DOE/RW-0160

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Nuclear Waste Policy Act
(Section 113)

Consultation Draft

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V

January 1988

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

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DOCUMENT ORGANIZATION

DOCUMENT ORGANIZATION (continued)

DOE/RW-0160

Chapter 8

Section 8.3.1.4

Nuclear Waste Policy Act
(Section 113)

M

ROCK CHARACTERISTICS

Consultation Draft

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8.3.1.4 Overview of the rock characteristics program: Description of the present and expected rock characteristics required by performance and design issues

Summary of performance and design requirements for rock characteristics information

Compliance with performance and design criteria for a geologic repository will require information about the rock characteristics of the Yucca Mountain site. This information will be used in the design of underground repository facilities and to support assessments of site performance related to ground-water travel time, waste-package lifetime, radionuclide releases from the engineered-barrier system (EBS), and radionuclide releases to the accessible environment. The various regulatory requirements are concerned with rock characteristics, conditions, and processes in different subsurface regions within and around Yucca Mountain.

The siting criteria discussed in 10 CFR 60.122 must also be evaluated, including the favorable condition for waste emplacement at a depth of 300 m and characterization of structural, stratigraphic, and geomechanical conditions to determine if potentially adverse conditions are present. Design criteria for the underground facility, seals of shafts and boreholes, and waste packages are also evaluated in the context of the natural rock properties of the site. Assessments of whether the performance objectives, siting criteria, and design criteria can be met will rely on information about the stratigraphy and structure of the Yucca Mountain site, the properties of the rock units occurring at the site, and the temperature and stress conditions before excavation of underground openings.

Approach to satisfy performance and design requirements

The geologic and geophysical site characterization activities described in this section provide an important category of information needed to develop a three-dimensional physical property model, i.e., the geometry associated with the material properties of the rock at the Yucca Mountain site. The objective of the three-dimensional model is to provide a computer-based representation of the physical properties of the rocks at the site. The data base for the model will contain the distribution of parameters (physical properties) within property-dependent units. An important function of the computer-based model will be to provide input for numerical computer analyses that involve hydrologic, thermal, thermomechanical, and geochemical processes.

The three-dimensional physical properties model is a representation of the Yucca Mountain repository site containing various kinds of data on its geologic, geohydrologic, thermal, mechanical, and geochemical properties. The model will allow predictions of how a physical property changes spatially within and across the boundaries of the model. The boundaries represent distinct changes in a property.

The location of the physical property boundaries will be based on three sources of information: (1) geologic studies, (2) geophysical studies, and (3) the physical property data. The physical properties model could be developed based entirely on the samples from site characterization. However, the geologic complexity of the Yucca Mountain site may cause large amounts of uncertainty associated with the variability of the properties between sample locations. Therefore, the geologic and geophysical data will be used to provide the geometric framework for the physical property data in the model. The nature and number of site characterization studies to be conducted will be determined by the level of confidence required for the physical properties and the numerical models in which they are being input.

Figure 8.3.1.4-1 provides the overall logic for developing the three-dimensional physical property model. The geologic, hydrologic, geochemical, and thermal/mechanical properties are the fundamental information to be contained in the model. The geologic framework serves as the geometric framework for the physical property model. The hydrologic, geochemical, and thermal mechanical properties will be developed in Sections 8.3.1.2, 8.3.1.3 and 8.3.1.15 respectively. These separate categories of properties are called on in this section in order to integrate them into the physical properties model. Table 8.3.1.4-1 serves as the first step in the correlation of parameter requests from design or performance issues (e.g., performance or design parameters in sections 8.3.5.12, 8.3.5.13, 8.3.2.2, and 8.3.3) and results from data gathering activities (activity parameters and associated characterization parameters). The parameter categories listed in Table 8.3.1.4-1 are topical categories that are used to translate data requests for types of design and performance information into similar types of site data to be collected. Because of the diversity and volume of data needs called for in the design and performance issues and data provided by characterization activities, it is inappropriate to expect a one-to-one correspondence between a requested performance parameter and an activity parameter. Rather, a given characterization parameter in almost every case will require data reduction and analysis of several related tests and data gathering activities to transform them into the information directly used in design or performance analysis.

Characterization parameters commonly will take the form of maps and other two- or three-dimensional illustrations, such as isopach maps, isopleth maps and structure contour maps, or diagrams displaying statistical distributions of activity parameters throughout the site. Many parameters will also include a spatial or unit-specific component such as an isopach map of a specific stratigraphic unit within a specified area. The eventual formulation of an appropriate testing basis for each characterization parameter will include the identification of (1) tentative parameter goals, (2) current estimate of parameter values, (3) current confidence level, and (4) needed confidence level. For example, if an isopach map of the thermomechanical unit TSw2 within the boundary of the repository perimeter drift is identified as a characterization parameter, then the tentative parameter goal may be that contours are accurate to within ± 30 m. Current estimates of the parameter will be obtained from information or references in Chapter 1 of the SCP. Needed confidence levels will indicate how important this information is to design and performance issues. Current levels of confidence will, in most cases, be low.

The grouping of performance parameters into categories is a necessary first step because individual parameter requests commonly differ with respect to such things as specific spatial locations, stratigraphic units, and

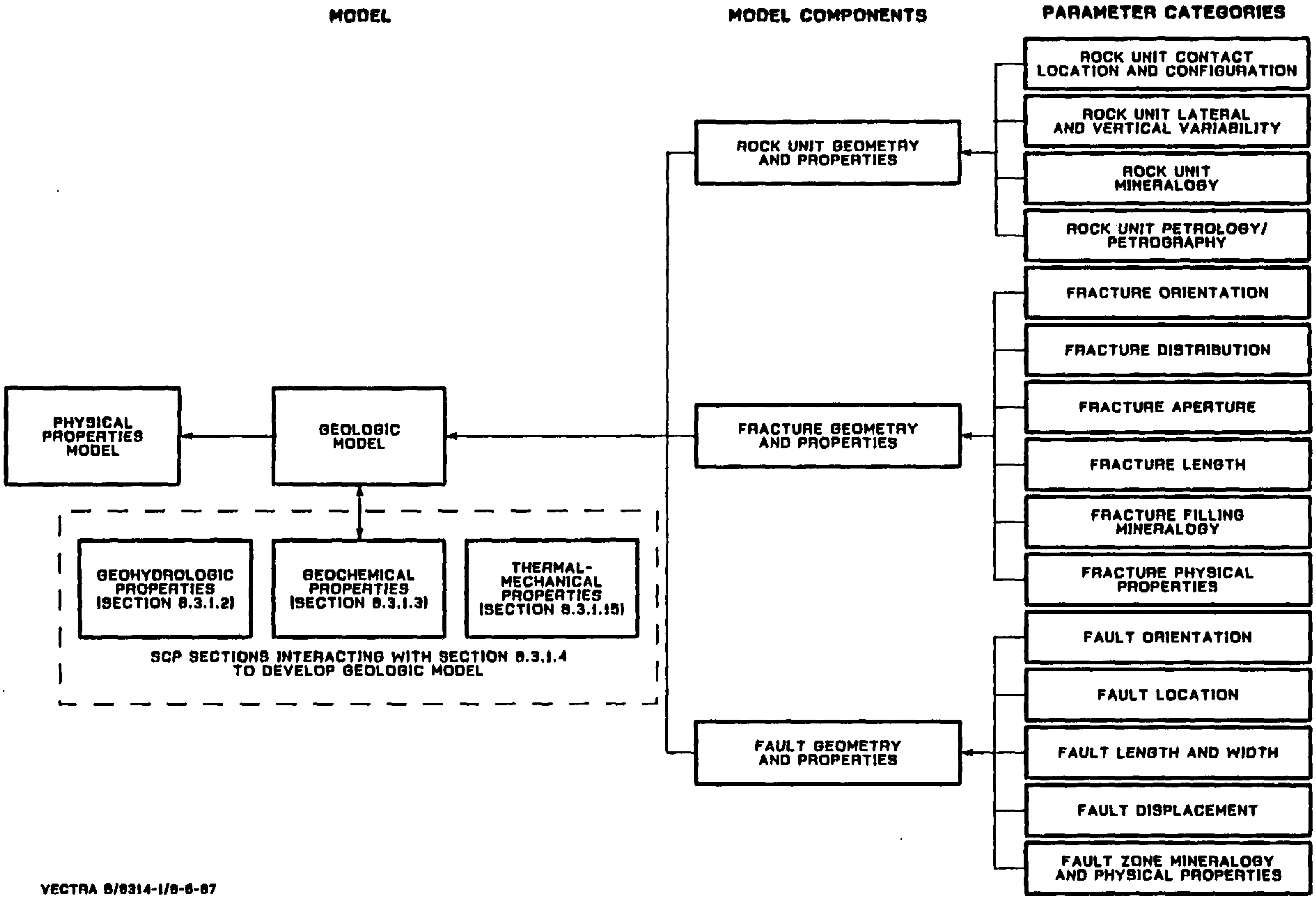


Figure 8.3.1.4-1. Logic diagram for the three-dimensional physical properties model.

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 1 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Rock-unit contact location and configuration	Attitude, ash-flow zones	8.3.1.4.2.2.1
1.6	8.3.5.12		Attitude, bedded-tuff zones	8.3.1.4.2.2.1
1.11	8.3.2.2		Attitude, lithostratigraphic units	8.3.1.4.2.1.1
1.12	8.3.3.2		Borehole diameter	8.3.1.4.2.1.3
4.4	8.3.2.5		Color, lithostratigraphic units	8.3.1.4.2.1.1
			Contacts, flow units	8.3.1.4.2.1.5
			Contacts, lithostratigraphic units, nature	8.3.1.4.2.1.1
			Correlatable sequences	8.3.1.4.2.1.1
			Depth, lithostratigraphic units	8.3.1.4.2.1.1
			Geophysical signature, lithostratigraphic markers	8.3.1.4.2.1.3
			Key marker beds	8.3.1.4.2.1.1
			Lateral continuity of horizons	8.3.1.4.2.1.2
			Lithology, stratigraphic sequence	8.3.1.4.2.2.4
			Locations, bedded tuff units	8.3.1.4.2.1.1
			Magnetic property changes, core samples	8.3.1.4.2.1.5
			Petrographic changes, core samples	8.3.1.4.2.1.4
			Seismic velocities	8.3.1.4.2.1.3
			Spontaneous potential	8.3.1.4.2.1.3
			Stratigraphic sequence, Topopah Spring welded unit	8.3.1.4.2.2.4
			Stratigraphic sequence, lithostratigraphic units	8.3.1.4.2.1.1
			Thickness, flow units	8.3.1.4.2.1.5
			Thickness, lithostratigraphic units	8.3.1.4.2.1.1

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 2 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Vertical distribution, lithostratigraphic units	8.3.1.4.2.1.2
1.1	8.3.5.13	Rock-unit lateral and vertical variability	Acoustic velocity, core samples	8.3.1.4.2.1.4
1.6	8.3.5.12		Age, potassium-argon, lithostratigraphic units	8.3.1.4.2.1.1
1.11	8.3.2.2		Areal extent, exposed bedrock	8.3.1.4.2.2.1
1.12	8.3.3.2		Density, bulk, in situ	8.3.1.4.2.1.3
4.4	8.3.2.5		Density, grain and bulk, core samples	8.3.1.4.2.1.4
			Density, variations	8.3.1.4.2.1.2
			Depositional characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Depositional units, Topopah Spring Member	8.3.1.4.2.1.5
			Electrical conductivity	8.3.1.4.2.1.3
			Electrical resistivity, core samples	8.3.1.4.2.1.4
			Electromagnetic properties, variations	8.3.1.4.2.1.2
			Emplacement history, ash-flow tuffs	8.3.1.4.2.1.1
			Extent, lithostratigraphic units	8.3.1.4.2.1.1
			Gravitational field, variations	8.3.1.4.2.1.2
			Hydraulic conductivity, core samples	8.3.1.4.2.1.4
			Induced polarization, core samples	8.3.1.4.2.1.4
			Laboratory/in situ rock property correlation, surface and subsurface geophysics	8.3.1.4.2.1.4
			Lateral continuity, horizons	8.3.1.4.2.1.2
			Lateral continuity, repository host horizon	8.3.1.4.2.2.4

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 3 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
			Lateral extent, ash-flow zones	8.3.1.4.2.2.1
			Lateral extent, bedded-tuff zones	8.3.1.4.2.2.1
			Lateral variability, lithostratigraphic units, exploratory shaft facility drifts	8.3.1.4.2.2.4
			Lithic fragments, concentration variations, subunit contacts	8.3.1.4.2.1.5
			Lithic fragments, type and abundance, lithostratigraphic units	8.3.1.4.2.1.1
			Lithic-rich subzones, locations, flow units	8.3.1.4.2.1.5
			Lithologic uniformity, relations to density, seismic velocity, porosity, and resistivity	8.3.1.4.2.1.4
			Lithophysal zone characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Lithophysal zones, geophysical signatures	8.3.1.4.2.1.3
			Magnetic field intensity, total	8.3.1.4.2.1.2
			Magnetic field, variations	8.3.1.4.2.1.2
			Magnetic susceptibility	8.3.1.4.2.1.3
			Magnetic susceptibility	8.3.1.4.2.1.5
			Porosity, core samples	8.3.1.4.2.1.4
			Porosity, variations	8.3.1.4.2.1.3
			Pumice characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Pumice clasts, concentration variations, subunit contacts	8.3.1.4.2.1.5

