement of specific, macroscopically-observable rock parameters listed in Table 2.1-1. Special attention will be given to larger, outcrop-scale fabrics and structures which will provide important information for volcanologic/petrologic interpretations of tuffaceous units. These larger, two-dimensional features, for example, nature and attitudes of bedding structures, contact geometries, large pumice block and lithic fragment distributions and orientations, fabric attitudes, and distributions of volcanic breccias, are difficult to observe and document in drill core and cutting samples, yet are influential to geological interpretations such as ashflow transport directions, proximity to vent areas, location of caldera margins, and for identifying potential hydrologic pathways. Surface samples will be collected to meet the same sampling strategies outlined above (section 3.1.1) for further petrographic, geochemical and isotopic analysis (section 3.1.1.4). Resulting data from carefully mapped surface exposures will be used to prepare detailed geologic sections for the selected areas. Construction of sections to standard scale-specifications will allow direct comparisons between data collected from outcrops with similar data contained in detailed drill logs (borehole lithologic, video and geophysics logs, sections 3.1.1.2, 3.1.1.3, 3.3, respectively, of this study plan).

Most of the data that will be used to produce two- and three-dimensional geological framework models of Yucca Mountain will be obtained from areas of natural outcrops, drill holes and future trenching/excavation activities largely within the potential site area. However, travel paths to the accessible environment may involve substantially greater distances. In order to more accurately predict lateral variability of Tertiary volcaniclastic units outside the immediate repository area, available exposures will be studied at selected localities surrounding Yucca Mountain. Areas of particular interest for identifying and correlating lateral variations of subunits of the Topopah Spring member include northern Crater Flat, Calico Hills, Fortymile Canyon, Little Skull Mountain, Skull Mountain and the northern part of Yucca Mountain (fig. 2.1-4). Detailed outcrop mapping is particularly important for units below the repository horizon (i.e., the Topopah Springs Member), since deeper portions of the Yucca Mountain section will be sampled much less extensively by subsurface drilling and excavation activities. The lower portions of the Topopah Springs Member, tuffaceous beds of the Calico Hills, and the Prow Pass, Bullfrog and Tram

Members of the Crater Flat Tuff will be studied in exposures surrounding Yucca Mountain and parameters ascertained from outlying exposures will be compared to data from these units obtained in drill holes beneath the site area. Three dimensional lithologic variations of these units must be adequately characterized to provide sufficient data for geohydrological modeling of flow paths and groundwater travel times in the lower parts of the unsaturated zone and upper portions of the saturated zone. Exposures of older volcanic rocks underlying the Crater Flat Tuff will also be examined to augment the very limited amounts of stratigraphic and petrologic data which will be obtained from limited core samples from the few deep drill holes planned for the site.

3.1.1.2 Sampling, lithologic examination, and analysis of drill-bit cuttings and core

Core and cuttings from present and planned drill holes will provide subsurface information and samples necessary to help characterize the volcaniclastic deposits immediately adjacent to the repository site area. Cored intervals in drill holes will receive preferential examination over holes or intervals drilled by rotary techniques due to preservation of spatial relationships of rock units and geological features within core which are destroyed by the rotary drilling process. However, cuttings combined with borehole video logs (section 3.1.1.3) will provide an accurate, reliable means of examining and sampling rock units in the Yucca Mountain subsurface.

Logging and sampling activities will be done on site at the Sample Management Facility. Core from seven existing holes (UE25 A-1, UE25 b-1, USW G-1, USW G-2, USW G-3/GU-3, USW G-4, UE25-p1) is currently available for examination (fig. 2.1-1). Three additional cored holes, (G-5, -6, -7), deep enough to intersect Paleozoic basement (i.e., >2000 m), and as many as 50 additional non-cored or partially cored holes >150 m (500 ft.) are proposed over the next several years (fig. 2.1-2). All core will be examined and described in detail utilizing macroscopic observations, assisted by hand lens and binocular microscope were necessary. As many of the rock parameters listed in Table 2.1-1 as appropriate will be quantified versus depth within the hole. Fully qualified core will be sampled for further characterization studies with regards to the sampling strategy outlined above in section 3.1.1. Core samples collected under this activity will be submitted for petrographic, geochemical and petrophysical studies (sections 3.1.1.5 and 3.4) to be used for interpreting rock/stratigraphic correlations, volcanologic/petrologic models, spatial distribution of diagenic minerals, and borehole geophysical logs. Sample spacing within the core will depend on the thickness of transected units as well as the extent of observed physical variations within each unit. We expect that systematic characterization will involve sampling intervals in thick, "homogeneous"-appearing units on the order of every three to five meters. Thinner units will require a closer sample spacing to provide adequate representation, and specific volcanologic features and zones with anomalous geophysical signatures will require additional sampling. Borehole cuttings provide information with much less inherent spacial resolution, and thus will be sampled systematically in 3 m intervals.

Depending on the amount of core recovery, core depths will be calibrated to hole depths measured by the drill-stem length. Known collar elevations, drill hole attitudes and stem lengths will allow recalculation of depths to a standard datum (mean sea level). Resulting observational and quantitative data will be incorporated into borehole logs constructed to standard scale-specifications that will allow direct comparisons between lithologic and geophysical data collected from other boreholes, as well as similar data contained in surface sections.

3.1.1.3 Borehole video surveys and logging

Video camera surveys will be run in most, if not all, boreholes deeper than 150 m (500 ft) sited in the vicinity of Yucca Mountain. The logging of video surveys will be run simultaneously with other downhole logs described in Activity 8.3. 1.4.2.1.3 using standard, commercially-available technology. As the camera records a view of the drill hole walls, it simultaneously records the hole depth. Thus, many of the parameters observed in the video log can be correlated with the same features observed in core. Video logs are also capable of allowing in place measurements of the attitudes of planar features facilitating the re-orientation of core and the proper spatial relationships of observed structures and fabrics (contacts, bedding planes, pumice flattening orientation, veins and fractures). More importantly, video logs provide downhole documentation of lithologic relationships over intervals were core recovery is poor or non-existent, and in rotary-drilled holes where only cuttings are available. Accurate information for non welded, bedded and lithophysal horizons that are poorly sampled by coring techniques are especially critical for both accurate measurement stratigraphic sections and for geohydrological modeling. Borehole video logs will also constitute a vital data source for structural interpretations in other activities (Activity 8.3.1.4.2.2.3 Borehole evaluation of fractures and faults).

3.1.1.4 Petrographic, geochemical and isotopic studies

Samples selected from outcrops and drill holes will be further characterized by microscopic examination and chemical analysis. Petrographic analysis of representative thin sections and grain mounts will focus on quantifying microscopic igneous and diagenic features important for correlating stratigraphic and lithologic units, and for characterization of parameters important to repository performance. Microscopic features important for these interpretations are listed in Table 2.1-1 and include matrix constituents, ash-shard size distribution and morphology, mineral modes, lithic clast lithology, pumice flattening, devitrification, spherulite development, porosity, and secondary mineral development. Mineralogical studies at LANL will provide initial characterization of primary assemblages and mineral chemistries within the Topopah Springs host horizon (Activity 8.3.1.3.2.1.1

Petrologic stratigraphy of the Topopah Springs Member) and underlying volcanoclastic units (Activity 8.3.1.3.2.1.2 Mineral distributions between the host rock and the accessible environment). If these studies indicate that mineral and/or glass compositions are an important tool for correlating rock units, scanning electron microscopy and/or electron microprobe analysis will be employed for routine quantification of these parameters in widely separated samples. In addition to the primary attributes of the volcanic rocks, determination of the three-dimensional distributions of diagenic minerals throughout the Yucca Mountain area will also be an important part of the present activity. Identification of secondary phases will incorporate results from the detailed alteration studies planned at LANL (Activity 8.3.1.3.2.2.1 History of mineralogic and geochemical alteration of Yucca Mountain; Activity 8.3.1.3.2.2.2 Smectite, zeolite, manganese minerals, glass dehydration, and transformation). Petrographic and/or SEM identification of individual phases and secondary assemblages in widely-spaced outcrop and drill core samples collected in this study will be based on mineralogical descriptions and interpretations determined at LANL. Drillhole intervals containing abundant secondary phases may also yield unique geophysical signatures observed in surface-based or borehole surveys (Activities 8.3.1.4.2.2 and 8.3.1.4.2.3, this study plan). Therefore, these intervals must be characterized mineralogically in order to predict lateral variations in areas of little or no subsurface samples. It is also likely that work in this activity will identify samples requiring further detailed mineralogical study at LANL.

Initial geochemical studies will focus on analysis of bulk-rock and individual pumice clast samples by EDS x-ray fluorescence (XRF). This technique allows rapid and precise acquisition of up to twenty major and trace elements (Si, Al, Fe, Mg, Ca, Na, K, Mn, Ti, P, Rb, Sr, Y, Nb, Zr, Ba, La, Ce, V, Cu, Zn). Determination of this suite of elements on a relatively large number of samples will allow statistical assessment of the "representativeness" of samples assigned to individual rock units and subunits. These data (especially the compositions of individual pumices from pyroclastic flow and fall deposits) will provide important data useful for lateral correlations of stratigraphic units and subunits. Acquisition of the limited suite of XRF elements on a larger number of samples will also establish ranges of chemical variability within an individual rock unit or subunit. This information will be used to select smaller sample subsets which will undergo further chemical and isotopic characterization by instrumental neutron activation analysis (INAA) for Th, Ta, Hf, Cs, La, Ce, Nd, Sm, Eu, Gd, Tm, Yb, and Lu and radiogenic isotopic analysis of Sr, Ca, Nd, and Pb systems. This work will be focused on characterizing the primary chemical variability within unaltered tuffaceous rocks. Combined geological, stratigraphic, chemical and isotopic data will be integrated into petrologic models describing the volcanic and emplacement histories which are important in interpreting the three-dimensional geological framework models within the thick Tertiary volcanic pile at Yucca Mountain.

In addition, isotopic studies of Rb-Sr, K-Ca, Sm-Nd, U-Th-Pb (including U-series) systems will be used to help characterize the effects of post-emplacement alteration. These studies will be coordinated with mineralogical results obtained from alteration studies at LANL. Once an initial working hypothesis for low-temperature aqueous alteration has been established at LANL, a subset of samples will be chosen to assess: (1) the long-term integrity of these natural radioisotope systems in least altered facies of the rock units, (2) the time framework of alteration in both the saturated and unsaturated zones, and (3) the nature and extent of element mobility in fractures and in bulk rock. The alteration zones in the tuffs are especially well suited to isotopic studies using the Rb-Sr, K-Ar-Ca, Sm-Nd, U-Th-Pb systems because these and geochemically similar elements were mobile during the alteration. In addition, these elements are excellent analogs to uranic, transuranic, and fission-product elements in the waste package. By coupling isotope-ratio variations with elemental concentrations (e.g., 87Sr/86Sr with ppm Sr; 143Nd/144Nd with ppm Nd; 208Pb/206Pb, 206Pb/204Pb, and 207Pb/204Pb with ppm Pb; and 40Ca/42Ca with percent Ca), quantitative mass balance models will be developed to describe the movement of these and analogous elements during alteration. These estimates will be especially useful in evaluating scenarios in which the water table rises to a level where the repository would be flooded.

Lateral variability in the isotopic characteristics of the various units will be examined by analyzing representative samples from selected localities outside the site area such as Prow Pass. Comparison of the natural radioelement systems in samples representing various stages of alteration, both in fractures and in the bulk rock, will be necessary, and sampling strategies will be planned accordingly.

3.1.2 Test Methods

Table 3.1-1 lists several of the technical procedures to be followed in conducting the tests for this activity; others are given in Baedecker (1987). All of the tests employ standard, widely used methods.

3.1.3 QA requirements

Quality Assurance (QA) will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate 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

No explicit requirements for tolerance, accuracy, or precision have been specified for any of the tests in this activity. Certain levels of accuracy, however, will result from the particular methods and procedures involved, including:

- Accuracies for the quantification of lithological characteristics required by hydrological, thermal/ mechanical and other, related investigations will be determined through initial scoping studies both under this study plan as well as in other activities dependent on the geological data collected here. For parameters determined by visual estimation in the field, accuracies within 10 to 25% of the actual values are achievable by experienced geologists. The nature of some of these parameters does not permit highly-reliable quantification, however, these levels of accuracy can probably be tolerated for much of the geologic framework interpretive work (e.g., maximum pumice/lithic clast size, presence and orientation of internal volcanic structures). Other parameters which are more readily quantifiable, or which have greater importance for repository design and performance assessment (e.g., rock-unit thickness, distribution and volume percentage of lithophysal cavities, matrix porosity, grainsize distribution of non-welded deposits, degree of compaction/welding (flattening), constituent percentages, modal mineralogy), will be determined by more reliable techniques allowing accuracies of less than 5% of the actual values. Where possible, important parameters will be measured by several different techniques to assure reliability of results (e.g., porosity measurement by point-counting thin sections as well as borehole geophysical logs; measurement of volume percent lithophysal cavities in core and in borehole video logs; degree of welding by petrographic estimation of flattening and by density determinations in borehole geophysical logs). As work progresses, communication with investigators in other programs (i.e., hydrology, geochemistry, thermal/mechanical and tectonics) will be maintained in order to assure that adequate data reliability is being achieved without unnecessary detail.

- Thicknesses and depths of stratigraphic units encountered in boreholes, and samples selected for analyses, can be measured to within a few meters and plotted on strip logs;

- Depths recorded and features measured from the video logs are accurate to within a meter in intervals of complete core recovery, and within several meters over intervals of incomplete recovery;

- Stratigraphic contacts and locations of boreholes and other surficial features plotted on aerial photographs are accurate to ±24 m on 1:24,000 scale photographs and geologic base maps; and

- All geochemical analyses will employ procedures that provide standard, generally accepted limits of accuracy and reproducibility of analytical results. Uncertainties in isotope ratio measurements are a combination of internal precision derived from the mass spectrometry and the precision of the standards against which ratios for the samples are compared. The isotope ratios for 87Sr/86Sr, 143Nd/144Nd, and 40Ca/42Ca will be determined to better than ±0.02 percent of their values (uncertainty values here and subsequently are given at the 95 percent confidence level). Ratios 206Pb/204Pb, 207Pb/204PB, and 208Pb/204Pb will be measured to ±0.10, ± 0.15, and ±0.20 percent, respectively. Concentration ratios (e.g., Rb/Sr, K/Ca, U/Pb, Th/Pb, and Sm/Nd) will be determined to ±2 percent of their values by isotope dilution methods. Uncertainties in concentrations of selected trace elements determined by energy dispersive X-ray fluorescence methods will be better than ±10 percent of their values. Other uncertainties are given in the appropriate technical procedures (table 3.1-1).

3.1.5 Range of expected results

Table 3.1-2 shows expected ranges of the parameters listed in section 3.1. Table 3.1-3 shows the geologic ages and thickness ranges of various stratigraphic units at Yucca Mountain, based on previous studies in the area. New data obtained during this activity will refine these parameters, but age and thickness values are expected to generally fall within the ranges shown in the table.

Strike directions of lithologic contacts measured on borehole video camera logs will be comparable to the strikes of these features measured during surface mapping activities, but the dips will be only reported by quadrant (i.e., SW, NE, N) and will not have a dip amount in degrees. The expected ranges of isotope values are listed in table 3.1-4.