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 4 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Pumice clasts, concentrations, flow units	8.3.1.4.2.1.5
			Rock characteristics, changes, Topopah Spring Member	8.3.1.4.2.1.5
			Seismic velocity, contrasts	8.3.1.4.2.1.2
			Statistical analysis crossplots, geophysical measurements	8.3.1.4.2.1.3
			Thickness, ash-flow zones	8.3.1.4.2.2.1
			Thickness, bedded-tuff zones	8.3.1.4.2.2.1
			Thickness, volcanic section, from electromagnetic surveys	8.3.1.4.2.1.2
			Transport history, ash-flow tuffs	8.3.1.4.2.2.1
			Variability, lateral, lithostratigraphic units	8.3.1.4.2.1.1
1.1 4.4	8.3.5.13 8.3.2.5	Rock-unit mineralogy and petrology	Alteration history, ash-flow tuffs	8.3.1.4.2.2.1
			Alteration, degree and type, lithostratigraphic units	8.3.1.4.2.1.1
			Clay concentrations, from induced polarization data	8.3.1.4.2.1.4
			Compositional changes, anomalous, subunit contacts	8.3.1.4.2.1.5
			Cooling history, ash-flow tuffs	8.3.1.4.2.2.1
			Curie temperature	8.3.1.4.2.1.5
			Demagnetization, alternating field	8.3.1.4.2.1.5
			Demagnetization, thermal	8.3.1.4.2.1.5
			Depositional breaks, locations, flow units	8.3.1.4.2.1.5
			Essential minerals, abundance	8.3.1.4.2.1.1

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 5 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
			Gamma-radiation intensity temperature, relative	8.3.1.4.2.1.3
			Glassy intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, bedded-tuff intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, variations, flow units	8.3.1.4.2.1.5
			Induced polarization	8.3.1.4.2.1.3
			Isotopes, gamma-ray spectrometry	8.3.1.4.2.1.1
			Magnetic minerals, composition	8.3.1.4.2.1.5
			Magnetic minerals, grain size	8.3.1.4.2.1.5
			Magnetic minerals, grain size variation	8.3.1.4.2.1.5
			Magnetic minerals, relative abundance	8.3.1.4.2.1.5
			Magnetization, anhysteritic remanent	8.3.1.4.2.1.5
			Magnetization, isothermal remanent	8.3.1.4.2.1.5
			Magnetization, remanent, orientation and magnitude	8.3.1.4.2.1.5
			Magnetization, saturation	8.3.1.4.2.1.5
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1
			Mineral phases, distinctive morphologies	8.3.1.4.2.1.1
			Mineralogy, bedded-tuff units	8.3.1.4.2.1.1
			Mineralogy, lithostratigraphic units	8.3.1.4.2.1.1
			Paleomagnetic directions, lithostratigraphic units	8.3.1.4.2.1.5
			Petrography, lithostratigraphic units	8.3.1.4.2.1.1

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 6 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Petrography, stratigraphic sequence	8.3.1.4.2.2.4
			Potassium, uranium, thorium content	8.3.1.4.2.1.3
			Primary crystallization, lithostratigraphic units	8.3.1.4.2.1.1
			Smectite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Sorting, bedded-tuff units	8.3.1.4.2.1.1
			Sorting, lithostratigraphic units	8.3.1.4.2.1.1
			Spherulitic zones, lithostratigraphic units	8.3.1.4.2.1.1
			Textural variation, across flow-unit boundaries	8.3.1.4.2.1.5
			Texture, lithostratigraphic units	8.3.1.4.2.1.1
			Welding characteristics, anomalous, subunit contacts	8.3.1.4.2.1.5
			Welding, lithostratigraphic units	8.3.1.4.2.1.1
			Zeolite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Zeolites, concentrations, from induced polarization	8.3.1.4.2.1.4
		FRACTURE GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fracture distribution	Fractal analysis	8.3.1.4.2.2.2
1.6	8.3.5.12		Fracture characteristics, spatial variation	8.3.1.4.2.2.6
1.11	8.3.2.2		Fracture distribution, spatial	8.3.1.4.2.2.2
1.12	8.3.3.2		Fracture frequency, apparent, lateral variability	8.3.1.4.2.2.3
4.4	8.3.2.5			

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 7 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
			Fracture frequency, variation with depth	8.3.1.4.2.2.3
			Fracture frequency, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture location	8.3.1.4.2.2.3
			Fracture network geometry	8.3.1.4.2.2.2
			Fracture network, three-dimensional distribution, exploratory shaft facility	8.3.1.4.2.2.4
			Fracture networks	8.3.1.4.2.2.2
			Fracture patterns, local, variations	8.3.1.4.2.2.2
			Fracture, spatial distribution	8.3.1.4.2.2.4
			Fractures, subsurface, near fault zones, lateral variability	8.3.1.4.2.2.3
			Seismic properties, relation to fracture properties	8.3.1.4.2.2.6
			Seismic shear-wave amplitudes	8.3.1.4.2.2.6
			Seismic shear-wave polarizations	8.3.1.4.2.2.6
			Seismic shear-wave travel times	8.3.1.4.2.2.6
			Seismic-wave propagation characteristics	8.3.1.4.2.2.6
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture orientation	Fracture attitude, statistical distribution	8.3.1.4.2.2.3
			Fracture attitude, variation with depth	8.3.1.4.2.2.3
			Fracture attitude, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture orientation	8.3.1.4.2.2.2
			Fracture orientation	8.3.1.4.2.2.3

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 8 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Fracture orientation, statistical distribution	8.3.1.4.2.2.2
			Fracture orientation, statistical distribution	8.3.1.4.2.2.4
			Fracture strike direction, lateral variability	8.3.1.4.2.2.3
1.6	8.3.5.12	Fracture aperture	Fracture aperture	8.3.1.4.2.2.2
1.11	8.3.2.2		Fracture aperture	8.3.1.4.2.2.3
4.4	8.3.2.5		Fracture aperture	8.3.1.4.2.2.4
1.6	8.3.5.12	Fracture length	Fracture connectivity	8.3.1.4.2.2.2
1.11	8.3.2.2		Fracture dimension, maximum	8.3.1.4.2.2.3
4.4	8.3.2.5		Fracture intersections, distribution	8.3.1.4.2.2.2
			Fracture trace length	8.3.1.4.2.2.2
			Fracture trace length	8.3.1.4.2.2.4
			Fracture trace length, statistical distribution	
1.11	8.3.2.2	Fracture-filling mineralogy and physical properties	Fracture mineralization, degree	8.3.1.4.2.2.3
4.4	8.3.2.5		Fracture mineralization, relation to orientation	8.3.1.4.2.2.5
			Fracture roughness	8.3.1.4.2.2.2
			Fracture roughness	8.3.1.4.2.2.4
			Fracture roughness coefficient	8.3.1.4.2.2.3
			Fracture surface profile	8.3.1.4.2.2.3
			Fracture types	8.3.1.4.2.2.3
			Fracture-filling ages, potassium-argon dates, clay coatings	8.3.1.4.2.2.5
			Fracture-filling mineralogy	8.3.1.4.2.2.2

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 9 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Fracture-filling mineralogy	8.3.1.4.2.2.3
			Fracture-filling mineralogy	8.3.1.4.2.2.4
			Fracture-filling mineralogy, fracture coatings	8.3.1.4.2.2.5
		FAULT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fault location	Fault location	8.3.1.4.2.2.3
1.6	8.3.5.12		Fault trends, from electromagnetic surveys	8.3.1.4.2.1.2
1.11	8.3.2.2		Structural domains	8.3.1.4.2.2.4
4.4	8.3.2.5		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
			Tectonic style, faults	8.3.1.4.2.2.4
			Tectonic style, faults, Ghost Dance fault	8.3.1.4.2.2.4
1.1	8.3.5.13	Fault orientation	Fault and fault-zone attitude	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault orientation	8.3.1.4.2.2.4
1.11	8.3.2.2		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
4.4	8.3.2.5			
1.1	8.3.5.13	Fault length and width	Fault and fault length	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault-zone length and width	8.3.1.4.2.1.2
1.11	8.3.2.2		Fault-zone width	8.3.1.4.2.2.1
4.4	8.3.2.5		Fault-zone width	8.3.1.4.2.2.3

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 10 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
1.11 2.3 4.4	8.3.2.2 8.3.5.5 8.3.2.5	Fault displacement	Fault displacement, deep-seated faults, indication from lateral discontinuities	8.3.1.4.2.1.2
			Fault displacement, faults and fault zones	8.3.1.4.2.2.1
			Strike-slip faults, indications from lateral discontinuities	8.3.1.4.2.1.2
			Structural domains	8.3.1.4.2.2.4
			Tectonic styles, faults	8.3.1.4.2.2.4
			Tectonic styles, faults, Ghost Dance fault	8.3.1.4.2.2.4
4.4	8.3.2.5	Fault-zone mineralogy and physical properties	Alteration characteristics, fault zones	8.3.1.4.2.1.2
			Fault and fault-zone characteristics, near-surface faults and zones	8.3.1.4.2.2.1
			Fault physical characteristics	8.3.1.4.2.2.4
			Fault-zone hydraulic connectivity, from alteration zones	8.3.1.4.2.1.2
		GEOLOGIC FRAMEWORK		
1.1 1.6 1.11 1.12 4.4	8.3.5.13 8.3.5.12 8.3.2.2 8.3.3.2 8.3.2.5	Geologic framework	Correlation diagrams, lithostratigraphic units	8.3.1.4.2.3.1
			Correlation of laboratory values and in situ values for rock properties	8.3.1.4.2.3.1
			Cross sections, lithostratigraphic units	8.3.1.4.2.3.1

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 11 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Fractures, spatial distribution	8.3.1.4.2.3.1
			Fractures, spatial distribution	8.3.1.4.2.3.1
			Geologic model, three-dimensional	8.3.1.4.2.3.1
			Interpretation of depositional and and diagenetic history of rock units	8.3.1.4.2.3.1
			Interpretation of distribution of lithology, petrology, petrography, and mineralogy of rock units	8.3.1.4.2.3.1
			Isopach maps, lithostratigraphic units	8.3.1.4.2.3.1
			Isopleth maps, rock property values	8.3.1.4.2.3.1
			Relations between geologic and geophysical characteristics of rock units	8.3.1.4.2.3.1
			Rock properties, three-dimensional distribution	8.3.1.4.2.3.1
			Structure contour maps, lithostratigraphic units	8.3.1.4.2.3.1
			Surface geologic maps	8.3.1.4.2.3.1
			GEOLOGIC MODEL	
1.1	8.3.5.13	Geologic model synthesis	Age, fracturing	8.3.1.4.2.2.4
1.6	8.3.5.12		Age, fracturing	8.3.1.4.2.2.5
1.11	8.3.2.2		Chronology, faulting	8.3.1.4.2.2.1
1.12	8.3.3.2		Chronology, faulting, relative	8.3.1.4.2.2.3
4.4	8.3.2.5		Faulting chronology	8.3.1.4.2.2.1
			Fracture age, ESR dates, quartz	8.3.1.4.2.2.5

Table 8.3.1.4-1. Activity parameters provided by the rock characteristics program that support performance and design issues (page 12 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			Fracture age, uranium-thorium, calcite, uraniferous opal	8.3.1.4.2.2.5
			Fracture chronology, fracture development	8.3.1.4.2.2.2
			Fracture chronology, relative changes due to tectonism--see tectonism studies	8.3.1.4.2.2.3 8.3.1.8.2
			Fracture chronology, relative changes due to erosion--see erosion studies	8.3.1.6.4.1
			Saturation	8.3.1.4.2.1.3
			Water content	8.3.1.4.2.1.3
			Relationships among hydrologic test results, VSP fracture data and lithologic data	8.3.1.4.2.2.6
			Relationships among geochemical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.6
			Poisson's ratio	8.3.1.4.2.1.3
			Young's modulus	8.3.1.4.2.1.3
			Relationships among geomechanical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.6

associated goals, in some cases for the same parameter type within a given category. Thus, the parameter categories are defined to properly correlate sets of related design or performance parameters with corresponding sets of characterization parameters.

Table 8.3.1.4-1 lists activity parameters associated with each parameter category that incorporates information provided by the Rock Characteristics Program. The following explanation is provided to summarize the types of design and performance parameters encompassed by each category.

The table entries labelled "rock unit geometry and properties," "fracture geometry and properties," "fault geometry and properties," and "geologic framework" each represents a broad group of geologic and geophysical information (Figure 8.3.1.4-1). "Rock unit geometry and properties" is divided into three parameter categories: rock unit contact location and configuration; rock unit lateral and vertical variability; and rock unit mineralogy and petrology. The performance and design parameters associated with "rock unit contact location and configuration" include such items as unit contact attitudes for geohydrologic, geochemical, thermomechanical, and lithologic units; thickness of the Topopah Spring and other rock units; lateral extent of thermomechanical units; attitudes of various units; and depths to various unit contacts. Rock unit lateral and vertical variability includes such performance and design parameters as spatial correlation scales for hydrologic and geochemical properties, and extent and abundance of lithophysal cavities in the Topopah Spring Member. The category "rock unit mineralogy and petrology" combines requests for site information on such parameters as calcite cementation above the repository, radionuclide concentrations, and mineralogy around the waste packages.

The second group of parameter categories, "fracture geometry and properties," addresses information about the fracture network of Yucca Mountain. It includes five parameter categories. The first, "fracture distribution," includes design and performance requests primarily for fracture frequency, spacing, and abundance, as well as for spatial distribution to aid classification of fracture and joint sets. The second category, "fracture orientation," is self explanatory and provides a rare one-to-one match with performance and design requests. The next category in this group, "fracture aperture," includes requests for fracture widths and their local spatial distribution. The category for "fracture length" includes requests for fracture persistence, as well as fracture length. The last category in this group, "fracture filling mineralogy and physical properties," includes parameter requests for such items as roughness coefficients of fracture walls, distribution and concentrations of fracture fillings in the repository, and fracture weathering information in the Topopah Spring Member.

The next broad group of parameters categories, "fault geometry and properties," deals with the characteristics of faults and fault zones. The first four of these categories are self-explanatory and summarize design and performance requests for information on fault locations, orientations, length and width, and displacement. The fifth and last entry, "fault zone mineralogy and physical properties," has no specific corresponding requests from design and performance issues that are directly addressed by the characterization program for rock characteristics. The hydrological, thermomechanical, and geochemical properties of rock materials within fault zones are requested, but are listed under parameter categories for the type of property (e.g., permeability or retardation coefficient) in the appropriate characterization program (Sections 8.3.1.2, geohydrology program; 8.3.1.3, geochemistry program; and 8.3.1.15, thermal and mechanical properties program). Also, several requests for information relating to faulting potential and to location of faults with such potential are not listed here but are addressed in the sections on postclosure tectonics (Section 8.3.1.8) and in preclosure tectonics (Section 8.3.1.17).

The last general category of parameters, "geologic framework," represents a set of synthesized parameters that will eventually constitute "characterization parameters." The form and content of these parameters are under development but will provide a vehicle for reducing the data represented by "activity parameters" to a proper form for transfer to uses in design and performance analysis.

As previously mentioned, a three-dimensional model could be developed based only on physical property data from core samples. Various interpolation methods can be used to estimate the variation in the value of a property of the rock between the locations of the samples. The use of the rock property data determines the degree to which it is important to know precisely how a particular property varies with the distance from the sample location. For example, if a hydrologic numerical model for calculating ground-water travel time requires a value for the effective permeability, several considerations will determine how well effective permeability must be known. First, the question of what level of uncertainty on travel time is acceptable should be addressed. Second, the sensitivity of the travel-time calculation to the effective permeability must be determined. If the travel time is very sensitive to permeability and the uncertainty associated with the calculation must be small, activities to obtain additional information to better describe the spatial variability of the parameter are justified. The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and other properties that must be estimated. The results of the geologic studies will therefore be used to calibrate the geophysical data and provide additional sources for correlating parameter information.

Interrelationships of rock characteristics investigations

This characterization program has been divided into three investigations: (1) development of an integrated drilling program, Investigation 8.3.1.4.1; (2) geologic framework of the Yucca Mountain site, Investigation 8.3.1.4.2; and (3) development of three dimensional models of rock characteristics at the repository site, Investigation 8.3.1.4.3. Feeding into Investigation 8.3.1.4.3 will be the results of investigations in Section 8.3.1.2 (geohydrology), Section 8.3.1.15 (thermal and mechanical rock properties) and Section 8.3.1.3 (geochemistry).

The schedule information provided for investigations in this section includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.1.4.1 Investigation: Development of an integrated drilling program

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

A summary of previous NNWSI Project drilling is contained in Chapter 1, Section 1.6 (drilling and mining).

Purpose and objectives of the investigation

Drilling is an integral portion of many investigations which are planned to obtain information needed for repository design and performance assessment. The specific activities and proposed boreholes are summarized in Table 8.3.1.4-2 and shown on Figure 8.3.1.4-2. Proposed boreholes are currently sited on the basis of two differing strategies: (1) characterize anomalies and gather data on subsurface conditions by siting of boreholes in order to sample known or inferred features of interest and (2) characterize the statistical distribution of needed parameters by random or gridded siting of boreholes to sample an entire volume of interest, without consideration of specific geologic features or known subsurface data. The overall purpose of the integration of drilling activities will be to most effectively meet the needs of the NNWSI Project.

To this end, the integration of borehole siting, sampling, and testing has several objectives that will be optimized by consideration of applicable tradeoffs: (1) coordinate sampling and testing programs to reduce redundant sampling and testing; (2) minimize both the potential alteration of ambient surface and subsurface conditions within the repository environment and the creation of possible preferential pathways caused by drilling that need to be sealed as required by 10 CFR 60.134; (3) ensure that drilling and sampling methods are well matched to applicable technical, regulatory, and scientific requirements; (4) maximize cost-effectiveness of drilling program; and (5) maximize returns from drilling in order to increase both sampling of the subsurface volume of interest and data returns from in situ monitoring activities. Each drill hole proposed in various site characterization programs (see Table 8.3.1.4-2 and Figure 8.3.1.4-2) represents a source for data intended to answer a particular requirement of design or performance assessment. Where feasible, objectives for separate, currently planned holes may be combined, if appropriate data can be obtained from a single hole. The process of integrating proposed drilling may result in the addition of new drill holes or deletion of previously scheduled holes as result of data obtained from completed studies and activities.

Technical rationale for the investigation

Drilling will provide physical samples of the subsurface materials and access to locations for long- and short-term subsurface testing and monitoring that will augment existing boreholes. However, drilling proposed in this document will require resolution of various regulatory and technical questions. These questions involve the impact of possible contamination of the unsaturated zone by water-based drilling fluids and whether holes should be drilled through the primary repository area to the saturated zone. This

Table 8.3.1.4-2. Site characterization plan proposed drilling requirements (page 1 of 4)

Hole Number	Proposed depth (in feet)	SCP activity	Remarks
USW H-7	3,000	8.3.1.2.1.1	Hydrologic drilling
VSP Support	1,800	8.3.1.2.2.2.1	Unsaturated zone drilling
USW UZ-2	2,500	8.3.1.2.2.2.1	
USW UZ-3	1,500	8.3.1.2.2.2.1	
USW UZ-8	350	8.3.1.2.2.2.1	
USW UZ-9	2,000	8.3.1.2.2.2.1	
USW UZ-9a	1,500	8.3.1.2.2.2.1	
USW UZ-9b	1,500	8.3.1.2.2.2.1	
USW UZ-10	1,500	8.3.1.2.2.2.1	
USW UZ-11	400	8.3.1.2.2.3.1	
USW UZ-12	400	8.3.1.2.2.3.1	
USW UZ-14	400	8.3.1.2.2.2.1	
N11	50	8.3.1.2.2.1.1	Unsaturated zone neutron moisture logging
N15	50	8.3.1.2.2.1.1	
N16	50	8.3.1.2.2.1.1	
N17	50	8.3.1.2.2.1.1	
N27	50	8.3.1.2.2.1.1	
N31	50	8.3.1.2.2.1.1	
N32	50	8.3.1.2.2.1.1	
N33	50	8.3.1.2.2.1.1	
N34	50	8.3.1.2.2.1.1	
N35	50	8.3.1.2.2.1.1	
N36	50	8.3.1.2.2.1.1	
N37	50	8.3.1.2.2.1.1	
N38	50	8.3.1.2.2.1.1	
N39	50	8.3.1.2.2.1.1	
N46	50	8.3.1.2.2.1.1	
N53	50	8.3.1.2.2.1.1	
N53a	50	8.3.1.2.2.1.1	
N54	50	8.3.1.2.2.1.1	
N57	50	8.3.1.2.2.1.1	
N58	50	8.3.1.2.2.1.1	
N59	50	8.3.1.2.2.1.1	
N61	50	8.3.1.2.2.1.1	
N62	50	8.3.1.2.2.1.1	
N63	50	8.3.1.2.2.1.1	
N64	50	8.3.1.2.2.1.1	
LPRS1	<35 (10 holes)	8.3.1.2.2.1.1	Large plot rainfall simulation study
LPRS2	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS3	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS4	<35 (10 holes)	8.3.1.2.2.1.1	

Table 8.3.1.4-2. Site characterization plan proposed drilling requirements (page 2 of 4)

Hole Number	Proposed depth (in feet)	SCP activity	Remarks
LPRS5	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS6	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS7	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS8	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS9	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS10	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS11	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS12	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS13	<35 (10 holes)	8.3.1.2.2.1.1	
LPRS14	<35 (10 holes)	8.3.1.2.2.1.1	
SPRS1	<5 (4 holes)	8.3.1.2.2.1.1	Small plot rainfall simulation study
SPRS2	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS3	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS4	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS5	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS6	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS7	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS8	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS9	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS10	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS11	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS12	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS13	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS14	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS15	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS16	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS17	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS18	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS19	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS20	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS21	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS22	<5 (4 holes)	8.3.1.2.2.1.1	
SPRS23	<5 (4 holes)	8.3.1.2.2.1.1	
USW WT-8	2,200	8.3.1.2.3.1.1	Water table drilling
USW WT-9	2,200	8.3.1.2.3.1.1	
UE25 WT-19	1,100	8.3.1.2.3.1.2	
UE25 WT-20	1,100	8.3.1.2.3.1.2	
UE25 WT-21	1,800	8.3.1.2.3.1.2	
USW WT-22	1,300	8.3.1.2.3.1.2	
USW WT-23	2,200	8.3.1.2.3.1.2	
USW WT-24	2,200	8.3.1.2.3.1.2	

Table 8.3.1.4-2. Site characterization plan proposed drilling requirements (page 3 of 4)

Hole Number	Proposed depth (in feet)	SCP activity	Remarks
FMN-1	>33	8.3.1.2.1.3.3	Neutron moisture logging as part of Fortymile Wash recharge study
FMN-2	>33	8.3.1.2.1.3.3	
FMN-3	>33	8.3.1.2.1.3.3	
FMN-4	>33	8.3.1.2.1.3.3	
FMN-5	>33	8.3.1.2.1.3.3	
FMN-6	>33	8.3.1.2.1.3.3	
FMN-7	>33	8.3.1.2.1.3.3	
FMN-8	>33	8.3.1.2.1.3.3	
FMN-9	>33	8.3.1.2.1.3.3	
FMN-10	>33	8.3.1.2.1.3.3	
UE25 FM#1	500	8.3.1.2.1.3.3	Fortymile Wash recharge study
UE25 FM#2	500	8.3.1.2.1.3.3	
UE25 FM#3	500	8.3.1.2.1.3.3	
STC-1	3,000	8.3.1.2.3.1.6	Southern Tracer Complex test holes; drilling decision based on C-hole Complex tests
STC-2	3,000	8.3.1.2.3.1.6	
STC-3	3,000	8.3.1.2.3.1.6	
STC-4	3,000	8.3.1.2.3.1.6	
SH-1	1,000	8.3.1.2.2.2.1.2	Solitario Canyon horizontal hole
USW G-5	5,000	8.3.1.4.2.1.1	Geologic drilling
USW G-6	5,000	8.3.1.4.2.1.1	
USW G-7	5,000	8.3.1.4.2.1.1	
USW SD-1	2,000	8.3.1.4.3.1	Sandia National Laboratories Performance Assessment-based drilling program SD-13 to SD-24 to be drilled only if results from SD-1 to SD-12 continued drilling
USW SD-2	2,000	8.3.1.4.3.1	
USW SD-3	2,000	8.3.1.4.3.1	
USW SD-4	2,000	8.3.1.4.3.1	
UE25 SD#5	2,000	8.3.1.4.3.1	
USW SD-6	2,000	8.3.1.4.3.1	
USW SD-7	2,000	8.3.1.4.3.1	
UE25 SD#8	2,000	8.3.1.4.3.1	
USW SD-9	2,000	8.3.1.4.3.1	
USW SD-10	2,000	8.3.1.4.3.1	
USW SD-11	2,000	8.3.1.4.3.1	
USW SD-12	2,000	8.3.1.4.3.1	
USW SD-13	2,000	8.3.1.4.3.1	
USW SD-14	2,000	8.3.1.4.3.1	
USW SD-15	2,000	8.3.1.4.3.1	
USW SD-16	2,000	8.3.1.4.3.1	
USW SD-17	2,000	8.3.1.4.3.1	

Table 8.3.1.4-2. Site characterization plan proposed drilling requirements (page 4 of 4)

Hole Number	Proposed depth (in feet)	SCP activity	Remarks
USW SD-18	2,000	8.3.1.4.3.1	
USW SD-19	2,000	8.3.1.4.3.1	
USW SD-20	2,000	8.3.1.4.3.1	
USW SD-21	2,000	8.3.1.4.3.1	
USW SD-22	2,000	8.3.1.4.3.1	
UE25 SD#23	2,000	8.3.1.4.3.1	
USW SD-24	2,000	8.3.1.4.3.1	
UE#25 SF#11	300	8.3.1.14.2.1	Engineering drilling for repository surface facilities construction
UE25 SF#2	300	8.3.1.14.2.1	
UE25 PH#1A	60 (5 holes)	8.3.1.5.2.1.5	Calcite-silica drilling
UE25 PH#1B	260	8.3.1.5.2.1.5	
V-1	1,000	8.3.1.8.5.1.1	Volcanic K-Ar drilling
V-2	1,000	8.3.1.8.5.1.1	
V-3	1,000	8.3.1.8.5.1.1	
V-4	1,000	8.3.1.8.5.1.1	
USW ISS-1	1,000	8.3.1.17.4.8.2	In situ stress drilling USW ISS-3 through USW ISS-22 based on results of USW ISS-1 and USW ISS-2
USW ISS-2	1,000	8.3.1.17.4.8.2	
USW ISS-3	1,000	8.3.1.17.4.8.2	
USW ISS-4	1,000	8.3.1.17.4.8.2	
USW ISS-5	1,000	8.3.1.17.4.8.2	
USW ISS-6	1,000	8.3.1.17.4.8.2	
USW ISS-7	1,000	8.3.1.17.4.8.2	
USW ISS-8	1,000	8.3.1.17.4.8.2	
USW ISS-9	1,000	8.3.1.17.4.8.2	
USW ISS-10	1,000	8.3.1.17.4.8.2	
USW ISS-11	1,000	8.3.1.17.4.8.2	
USW ISS-12	1,000	8.3.1.17.4.8.2	
USW ISS-13	1,000	8.3.1.17.4.8.2	
USW ISS-14	1,000	8.3.1.17.4.8.2	
USW ISS-15	1,000	8.3.1.17.4.8.2	
USW ISS-16	1,000	8.3.1.17.4.8.2	
USW ISS-17	1,000	8.3.1.17.4.8.2	
USW ISS-18	1,000	8.3.1.17.4.8.2	
USW ISS-19	1,000	8.3.1.17.4.8.2	
USW ISS-20	1,000	8.3.1.17.4.8.2	
USW ISS-21	1,000	8.3.1.17.4.8.2	
USW ISS-22	1,000	8.3.1.17.4.8.2	