3.1.6 Equipment

Equipment used in each of the tests is listed in the appropriate technical procedures listed in table 3.1-1.

3.1.7 Data-reduction techniques

Vertical columnar sections will be prepared (generally at a scale 1:1,200, but other scales may be used where appropriate) for each borehole, based on the descriptions of cuttings and cores. Data plotted on the columns will include stratigraphic assignment, depth, lithology, and other distinguishing characteristics. The columns will be presented graphically in a manner that will facilitate recognition of the lateral and vertical changes in rock properties from one place to another.

Borehole video camera data will be obtained by measuring the strike and dip directions directly from the televised image and plotted as histograms, bar graphs, rose diagrams, and equal area stereographs. Stratigraphic and lithologic data such as contacts, lithophysal and lithic-rich zones, and fractured intervals that may not be available from other sources are recorded from the video tape and included in the core description logs.

Data-reduction techniques for surface-outcrop mapping consist of plotting field notes recorded on aerial photographs onto scale-stable base maps using a PG-2 plotter. Data from measured sections, recorded in field notebooks, are transcribed and reformatted into tabular form for publication. Mode counts from thin sections will be displayed graphically to show relative amounts of phenocrysts, lithic fragments, and other microscopic features versus stratigraphic units and depth.

Geochemical spectral data, obtained in the laboratory, will be converted to weight percent for the major elements and parts-per-million (ppm) for the trace elements. The isotope and trace element variations will be evaluated and interpreted in the context of lithostratigraphic units and subdivisions as well as alteration zones. These data will be stored in a data base management system where they can be easily accessed and manipulated for plotting on conventional plots that will most effectively illustrate variations of importance to the study, e.g., 87Sr/86Sr vs. 87Rb/86Rb; 206Pb/204Pb vs. 207Pb/204Pb; 87Sr/86Sr vs. Sr content; and 143Nd/144Nd vs. Nd content. In addition, such ratios and trace element contents will be displayed in spatial formats such as on maps and on drill hole logs to assess lateral and vertical variations. Correlations among isotope ratios and major and trace elements will be studied using such plots. Demonstrated element mobility will be modeled using immobile elements as bases of comparison.

3.1.8 Representativeness of results

The information to be obtained during this activity is expected to be representative of the lithological characteristics and spatial distributions of the stratigraphic units and subunits of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, Crater Flat Tuff, and possibly older rocks in the Yucca Mountain area. In areas where closely-spaced surface and subsurface samples are available, correlation of individual units can typically be made at high degrees of confidence, and hence lateral and vertical representativeness can be tested through observational assessments and statistical treatments of a sufficiently large sample population. Sampling strategies will be designed to define subunits which display visual homogeneity, the degree of which can then be tested by analytical and statistical techniques. Correlations over greater distances lacking subsurface samples introduces increased uncertainties which will be reduced substantially by integration of surface-based geophysical surveys. Causes of heterogeneity within correlated stratigraphic units and subunits will be assessed by applying models accounting for variability introduced by magmatic, volcanologic, or secondary alteration processes. However, uncertainties in subsurface relations may arise if abrupt changes take place between boreholes and there is no intervening data (e.g., geophysical) that can be used to precisely locate and fully characterize that particular lithologic variation. If the need for additional data is critical it may be necessary to recommend drilling another borehole.

The degree to which the isotope and geochemical results represent the rock units and alteration zones depends solely on the adequacy of the sampling and sample preparation. Samples collected in this study must represent both bulk thermal/mechanical characteristics of various subunits within each tuff, as well as unaltered chemical/ petrological characteristics used to most accurately correlate individual volcanic events. Therefore, both bulk tuff samples as well as individual pumice clasts will be analyzed. Rapid, inexpensive EDS XRF chemical analyses of a large number of samples (prepared to exclude contamination from lithic clasts) will define basic chemical trends and the degree of variability within a defined subunit. The total number of samples targeted for any one unit or subunit will depend on the observed variability such that an adequate sample population has been included. At least three broad mechanisms are likely to contribute to observed variability within any individual tuff including 1) pre-eruptive compositional zoning established within magma chambers and subsequent mixing patterns associated with magma evacuation, 2) transportive/depositional processes, e.g., fractionation of constituents by size and density factors, ash elutriation, post-depositional compaction, and 3) secondary elemental mobility (vapor-phase mineralization, high-temperature elemental mobility during cooling, low-temperature aqueous diagenetic effects). Sample collection will incorporate strategies to allow identification of these different processes (e.g., pumice clast versus bulk rock, welded versus non-welded, least altered versus most altered) so that their effects can be evaluated within any one unit or subunit at a particular sampling site. Once the degree of variation within a particular unit is established from the larger group of XRF samples, evaluation of whether that unit is well-represented or not will be made. Further action will involve either additional sampling, or selection of smaller, representative subsets for further characterization. Correlations of units between sample localities, and hence a representation of the lateral variability, will follow an iterative process as the database is extended throughout the Yucca Mountain area.

3.1.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

3.2 Activity 8.3.1.4.2.1.2 Surface-based geophysical surveys

The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints. Four tests, described in detail below (sections 3.2.1, 3.2.2, 3.2.3, and 3.2.4) will be conducted to address the following SCP parameters:

- Seismic velocity contrasts, seismic attenuation, seismically reflective horizons, density variation, local variations in magnetic field orientation and strength, and variations in electrical properties which are associated with vertical or lateral changes in lithology

- Lateral continuity of horizons defined by geophysical surveys

3.2.1 Seismic reflection surveys

3.2.1.1 General approach

The extent to which shallow reflection (Mini-Sosie) surveys will be conducted in this test has not yet been determined, but it is anticipated that sufficient profiling will be run along some of the profiles discussed in section 2.2.1.1 to determine this method's effectiveness in imaging shallow geologic features. The method uses one or more portable, soil compaction vibrators as the source, and a closely spaced array of single geophones. Data quality is achieved by stacking a large number of traces, each triggered from a single vibrator cycle (Oliver and others, 1990, p. 60).

Intermediate and deep seismic reflection surveys will be conducted along the five profiles described in section 2.2.1.1 and shown on Figure 2.2-1. Because it is recognized that this is a difficult area to acquire high quality reflection data (Report of the Seismic Methods Peer Review Panel to DOE, January 22, 1991), a significant portion of the field effort will be in testing field acquisition parameters (noise tests) with emphasis on geophone-spread length and configuration, sweep length, sweep-frequency content, number of surveys, explosive shot depth and size, and shear wave sources. It is anticipated that the upper 0-8 sec of record will be acquired using either high-fold vibroseis or minihole methods, and that the lowermost 8-20 sec will be acquired with low-fold (3-4 fold) large single shot holes. However, two field tests will be conducted in the initial stages of the seismic reflection program to determine and confirm optimum specifications for minihole depth and shot size, vibroseis sweep frequency, number of sweeps per vibrator point, background noise, and both in-line and weighted geophone arrays.

Profiles 1-5 (fig. 2.2-1) have a total combined length of about 34 miles, of which 25 miles will be full (60) fold. With some exceptions, 0.9 mile-long tail spreads at the beginning and end of each of Profiles 1-4 will be used to maintain fold where the lines intersect; tail spreads will total about 9 miles. Symmetric split spreads will be used to acquire the 60-fold data. Source points will be at 50 m intervals in most cases. Data-collection specifications for geophone spreads include: 25 or 50 m group interval, 24 geophones per group (8-10Hz), 240 groups per spread, 110- or 220-foot group arrays, and 6,000 m minimum noise spread length. Depending on the results of the noise testing, minihole sources may be used for the entire length of the 60-fold lines. However, single large (100-200 lb) explosive shots will be fired in 200-foot deep holes at one-mile intervals to generate a low-fold profile of the lower crust (8-20 seconds).

In addition to vibroseis and explosive sources, an array of 4 or 5 large air gun trucks will be tested as a seismic source during the two initial noise tests. The optional field trial of the shear wave reflection method may also be conducted during the noise tests, using shear wave sources and oriented horizontal seismometers.

Timing of source activation and seismograph recordings is provided by chronometers within seismographs and source systems that are calibrated by satellite time receivers. Locations are determined by surveys that employ either global positioning satellite receivers or electrical distance measuring devices.

3.2.1.2 Test Methods and Procedures

Procedures for conducting the seismic reflection surveys are explained in Technical Procedure SP-10 (Deep seismic reflection study of the tectonic environment) and SP-14 (Shallow reflection survey -- Mini-Sosie) (table 3.2-1).

3.2.1.3 QA requirements

See section 3.1.3. .

3.2.1.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerances, accuracy, or precision have been specified for this test. Table 3.2-3 lists the relevant tolerances, accuracies, and precisions that are standard for reflection surveys.

3.2.1.5 Range of expected results

Shallow seismic reflection methods have been demonstrated to produce useful reflections at depths corresponding to two-way travel times of about 0.3 to 1.0 seconds, depending on site conditions; however, the uppermost 50-150 m (depending on velocity) are not imaged. According to Oliver, et al (1990, p. 65), the previous experience gained in acquiring, processing, and interpreting shallow reflection data in southern Nevada is judged to be applicable to site characterization of Yucca Mountain.

An intermediate and deep seismic reflection survey in the Amargosa Desert, southwest of Yucca Mountain, shows that reflections can be observed as shallow as 25 meters and as deep as 33 km (Brocher, et al, 1990). These data provide clear images of the Tertiary basin fill, indicate that the fill is locally more than 1.5 km thick, and show where it is offset by subsequent faulting. Also in the Amargosa Desert, a shallow, widespread, subhorizontal low-frequency reflection about 100 m deep is interpreted as a basalt flow, an interpretation which is confirmed by nearby shallow drill data. This reflection line also images the pre-Tertiary/Tertiary contact as a series of tilted basement blocks, apparently bounded by high-angle normal faults (T. Brocher, personal commun., 1991). Prominent reflections are observed from the middle to lower crust, corresponding to two-way travel times of 5-10 seconds. Although more seismic profiling will be required, such as the test lines across Crater Flat and Yucca Mountain and along Yucca Wash as are being planned for this activity, the results relative to detecting buried faults, mapping the extent of fault zones and buried intrusive bodies, and investigating the subsurface geometry of fault zones are encouraging.

3.2.1.6 Equipment

Equipment used for the planned reflection surveys is listed in Technical Procedures SP-10 and SP-14 (Table 3.2-1).

3.2.1.7 Data-reduction techniques

Steps used in the processing of data obtained from shallow seismic reflection surveys typically include: common-depth-point (CDP) sorting, constant velocity analysis, normal movement correction, spectral whitening, deconvolution, bandpass filtering, datum and residual statics, and final CDP stage migration (Barbier, 1983; Carr and Yount, 1988).

Standard data-reduction techniques described in Technical Procedure SP-10 (Table 3.2-1) will be used to compile the field observations for the intermediate and deep reflection surveys. The recorded and processed data will be plotted on scale stable topographic base maps (scale 1:24,000 or other, as appropriate). The reflection data recorded on digital magnetic tapes will be processed using standard industry procedures. These procedures will include: sort to CDP geometry, bandpass filter, velocity analysis, application of elevation and refraction statics, application of normal-movement corrections, stack of CDP gathers, deconvolution, and migration.

3.2.1.8 Representativeness of results

Results of the planned reflection surveys should be representative of data collected from surveys in other parts of the area with similar geological environments (see section 3.2.1.5). However, limitations in the ability of the methods to provide useful seismic reflection data along the planned traverses will not be known until the surveys are completed.

3.2.1.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

3.2.2 Seismic refraction surveys

3.2.2.1 General approach

Seismic refraction data will be obtained during the seismic reflection profiling to be conducted along the five profiles described in section 2.2.1 and shown on Figure 2.2-1. The Seismic Methods Peer Review Panel, in their January 22, 1991 report to DOE, recommends the recording of wide angle refraction data resulting from the explosive sources used in reflection profiling, and suggests that closer station spacing and more numerous shots be used than in previous refraction seismic surveys in the area. According to Oliver, et al (1990, p. 51), shot holes along the profiles of several previous surveys in the Yucca Mountain area were spaced 8-15 km apart and 120 portable event recorders were used for each shot.

3.2.2.2 Test methods and procedures

Procedures for conducting the planned seismic refraction surveys are described in the technical procedure listed in table 3.2-1.

3.2.2.3 QA requirements

See section 3.1.3.

3.2.2.4 Required tolerances, accuracy and precision

No explicit requirements for tolerance, accuracy, or precision have specified for this test. Table 3.2-2 lists the relevant tolerances, accuracies, and precisions that are standard for refraction surveys.

3.2.2.5 Range of expected results

As reported by Oliver, et al (1990, p. 55), previous seismic refraction surveys in the Yucca Mountain area and adjacent areas have provided reconnaissance data on the general upper-crustal (0-5 km) structure near the potential repository site. Interpretations to date suggest seven distinct upper-crustal refracting layers, corresponding to successive alluvial, volcanic, and pre-Tertiary units; these are in agreement with other velocity data and with observations in boreholes.

The indication from the seismic refraction data is that the potential repository overlies complex extensional features present in the pre-Tertiary strata (Oliver, et al., 1990, p. 55). Also, a large structural depression is apparent beneath Crater Flat; it is an asymmetrical, westward-deepening structure that extends from the Bare Mountain front eastward to the eastern flank of Yucca Mountain. It is expected that the data obtained during the refraction test described here will help to define more precisely the stratigraphic and structure features underlying Yucca Mountain.

3.2.2.6 Equipment

The equipment used for seismic data acquisition and surveying is listed in the technical procedure listed in table 3.2-1.

3.2.2.7 Data-reduction techniques

Following field acquisition, the seismic refraction data are compiled onto seismic industry-standard 9-track computer tapes. These tapes are suitable for use with a variety of computer programs that display and filter the data. First-break arrival times are digitized from plots of the data. The arrival times for all shots are analyzed to determine standard seismic parameters such as apparent velocity, intercept time, and reciprocal time. These standard seismic parameters are then used as input parameters for direct inversion (i.e., determination of the seismic model) of the seismic horizons beneath the profile. In order to provide an estimate for the accuracy of the seismic model, model-predicted seismic traveltimes are compared with the observed traveltimes. The seismic model is complete when the predicted and observed data agree to within the accuracy of the field measurements. When available, ground truth is provided by sonic and stratigraphic logs obtained in nearby drill holes.

3.2.2.8 Representativeness of results

The seismic refraction profiles planned for this test are expected to result in data that are representative of the types of structures and lithologies underlying the lines of traverse. However, it has also been found that seismic refraction horizons in the ?Tertiary section in and around Yucca Mountain sometimes do not correlate precisely with the formational boundaries encountered in drill holes. This observation provides evidence that the seismic contrasts at some formational boundaries are not as strong as some that occur within formations. Three primary factors control the existence of seismic horizons in the study area: (1) an overall increase in seismic velocity with depth is due to increasing confining pressure; (2) sharp seismic contrasts at formational boundaries probably correspond to changes in composition and bulk physical properties (e.g., density and porosity); and (3) seismic contrasts within formations are probably indicative of lava flows or variations in fracturing, cementation, or degree of welding.