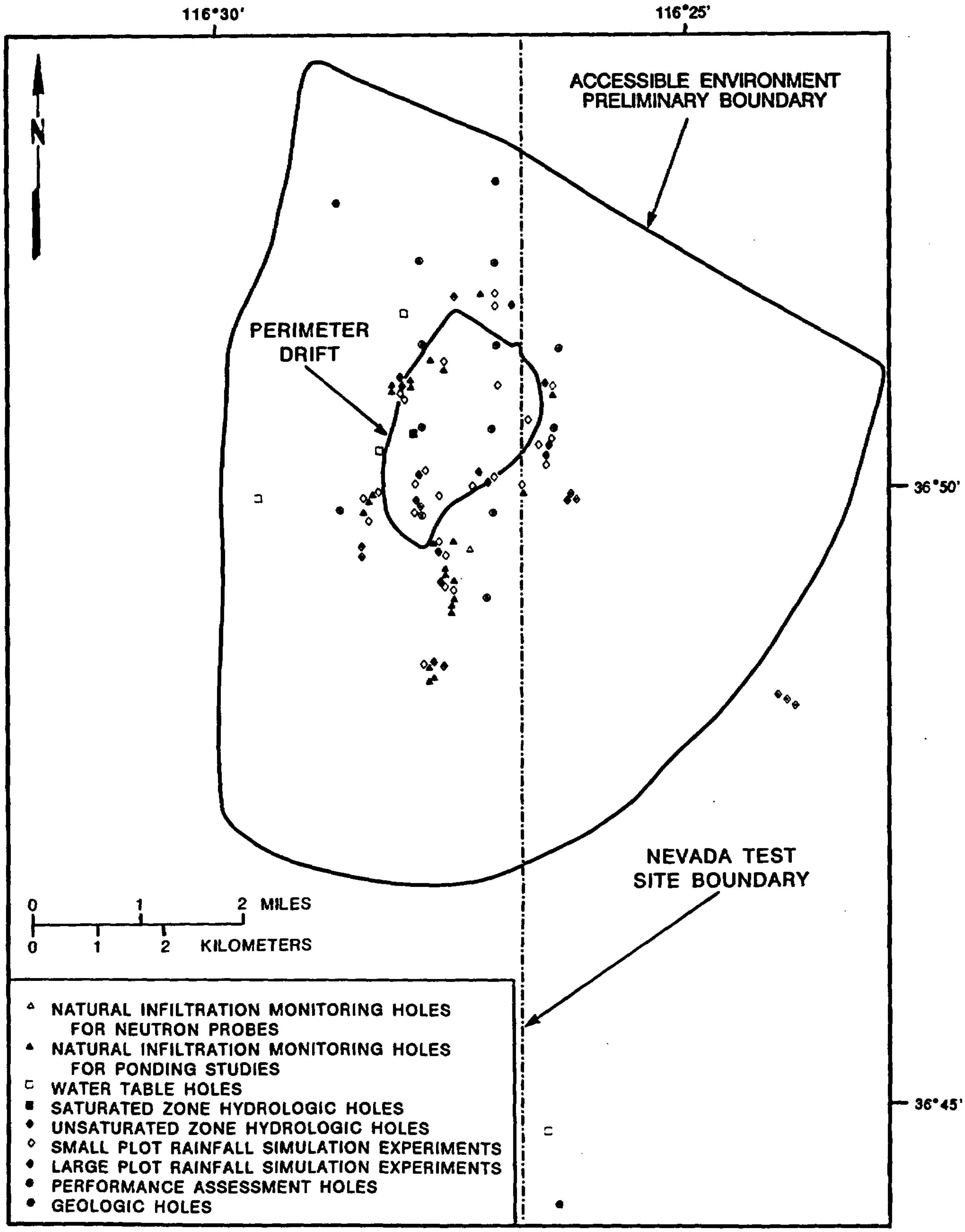


Figure 8.3.1.4-2. Proposed boreholes for site characterization.

investigation will evaluate the scientific, regulatory and technical concerns associated with the proposed drilling, and will lay out a plan for integrating NNWSI Project drilling throughout site characterization.

8.3.1.4.1.1 Study: Develop positions on drilling issues that pertain to site characterization

The objective of this study is to investigate the various technical, regulatory, and scientific questions that have been raised concerning the drilling proposed in this document.

Activities planned for this study will: (1) develop and apply technical and regulatory positions on drilling through the waste emplacement area; (2) analyze the potential effects of wet borehole construction on the unsaturated zone; (3) assess the impacts on design and performance assessment if core samples cannot be recovered from the repository horizon and below because of adverse impacts determined as a result of items (1) and (2); (4) investigate alternative scheduling or methods for drilling and coring using dry drilling techniques that are different from those used in previous drilling; and (5) apply statistical methods to the existing data as an aid to determining the need for, and potential siting of, future drill holes.

8.3.1.4.1.1.1 Activity: Develop a position on drilling within the boundaries of the repository perimeter drift

Objectives

The objective of this activity is to determine if plans for drilling holes that will penetrate the repository horizon and extend below the water table may be precluded by existing regulations.

Parameters

Existing regulations covering site characterization.

Description

This activity will review the available data, technical analyses, modeling results, preliminary performance assessment calculations and existing regulations to document the regulatory and technical arguments for and against drilling that penetrate the repository horizon and reach the saturated zone within the boundary of the repository perimeter drift. The regulatory review will include the Nuclear Waste Policy Act of 1982, 10 CFR Part 60, 10 CFR Part 960, U.S. Nuclear Regulatory Commission Regulatory Guide 1.132, and 40 CFR Part 191.

The product of this activity will be a project position paper discussing the regulatory concerns pertaining to drilling within the boundary of the repository as defined by the perimeter drift. The report will develop a DOE position on the rationale and methodology for addressing these concerns in the performance of the overall site characterization program.

8.3.1.4.1.1.2 Activity: The effects of drilling boreholes on the unsaturated zone using water, mud, or air foam as a drilling circulation medium

The objective of this activity is to evaluate, through various subactivities, the potential problems associated with drilling and coring in the unsaturated zone posed by either the use or prohibition of use of conventional water-based drilling fluids. Four subactivities are included in this activity.

8.3.1.4.1.1.2.1 Subactivity: The effect of use of water-based drilling fluids

Objectives

The objective of this subactivity is to analyze the effects on hydrologic characterization of the unsaturated zone caused by the use of conventional circulation media such as drilling mud or foam in drillholes conducted before site characterization.

Parameters

There are no parameters for this subactivity.

Description

During pre-site characterization investigations, approximately 35 boreholes were drilled to depths >1,000 ft using a variety of drilling techniques, including extensive use of water-based polymer mud and air foam. Some preliminary assessment of the effects of drilling these holes has been made (Montazer, 1985, 1986). This subactivity will consider the amount of drilling fluid that has been introduced into the unsaturated zone as a result of the previous boreholes and the effects of the introduction of this fluid into the unsaturated zone.

The product of this subactivity will be a topical report describing the projected relative impact on site characterization studies of the unsaturated zone caused by past and continued use of water-based drilling fluids.

8.3.1.4.1.1.2.2 Subactivity: Evaluation of data losses to design and performance assessment caused by drilling restrictions

Objectives

The objective of this subactivity is to assess the potential loss of data for design and performance assessment issues, resulting from a decision not to use water-based drilling fluid in constructing coreholes in the unsaturated zone.

Parameters

There are no parameters for this subactivity.

Description

Drilling conducted before site characterization demonstrated the feasibility of drilling coreholes to 500 ft depth using only compressed air as the circulation medium. An analysis will be made to assess the effects to performance assessment and design issues incurred if it is not feasible to return core from >500 ft total depth by dry drilling methods. This analysis should consider, but not be limited to, the particular impacts that will result if no data or only poorly constrained data exist for the rock units critical to construction of the proposed repository or to assessment of critical performance measures.

This subactivity will produce a topical report detailing the results of the analysis and developing a DOE position on the need for returning core samples from depths >500 ft.

8.3.1.4.1.1.2.3 Subactivity: Review of alternate methods for dry drilling for core recovery below 500 ft

Objectives

The objective of this subactivity is to investigate methods for recovering core from depths of more than 500 ft using a dry drilling technology different from technology currently used at the Nevada Test Site.

Parameters

There are no parameters for this subactivity.

Description

A review will be made of currently available industry practices, services, and apparatus that may be applied to deep coring using dry drilling techniques.

The expected product of this subactivity will be a written report on the results of the investigation.

8.3.1.4.1.1.2.4 Subactivity: Investigation of alternate scheduling practices for wet drilling

Objectives

The objective of this subactivity is to determine if alternative scheduling or two-phased drilling of coreholes in the unsaturated zone may allow drilling of holes using conventional water-based drilling fluid.

Parameters

There are no parameters for this subactivity.

Description

Disturbing the ambient conditions in the unsaturated zone may be avoided if wet drillholes are begun after testing and monitoring in the unsaturated zone is complete, or if the wet holes are drilled in a phased approach, with the upper segments drilled dry and the lower segments drilled wet.

An analysis will be made to assess the applicability of alternative scheduling or construction techniques. The expected output from this subactivity will be a written report on the results of the analysis.

8.3.1.4.1.1.3 Activity: Evaluation of drillhole and other subsurface data for the purpose of siting additional drillholes

Objectives

The objective of this activity is to perform evaluations of data available from drillholes, core samples, and other geologic and geophysical studies, in order to support determination of the need, location, and technical specifications for additional drillholes.

Parameters

There are no parameters for this activity.

Description

Two distinct approaches to siting, sampling, and testing of drillholes are planned by the NNWSI Project. One approach can be described as feature-of-interest sampling, and is intended to investigate known or suspected anomalous features that are associated with processes or variation of properties that impact the safe design or performance of a repository. Investigation of such anomalies will help ensure that potential design or performance failure modes have been characterized. The other approach can be described as representative sampling, whereby the overall variation of properties is estimated using data from spatially distributed drillholes. This approach is designed to support a representative model of rock characteristics at the site, and will also provide a basis for evaluating the distribution and relative importance of anomalous features.

The two approaches are complementary, but must be carefully integrated to ensure effective application of effort. For example, statistical evaluations of existing data may indicate that a particular location for a future drillhole will effectively reduce interpolation errors for properties of interest between drillholes, but near the statistically optimal location is a suspected anomaly. In the hypothetical example, investigation of the anomaly by drilling could resolve a licensing issue concerning possible effects on repository performance. Several drilling and sampling options would be available, including (1) drilling both locations, (2) drilling the anomaly only and using an appropriate interpretation of the results in developing the model of rock characteristics, or (3) drilling only the statistically optimal location and assuming "worst-case" properties for the suspected anomaly. In the example, the evaluation activity would consider the tradeoffs and balance the objectives of the two general sampling approaches by performing applicable statistical analysis of existing data and defining the potential licensing issues raised by the anomaly. The product of this activity will be an analysis and issues evaluation report that will be provided to Project management for action.

Another facet of this activity will address the tradeoffs between (1) maximizing sampling density within the repository area and along potential flow paths to the accessible environment, and (2) maximizing sampling of features related to genesis of tuff units and structures at the site. Favorable locations for investigating tuff genesis may not occur directly within the area of concern for design or performance assessment issues, but sampling such locations may enhance general understanding of the rock unit variability and thereby provide information for inferring properties within the area of interest. In some instances such geological inference may better address uncertainty than direct sampling. There may be no unequivocal answer to determine where and how much drilling will best address the information requirements of design and performance assessment. Therefore, this activity will draw upon statistical analysis, professional judgment, and projections of likely licensing issues to focus the options for management disposition of drillhole siting.

8.3.1.4.1.2 Study: Integration of the drilling proposed during the first year of site characterization

Objectives

The objective of this study is to integrate the drilling activities for the first year of site characterization.

Parameters

There are no parameters for this study.

Description

Using existing schedules, representatives from all appropriate participating organizations will meet to integrate drilling planned for the first year of site characterization. This integrating effort will include (1) considerations of the results of activities proposed in Study 8.3.1.4.1.1; (2) prioritization of boreholes based on testing and monitoring intervals required and on potential interference with testing, monitoring, and sampling activities in the unsaturated zone caused by localized effects of drilling techniques; and (3) requirements of design and performance assessment for borehole-derived data to satisfy milestones or decision points for site characterization.

8.3.1.4.1.3 Study: Ongoing integration of the NNWSI Project drilling

Objectives

The objective of this study is to continue at regular intervals to integrate the NNWSI Project drilling.

Parameters

There are no parameters for this study.

Description

Following similar guidelines proposed in Study 8.3.1.4.1.2, integration of future boreholes will be carried out by a group of representatives from all participating organizations. This effort will cover approximately one year intervals ahead of existing schedules and will consider, in addition to the criteria considered in Study 8.3.1.4.1.2, (1) the results of the previous years drilling and (2) the additional site characterization studies that either may call for changes in the scheduled drilling of additional holes or may be affected by future drilling. Of paramount importance will be the requirement of this group to factor into future borehole siting the results of the completed site characterization studies.

The product of this group will be an updated drilling schedule plus an update of affected site characterization studies on the basis of data obtained since the last revision of the drilling.

8.3.1.4.1.4 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, seal systems, and performance assessment:

For site characterization, the SCP sections include

Section	Subject
8.3.1.1	Site overview
8.3.1.2	Geohydrology program
8.3.1.3	Geochemistry program

8.3.1.4	Rock characteristics program
8.3.1.8	Postclosure tectonics program
8.3.1.9	Human interference program
8.3.1.14	Surface characteristics program
8.3.1.15	Thermal and mechanical rock properties program
8.3.2.2	Configuration of underground facilities (postclosure) program

Section 8.3.3.2 (shaft and borehole seals characteristics) uses the information for seal systems. Section 8.3.5.12 (ground-water travel time) uses the information for performance assessment.