3.2.2.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

3.2.3 Gravity and magnetic surveys

3.2.3.1 General approach

Gravity surveys will include acquisition, reduction, and interpretation of data. Along with gravity data acquired from studies in Activity 8.3.1.17.4.7.2 (Detailed gravity survey of the site area) selected profiles will be run in the Yucca Mountain area along the five traverses shown on figure 2.2-1, using high-precision portable gravimeters controlled by base-station cryogenic meters. Gravity stations will be spaced about 200 ft apart along east-west lines that are spaced about 500 ft apart (where topography permits). At the present time there is one high-precision gravity profile across southern Yucca Mountain which was determined relative to the absolute gravity base station at Mercury, Nevada.

Absolute gravity measurements will be made and repeated at a number of sites at the NTS and Yucca Mountain, using the absolute gravity meter free-fall equipment. These measurements will provide absolute gravity tests of stability and also will be used as references for high-precision temporal gravity measurements over Yucca Mountain and to help constrain gravity meter calibration factors.

Magnetic surveys will be run in the same areas as the seismic and gravity surveys (fig. 2.2-1). Ground-based magnetometers and truck-mounted magnetometers (Activity 8.3.1.17.7.4, Detailed ground magnetic surveys of specific features within the site area) and high-precision airborne magnetometers in low-flying aircraft (Activity 8.3.1.17.4.7.3, Detailed aeromagnetic survey of the site area) may be used to acquire data. The ground-based observations will be collected at 10- to 20-ft intervals along existing roads for truck-mounted observations and at 200-ft intervals along E-W grid lines spaced 500 ft apart where topography permits. The airborne observations will be recorded along lines spaced approximately 1/16 mile apart and about 400 ft above ground level. The location and extent of concealed faults in the Yucca Mountain area, as well as other structures and anomalies inferred from aeromagnetic data. may be investigated from ground-based magnetic data.

3.2.3.2 Test methods and procedures

Procedures for conducting the gravity and magnetic surveys are found in the technical procedures listed in table 3.2-1.

3.2.3.3 QA requirements

See section 3.1.3.

3.2.3.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this test other than the general guidelines in the technical procedures for this activity (see technical procedures NWM-USGS-GPP-01, R1 and -GPP-11, R0). Gravity surveys measure the acceleration of gravity in units of milligals (mGal) (1 mGal = 10-3 cm/s2) relative to a gravity base station, and in general, magnetic surveys measure the total magnetic intensity of the Earth in units of nanoteslas (nT) (1 nT = 1 gamma). Generally, observed gravity measurements are accurate to about 0.05 to 0.10 mGal and ground magnetic data are collected with an instrument with a sensitivity of about 0.5 nT and which generally yield data with a precision after diurnal corrections of about ±.5 nT. Airborne magnetic instruments have a sensitivity of about 0.5 nT, but random magnetic noise associated with the aircraft during flight reduces the reliability of the aeromagnetic measurements to about ±2 nT. Moreover, the problems of correcting for diurnal variations and the greater spatial differences relative to base station monitors introduce about an additional ±2 nT uncertainty between adjacent flight lines of 1/4 mile-spaced survey. Thus, the overall precision of airborne magnetic data is about ±4 nT although local anomalies are generally defined more accurately depending on the concurrent level of magnetic storms.

3.2.3.5 Range of expected results

Interpretation of gravity and magnetic data is expected to result in qualitative and quantitative models of subsurface geology and to aid in the delineation of concealed faults. Previous gravity studies have shown that depth to the Tertiary/pre-Tertiary contact can be estimated with a relatively high degree of accuracy (Oliver, et al, 1990, p. 11), reflecting the sharp contrast in densities above and below that contact and offering the possibility that gravity measurements will reveal fault displacements. Gravity methods have also helped to identify buried caldera structures in the vicinity of Yucca Mountain (Oliver, et al, 1990, p. 11).

3.2.3.6 Equipment

Equipment and calibration requirements for absolute gravity measurements are listed in Technical Procedure NWM-USGS-GPP-16. Equipment and calibration requirements for LaCoste and Romberg or Worden gravity meters are listed or referenced in Technical Procedure NWM-USGS-GPP-01. Table 3.2-4 also lists equipment that may be used in gravity and magnetic surveys.

3.2.3.7 Data-reduction techniques

Standard gravity and magnetic data reduction procedures will be used. For gravity data, field readings and their locations are converted to digital format and observed gravity values are determined. Standard gravity corrections are made to the data which include an Earth-tide correction, instrument drift correction, latitude correction, free-air correction, bouguer correction, curvature correction, and terrain correction.

Magnetic data and their locations are collected in digital form, and are corrected for diurnal time variations of the Earth's magnetic field. In addition, a regional field will be removed from the airborne data by subtracting an International Geomagnetic Reference Field.

3.2.3.8 Representativeness of results

The ability to resolve a particular geologic feature from gravity or magnetic data is, in part, related to the spacing of individual measurements. For example, gravity and magnetic profiles with 200-ft spaced data may provide shallow fault locations with fair accuracy, whereas deeper structures such as synforms in the contact between rocks of Tertiary age and rocks older than Tertiary may be less well defined.

Interpretations of gravity and magnetic data are affected by the nonuniqueness property of potential fields; that is, an infinite number of interpretational models can produce the observed anomaly. To better constrain gravity and magnetic interpretations, other geological or geophysical data are needed. In general, the combined use of both gravity and magnetic methods is considerably more informative than that obtained from either one alone.

3.2.3.9 Relations to performance goals and confidence levels

See sections 1.2 and 4.

3.2.4 Electrical surveys

As discussed in section 2.2.1.4, electrical geophysical data from other activities will be evaluated and applied in this test to the general objective of characterizing the vertical and lateral distribution of stratigraphic units within the site area. These geoelectric data include the results of surveys in the Drill Hole Wash area (U.S. Department of Energy, 1990). Descriptions of the procedures and methods being used to acquire, analyze, and assess the quality of the various kinds of electrical geophysical data are included in the appropriate study plans for those activities.

3.3 Activity 8.3.1.4.2.1.3 Borehole geophysical surveys

The objectives of this activity are:

- To aid in the definition and refinement of the location and character of lithostratigraphic units and contacts between units

- To determine the distribution of rock properties within lithostratigraphic units

3.3.1 General approach

The parameters for this activity involve direct measurements and quantities derived from geophysical logs, statistical analysis, cross plots, and correlation of core data, including: borehole diameter, gamma radiation intensity, temperature, induced polarization, porosity, saturation, potassium-uranium-thorium content, water content, seismic velocities, deformation moduli, magnetic susceptibility, and total magnetic field intensity. Suites of commercial geophysical logs to be obtained in future holes drilled in the vicinity of Yucca Mountain, additional experimental geophysical logs to be run in selected boreholes, and the available logs from selected existing boreholes will be interpreted to provide the basic information. The geophysical log data will be correlated with physical property measurements performed on cores in other activities (e.g., 8.3.1.4.2.1.4 and 8.3.1.4.2.1.5), such as grain density, bulk density, porosity, resistivity, sonic velocity, hydraulic conductivity, and magnetic properties.

This activity will produce correlation plots consisting of one or two types of logs from selected boreholes, typically arranged as cross sections. These cross sections will be used for lithologic correlations and for helping to determine the continuity of lithostratigraphic units in conjunction with the borehole sample studies and video camera surveys conducted in Activity 8.3.1.4.2.1.1. Summary statistics on measured and derived parameters, such as bulk density, porosity, and water saturation, will also be produced.

Figure 2.1-2 shows the locations of wells from which geophysical logs will probably be studied during the conduct of this activity. An average of 10 logs per well will be used, although this number depends upon several factors and cannot be accurately estimated at present.

3.3.2 Test methods and procedures

The various kinds of geophysical logs and their primary uses in this activity are listed in table 2.3-1, and some of the technical procedures are listed in table 3.3-1. Virtually all logging methods, procedures, and equipment are fully described in the technical manuals prepared and issued by major commercial logging companies (e.g., Schlumberger; Dresser-

Atlas). Density, electrical resistivity, magnetic-property, and spectral-gamma logs will be used frequently for lithologic correlations, although other logs may be used such as caliper, neutron, and dielectric. Identification of dominant lithophysal zones, in boreholes where only drill-bit cuttings are available or where poor resolution exists on borehole video camera logs (Activity 8.3.1.4.2.1.1), will be based principally on signatures derived from caliper and compensated-density logs. Resistivity and spectral-gamma logs are expected to be the best indicators of smectite- and zeolite-rich intervals. These logs will be used, in turn, to identify key stratigraphic markers at the top and base of major ash-flow tuffs, which commonly show an increase in alteration.

Borehole gravimetry will be used in selected boreholes to obtain bulk density and structural information for the rocks surrounding each hole. In addition, data from this technique will be used to study lithophysal zones, and to model the Tertiary-Paleozoic contact surface at the site.

3.3.3 QA requirements

See section 3.1.3.

3.3.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. Standard practice is to compare logging results with core measurements in order to determine statistical measures of accuracy. This practice will be followed during the geophysical logging efforts in this activity to determine the bias and standard deviation of measured and derived parameters.

3.3.5 Range of expected results

The ranges of expected results for geophysical logs, based on log and core data obtained in boreholes drilled before 1985, are tabulated in table 3.3-2.

3.3.6 Equipment

Log acquisition will involve the use of standard logging tools, electronic equipment, recorders, and trucks supplied by contractors and by the USGS as listed in table 3.3-3. Log analysis will require computer hardware and software also listed in table 3.3-3.

3.3.7 Data-reduction techniques

Data reduction will involve commercial software packages for managing data files, editing, computing, and plotting. The use of a log analysis software package referred to as

"ESLOG" (from Energy Systems, Denver, Colo.), a commercially available log analysis package used extensively by the petroleum industry as well as by government agencies is currently being planned. Statistical analysis and plotting of computed results will also be done using commercial software.

3.3.8 Representativeness of results

The geophysical logs, derived logs, and statistical averages of logs obtained in this activity will be representative of the rocks penetrated by a given borehole, out to a radial distance determined by the particular capability and sensitivity of the logging tool involved. This distance ranges from a few centimeters to as much as a meter from the borehole, depending not only on the type of tool but also on rock properties. (An exception is the gravimeter; its radius of investigation is much greater than any other logging tool.) The certainty with which correlations of physical rock properties can be made from one borehole to an adjacent borehole will help to determine qualitatively the degree of confidence that can be applied to interpolating values between boreholes.

3.3.9 Relation to performance goals and confidence levels

Information on rock properties in the subsurface as derived from the interpretation of borehole geophysical logs will materially supplement the data being obtained in other activities that bear on the vertical and lateral distribution of stratigraphic units and the development of a three-dimensional rock properties model for the Yucca Mountain area. See sections 1, 2, and 4 for further discussion.

3.4 Activity 8.3.1.4.2.1.4 Petrophysical properties testing

The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

3.4.1 General approach

To achieve the above objective, laboratory measurements of rock properties will be performed to determine the following parameters:

- Electrical resistivity and bulk density of core samples containing in situ pore waters; and

- Electrical resistivity, dielectric permittivity, induced polarization, bulk density, grain density, porosity, seismic velocity, and hydraulic conductivity on saturated samples.

Laboratory measurements of core samples to be made in this activity will be those related primarily to electrical resistivity, dielectric permittivity, induced polarization, and formation factor. Data pertaining to grain density, bulk density, porosity, water saturation, and hydraulic conductivity will be obtained from Activity 8.3.1.2.2.3.1 (Matrix hydrologic properties testing). Sonic velocity measurements (on cores) are not planned inasmuch as in situ sonic velocities are difficult to verify with laboratory data, whereas borehole sonic logs provide sufficiently accurate data for this purpose.

The electrical properties of tuffs depend upon the conductivity and saturation of the fluid in the pore space, the nature of the pore space, and the type, amount, and distribution of zeolites and clays. The porosity and mineralogy of a small suite of core samples will first be determined. Mineralogical data will be obtained from Activity 8.3.1.4.2.1.1 (see section 3.1.1.4 of this study) and from Study 8.3.1.3.2.1 (Mineralogy, petrology, and chemistry of transport pathways). The electrical properties of this suite will then be examined in frequency ranges at both low (0.1 Hz-50 kHz) and high (10 MHz-100 MHz) frequencies. At low frequencies the amplitude and phase shift of electrical resistivity will be measured. At high frequencies the relative dielectric permittivity and loss tangent will be measured. The properties will be measured at full water saturation and at known levels of partial water saturation. Plots of the electrical parameters as a function of water saturation and mineralogy will be used to establish the values of parameters in empirical models. These models will then be applied to the estimation of water content from the resistivity and dielectric logs.

As indicated above, rock property data will be used to make comparisons between the values derived from laboratory measurements and those obtained from surface and borehole geophysical surveys. By comparing bulk density measurements of core samples with the densities obtained from a gamma-gamma density log, for example, it can be ascertained whether calibration corrections need to be made to the logs. In cases where a workable physical model cannot be established, statistical methods may be needed to estimate a particular physical property from logs. For example, porosity measurements of core samples can be used to establish a regression model to estimate porosity from gamma-ray, density, and neutron logs.

The petrophysical properties testing program will establish petrophysical models that can be used in interpreting (1) suites of well logs in cored and non-cored boreholes, and (2) surface-based geophysical records. Examples of the application of such data are the determination of water saturation from resistivity logs through the use of a saturation model, or from a dielectric log using the mixing law, which includes the dielectric response of the rock constituents.

3.4.2 Test methods and procedures

Methods and procedures involved in this test are described in the technical procedure listed in Table 3.4-1.

3.4.3 QA requirements

See section 3.1.3.

3.4.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerance, accuracy, or precision have been specified for this activity. However, the planned laboratory procedures will result in data that satisfy the standard limits of accuracy commonly accepted for the particular analysis involved.

3.4.5 Range of expected results

The range of expected results for various measurements of parameters are tabulated in Table 3.4-2; these results are based primarily on core data obtained prior to 1985.

3.4.6 Equipment

Core tests for density, porosity, and water saturation will use electronic equipment and recorders to be specified by the contractor who will be conducting the laboratory work for the USGS. Core tests for electrical and dielectric properties and mineralogical determinations will use equipment presently available in USGS laboratories. Most, if not all, equipment items are standard as specified in Technical Procedure NWM-USGS-GPP-10, R1.

3.4.7 Data-reduction techniques

This activity will produce tabulations of laboratory data, reported in table and (or) graph form to display the varying properties of lithostratigraphic units.

3.4.8 Representativeness of results

Rock property data resulting from the planned core studies in this activity are expected to be representative of the various lithostratigraphic units penetrated in the boreholes from which the cores were collected. How far these data can be extrapolated away from each of the boreholes, however, cannot be estimated until the studies are well under way and the lateral variabilities in petrophysical properties become better known. If considerable differences are detected between one borehole and an adjacent one separated by a few kilometers, it will be difficult to accurately determine where lateral changes take place on the basis of core studies alone.