For schedule, the SCP sections include

Section	Subject
8.5.1	Site characterization
8.5.5	Major decision points
8.5.6	Schedules

8.3.1.4.1.5 Schedule and milestones

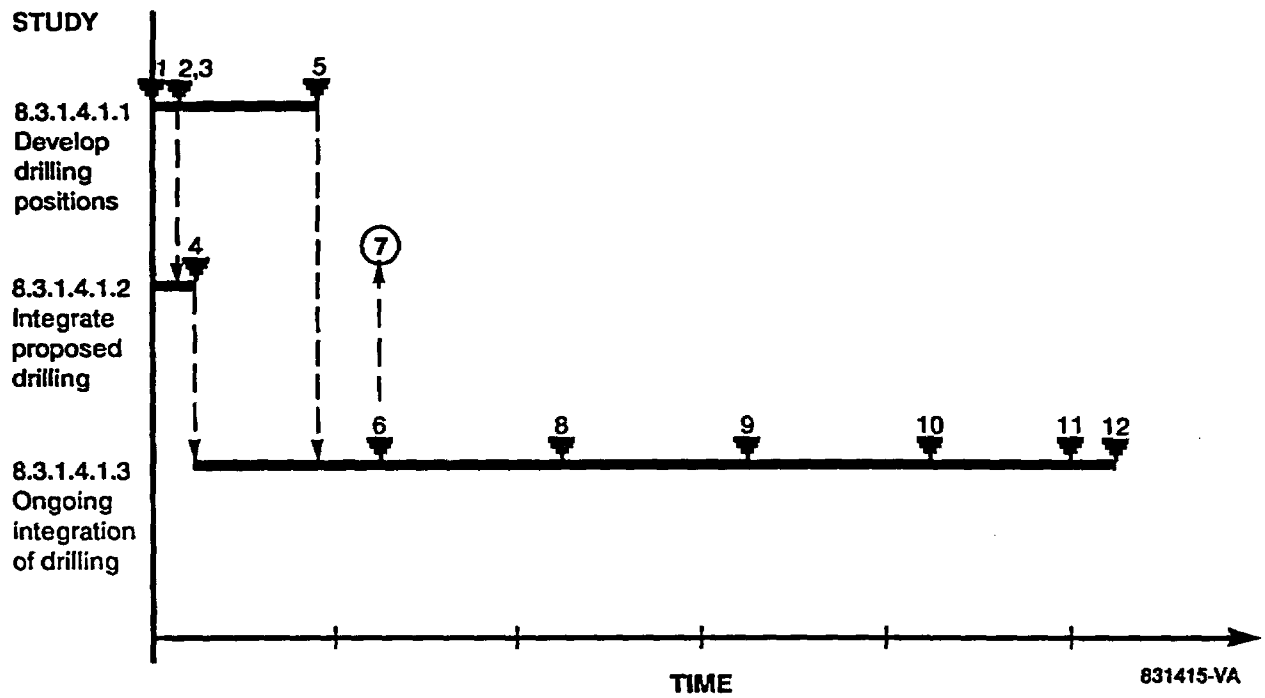
This investigation on the integrated drilling program contains three studies: 8.3.1.4.1.1 (develop positions on drilling issues), 8.3.1.4.1.2 (integration of the drilling proposed during the first year of site characterization), and 8.3.1.4.1.3 (ongoing integration of the NNWSI Project drilling). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

In this investigation, Studies 8.3.1.4.1.1 and 8.3.1.4.1.2 are ongoing. The integration efforts of Study 8.3.1.4.1.3 will begin following completion of an integrated drilling plan for the first year of site characterization.

The studies in this investigation will evaluate the scientific, regulatory, and technical concerns associated with the proposed drilling, and will lay out a plan for integrating drilling throughout site characterization. Planning for successive years of site characterization (Study 8.3.1.4.1.3) will consider criteria considered in Study 8.3.1.4.1.2, as well as the results of the previous year's drilling and additional site characterization studies that may call for changes in the scheduled drilling or may be affected by future drilling. The implementation of Study 8.3.1.4.3.1 (systematic acquisition of site-specific subsurface information) is contingent on the results of drilling integration from the first such effort in Study 8.3.1.4.1.3.

The studies in this investigation are not constrained by other program elements and can begin when the study plan is available.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Milestone Q082. Complete technical reports on drilling concerns.
2	Milestone Q083. Decision on whether to drill within the repository block.
3	Milestone Q084. Decision on the use of drilling fluids within the repository block.
4	Milestone Q085. Produce integrated drilling plan for the first year of site characterization.

Point number	Description
5	Milestone Q087. Evaluation of existing borehole and subsurface data for use in siting new boreholes.
6	Milestone Q094. Produce integrated drilling plans for successive years of site characterization.
7	Results of drilling integration available to Study 8.3.1.4.3.1 (systematic acquisition of site-specific subsurface information).
8-10	Milestones Q100, Q105, and Q116. Produce integrated drilling plans for successive years of site characterization.
11	Milestone Q120. Complete all borehole construction and testing for licensing application.
12	Milestone Q121. Issue final report on integration of site characterization borehole construction.

8.3.1.4.2 Investigation: Geologic framework of the Yucca Mountain site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of Chapter 1 of this document summarize available data relevant to the Yucca Mountain stratigraphy and structure, and identify areas of insufficient or inconclusive information:

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology
1.8.1.3	Structural geology and tectonics
1.8.2.1	Relation of geology to repository design

Parameters

Table 8.3.1.4-1 summarizes the geologic characteristics that will be measured or calculated as a result of the studies planned for this investigation. The geologic characteristics provided through this program 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 developed in Investigations 8.3.1.15.1 and 8.3.1.15.2 and in Characterization Programs 8.3.1.2 and 8.3.1.3 to develop three-dimensional models of thermal, mechanical, hydrologic, and geochemical properties in Study 8.3.1.4.1.3.

Purpose and objectives of the investigation

The objectives of this investigation are three-fold and, in general, cover those studies and activities that will allow an understanding of the large-scale variation in stratigraphy and structure in support of design and performance assessment calculations. First, this investigation will provide primary data on the lateral and vertical variations in site stratigraphy through acquisition of borehole cores and cuttings and surface geologic mapping. Second, it will provide information that will allow three-dimensional modeling (through the use of borehole and surface geophysical surveys) of the variation in properties of interest between points of primary data. Lastly, it will provide information on the lateral and vertical variation of structural elements that may affect in situ properties of interest (e.g., fracture-related flow) in conjunction with site characterization investigations on geohydrology, geochemistry, postclosure tectonics, and seismicity (i.e., preclosure tectonics) (Sections 8.3.1.2, 8.3.1.3, 8.3.1.8, and 8.3.1.17).

Technical rationale for the investigation

Development of a comprehensive, three-dimensional description of geologic and geophysical characteristics of the site requires integration of information from subsurface investigations, geologic mapping, surface-based and subsurface geophysical surveys, and geologic studies in the exploratory shaft and underground drifts. This model provides the geologic constraints for developing quantitative three-dimensional models of rock properties in Investigation 8.3.1.4.3. Such a model must be compatible with the stratigraphic, structural, and tectonic setting of the region, and must incorporate genetic models that address depositional, thermal, and alteration histories of local volcanic rock units, part of which are developed under Characterization Program 8.3.1.8.

On the basis of structural considerations, the areal extent of geologic investigations at Yucca Mountain can be divided into two areas, repository perimeter drift and site, as defined below (Figure 8.3.1.4-3). The perimeter drift defines an area where a significantly lower concentration of faults has been mapped relative to surrounding areas. This area is bounded on the north and northeast by Drill Hole Wash. The Solitario Canyon fault zone marks its western border, and a belt of small-scale structural features north of Abandoned Wash limits its eastern and southeastern extents. The site area boundary is located outward approximately 4 to 6 km from the boundaries of the perimeter drift. The northern, eastern, and southern limits of the region of investigation around the site are selected primarily on the basis of differences in structural styles inferred from existing geologic and geophysical data. They include Prow Pass (Claim Canyon Caldron), Fortymile Wash, and a northeast-trending lateral fault south of Busted Butte. The western boundary of the study region has been selected at the Windy Wash fault zone on the basis of maintaining a similar amount of lateral distance from the perimeter drift.

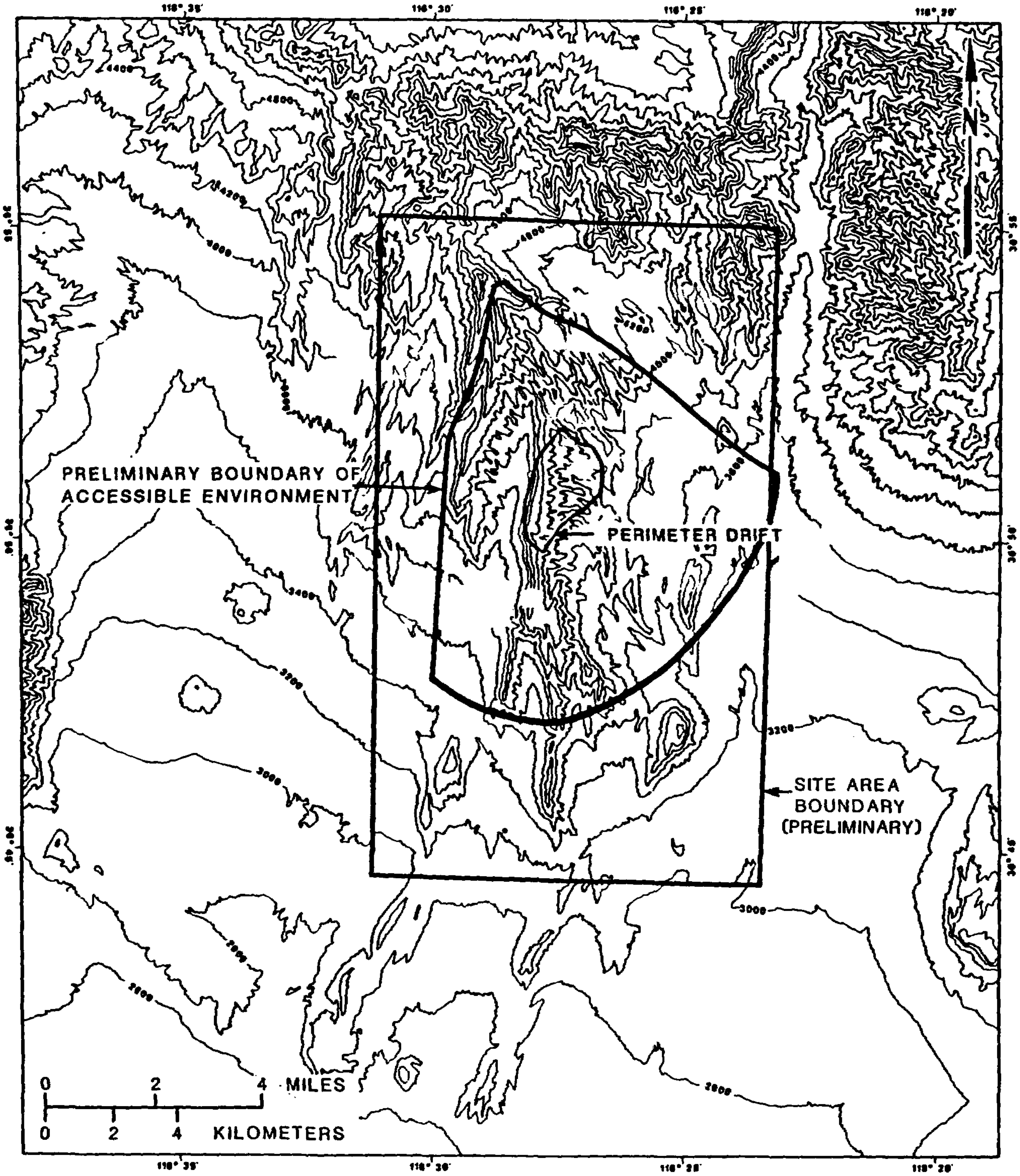


Figure 8.3.1.4-3. Areas of geologic investigation at Yucca Mountain.

The area of investigation will include a larger area than the site as the understanding of the characteristics of each lithostratigraphic unit on a regional scale will allow a higher level of confidence when using deterministic information to interpolate between drillholes, shafts, and surface exposures within the site area.

The site geologic investigations can be divided into three principal investigations: (1) development of an integrated drilling program (8.3.1.4.1), (2) geologic framework of the Yucca Mountain site (this investigation), and (3) development of three-dimensional models of rock characteristics at the repository site (8.3.1.4.3). The area of investigation will include a larger area than the site as the understanding of the characteristics of each lithostratigraphic unit on a regional scale will allow a higher level of confidence when using deterministic information to interpolate between drillholes, shafts, and surface exposures within the site area. Integration of these investigations requires continual correlation at all levels from data collection to analysis and interpretation. These investigations will provide geologic, geomechanical, geothermal, geohydrologic, and geochemical information for the data base needed by the performance and design issues (Table 8.3.1.4-1).