3.4.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

3.5 Activity 8.3.1.4.2.1.5--Magnetic properties and stratigraphic correlations

The objectives of this activity are to:

- Provide magnetic data to aid in the interpretation of volcanic stratigraphy and structure of rock units within the Yucca Mountain site area

- Use paleomagnetic directions to provide orientation for drill core segments

- Assess the rotation of rock units in relation to the geologic structure of Yucca Mountain from paleomagnetic data

To achieve these objectives, the following three categories of parameters will be studied:

1. Measured magnetic parameters
    a. Orientation and magnitude of remanent magnetism
    b. Magnetic susceptibility
    c. Curie temperature

2. Measured properties of flow units
    a. Textural variations across boundaries
    b. Grain size variations
    c. Pumice clast concentrations
    d. Locations of lithic-rich subzones
    e. Nature of contacts between flow units
    f. Attitudes of compaction foliation

3. Inferred properties of flow units
    a. Location of depositional breaks
    b. Thicknesses of individual flow units

The tests listed in the second paragraph of section 2.5.1 are designed to provide the required information by: (1) collecting and evaluating magnetic property data, petrographic data, and other physical property data; (2) assessing the sense and amount of vertical-axis rotation in relation to geologic structure at the site area using paleomagnetic directions; and (3) orienting drill core segments using directions of remanent magnetism. Because all of the tests have a common focus, most of the discussions in the following sections will be given on an activity-wide basis rather than a test-by-test basis.

3.5.1 General approach

Cores collected from the ash-flow units of the Paintbrush and Crater Flat Tuffs penetrated in existing and proposed boreholes (figs. 2.1-1 and 2.1-2) will be utilized for measurements of:

- Magnetic susceptibility at sample intervals of 0.1 and 3 m using a pass-through susceptibility device or a hand-held susceptibility meter,
- Remanent magnetism and magnetic susceptibility in the laboratory on samples approximately 2.5 cm in diameter taken from intervals several meters apart, and
- Other magnetic properties in the laboratory (e.g., saturation magnetization, coercivity, coercivity of remanence, Curie temperature) on selected samples.

Cores (from the sampled boreholes as indicated above) will also be utilized for petrographic studies to determine textural and grain-size variations, pumice clast concentrations, and lithic-rich zones. Some, if not most, of these kinds of information may be provided by Activity 8.3.1.4.2.1.1 (see secs. 2.1 and 3.1 of this study plan). However, additional study of these parameters may be required, especially near the contact zones between ash-flow units. Other physical property measurements such as dry bulk density (also part of Activity 8.3.1.4.2.1.4) as well as inferred properties of flow units such as location of depositional breaks and thickness of individual flow units (also part of Activity 8.3.1.4.2.2.1, Geologic mapping of zonal features in the Paintbrush Tuff) may likewise be required to meet the objectives of the activity.

Samples will be collected from outcrops of ash-flow units of the Timber Mountain, Paintbrush, and Crater Flat Tuffs on and adjacent to the site area (figs. 2.1-3 and 2.1-4). Six to 12 oriented samples from each of the 30 to 60 surface locations will be utilized for determining (1) characteristic direction of remanent magnetism, (2) site mean remanence direction, and (3) structural attitude of the ash-flow tuff at each sample locality. The resulting magnetic data, combined with stratigraphic and structural data bearing on ash-flow units from other activities, will be applied to interpretations of the sense and amount of vertical-axis rotation of individual structural blocks.

In order to provide magnetic data for orienting cores, both core and outcrop samples will be utilized. For an individual ash-flow cooling unit, six or more oriented samples will be collected from at least one surface site and (or) oriented drill core within two kilometers of the drill hole from which the core is to be oriented. One or more samples, oriented with respect to the drill core itself, will be obtained from each core segment for which an orientation is desired. Data generated will include:

- Characteristic direction of remanent magnetism for each oriented sample,
- Site mean remanence direction for surface sampling location or for oriented drill core,
- Characteristic direction of remanent magnetism relative to some arbitrary reference direction for each sample of the core segment to be oriented, and
- Orientation of the arbitrary reference direction for each of the unoriented core segments.

Oriented core data for use in the above series of magnetic measurements are expected to be supplied by Activity 8.3.1.4.2.1.3.

3.5.2 Test methods and procedures

This activity will use current, standard procedures for:

- Collection of core and outcrop samples for paleomagnetic measurements,
- Measurement of structural attitude,
- Measurement of remanent magnetization,
- Measurement of magnetic susceptibility,
- Measurement of other rock magnetic parameters, including saturation magnetization, saturation isothermal remanent magnetization, coercivity, coercivity of remanence, and Curie temperature,
- Measurement of dry bulk density, and
- Petrographic examination of thin sections.

The relevant technical procedures are listed in table 3.5-1.

3.5.3 QA requirements

See section 3.1.3.

3.5.4 Required tolerances, accuracy, and precision

No explicit requirements for tolerances, accuracy, or precision have been specified for the tests in this activity (see sec. 3.5.1). Accuracy and precision of measurement for some characterization parameters are dependent only upon the instruments used for such measurements; the results of some tests, however, depend upon geologic factors as well, so that for these tests levels of accuracy can only be estimated.

Measurements of the following characterization parameters are dependent only upon instrumental accuracy and precision:

- Magnetic susceptibility of drill core using pass through susceptibility device--accuracy ±10 %, precision ±3 %;
- Magnetic susceptibility of 2.5-cm-diameter sample in laboratory-- accuracy ±5 %, precision ±2 %;
- Magnitude of sample's remanent magnetism (single measurement): accuracy ±5 %, precision ±2 %;
- Direction of sample's remanent magnetization (single measurement)-- accuracy ±3°, precision ±4°;
- Saturation magnetization-- accuracy ±5 %, precision ±2%;
- Coercivity and coercivity of remanence--accuracy ±2 millitesla, precision ±1 millitesla; and
- Curie temperature--accuracy ±10°, precision ±5°.

The accuracy of the following tests depends not only upon the accuracies of measurements but also upon geological factors:

- Characteristic direction of remanence for a sample-- expected accuracy, ±2°;
- Site mean remanence direction-- expected accuracy, ±5°; and
- Structural attitudes-- expected accuracy, ±5°.

3.5.5 Range of expected results

Range of expected results can be estimated for many of the parameters from existing data from the Yucca Mountain area (Rosenbaum and Snyder, 1985; Schlinger and others, 1988) and results from other volcanic rocks. For some parameters, such as direction of remanent magnetization and structural attitude, all possible value can be measured. Expected values for other parameters are listed in figure 3.5-2.

3.5.6 Equipment

This activity requires a variety of field equipment, listed in table 3.5-3. Laboratory equipment is listed in table 3.5-4. The electrobalance and furnace are used in conjunction with the electromagnet to measure saturation magnetization as a function of temperature and to consequently determine Curie temperatures as described by Larson and others (1975).

3.5.7 Data-reduction techniques

This activity will generate data which consist of directions of remanent magnetization and magnitudes (scalars) of various magnetic properties. Characteristic directions of remanent magnetization will be determined for paleomagnetic samples (1) by means of a best fit line (Kirschvink, 1980), (2) by vector subtraction, or (3) by use of the direction after some level of demagnetization. The characteristic direction will be determined using Fisher statistics. Standard statistical methods including mean value and standard deviation will be used to analyze scalar data.

3.5.8 Representativeness of results

The representativeness of test results for each of the three objectives listed in the first paragraph of section 3.5 will be discussed separately.

Magnetic properties of ash-flow tuffs at Yucca Mountain vary both laterally and vertically. Previous work has demonstrated that vertical changes in properties are systematic and that the planned study of drill core will closely reflect changes in magnetic properties with depth at the location of drill holes. Results from drill holes USW G-1, USW G-2, and USW GU-3 demonstrate both similarities and major differences in the magnetic signatures of ash-flow tuff sheets. Therefore, results from magnetic property measurements will not provide a complete representation of the lateral variation of magnetic properties. Mapping of lateral variations will depend upon borehole magnetic-field and magnetic-susceptibility logging (Activity 8.3.1.4.2.1.3).

The representativeness of the paleomagnetic study to assess rotation will depend upon (1) whether each site mean remanent direction is representative of the average direction for the structural block in which the site is located, and (2) a satisfactory distribution of sampling localities. Many previous paleomagnetic studies have demonstrated that six individually oriented specimens from a single site in volcanic rock are sufficient to provide a well-defined site mean direction; therefore, site data are expected to be representative. Sampling sites for the various ash-flow sheets are limited to areas of outcrop. The Tiva Canyon Member of the Paintbrush Tuff is exposed over much of the area so that sites within the Tiva Canyon can be dispersed and, therefore, results from this unit are likely to provide an excellent representation of the distribution of differential rotation throughout the Yucca Mountain area. However, outcrops of the Timber Mountain and Crater Flat Tuff are limited in their distribution. Results from these units will demonstrate rotations between relatively isolated sites but may not provide the same detailed representation of rotations as provided by the Tiva Canyon Member.

Paleomagnetic orientation of drill core segments will provide a good representation of the in situ orientation for those geologic units that possess a uniform direction of magnetization throughout. Present data suggest that core from all welded units at Yucca Mountain in and above the Crater Flat Tuff, except for the Topopah Spring Member of the Paintbrush Tuff, can be successfully oriented on the basis of remanent direction.

3.5.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

4. APPLICATION OF RESULTS

This section identifies other studies that will use the information obtained in the present study. The discussion is summarized from information in the SCP. Table 4-1 shows which information from the study will be used in other site characterization studies.

The stratigraphic and rock properties measured or calculated as a result of this study provide an important category of information needed to develop a three dimensional geologic model of the Yucca Mountain site (Study 8.3.1.4.2.3). In addition, the results derived from this study, in concert with other studies in this investigation, will be used in developing the hydrogeologic stratigraphy in Section 8.3.1.2, and the geochemical stratigraphy in Section 8.3.1.3. The geologic characteristics will also be combined with the data in Investigations 8.3.1.15.1 and 8.3.1.15.2 and in Site Programs 8.3.1.2 and 8.3.1.3 to develop three-dimensional models of thermal, mechanical, hydrologic, and geochemical properties in Study 8.3.1.4.3.2. In addition, Study 8.3.1.4.3.2 also will result in models that will be the means by which these data pass from site characterization activities to design and performance assessment studies (see section 1.2 and figure 1.2-1).

5. SCHEDULES AND MILESTONES

Because of the broad scope, diversity, and complexly integrated nature of the five activities in this study, which have been discussed in several earlier sections of this study plan, only a general charting of the scheduled investigations and preparation of reports is shown on Figure 5-1. This brief summary is based on the detailed and specific scheduling of all the work elements in Study 8.3.1.4.2.1 as abstracted from the most current and complete schedule information available. For each of the activities (labeled 1-5), Figure 5-1 shows the period of time involved in data collection, analysis, and interpretation, and for the preparation of interim and final reports, which adheres to certain SCP-designated milestones. Data from each activity will ultimately be provided as input to the final report of Study 8.3.1.4.2.1 on the lateral and vertical variability of stratigraphic units in the potential site area.

Data contributions in support of other studies/activities in the site characterization program are listed in Table 4-1.

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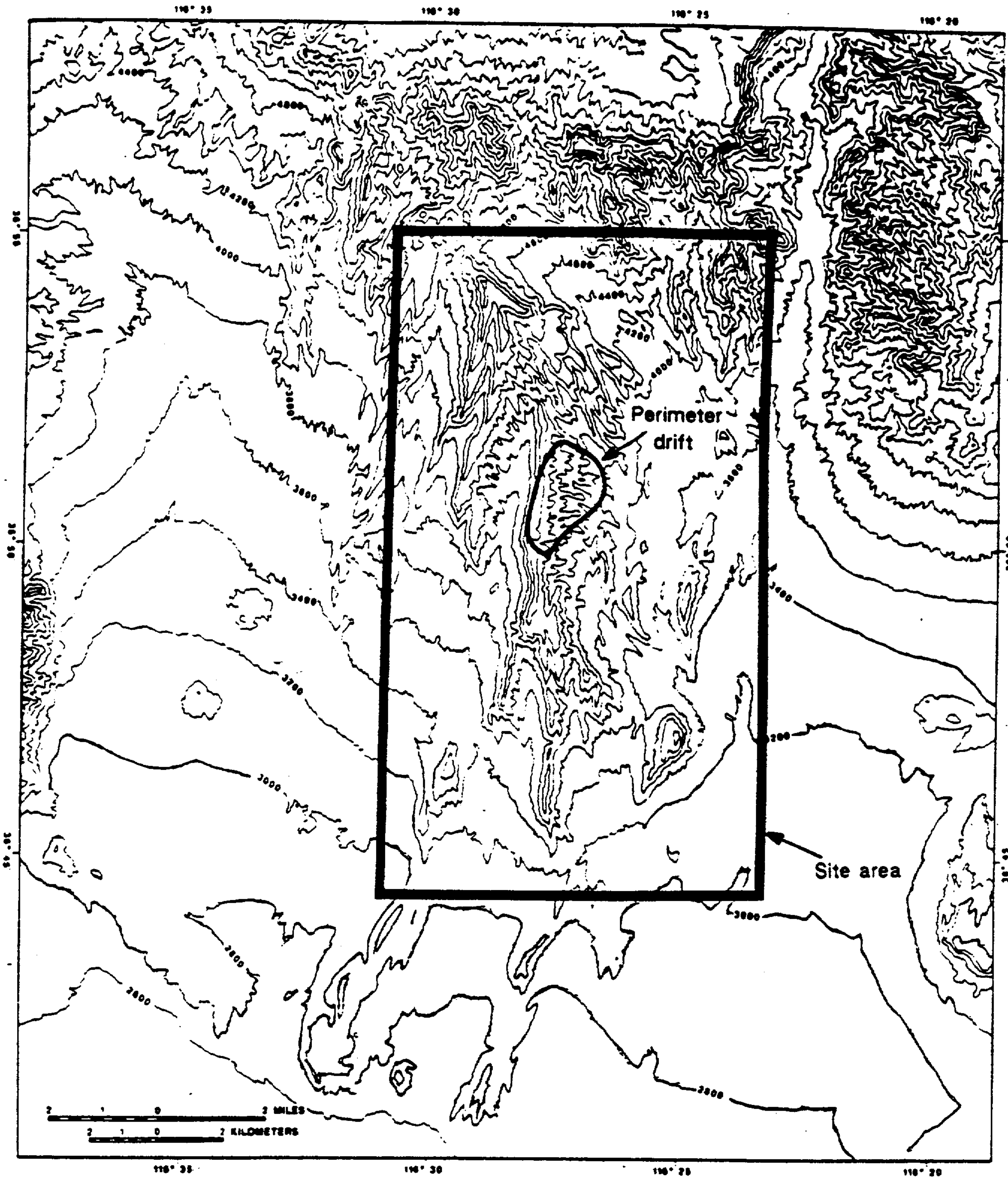

Figure 1.1-1 Area of geologic investigation at Yucca Mountain

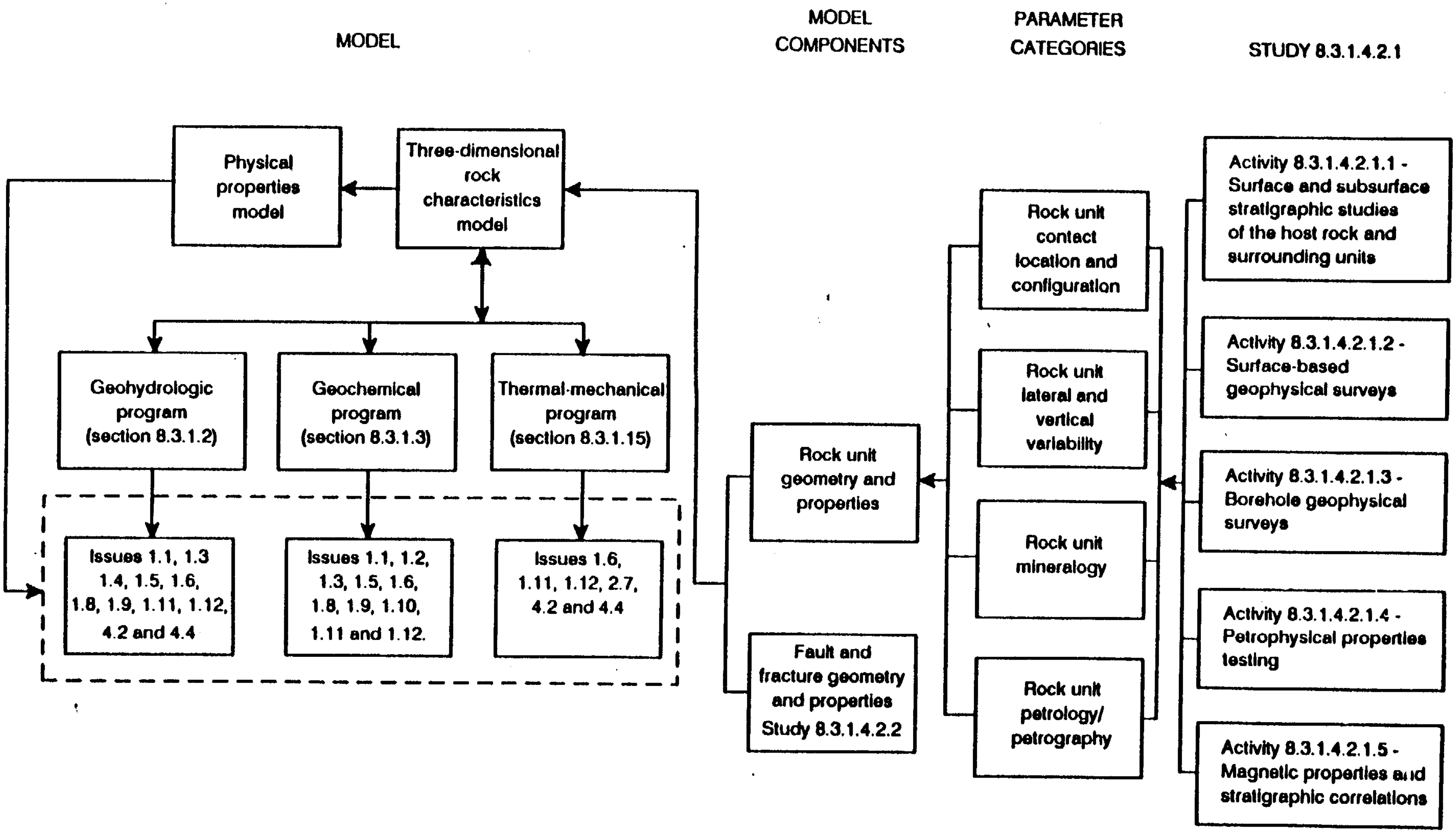

Figure 1.1-2. Logic diagram showing contribution of Study 8.3.1.4.2.1 to the three-dimensional rock characteristics model and model interfaces with other site characterization programs and their associated design and performance issues.

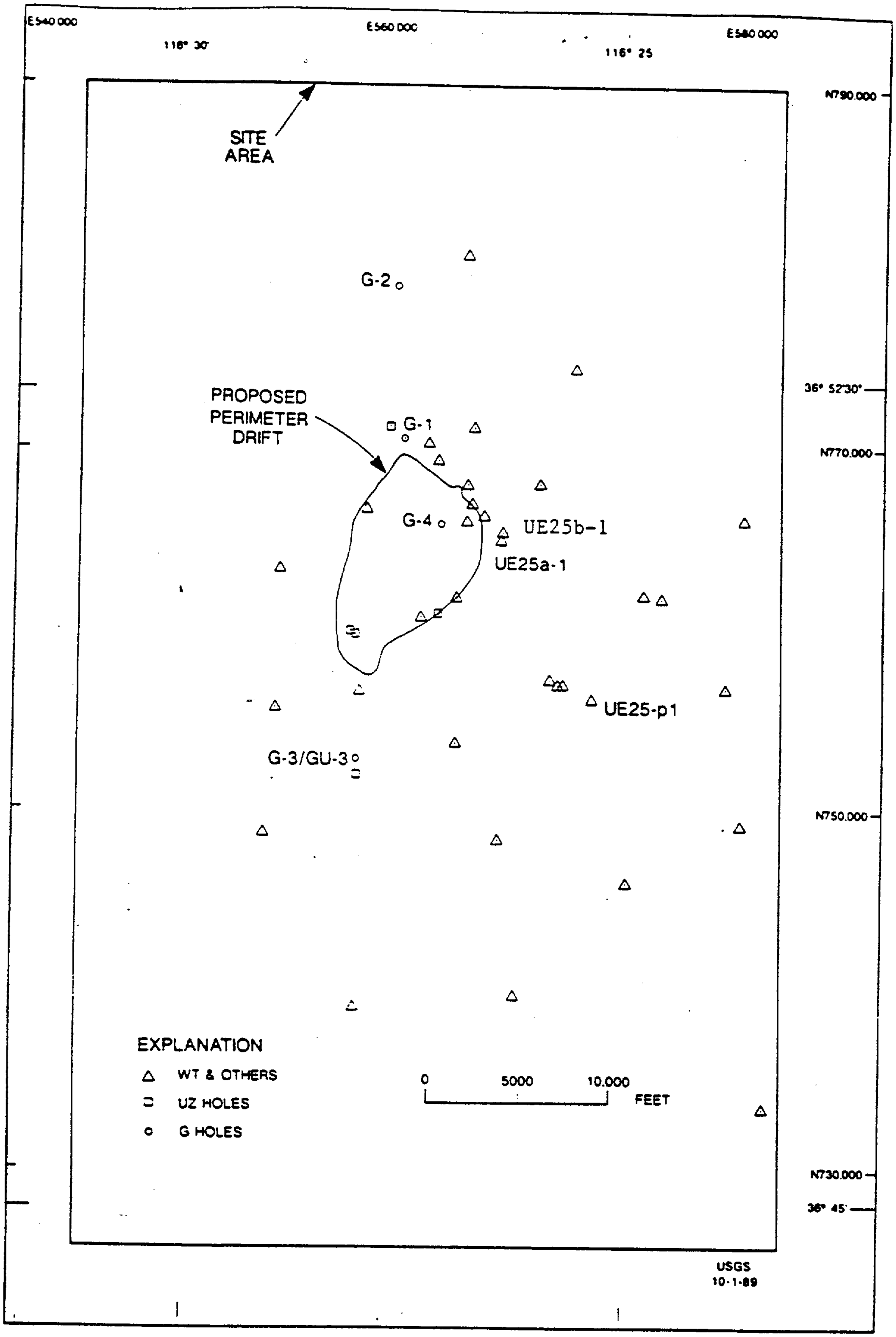

Figure 2.1-1. Existing drill holes greater than 500 feet deep at the potential Yucca Mountain site. Labeled holes have been continuously cored. WT-drill holes that penetrate a short interval below water table; UZ-drill holes that do not penetrate below water table; G-holes drilled primarily to provide geologic data; others - all drill holes not included in labeled categories.

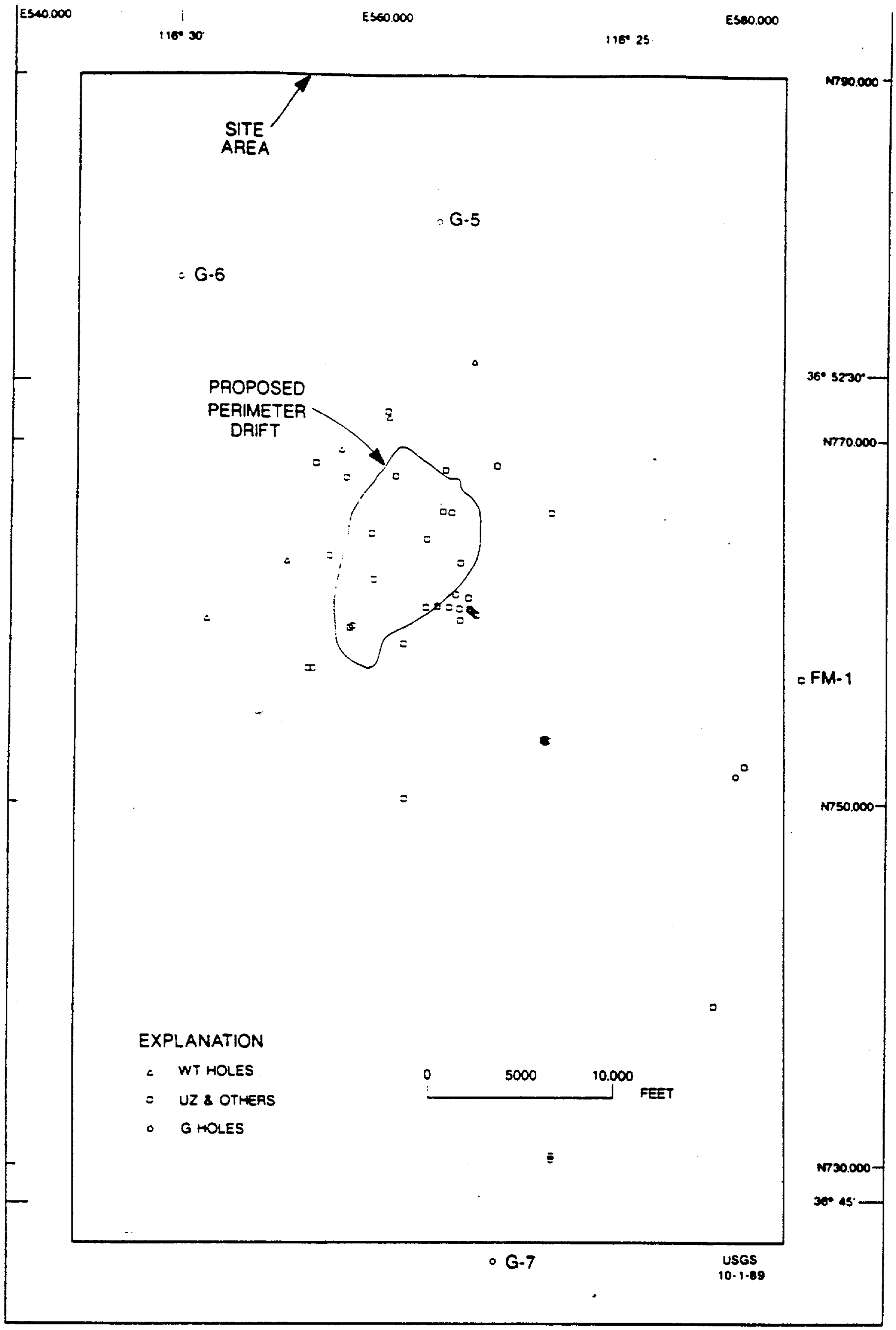

Figure 2.1-2. Planned drill holes greater than 500 feet deep at the potential Yucca Mountain site. Labeled holes will be cored. Note: drill hole categories same as designated for figure 2.1-1, except that "others" also include the "Sd" holes which are part of a systematic drilling program.

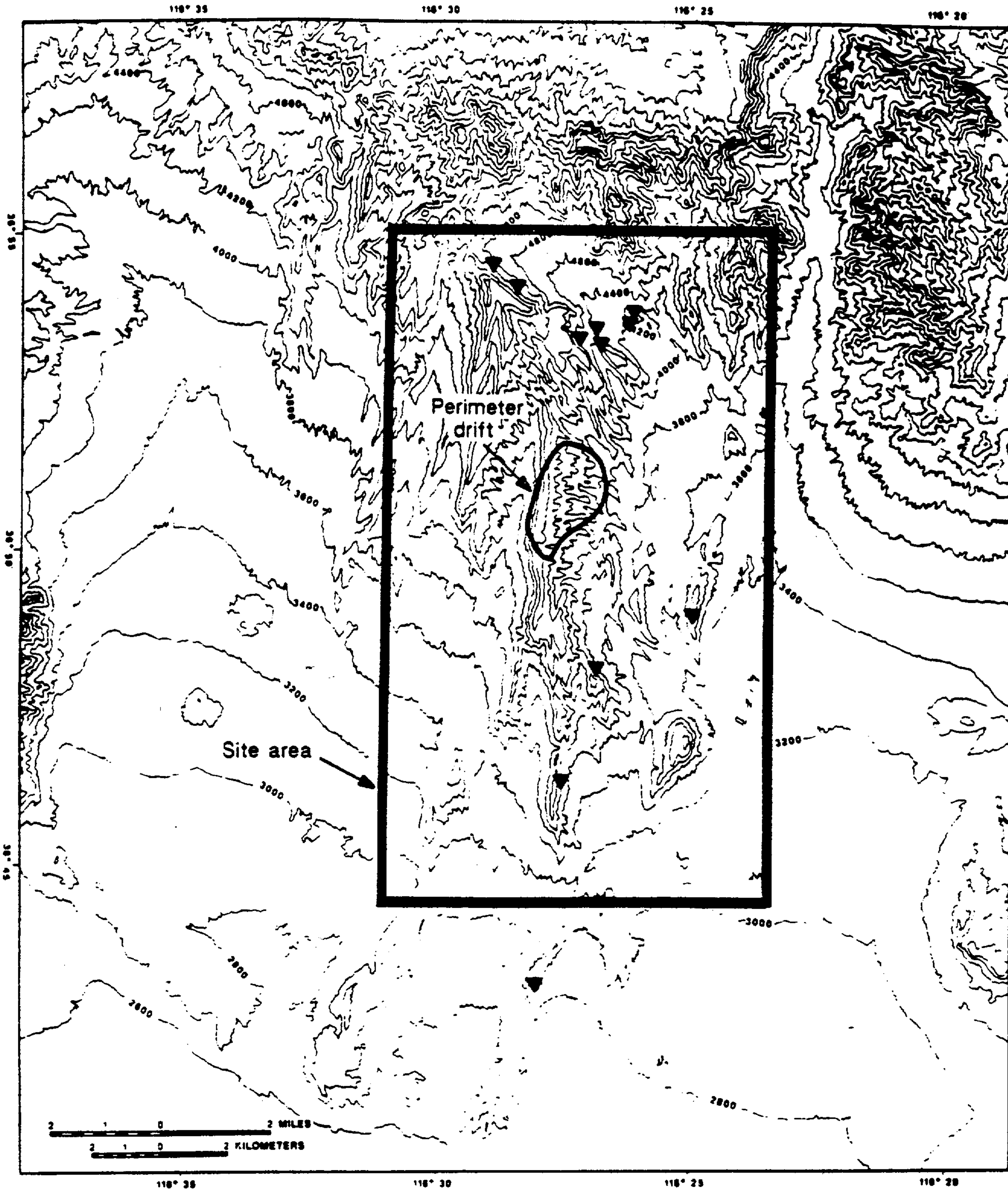

Figure 2.1-3 Approximate locations of additional surface stratigraphic studies of the Yucca Mountain and Pah Canyon Members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Prow Pass and Bullfrog Members of Crater Flat Tuff