Geophysical surveys may play a major role in providing information on the gross spatial distribution of bulk properties. They also will be used at particular drillholes to interpolate between depth intervals from which cores or other samples were acquired. Geophysical surveys will be evaluated, and if proven effective, will be used to detect possible rock property contrasts between drillholes. Surveys not proven to be effective will be eliminated from the investigations program. The results of direct in situ measurements made from drillholes and from the exploratory shaft facility, will be used to analyze data from methods such as seismic or electrical tomography to develop quantitative and empirical relationships needed to characterize subsurface variability between shafts and drillholes.A fundamental element of stratigraphic studies is the development of a data base of rock sample analyses collected from holes drilled for geologic and hydrologic purposes. Continuously cored geologic drillholes will continue to be used to establish the reference stratigraphic framework to currently planned depths of 1,828 m from which comparative studies between geophysical and geologic characteristics can be made. Geophysical relationships that are established in core studies can then be applied to the stratigraphic study of rotary drillholes (where rock samples are limited to drill bit-cuttings and sidewall samples) and to the geologic interpretation of data derived from surface-based and subsurface geophysical surveys. With the incorporation of additional stratigraphic data collected from surface field studies, a more complete stratigraphic data base will be used to map the distribution of intrinsic lithologic characteristics within Yucca Mountain. Primary geologic parameters that influence the distribution of rock properties include chemical composition, degree of welding, primary crystallization, and type and degree of alteration. Surface and subsurface mapping of lithologic characteristics within stratigraphic units aids in interpreting the transportation, emplacement, cooling, and alteration histories of major ash-flow tuff sheets. In turn, these interpretations will aid in the prediction of physical properties in parts of the repository block where relatively few subsurface samples will be collected. Stratigraphic investigations are grouped under Study 8.3.1.4.2.1.

Characterization of the structural setting of the site requires detailed study of local fault and fracture systems and their relation to the local and regional stratigraphic, tectonic, and geophysical framework. Recognition of small-scale structures within and near the site area is achieved through detailed mapping of zonal features of exposed ash-flow tuffs and interpretation of detailed surface and subsurface geophysical surveys. An understanding of the fracture network at the site requires the application of innovative approaches because the fracture system (1) is poorly exposed at the surface, (2) is predominantly composed of steeply dipping (high-angle) fractures, (3) includes fractures induced by both tectonic and cooling processes, and (4) includes strata-bound subsystems. Lateral components of the system are studied principally by mapping and analyzing surface exposures. Characterization of the vertical component of the fracture system will largely be achieved through detailed study of the exploratory shaft and drifts, and to a lesser degree, by examination of drillhole walls and core samples. In addition, borehole geophysics, particularly surface-to-borehole seismic profiling, cross-hole seismic surveys, and borehole-to-surface electrical resistivity methods may provide information regarding bulk distribution of fractures. Structural investigations are grouped under Study 8.3.1.4.2.2.

Stratigraphic and structural information will be used in Investigation 8.3.1.4.3, to constrain the interpretation of: thermal and mechanical properties (Investigation 8.3.1.15.1), the in situ thermal and stress conditions (Investigation 8.3.1.15.2), geohydrologic properties (Investigations 8.3.1.2.1 and 8.3.1.2.2), and geochemical properties (Investigation 8.3.1.3.2). The final product (Study 8.3.1.4.3.2) is a three-dimensional model of rock characteristics of Yucca Mountain, which will be used in designing the underground facility and assessing performance.

8.3.1.4.2.1 Study: Characterization of the vertical and lateral distribution of stratigraphic units within the site area

The objective of this study is to determine the vertical and lateral variability and emplacement history of stratigraphic units and lithostratigraphic subunits within the Yucca Mountain site area.

Geologic mapping, geophysical surveys, borehole evaluations, and geologic sampling, testing, and analysis will be used to gather pertinent geologic data, develop lithologic correlations, and describe the geologic stratigraphy of the site area. Surface-based mapping and borehole activities will be complemented by geologic mapping and testing in the exploratory shaft and drifts (Activity 8.3.1.4.2.2.4).

Activities planned for this study include (1) surface and subsurface stratigraphic studies of the host rock and surrounding units, (2) surface-based geophysical surveys, (3) borehole geophysical surveys, (4) petrophysical properties testing, and (5) correlation of stratigraphy and rock magnetic properties.

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

Objectives

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.

Parameters

The characterization parameters for this activity are

1. Welding and primary crystallization characteristics of lavas and ash-flow tuffs.

2. Petrographic characteristics.

3. Pumice characteristics.

4. Type and abundance of lithic fragments.

5. Characteristics of lithophysal zones.

6. Degree and type of alteration.

7. Depth, thickness, attitude, and extent of lithostratigraphic units.

8. Location and general characteristics of bedded tuff intervals, including grain size and sorting characteristics, diagenetic mineral phases, and depositional characteristics.

Description

Characterization of the stratigraphic sequence within the site area will use (1) borehole drilling and coring, (2) sampling, lithologic examination, and analysis of drill-bit cuttings and core, (3) borehole video surveys and logging, (4) surface-outcrop mapping; (5) petrographic and geochemical analysis of drillcore, cuttings, and outcrop samples, and (6) surface and borehole geophysical surveys.

Geologic and geophysical data derived from existing holes and additional holes will provide information to aid in the development of three-dimensional rock characteristics models of the proposed repository area.

Pending the integration of the drilling program, three additional continuously cored holes may be drilled (Figure 8.3.1.4-4) in the vicinity of the site to better explain inferred geologic and geophysical anomalies and to help determine the lithologic variability in the Paintbrush Tuff, tuffaceous beds of Calico Hills, and Crater Flat Tuff. One hole (USW G-5) would be located along the northeast flank of Yucca Mountain, to determine if abrupt changes in lithologies of underlying units or changes in structural style within Yucca Wash are factors that influence the steeper gradient in the

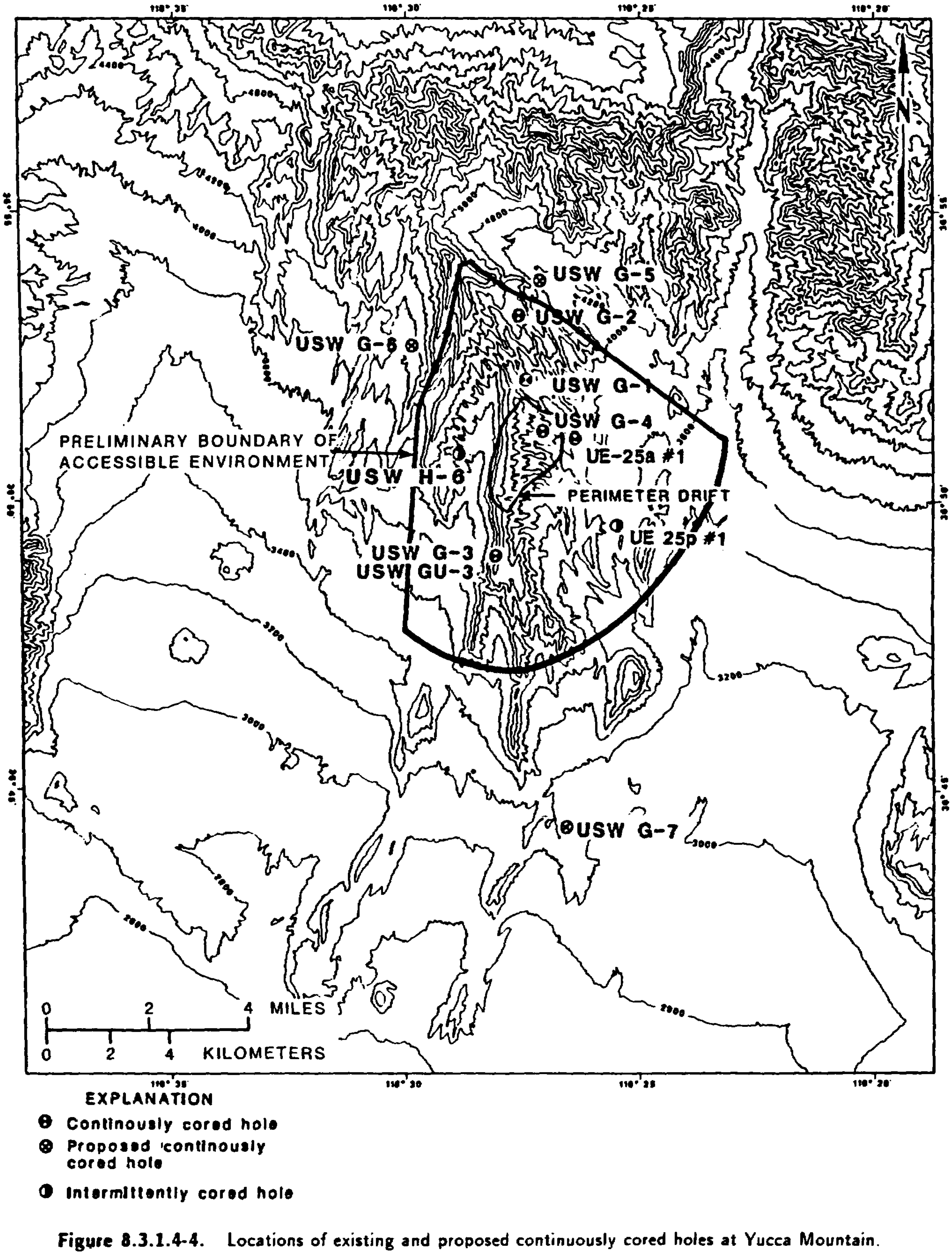


Figure 8.3.1.4-4. Locations of existing and proposed continuously cored holes at Yucca Mountain.

potentiometric surface north of drillhole USW G-1. Another hole (USW G-6) is planned along the northwest flank of Yucca Mountain in the vicinity of Windy Wash. This hole is expected to provide representative stratigraphic data for this area and allow correlation of thicknesses of key stratigraphic units across the site area. A third hole (USW G-7) may be located about 5 km southwest of Busted Butte in the southern part of Yucca Mountain. Within this area the Paintbrush Tuff is extremely thin and appears to onlap an inferred high point in the preexisting topography. This hole will be used to determine the nature of this feature and its effect on ground-water travel times and potential flow paths in southern Yucca Mountain for saturated zone flow modeling (Section 8.3.1.2.3.4). These holes will allow interpolation of lithologic characteristics between the repository area where more densely spaced holes may be drilled (Investigations 8.3.1.4.1 and 8.3.1.4.3) and the preliminary boundary of the accessible environment.

Studies of the hydrology of the unsaturated and saturated zones include plans for borehole drilling and coring (Section 8.3.1.2). The total suite of holes drilled by the DOE will provide an opportunity to study the lateral variability of the Topopah Spring Member, other members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, Crater Flat Tuff, and other units, and will provide samples for geologic evaluation.

Excavation of the exploratory shaft and drifts, and vertical and lateral boreholes drilled from the underground openings will provide additional opportunity to sample and perform geophysical measurements for characterizing the lithostratigraphic subunits between the ground surface and the upper part of the tuffaceous beds of the Calico Hills. The distribution of lithophysal zones within the Topopah Spring Member will be mapped in the exploratory shaft facility.

Bedded tuffs that divide major ash-flow tuffs commonly range in thickness from less than 1 m to about 61 m (Table 8.3.1.4-3) and include a variety of lithologies that range from fine-grained tuffaceous sandstone to verycoarse ash-fall tuff. Core recovery is typically poor in the unsaturated zone; consequently nearby outcrops will be sampled in the northern part of Yucca Mountain to fill gaps in the data. This study will aid in identifying stratigraphic lateral continuity and inhomogeneities that may act as potential lateral flow paths.

Video camera surveys will be performed in all holes drilled in the vicinity of Yucca Mountain. The textural and tonal contrasts that are seen on camera logs will provide valuable information about key stratigraphic features such as the vertical distribution of lithophysal cavities, thin-reworked and ash-fall tuff intervals, non- to partially welded zones, lithic-rich zones, spherulitic zones, glassy intervals, relative degree of sorting, relative sizes of pumice clasts, and nature of contacts between units. Video-camera observations will be correlated with core, drill bit-cuttings, and geophysical logs to interpret the subsurface characteristics of rock units.

The ability to predict lateral variability of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff beyond the perimeter drift can be enhanced by conducting a study of outcrops in highlands surrounding the site area. Stratigraphic sections of sufficient thickness will

Table 8.3.1.4-3. Volcanic stratigraphy at Yucca Mountain

Potassium-argon dating method age (million years)	Magnetic polarity[b]		Rock unit[a]	Range in thickness (m)
10.2			Basalt dikes	
		*	Timber Mountain Tuff	
11.3		*	Rainier Mesa Member	0-46
			Bedded tuff	0-61
		*	Paintbrush Tuff	
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[c]			Tuffaceous beds of Calico Hills	27-289
			Bedded tuff	0-21
		*	Crater Flat Tuff	
	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
			Bedded tuff	0-14
	I	*	Lithic Ridge Tuff	
			Bedded tuff	3-7
13.9			Older volcanic rocks and volcanogenic sedimentary rocks	345+

[a]Names and rankings of some units do not conform to U.S. Geological Survey usage. Formally recognized names are preceded by asterisks.
[b]Polarity symbols: R = reversed, N = normal polarity, I = intermediate between reversed and normal.
[c]Age determined from associated lava flow.

be described and measured principally within the southwest quadrant of the NTS and in Crater Flat. Areas of particular interest will include northern Crater Flat, Calico Hills, Fortymile Canyon, Little Skull Mountain, Skull Mountain, and the northernmost part of Yucca Mountain. Efforts will focus on identifying and correlating lateral variations of subunits of the Topopah Spring Member (Figure 8.3.1.4-5). Additional thickness data also will be collected for the Yucca Mountain and Pah Canyon members, tuffaceous beds of Calico Hills, and Prow Pass and Bullfrog members (Figure 8.3.1.4-6).

Rock samples will be examined megascopically as well as with hand lens and binocular microscope. Samples of particular interest will be selected for further petrographic, mineralogical, and isotopic analyses. Samples also will be selected for detailed petrographic and geochemical analyses (see activities described in the geochemistry program (Section 8.3.1.3)). Megascopic descriptions, coupled with analyses of selected thin sections and grain mounts, will focus on identifying distinctive lithologies, key marker beds, and correlatable sequences. Scanning electron microscopy (SEM) will be used to identify distinctive morphologies and interpret modes and environments of deposition. X-ray powder diffraction and microprobe analyses on selected samples will be used to identify relative abundance of mineral phases.

On the basis of the mineralogical studies of core from Yucca Mountain, about 100 intervals (samples) of mordenite-bearing or suspected mordenite-bearing core from drillholes USW G-1, USW G-2, USW G-4, and UE-25 b#1h will be selected for additional studies. All samples will be from the Crater Flat Tuff, tuffaceous beds of Calico Hills, and the lower part of the Paintbrush Tuff. The mineralogy of each sample will be determined by X-ray powder diffraction. Results of these determinations will provide the abundance of mordenite in each sample and will be the basis for further selecting of certain samples for additional investigation by optical microscopy of these sections and grain mounts, SEM, and electron microprobe analysis. Studies by optical microscopy and SEM will provide information on the morphology of the mordenite, on the paragenetic relationships of mordenite with diagenetic clinoptilolite, and analcime. However, paragenetic relationships are poorly understood. Electron microprobe analyses of mordenite and associated diagenetic minerals will provide the chemical composition and suggest those chemical conditions that favored the growth of mordenite. Attempts will be made to prepare pure mordenite separates from mordenite-rich samples by size fractionation and heavy liquid separation. Chemical analyses by X-ray fluorescence and unit-cell parameters by X-ray powder diffraction will be obtained for the pure mordenite separates. In addition, unit-cell parameters by X-ray powder diffraction will be obtained for other suitable mordenites and then examined with respect to the zeolite composition, paragenetic sequences, host stratigraphic unit, and geographic location.

Data obtained from geologic mapping, borehole drilling, coring, video surveys, sampling and petrographic analysis and geophysical studies will be compiled into stratigraphic and lithologic models. This information will be used with geophysical data (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3 petrophysical data (Activity 8.3.1.4.2.1.4), rock magnetic properties (Activity 8.3.1.4.2.1.5), and data from investigation of tectonics and igneous processes (Programs 8.3.1.8 and 8.3.1.17) to formulate the site geologic model in Study 8.3.1.4.2.3. These models will provide the geologic

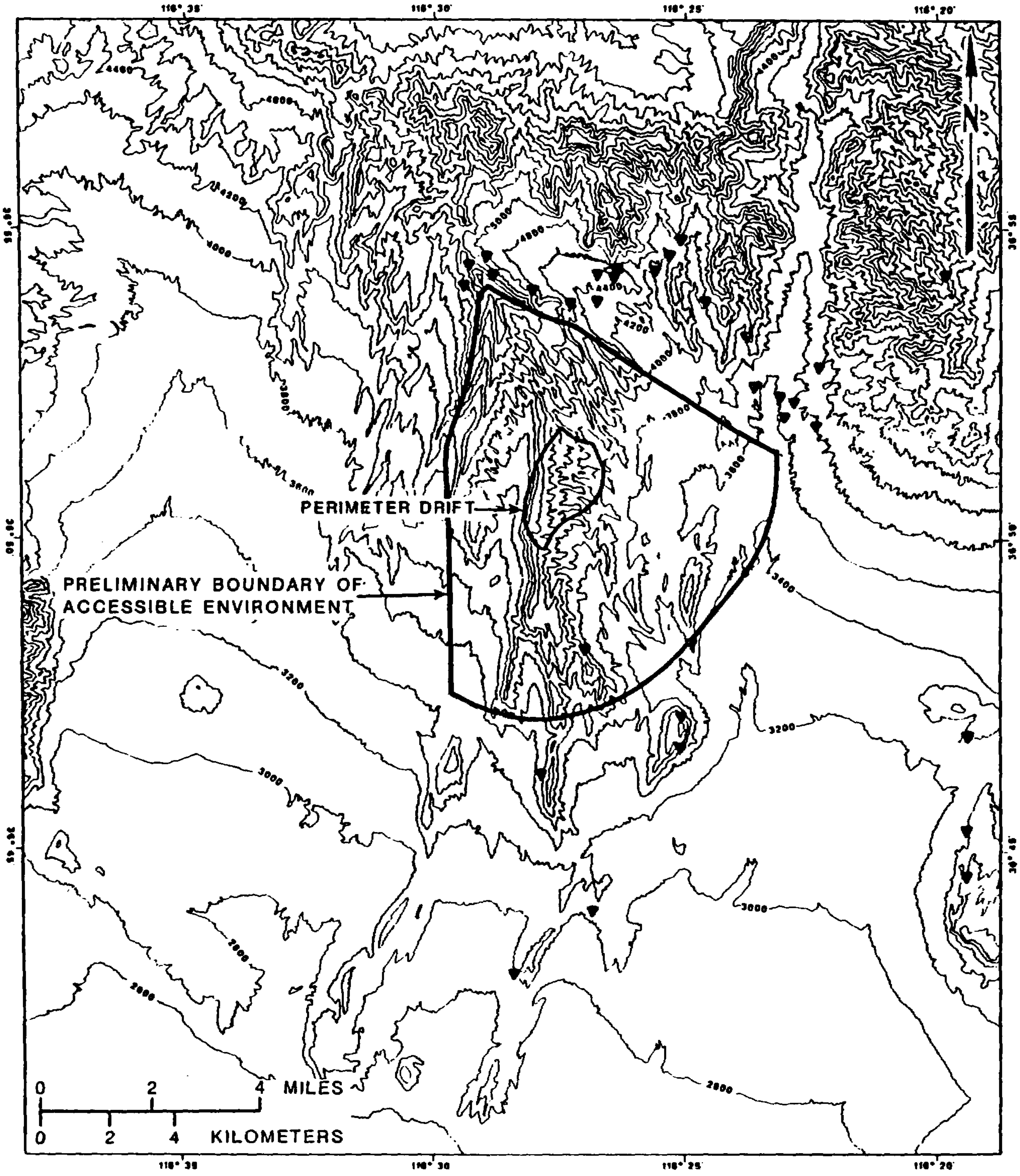


Figure 8.3.1.4-5. Approximate locations of additional surface stratigraphic studies of the Topopah Spring Member of the Paintbrush Tuff.

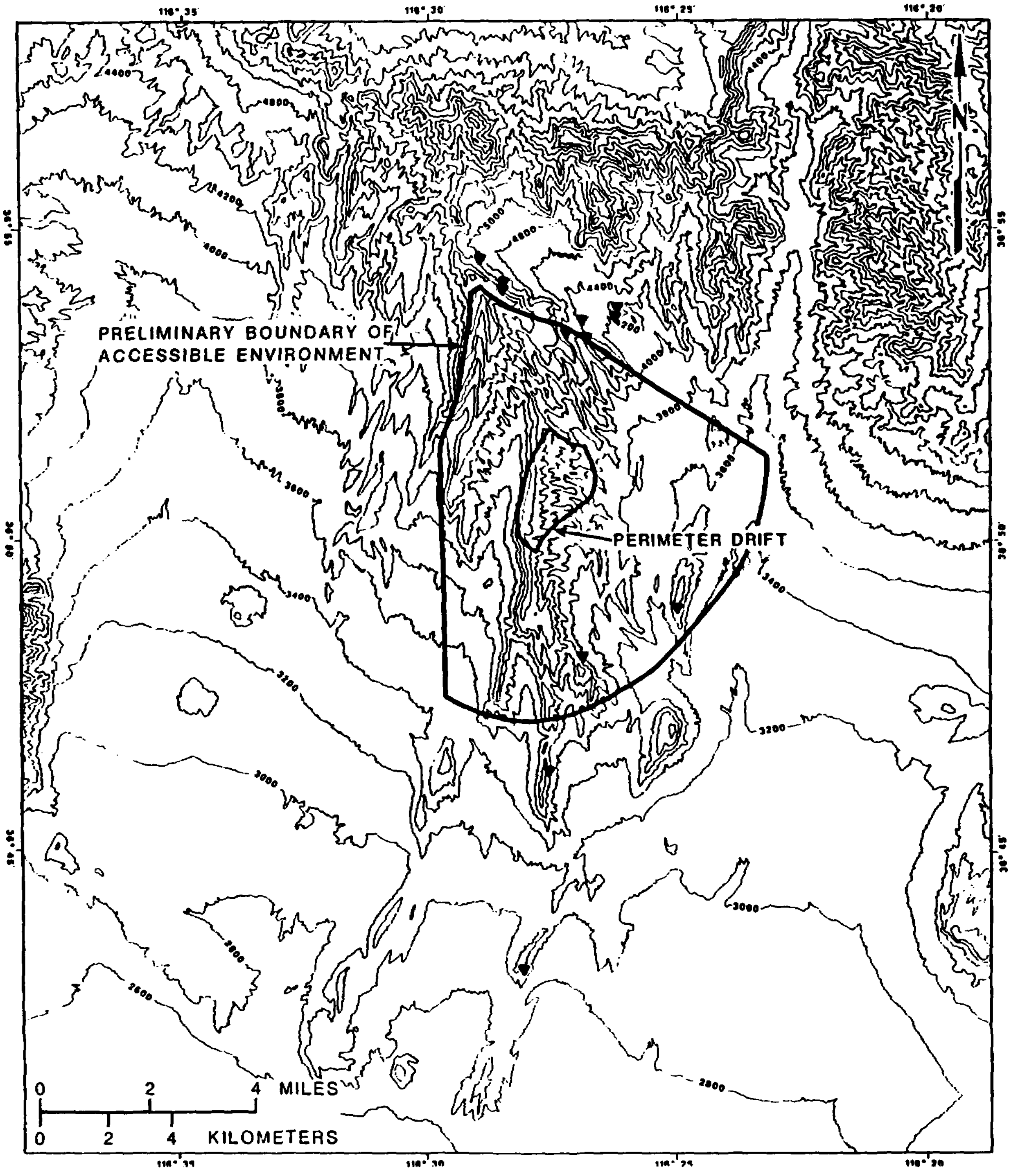


Figure 8.3.1.4-6. Approximate locations of additional surface stratigraphic studies of the Yucca Mountain and Pah Canyons Members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Prow Pass and Bullfrog Members of Crater Flat Tuff.

framework for use in the development of models of the vertical and lateral variability of subsurface rock properties.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole drilling and coring	TBD[a]	NNWSI Project borehole drilling and coring procedures	TBD
Sampling, lithologic examination, and analysis of drill bit-cuttings and core	TBD	NNWSI Project sampling and lithologic examination procedures for drill-bit cuttings and core samples	TBD
	GP-19, RO	Procedure for the identification, handling, and disposition of drillhole core and cutting samples from the drill site to the core library	6 Mar 87
	(NWM-USGS-)		
	GP-02, RO	Subsurface investigations	1 Mar 83
	GP-05, RO	Geologic support activities	1 Mar 83
	GP-18, RO	Volcanic stratigraphic studies	24 Sep 86
	GP-20	Volumetric estimation of lithophysae	TBD
Borehole video surveys and logging	GP-02, RO	Subsurface investigations	1 Mar 83
	GP-10, RO	Borehole video fracture logging	12 Apr 85

Method	Technical procedure Number	Title	Date
Surface-outcrop mapping of exposures of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff units	GP-01, R0	Geologic mapping	1 Mar 83
	GP-05, R0	Geologic support activities	1 Mar 83
	GP-18, R0	Volcanic stratigraphic studies	24 Sep 86
Isotopic and geochemical studies	GP-18, R0	Volcanic stratigraphic studies	24 Sept 86
	GCP-01, R0	Radiometric-age data base	15 June 81
	GCP-02, R1	Labeling, identification and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-05, R0	Radium, equivalent uranium, thorium, and potassium analysis by gamma-ray spectrometry	15 June 81
	GCP-07, R0	Geochemical mineral separation	15 June 81

[a]TBD = to be determined.

8.3.1.4.2.1.2 Activity: Surface-based geophysical surveys

Objectives

The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

Parameters

The parameters of this activity are

1. 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.

2. Lateral continuity of horizons defined by geophysical surveys.

Description

Surface-based geophysical surveys will be used to help define the lateral and vertical distribution of the stratigraphic units and lithostratigraphic subunits of the Yucca Mountain tuffs. Table 8.3.1.4-4 summarizes the geophysical techniques that will be used to study the vertical and lateral continuity of rock units. The table provides information on the location and scope of the survey and is divided into two parts. The first part describes geophysical surveys to be used by Characterization Program 8.3.1.4, and the second part identifies geophysical surveys that are used primarily for Characterization Program 8.3.1.17 (preclosure tectonics) and Characterization Program 8.3.1.8 (postclosure tectonics) but will be used to develop the geologic model. Geophysical surveys will also aid in determining favorable sites for drillholes. These detailed geophysical surveys will include (1) seismic refraction, (2) seismic reflection by the Mini-sosie technique (Barbier, 1983), (3) gravity and magnetics, and (4) electromagnetic soundings.

A seismic refraction profile will be acquired in the Yucca Wash area (Figure 8.3.1.4-7). This profile will be used to investigate significant velocity contrasts in the volcanic section that are associated with abrupt lateral changes in lithology, and that may be the result of structural displacement or alteration associated with a steep gradient in the potentiometric surface north of drillhole USW G-1 and in the vicinity of proposed corehole USW G-5.

After proof-of-technique trials, as many as 15 seismic reflection profiles may be performed using a shallow penetrating, high-resolution method called Mini-sosie (Barbier, 1983). This technique will be used to study the position of marker-horizons that have a sufficient contrast in seismic velocity and is expected to be useful to a maximum depth of about 1,000 m. Of specific interest are possible marker horizons that may be buried beneath Yucca Wash and Midway Valley (Figure 8.3.1.4-8). Information collected will also be used to trace individual faults by studying the lateral continuity of reflecting horizons. This technique differs from previous reflection studies because it is designed to penetrate only the upper geologic section.

Two detailed ground magnetic and gravity surveys will be performed across Yucca Wash (near USW G-5) and south of Busted Butte (near USW G-7) (Figure 8.3.1.4-9) in association with proposed geologic coreholes USW G-5, G-6, and G-7. In situ magnetic and density variations will be used to map the local vertical and lateral distribution of lithostratigraphic units.