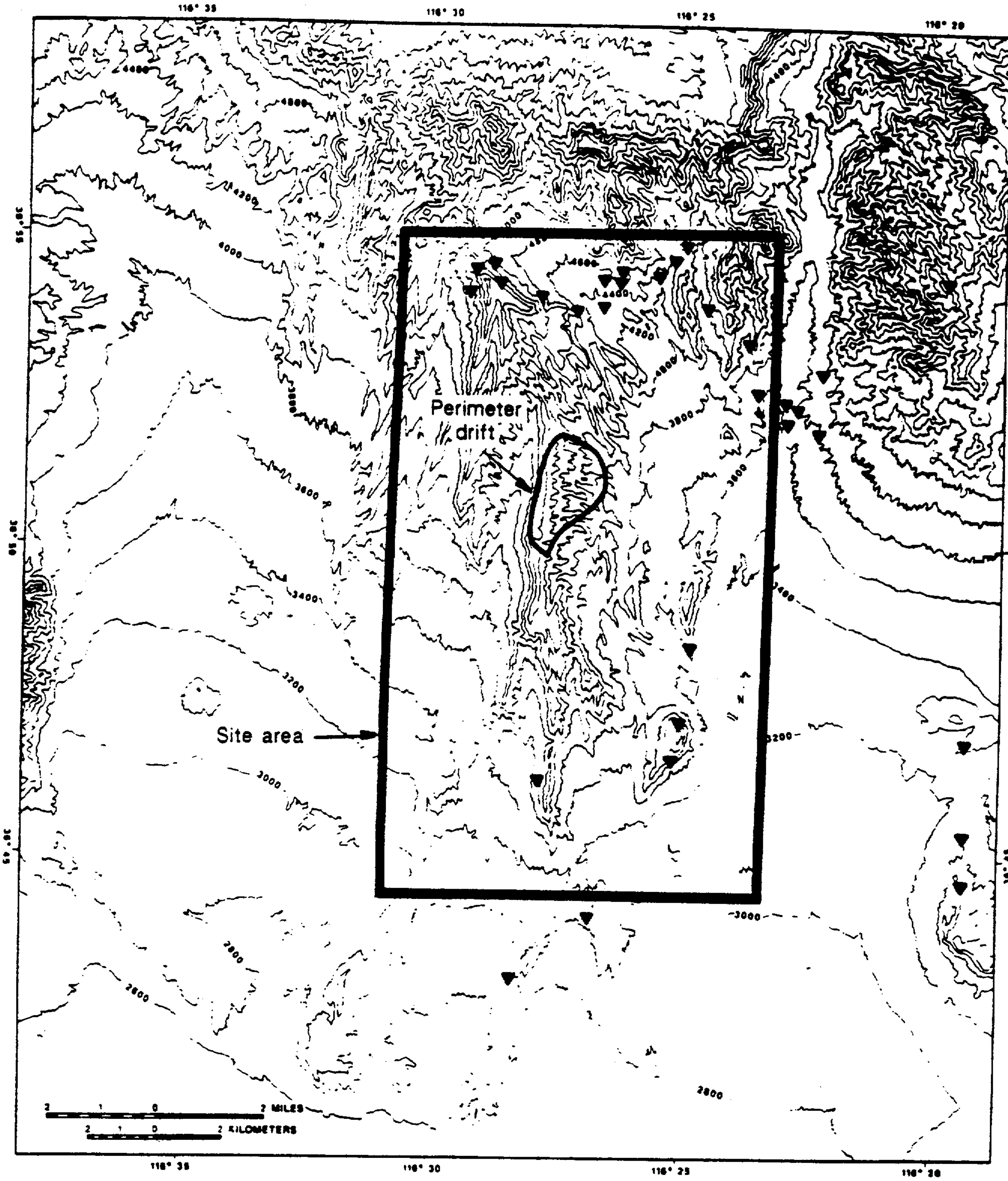

Figure 2.1-4 Approximate locations of additional surface stratigraphic studies of the Topopah Spring Member of the Paintbrush Tuff

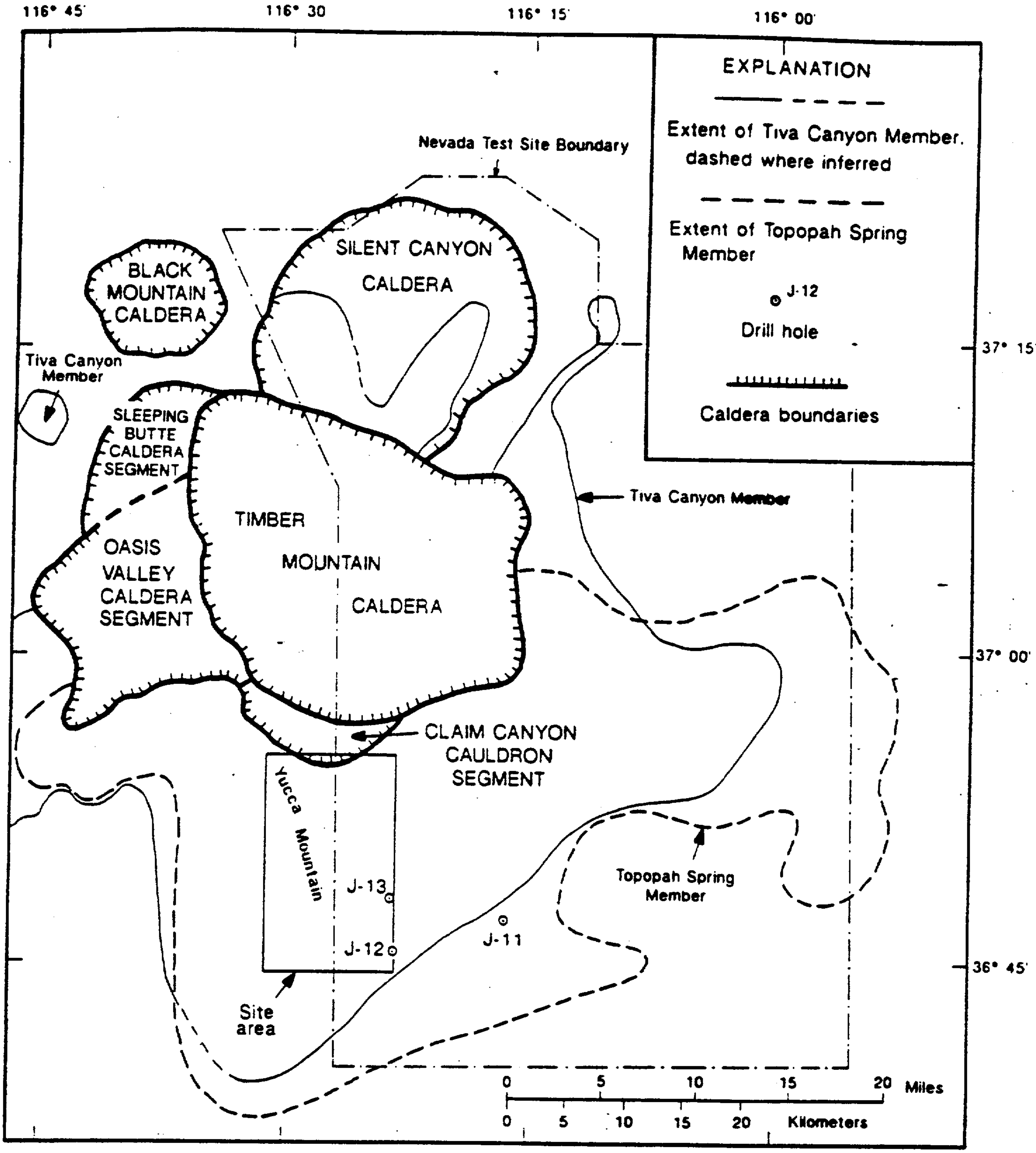

Figure 2.1-5 Areal extent of the Tiva Canyon and Topopah Spring members of the Paintbrush Tuff (modified from Byers and others, 1976)

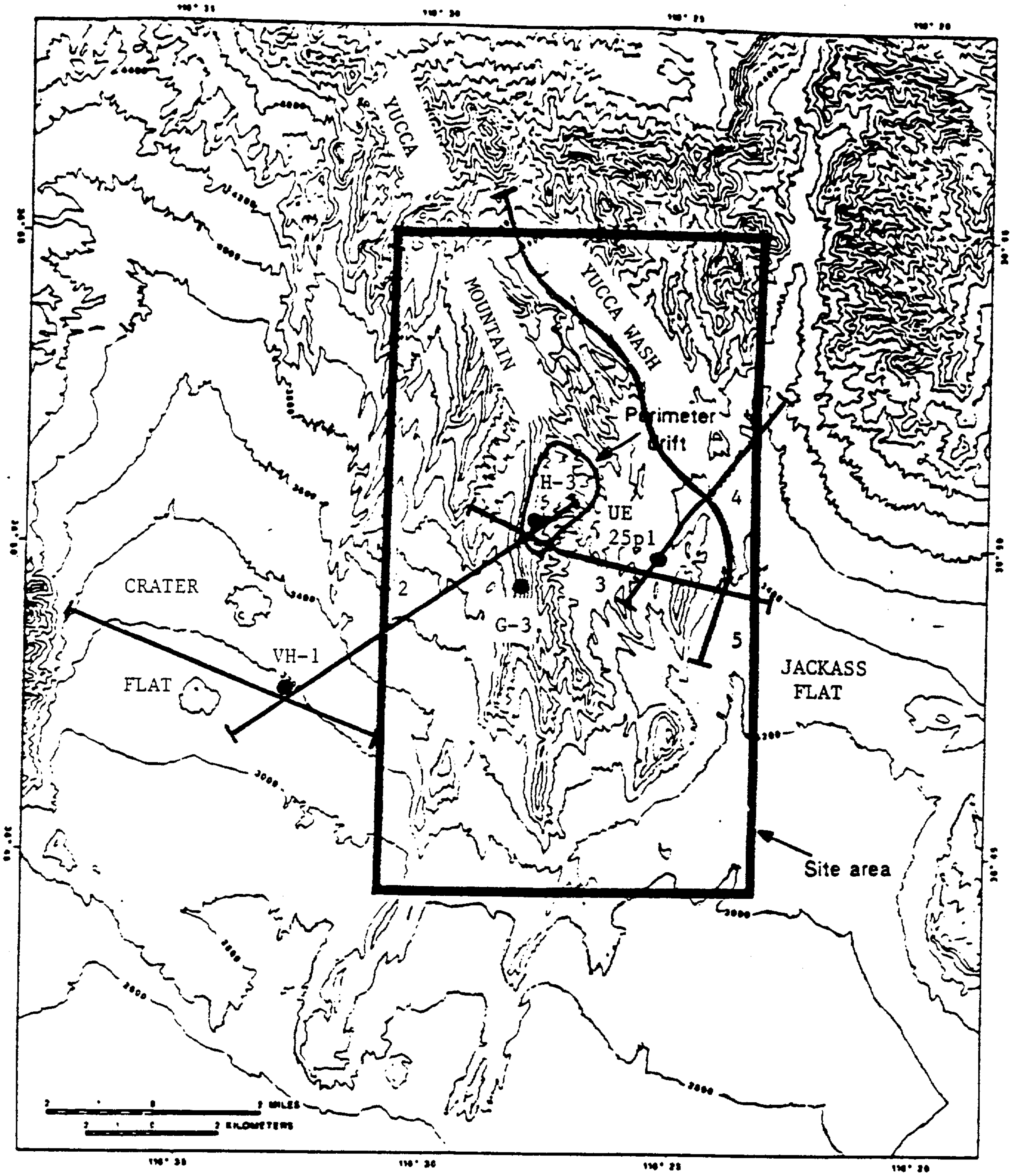

Figure 2.2-1. Approximate location of seismic, gravity, and magnetic surveys. Numbers refer to individual profiles described in text. Small solid circles are bore hole locations (labeled with well numbers).

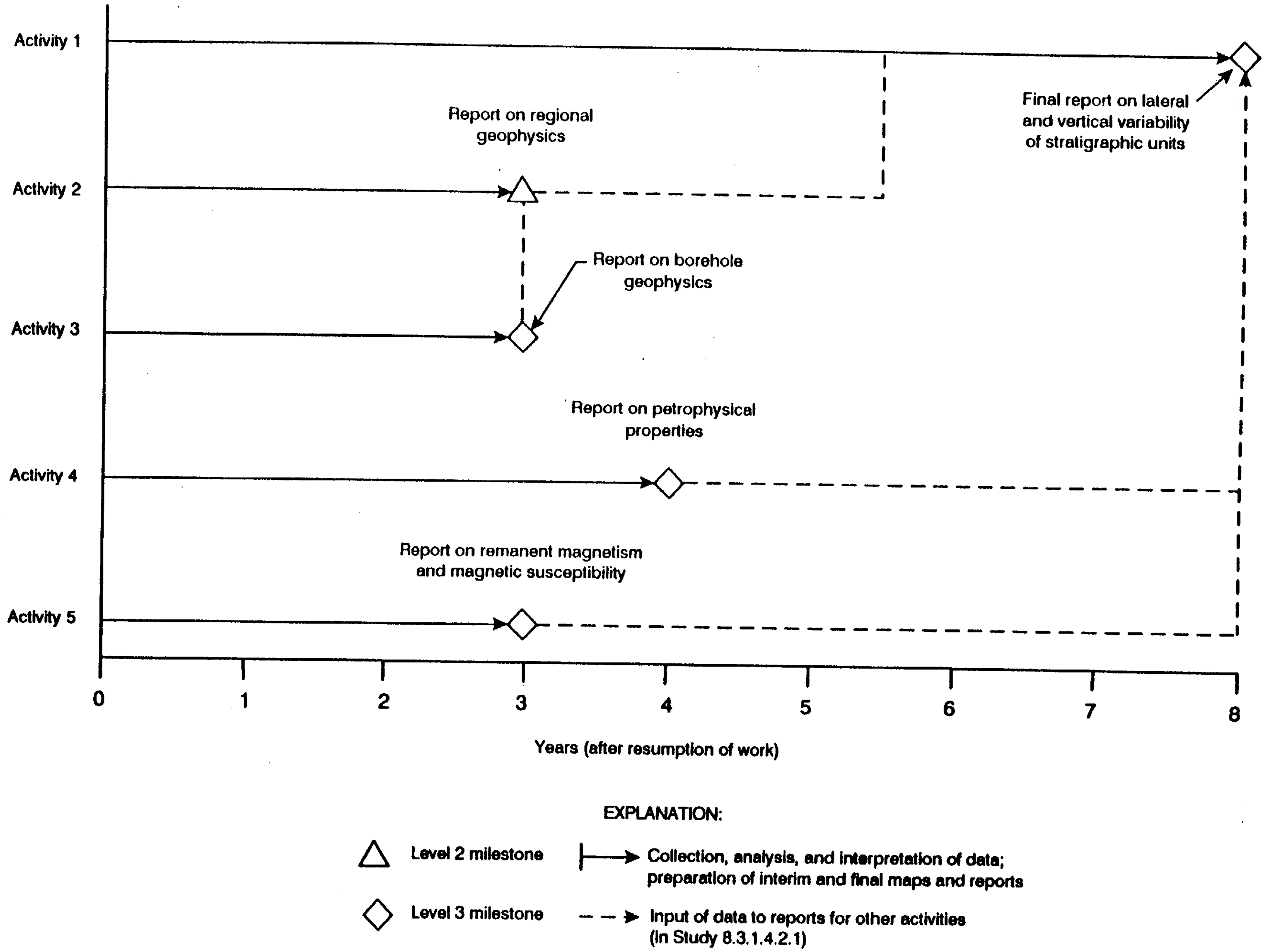

Figure 5-1. Generalized Schedule for Study 8.3.1.4.2.1

Table 1.2-1 Design & Performance Issues and Requirements Supported by this Study

ACTIVITY: 8.3.1.4.2.1.1 Surface and subsurface stratigraphic studies of the host rock and surrounding units

1.1 Limiting radionuclide releases to the accessible environment for 10,000 years after repository closure as required by 10 CFR 60.112 and 40 CFR 191.13

1.4 Containment of high-level waste in the waste package for 300 to 1,000 years after repository closure as required by 10 CFR 60.113

1.5 Limiting radionuclide releases from the engineered-barrier systems from the end of the containment period to 10,000 years following repository closure as required by 10 CFR 60.113

1.6 Pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment shall be at least 1,000 years as required by 10 CFR 60.113

1.10 Waste-package characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.135

1.11 Underground repository and engineered-barrier characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.133

1.12 Shaft and borehole seal characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.134

2.7 Repository design criteria for radiological safety that comply with the preclosure design criteria of 10 CFR 60.130 through 60.133

4.4 Repository preclosure design and technical feasibility

CHARACTERIZATION PARAMETERS:

Contact altitude
Lithostratigraphy, exposed bedrock
Lithostratigraphy, glass, pumice and spherulite
Lithostratigraphy, lithic fragments
Lithostratigraphy, lithophysae
Lithostratigraphy, mineralogy and petrography
Lithostratigraphy, particle sorting
Lithostratigraphy, particle-size distribution
Lithostratigraphy, subunits
Mineralogy, diagenesis, paragenesis, epigenesis
Stratigraphic depositional history, flow units
Stratigraphic orientation, attitude
Stratigraphic thickness

Table 1.2-1 (cont.)

DESIGN/PERFORMANCE REQUIREMENTS (PARAMETERS):

Contact altitude
Contact altitude, areas of minimum ground-water travel time
Contact altitude, areas of minimum overburden
Contact altitude, exploratory boreholes
Contact altitude, for positioning underground facility
Contact altitude, hydrologic units
Contact altitude, lithologic units
Contact altitude, rock unit lateral and vertical variability
Contact altitude, thermomechanical units
Morphology of bedrock surface, shaft locations
Rock-unit chemistry, mineralogy

Table 1.2-1 (cont.)

ACTIVITY: 8.3.1.4.2.1.2 Surface-based geophysical surveys

1.6 Pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment shall be at least 1,000 years as required by 10 CFR 60.113

1.11 Underground repository and engineered-barrier characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.133

4.4 Repository preclosure design and technical feasibility

CHARACTERIZATION PARAMETERS:

Electromagnetic signature (stratigraphy)
Gravity anomaly, mass difference
Lithostratigraphy, subunits
Magnetic intensity (geophysical), gradient, anomaly, lithologic correlation
Magnetism, lithologic correlation
Seismic motion, surface, subsurface and geologic bias, f(depth, direction)

DESIGN/PERFORMANCE REQUIREMENTS (PARAMETERS):

Contact altitude, lithologic units
Contact altitude, rock unit lateral and vertical variability
Seismic design basis, depth attenuation

Table 1.2-1 (cont.)

ACTIVITY: 8.3.1.4.2.1.3 Borehole geophysical surveys

1.5 Limiting radionuclide releases from the engineered-barrier systems from the end of the containment period to 10,000 years following repository closure as required by 10 CFR 60.113

1.6 Pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment shall be at least 1,000 years as required by 10 CFR 60.113

1.11 Underground repository and engineered-barrier characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.133

1.12 Shaft and borehole seal characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.134

2.7 Repository design criteria for radiological safety that comply with the preclosure design criteria of 10 CFR 60.130 through 60.133

4.4 Repository preclosure design and technical feasibility

CHARACTERIZATION PARAMETERS:

Borehole locations, characteristics
Borehole temperature profiles
Electrical conductivity (geophysical), lithologic correlation
Electrical resistivity (geophysical), lithologic correlation
Gamma-ray radiation (geophysical), intensity, lithologic/discontinuity correlation
In-situ thermal gradient
Induced polarization (geophysical), lithologic correlation
Magnetic intensity (geophysical), gradient, anomaly, lithologic correlation
Magnetism, susceptibility
Porosity, lithostratigraphic correlation
Spontaneous potential (geophysical), lithologic correlation
Water content, in-situ

DESIGN/PERFORMANCE REQUIREMENTS (PARAMETERS):

Borehole casing (location and condition), exploratory holes
Borehole depth, exploratory and waste-emplacement holes
Borehole diameter, exploratory and waste-emplacement holes
Borehole location, exploratory holes and waste-emplacement holes
Contact altitude, exploratory boreholes
Electrical resistivity (geophysical)
In-situ temperature, regional heat flow
Moisture content, volumetric, rock matrix

Table 1.2-1 (cont.)

DESING/PERFORMANCE REQUIREMENTS (PARAMETERS):
(Continued)

Porosity, total, fractures
Porosity, total, rock matrix
Water quantity, near-field

Table 1.2-1 (cont.)

ACTIVITY: 8.3.1.4.2.1.4 Petrophysical properties testing

1.1 Limiting radionuclide releases to the accessible environment for 10,000 years after repository closure as required by 10 CFR 60.112 and 40 CFR 191.13

1.6 Pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment shall be at least 1,000 years as required by 10 CFR 60.113

2.7 Repository design criteria for radiological safety that comply with the preclosure design criteria of 10 CFR 60.130 through 60.133

CHARACTERIZATION PARAMETERS:

- Density, bulk
- Density, grain
- Electrical resistivity (geophysical), lithologic correlation
- Induced polarization (geophysical), lithologic correlation
- Permeability, intrinsic, unsaturated-zone units
- Porosity

DESIGN/PERFORMANCE REQUIREMENTS (PARAMETERS):

- Density, bulk
- Density, grain
- Electrical resistivity (geophysical)
- Porosity
- Porosity, total, rock matrix

Table 1.2-1 (cont.)

ACTIVITY: 8.3.1.4.2.1.5 Magnetic properties and stratigraphic correlations

1.6 Pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment shall be at least 1,000 years as required by 10 CFR 60.113

1.11 Underground repository and engineered-barrier characteristics and configurations that comply with the postclosure design criteria of 10 CFR 60.133

CHARACTERIZATION PARAMETERS:

Contact type, depositional/tectonic
Curie temperature
Lithostratigraphy, glass, pumice and spherulite
Lithostratigraphy, particle variation, flow units
Lithostratigraphy, texture, fabric and grain size
Magnetic intensity (geophysical), gradient, anomaly, lithologic correlation
Magnetic minerals, abundance and saturation
Magnetic minerals, remnant paleomagnetism
Magnetism, demagnetism and alternating thermal fields
Magnetism, susceptibility
Stratigraphic depositional history, flow units
Stratigraphic thickness

DESIGN/PERFORMANCE REQUIREMENTS (PARAMETERS):

Contact altitude, lithologic units
Contact altitude, rock unit lateral and vertical variability

TABLE 2.1-1: Macroscopic, microscopic and chemical parameters used in characterization and stratigraphic correlation of volcaniclastic deposits at Yucca Mountain.

GENERAL FEATURES	SPECIFICALLY MEASURED PARAMETERS
Contacts: (interflow, internal cooling breaks, sedimentary)	attitude, geological nature
Deposit geometry (stratigraphic unit, rock unit)	local thickness, regional (isopach) thickness, paleotopographic influence, total volume
Internal structures (volcanologic, depositional)	presence and type of bedding, vitrophyric and lithophysal horizons, rheomorphic flow structures, pumice/lithic-rich horizons
Grainsize analyses (pumice, matrix and lithic clasts)	maximum grainsize, grainsize distribution, degree of sorting
Constituents (pumice, crystals, ash, lithics)	volume percentages, intraflow distributions mineral modes, lithic clast lithology
Primary cooling features	compaction, degree of type of welding, extent of devitrification, development of spherules and lithophysae, vapor phase mineralization, bulk density, porosity
Primary component chemistry (bulk rock, pumice clast, glass, minerals from pumice)	major and trace elements, radiogenic isotopes
Secondary alteration	type (high vs. low temperatures), major phases, extent of secondary mineral replacement, kinetics of natural radioisotope mobilities

Table 2.3-1 Utility of geophysical logs

Direct Parameters	Derived Parameters: Lithology	Porosity	Saturation	Zeolites and Clays	Moduli	Fractures	Permeability
C .... wd .... Caliper	2						
C .... wd .... Gamma-ray	1						
C .... wd .... Spectral gamma-ray	1			1		2	
C .... wd .... Density	1	1			1		3
C .... w .... Compensated neutron	1	1		2			3
C .... wd .... Epithermal neutron	1		1	2			3
C .... w .... Sonic velocity	1	1			1	2	3
C .... w .... Sonic waveform						1	3
C .... wd .... Induction resistivity	1	1	1	2			3
C .... w .... Normal resistivity	1	1		2			
C .... wd .... Dielectric	1	1	1	2			
G .... w .... Induced polarization				2			
G .... wd ... Magnetic susceptibility	1						
G .... wd ... Magnetic field	1						
G .... wd ... Gravimetry		1					
E .... d .... Nuclear magnetic resonance		x				x	

C .... commercial logging company
G .... USGS logging equipment
E .... experimental, no supplier at present
w .... tool operates in fluid-filled hole
d .... tool operates in air-filled hole

Measurements provide:
1 .... quantitative or excellent qualitative information
2 .... good qualitative information
3 .... qualitative information in some cases
x .... expected to provide quantitative information

Table 3.1-1 Technical procedures for Activity 8.3.1.4.2.1.1

Method	Technical Procedure	
	Number	Title
	(NWM-USGS-)	
Sampling, lithologic examination, and analysis of drill-bit cutting and core	GP-18	Volcanic stratigraphic studies
	GP-20	Volumetric estimation of lithophysae
Borehole video surveys and logging	GP-10	Borehole-video fracture logging
Surface-outcrop mapping of exposure of Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff units	GP-01	Geologic Mapping
	GP-05	Geologic support activities
	GP-18	Volcanic stratigraphic studies
	GP-20	Volumetric estimation of lithophysae
Geochemical and isotopic studies	GCP-01	Radiometric-age data bank
	GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
	GCP-05	Radium-equivalent uranium, thorium, and potassium analysis by gamma-ray spectrometry
	GCP-07	Mineral separation for geochemistry and isotope analysis
	GCP-09	Spike calibration for Uranium-series and Uranium-trend analyses
	GCP-12	Rb-Sr Isotope Geochemistry
	GCP-13	U-Th-Pb Isotope Geochemistry
	GCP-15	Oxygen Isotope Analysis of Opaline Silica, Chalcedony, and Quartz
	GCP-20	K-Ca Isotope Geochemistry
	GCP-21	Sm-Nd Isotope Geochemistry

Table 3.1-1 Technical procedures for Activity 8.3.1.4.2.1.1 (Contd)

Method	Technical Procedure	
	Number	Title
	GP-08	Correlation of tephra by means of chemical analysis
	GP-18	Volcanic stratigraphic studies

Table 3.1-2 Ranges of characterization parameters. Specific data for this table from Byers and others, 1976; Scott and Castellanos, 1984; and Spengler and Chornack, 1984.

Parameter	Unit	Range
Welding and primary characteristics of lavas and ash-flow tuffs	All units	Through base of Topopah Spring, non- to densely-welded, mostly devitrified, but major units have vitric portions near top and bottom; below Topopah Spring, non- to moderately welded, much of rock zeolitized; major flows range from simple to compound cooling units
Petrographic characteristics	All units	Phenocryst content in ash-flows 8 to 25%, in high-silica rhyolites 1 to 8%; composition ranges from quartz latite to high-silica rhyolite (66-78 weight percent SiO^2)
Pumice characteristics	All units	Devitrified to vitric; some units have vapor phase crystallization
Type and abundance of lithic fragments	All units	Range in composition from basalt to rhyolite; size range generally 1 mm to 7 cm; angular in flows; trace to 8 percent in Paintbrush Tuff, 1 to 4 percent in the Prow Pass Member of the Calico Hills Tuff, increasing downward in the Tram Member of the Calico Hills Tuff from 3 percent to as much as 34 percent, 16 to 30 percent in the Lithic Ridge Tuff.
Characteristics of lithophysal zones	Ash flow	Two major zones each in Tiva and Topopah Members; lower zone averages 3.1 x 2.5 cm, void content 2 to 5 percent of rock, and flattened; upper zone averages 2.7 x 2.1 cm, void content ranges from 11 to 29 percent of rock, only slightly flattened
Degree and type of alteration	All units	Unaltered to zeolite facies; altered rocks could contain heulandite, mordenite, clinoptilolite, and analcime
Depth, thickness, attitude, extent of lithostratigraphic units	All units	Depths to some units unknown; thickness ranges shown in table 3.1-3; strikes of units range from N20W to N35E, dips are mostly to the east, ranging from 4 to 10 degrees; extent of younger lithostratigraphic units shown on figure 2.1-5, older units are not expected to be as extensive.

Table 3.1-2 (Contd) Ranges of characterization parameters. Specific data for this table from Byers and others, 1976; Scott and Castellanos, 1984; and Spengler and Chornack, 1984.

Parameter	Unit	Range
Location and general characteristics of bedded tuff intervals, grain size, sorting characteristics, diagenetic mineral phases, and depositional characteristics	Bedded and reworked tuffs	These units are generally deposited prior to flow units and may cover more area than do the flows. Poorly indurated non-welded; poorly to well sorted; generally rounded and broken pumice; grain size ranges from silty ash to pebbles; diagenetic mineral phases (1) precipitation of smectitic rind-forming clay, (2) dissolution of volcanic glass, (3) precipitation of heulandite/clinoptilolite, (4) other phases of smectitic-clay, (5) precipitation of K-feldspar, (6) mordenite and analcime below Paintbrush; Bulk density range 1.47-2.01 g/cc; grain density range 2.35-2.62 g/cc; units can be bedded, non-bedded, or reworked.

TABLE 3.1-3 Volcanic stratigraphy at Yucca Mountain

Potassium-argon age-dating method, (million years)	Magnetic polarity[a]	Rock unit[b]	Range in thickness (m)
10.2	ND[c]	Basalt dikes	ND
		*Timber Mountain Tuff	ND
11.3		*Rainier Mesa Member	0-46
		Bedded tuff	0-61
		*Paintbrush Tuff	ND
12.5	R	*Tiva Canyon Member	69-148
		Bedded tuff	1-15
	R	*Yucca Mountain Member	0-29
		Bedded tuff	0-47
	R	*Pah Canyon Member	0-71
		Bedded tuff	0-9
13.1	N	*Topopah Spring Member	287-359
		Bedded tuff	1-17
13.4[d]		Tuffaceous beds of Calico Hills	27-289
		Bedded tuff	0-21
		*Crater Flat Tuff	ND
	n	*Prow Pass Member	80-193
		Bedded tuff	2-10
13.5	N	*Bullfrog Member	68-187
		Bedded tuff	6-22
	R	*Tram Member	190-369
		Bedded tuff	3-50
	N	Dacite lava and flow breccia	0-249

TABLE 3.1-3 Volcanic stratigraphy at Yucca Mountain (Contd)

Potassium-argon age-dating method, (million years)	Magnetic polarity[a]	Rock unit[b]	Range in thickness (m)
		Bedded tuff	0-14
	I	*Lithic Ridge Tuff	ND
		Bedded tuff	3-7
13.9		Older volcanic rocks and volcanogenic sedimentary rocks	>345

[a] Polarity symbols: R = reversed, N = normal, I = intermediate between reversed and normal.

[b] Names and rankings of some units do not conform to U. S. Geological Survey usage. Formally recognized names are preceded by asterisks.

[c] ND = not determined.

[d] Age determined from associated lava.

Table 3.1-4 Ranges of expected isotopic ratios

$^{87}Sr/^{86}Sr$	0.705-0.730
$^{40}Ca/^{42}Ca$	150.97-151.10
$^{143}Nd/^{144}Nd$	0.511-0.513
$^{206}Pb/^{204}Pb$	15-30
$^{207}Pb/^{204}Pb$	15-16
$^{208}Pb/^{204}Pb$	35-50

Table 3.2-1 Technical procedures for Activity 8.3.1.4.2.1.2

Method	Technical Procedure Number	Technical Procedure Title
	(NWM-USGS-)	
Seismic refraction method	SP-08	Seismic study of the tectonic environment
	SP-09	Calibration of seismic refraction equipment
	TBD	Seismic Refraction surveys
Seismic reflection method	SP-10	Deep seismic reflection study of the tectonic environment
	SP-14	Shallow reflection survey (Mini Sosie)
Gravity method	GPP-01	Gravity measurement and data reduction
	GPP-16	Absolute measurement of gravity
Magnetic method	GPP-11	Magnetic methods
	TBD	Acquisition of aeromagnetic data
Electrical method	GPP-18	Magnetotelluric measurements

TBD = to be determined

Table 3.2-2 Estimated accuracy for seismic reflection surveys

Parameter	Accuracy
Seismograph location	1 m horizontal, 3 m vertical
Shot point location	1 m horizontal, 3 m vertical
Seismograph timing	1 msec
Shot point timing	1 msec
Data sampling	1 msec (1000 samples/sec)
Signal amplitude calibration	± 10% of output signal
Seismic frequency response	uniform to ± 20% in ground velocity (cm/sec) at 10-70 Hz

Table 3.2-3 Estimated accuracy for seismic refraction surveys

Parameter	Accuracy
Seismograph location	1 m horizontal, 3 m vertical
Shot point location	1 m horizontal, 3 m vertical
Seismograph timing	5 msec
Shot point timing	5 msec
Data sampling	5 msec (200 samples/sec)
Signal amplitude calibration	± 10% of output signal
Seismic frequency response	uniform to ± 20% in ground velocity (dm/sec) at 10-30 Hz

Table 3.2-4 Expected anomaly amplitudes of surface-based measurements of magnetic induction (A/m - amperes/meter; nT - nanotesla)

	Magnetic Anomaly
Weakly magnetized (< 0.50 A/m)	< 150 nT
Moderately magnetized (0.50 to 1.50 A/m)	150 to 450 nT
Strongly magnetized (> 1.50 A/m)	> 450 nT

Table 3.2-5 Gravity and magnetic instruments (EDM, electronic distance measuring; TBD, To be determined)

Type	Example	Type of Data
Gravity meter	LaCoste & Romberg meter	Gravity
Magnetometer	GeoMetrics proton precession	Magnetic
Recording devices	TBD, Digital or analog	---
Survey/navigation	Hewlett-Packard EDM device	Location]
Balance	Sartorius electronic	Density
Susceptibility meter	Bison susceptibility bridge	Susceptibility

Table 3.3-1 Technical procedures for Activity 8.3.1.4.2.1.3

Method	Technical Procedure	
	Number	Title
	(NWM-USGS-)	
Borehole geophysical surveys	GPP-12	Borehole gravity measurement and data reduction
	GPP-14	Induced polarization borehole logging operations
	GPP-15	Magnetic susceptibility borehole logging operations
	GPP-17	Magnetometer borehole logging operations
	TBD	Other logging procedures

TBD = to be determined

Table 3.3-2 Table of expected ranges of parameters measured by geophysical logging tools (API -American Petroleum Institute)

Log Type (units)	Range of values
Caliper (inches)	4.0 - 30.0
Density (gm/cc)	1.4 - 2.8
Gamma-ray (API)	50 - 350
Compensated neutron (percent porosity)	2 - 50
Epithermal neutron (API)	0 - 10,000
Resistivity (ohm-meters)	2 - 4,000
Dielectric constant (dimensionless)	5 - 50
Compressional sonic velocity (m/s)	2,000 - 7,000

Table 3.3-3 Equipment to be used in Activity 8.3.1.4.2.1.3

Log acquisition

1. Logging trucks with digital recording capability providing routine logging services to depth of 5000 feet in boreholes ranging from 4 to 12 inches bit diameter. Logging tools include:

   Caliper, three-arm and six-arm
   Gamma-ray, scintillation detector
   Density, gamma-ray source and scintillation detector
   Compensated neutron, neutron source and He-3 detectors
   Epithermal neutron, neutron source and shielded He-3 detectors
   Dual induction resistivity with focussed array
   Normal resistivity
   Spectral gamma ray with minimum 64 energy channels
   Full waveform sonic log with variable density display
   Compensated acoustic log

2. Logging truck capable of lowering borehole gravimeter to a depth of 5000 feet.

3. Logging truck with digital recording capability providing magnetometer, magnetic susceptibility, and induced polarization logs.

Log Analysis

Terminals: three PCs with color graphics capability
Computer: VAX/780 or equivalent
Plot capability: two HP paint-jets, one Versatec V80 or equivalent,
one Versatec wide-bed or equivalent
Print capability: one HP laser-jet or equivalent
Digitizing: Calcomp 9800 or equivalent
Log analysis software: Energy Systems "ESLOG" or comparable
Statistical software: SAS Institute Inc. "SAS" or comparable
Mapping software: Dynamic Graphics "ISM" or comparable
Terminal emulation software: TGRAF-07 or comparable
Word processing software: Microsoft "WORD" or comparable

Table 3.4-1 Technical procedure for Activity 8.3.1.4.2.1.4

Method	Technical Procedure Number	Technical Procedure Title
	(NWM-USGS-)	
Laboratory measurements of rock properties	GPP-10	Rock properties analysis of Yucca Mountain core samples

Table 3.4-2 Ranges of expected values for petrophysical measurements and parameters

Log Type (units)	Range of values
Grain density (gm/cc)	2.3 - 2.8
Bulk density (gm/cc)	1.4 - 2.8
Porosity (percent)	0.02 - 0.5
Water saturation (percent)	0.3 - 1.0
Resistivity (ohn-meters)	2.0 - 4000
Dielectric constant (dimensionless)	5.0 - 50
Saturation exponent	1.5 - 2.5

Table 3.5-1 Technical procedures for Activity 8.3.1.4.2.1.5

Method	Technical Procedure	
	Number	Title
	(NWM-USGS-)	
Density variation in rock mass	GP-14	Measurement of dry bulk-rock densities from paleomagnetic samples
Use of hand-held magnetic susceptibility meter	GPP-06	Rock and paleomagnetic investigations
Borehole magnetic surveys and logging	GPP-15	Magnetic-susceptibility borehole logging operations
	GPP-17	Magnetometer borehole logging operations
Sampling and paleomagnetic testing and analysis of selected intervals of core and outcrop	GPP-06	Rock and paleomagnetic investigations
	TBD	Logging procedure

TBD = to be determined

Table 3.5-2 Ranges of values for paleomagnetic measurements

Susceptibility - 0.00001 to 0.04 (SI)
Natural remanent magnetization - 0.01 to 30 Amperes/meter (A/m)
Saturation isothermal remanent magnetization - 0.1 to 100 A/m
Saturation magnetization - 1 to 1000 A/m
Coercivity - 10 to 150 millitesla (mT)
Coercivity of remanence - 1 to 50 mT
Curie temperature - 500° to 640° C

Table 3.5-3 Field equipment for paleomagnetic surveys

Geologic and topographic maps
Rock hammer
Portable gasoline-powered core drill and accessories
Diamond core bit
Paleomagnetic-core orienter
Sun compass
Magnetic compass
Watch
Brass scribe
Waterproof marking pens
Notebook
Sample bags

Table 3.5-4 Laboratory equipment for paleomagnetic studies

Rock saws and other lapidary equipment for sample preparation
Computer and computer software
Spinner magnetometer
Susceptometer
Alternating field demagnetizer
Thermal demagnetizer
Thermocouples and thermocouple readout
Electromagnet
Gaussmeter
Vibrating sample magnetometer
Electrobalance with an attached furnace

Table 4-1 Information to be provided to other studies by Study 8.3.1.4.2.1

General

Information to be obtained	Where information will be used[1]	How information will be used
Spatial distribution of lithostratigraphic units and subunits, history of emplacement, characteristics of lithostratigraphic units and subunits, geophysical and rock property information	8.3.1.4.2.3.1	To construct isopach maps, structural contour correlation diagrams, cross sections, stratigraphic and litho-logic models.
		To develop a three-dimensional geologic model of the Yucca Mountain site that incorporates stratigraphic, structural, geophysical, and rock properties information.
	8.3.1.4.3.2.1	To develop computer-based three-dimensional models that integrate data on rock characteristics in light of a constraining geologic framework (developed in Investigation 8.3.1.4.2.) for Yucca Mountain.
	8.3.1.17.4.12.1	To aid in the synthesis and evaluation of regional geologic, gravity, and magnetic studies.
		To aid in the preparation and interpretation of geologic, gravity, and magnetic maps of the Beatty 1:100,000 quadrangle.

Activity 8.3.1.4.2.1.1

Information to be obtained	Where information will be used[1]	How information will be used
Depth, thickness, attitude, and extent of lithostratigraphic units; location and general characteristics of bedded tuff intervals, including grain size and sorting characteristics, diagenetic minerals phases, and depositional characteristics	8.3.1.2.2	To aid in identifying stratigraphic lateral continuity and inhomogeneities that may act as potential lateral flow paths.
	8.3.1.2.3	To determine if abrupt changes in lithologies or structural styles within Yucca Wash are factors that influence the steeper gradient in the potentiometric surface north of drill hole USW G-1.
		To determine if the paleotopographic high in the Paintbrush Tuff (5 km southwest of Busted Butte) has an effect on ground-water travel times and potential flow paths in southern Yucca Mountain for saturated zone flow modeling.
Host rock mineralogy, geochemistry lithostratigraphy	8.3.1.3.2	To aid in determining the impact of repository development on the host rock.

Activity 8.3.1.4.2.1.2

Information to be obtained	Where information will be used[1]	How information will be used
Seismic velocity contrasts, seismic attenuation, seismic reflective horizons, density variations in magnetic field orientation and strength, and variations in electrical properties that are associated with vertical or lateral changes in lithology; lateral continuity defined by geophysical surveys	8.3.1.4.1	To aid in borehold siting, sampling, and testing.
	8.3.1.4.2.3.1	To improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical restraints.
	8.3.1.4.3.2.1	To provide constraints upon subsurface modeling.

Activity 8.3.1.4.2.1.3

Information to be obtained	Where information will be used[1]	How information will be used
Rock property data	8.3.1.2.2	To aid in the definition of the spatial distribution of unsaturated zone hydrogeological units and their hydraulic properties in order to determine conceptual models for the overall flow system within the unsaturated zone.
	8.3.1.2.2.3	To aid in the definition of the spatial distribution of hydrogeological units and their hydraulic properties in order to determine the internal and external boundary conditions that can be applied to the site saturated zone model.
	8.3.1.4.1.2	To be used in the integration of all geophysical site characterization activities.
	8.3.1.4.2.2.5	To aid in the analyses of data from seismic or electrical tomography to develop quantitative and empirical relationships needed to characterize subsurface variability between shafts and drill holes.

Activity 8.3.1.4.2.1.4

Information to be obtained	Where information will be used[1]	How information will be used
Electrical resistivity and bulk density of core samples containing in situ pore waters; electrical resistivity, induced polarization, bulk density, grain density, porosity, seismic velocities, and hydraulic conductivity on resaturated samples	8.3.1.2.2	To provide data on (a) moisture flux through the rock matrix, (b) preferential paths for water flow, and (c) the potential for contaminant transport by means of diffusion processes.
	8.3.1.2.3	To provide data on (a) the degree of water saturation within the rock above the static water level, (b) the moisture flux through the rock matrix, and (c) the potential paths for water flow.
	8.3.1.3.2	To provide information on the concentrations of clays and zeolites within the measured stratigraphic section.
	8.3.1.4.2.3.1	To provide data on statistical relationships of various rock properties (e.g., degree of welding, alteration, and compositional uniformity).
		To provide data on rock property variation for integration in a three-dimensional geophysical model of the site.
	8.3.1.4.3.2.1	To provide constraints on subsurface modeling.
	8.3.1.15.1.1 8.3.1.15.1.3	To aid in the correlation of downhole geophysical log data with laboratory thermal and mechanical property measurements.

Activity 8.3.1.4.2.1.5

Information to be obtained	Where information will be used[1]	How information will be used
Measured magnetic properties: orientation and magnitude of remanent magnetism, magnetic susceptibility, and Curie temperature.	8.3.1.4.2.2.3	To provide paleomagnetic directions and orientations for drill core segments.
Measured properties of flow units: textural variations across boundaries, grain size variations, pumice clast concentrations, locations of lithic-rich subzones, and nature of contacts between flow units.	8.3.1.4.2.3.1	To provide magnetic property data to aid in the interpretation of volcanic stratigraphy and structure of rock units within the Yucca Mountain site area.
Inferred properties of flow units: locations of depositional breaks and thicknesses of individual flow units.		
Rotation of paleomagnetic poles	8.3.1.17.4.3.2	To analyze the rotation (drag) of bedrock along or over suspected wrench faults (based on rotation of paleomagnetic poles). To evaluate preliminary results of paleomagnetic sampling at Yucca Mountain.

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[1] Investigation, study, or activity in which information will be used:

Investigation 8.3.1.2.2 Studies to provide a description of the unsaturated zone hydrologic system at the site

Study 8.3.1.2.2.3 Characterization of percolation in the unsaturated zone--surface-based study

Investigation 8.3.1.2.3 Studies to provide a description of the saturated zone hydrologic system at the site

Investigation 8.3.1.3.2 Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths

Activity 8.3.1.4.1.2 Integration of geophysical activities

Activity 8.3.1.4.2.2.3 Borehole evaluation of faults and fractures

Activity 8.3.1.4.2.2.5 Seismic tomography/vertical seismic profiling studies

Activity 8.3.1.4.2.3.1 Development of a three-dimensional geologic model of the site area

Activity 8.3.1.4.3.2.1 Development of three-dimensional models of rock characteristics at the repository

Study 8.3.1.15.1.1 Laboratory thermal properties

Study 8.3.1.15.1.3 Laboratory determination of mechanical properties of intact rock

Activity 8.3.1.17.4.3.2 Evaluate Quaternary faults within 100 km of Yucca Mountain

Activity 8.3.1.17.4.12.1 Evaluate tectonic processes and tectonic stability at the site

SP 8.3.1.4.2.1 R0

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