A number of geophysical surveys that will be performed for tectonics Investigation 8.3.1.17.4 will also provide information for evaluation of stratigraphy and structure. These surveys and methods are indicated in the second part of Table 8.3.1.4-4. Many of these methods have not been tried at the Yucca Mountain site and will be tested before application for data collection purposes.

Shallow seismic refraction and shear wave refraction and reflection, will be used for investigation of faults in the vicinity of Yucca Mountain, using sledgehammer and shear wave sources. The number and location of the traverses will be based on the results of detailed geologic mapping. These

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 1 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2					
Seismology					
Vertical seismic profiling	8.3.1.4.2.2.6	Repository block and vicinity	15 to 25 geotomographic profiles, 0.2 to 2 km in length, cross-hole and surface-down-hole surveys. Directional shear and compression energy sources	Decision to Proceed (DTP) after feasibility test DTP after calibration in shaft and drifts	Used to map 3-dimensional network of rock mass fractures. 20-m per pixel geometry.
Paleomagnetism					
Site	8.3.1.4.2.1.5	Yucca Mountain	Orient drill core as it becomes available. Establish reference orientation through study of outcrop samples. Determine magnetic character of outcrop samples to aid in interpretation of aeromagnetic data	None	See Rosenbaum (1983), Rosenbaum and Rivers (1984), Rosenbaum and Snyder (1985), Rosenbaum (1985)
Borehole geophysical methods					
Geophysical logging					
Borehole gravimetry	8.3.1.4.2.1.3	Yucca Mountain	15 water-table (WT) drillholes, existing deep holes that can be made available, and all new holes that reach the base of the Topopah Spring Member (Tpt)	None	Already have data in H-1, P 1, C 1, G-3, and G-4. Data will be used to model structure in the immediate vicinity of each borehole, to study lithophysal zones, and to model the Paleozoic surface beneath Yucca Mountain. See Robbins et al. (1982), Healy et al. (1984), and Healey et al. (1986)

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 2 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Borehole magnetic logs	8.3.1.4.2.1.3	Yucca Mountain	15 WT drillholes, and new drillholes before casing operations	None	Used to determine mappable magnetic events for studying structural integrity of Yucca Mountain, and to supplement paleomagnetic and lithophysal studies. See Hagstrum et al. (1980).
Induced potential logs	8.3.1.4.2.1.3	Yucca Mountain	Test in one or two drillholes	Evaluate for effectiveness after 1 or 2 drillholes	Feasibility study to determine if the method can be used to map zeolitized rock
Commercially available logs	8.3.1.4.2.1.3	Yucca Mountain	All existing unlogged drillholes, all new holes, and relog selected holes	None	To obtain parameters for hydrologic, geologic, and geophysical models, and to determine uniformity and lateral distribution of rock properties within the stratigraphic units. See Spengler et al. (1979), Maldonado et al. (1979), Daniels and Scott (1981), Hagstrum et al. (1980), Daniels et al. (1981), Muller (1982), Muller and Kibler (1983 and 1984), Spengler and Chornack (1984), Muller (1985), and Muller and Kibler (1985)
Borehole radar logs	8.3.1.4.2.2.3	Yucca Mountain	Drillholes that penetrate the base of the Topopah Spring Member	Evaluate for effectiveness after 1 or 2 drillholes	Primarily used for fracture detection or to demonstrate the absence of fractures in the unsaturated zone

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 3 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Acoustic televiewer logs and TV camera logs	8.3.1.4.2.2.3	Yucca Mountain	All Yucca Mountain drillholes	None	For fracture and fault zone detection, and stratigraphic and lithologic correlation. See Healy et al. (1984), Stock et al. (1984), Stock and Healy (1984), Stock et al. (1985)
Large spacing EM and resistivity logs	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	To determine accurate large-volume in situ values for studying fracture and litho-physal zones, and for interpreting anomalies detected with surface and borehole data
Borehole to surface methods					
Resistivity and EM methods	8.3.1.4.2.1.3, 8.3.1.4.2.2.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	For fracture studies in the unsaturated zone, to obtain detailed structure in areas of anomalous surface geophysical data and in critical locations such as the shaft site and surface facilities locations, and to verify projected faults at critical locations. See Daniels and Scott (1981)
High resolution P and S wave seismic	8.3.1.4.2.2.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as previous, and to obtain parameters for designing effective, deeper-penetrating seismic surveys

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 4 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Surface to hole seismic refraction	8.3.1.4.2.2.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as two previous, and for critical fault location and bed tracing
Borehole to borehole methods	8.3.1.4.2.2.3	Yucca Mountain close-spaced holes for hydrologic testing and for surface facilities studies	Selected drillholes	None	Geotomography to map fractures and demonstrate mappability of features that intersect the drillholes using resistivity, EM, radar, and high resolution P and S seismic (Yo Yo) methods
Petrophysics	8.3.1.4.2.1.4	Yucca Mountain	Selected core from cored drillholes	None	To verify geophysical log accuracy, calibrate computed logs, determine properties that are not or cannot be measured in situ, and to model and interpret surface geophysical studies

SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2

Method	SCP section	Location	Scope	Decision points	Comments
Seismology					
Deep refraction	8.3.1.17.4.3.1	E-W transect, Indian Spring-Stovepipe Wells (Figure 8.3.1.-17-12)	Reversed profiles and cross-profiles, shotpoints 8- to 20-km spacing	None	Existing surveys shown in Figure 8.3.1.17-13. See Pankratz (1982), Mooney et al. (1982), Hoffman and Mooney (1983), Hoover et al. (1982), Monfort and Evans (1982), and Sutton (1984)

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 5 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Shallow (Bison) refraction and shear wave refraction and reflection	8.3.1.17.4.5.1 and others	Quaternary faults, Yucca Mountain and vicinity	250-500 m traverses, portable instruments, sledgehammer energy source. Shear wave method uses 12 (or more) geophones, 3-m spacing	Number and location to be decided on the basis of geologic mapping	Maximum depth of penetration 100 m. Used to detect offset in surficial deposits. Shear wave method capable of detecting 30 cm offset
Evaluation of proposed deep reflection survey	8.3.1.17.4.3.1	Proposed survey 15 km test located to the south of Amargosa Valley or southwest of Beatty	To be determined	DTP after evaluation of preliminary tests (15 km recon. line) and peer review	COCORP survey extending northward into southern Death Valley produced marginal quality data, although data in the upper one second are locally good. Five- and ten-second reflections were imaged with fair continuity. See de Voogd et al. (1986).
Intermediate reflection and intermediate refraction	8.3.1.17.4.7.1	Controlled area, Yucca Mountain	Evaluate previous results, assess potential for application of this method to Yucca Mountain, plan new application if appropriate	None	This is a planning activity only. Previous reflection survey using Vibroseis at Yucca Mountain failed (McGovern, 1983). More recent surveys using air gun at Mid Valley produced useful results (McArthur and Burkhard, 1986). See also Hoover et al. (1982).
Shallow (Mini-sosie) reflection	8.3.1.17.4.7.8 and others	Crater Flat, Jackass Flats (Figure 8.3.1.-17-8)	7 to 15 profiles, 1 to 5 km in length, hand carried instruments. Energy from battery of hand-operated tampers	DTP after evaluation of two preliminary profiles selected from profiles indicated in Figure 8.3.1.4-8	Maximum depth of penetration 1 km. Used to map shallow structural and stratigraphic features. Additional Mini-sosie surveys at Yucca Mountain are planned in Activity 8.3.1.4.2.1.1

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 6 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Gravity investigations					
Regional maps	8.3.1.17.4.11.1	Yucca Mountain and vicinity	Beatty 1:100,000 quad, Pahute Mesa 1:100,000 quad, NTS 1:100,000 map area, Yucca Mountain, 1:48,000 map area	None	Field work complete, compilation complete, final results not yet available. See Snyder and Oliver (1981), Ponce (1981), Ponce and Oliver (1981), Hoover et al. (1982), Ponce and Hanna (1982), Jasma et al. (1982), Ponce (1984), and Snyder and Carr (1984).
Site area map	8.3.1.17.4.2	Yucca Mountain	1:24,000 map of site and vicinity, 200 ft spacing of stations along E-W lines spaced 500 ft apart (where topography permits)	None	Will require as many as 7,500 additional stations. Useful for establishing stratigraphic variability of repository host rock and fault location and offset. See Snyder (1981), Snyder and Carr (1982), Jansma et al. (1982), Kane et al. (1981), Ponce et al. (1985)
Detailed surveys, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Gravity determinations along profiles at 500 ft (150 m) spacing	DTP only if seismic surveys run	Assists interpretation of seismic results
Magnetic methods					
Regional aeromagnetic maps	8.3.1.17.4.11.1	Yucca Mountain and vicinity	Beatty, Pahute Mesa, Indian Springs, and Pahranagat 1:100,000 quadrangles to be	None	Field investigations complete; compilation 80% (?) complete. See Kane et al. (1981), Hoover

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 7 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Regional aeromagnetic maps (continued)			compiled from existing surveys		et al. (1982), Kane and Bracken (1983), U.S. Geological Survey (1984), Ponce (1984)
Site aeromagnetic maps	8.3.1.17.4.7.3	Yucca Mountain	1:12,000 scale map of site and vicinity, continuous aeromagnetic survey along E-W flight lines spaced 1/16 mile (0.1 km)	None	1:62,500 scale map complete (U.S. Geological Survey, 1984). See also Jansma et al. (1982), Bath et al. (1982), Kane et al. (1982), Kane and Bracken (1983), and Bath and Jahren (1984)
Ground magnetic survey, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Magnetic determinations along profiles at 10 to 20 ft (3 to 6 m) spacing where accessible by truck, 50 to 100 ft (15 to 30 m) spacing elsewhere	DTP only if seismic surveys run	Assists interpretation of seismic results
Site ground magnetic surveys	8.3.1.17.4.7.4	Yucca Mountain (Figure 8.3.1.4-9)	Ground magnetic surveys at (1) known and inferred structures, (2) vicinity of drillholes, (3) vicinity of shaft and surface facilities, (4) anomalies detected. Surveys to be semicontinuous: 10 to 20 ft (3 to 6 m) spacing	Number and location to be determined through evaluation of geologic and geophysical mapping	Primary purpose is to locate concealed extensions of faults. See Bath and Jahren (1984), Scott et al. (1984), and Bath and Jahren (1985)
Curie isotherm	8.3.1.8.5.2.1	Yucca Mountain region	Analysis of existing regional aeromagnetic data	None	Purpose is to map configuration of Curie isothermal surface, and to compare areas of shallow isotherms with areas of high heat flow and recent volcanism. See Connard et al. (1983).

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 8 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Electrical methods					
Regional magnetotelluric (MT)	8.3.1.17.4.3.1	Yucca Mountain, Crater Flat, Jackass Flats, Amargosa Desert, Death Valley (Figure 8.3.1.17-12)	Detailed survey with stations at 3 to 5 km spacing of Yucca Mountain, Crater Flat, and northern Amargosa Desert. Reconnaissance survey with stations at 10 km spacing in remainder of area	None	Previous survey by Furgerson (1982) shows mappable conductivity contrasts in 1 to 15 km depth range. See also Kauahikaua (1981), and Hoover et al. (1982)
Surface geoelectric investigations (airborne EM, slingram, VLF, dc resistivity, EM soundings, tensor audio magnetotelluric and telluric profiling filing)	8.3.1.17.4.7.5	Yucca Mountain	Assess potential for application of these methods, evaluate previous results, plan new applications if appropriate, conduct prototype tests	DTP with fullscale application of selected methods only if warranted by results of prototype testing	Applied to structural and stratigraphic problems at the site by Flanigan (1981), Smith and Ross (1982), Fitterman (1982), Hoover et al. (1982), Senterfit et al. (1982), Scott et al. (1984), Frischkenecht and Raab (1984). Other studies in region include Zablocki (1979), Anderson et al. (1982), Smith et al. (1981), Greenhaus and Zablocki (1982).
Radiometric and remote sensing methods					
Surface and airborne gamma ray investigations	8.3.1.17.4.7.6	Yucca Mountain	Assess potential for application of these methods with preliminary survey over known faults using static ground measurements	DTP with full-scale application of airborne methods only if warranted by results of preliminary survey	Could detect percolation of radon through fault zones (gamma emitting daughter bismuth-214)

CONSULTATION DRAFT

Table 8.3.1.4-4. Summary of geophysical studies for Program 8.3.1.4 (rock characteristics) (page 9 of 9)

Method	SCP section	Location	Scope	Decision points	Comments
Thermal infrared investigations	8.3.1.17.4.7.7	Yucca Mountain	Assess potential for application of aircraft and satellite thermal infrared imagery in mapping of fracture network	DTP based on evaluation of cost and expected results	Method depends on detection of surface temperature variation, which are largely dependent on soil moisture content, which in turn is in part related to infiltration along fractures.
Thematic Mapper Satellite Imagery	8.3.1.17.4.7.7	Yucca Mountain and vicinity	Tapes of the four Thematic Mapper V scenes encompassing the Yucca Mountain Region (Beatty, Indian Springs, Pahute Mesa, and Pahranagat 1:100,000 quads) to be used to produce spectral and spectral ratio maps, from which areas containing distinctive patterns of lineations will be delineated.	None	Used to define structural domains, areas of well-developed desert varnish, and areas of hydrothermal alteration.
<u>Paleomagnetism</u>					
Region	8.3.1.17.4.7.2	Little Skull Mountain, Crater Flat, Skull Mountain, southern Yucca Mountain, eastern Yucca Flat.	10 to 20 sites at Little Skull Mountain will be sampled. If useful results are obtained, other sites as listed may be sampled.	DTP only if useful results obtained at Little Skull Mountain, and if suitable strata are present.	Preliminary results at Yucca Mountain indicate 30 degrees rotation (Scott and Rosenbaum, 1986)

CONSULTATION DRAFT

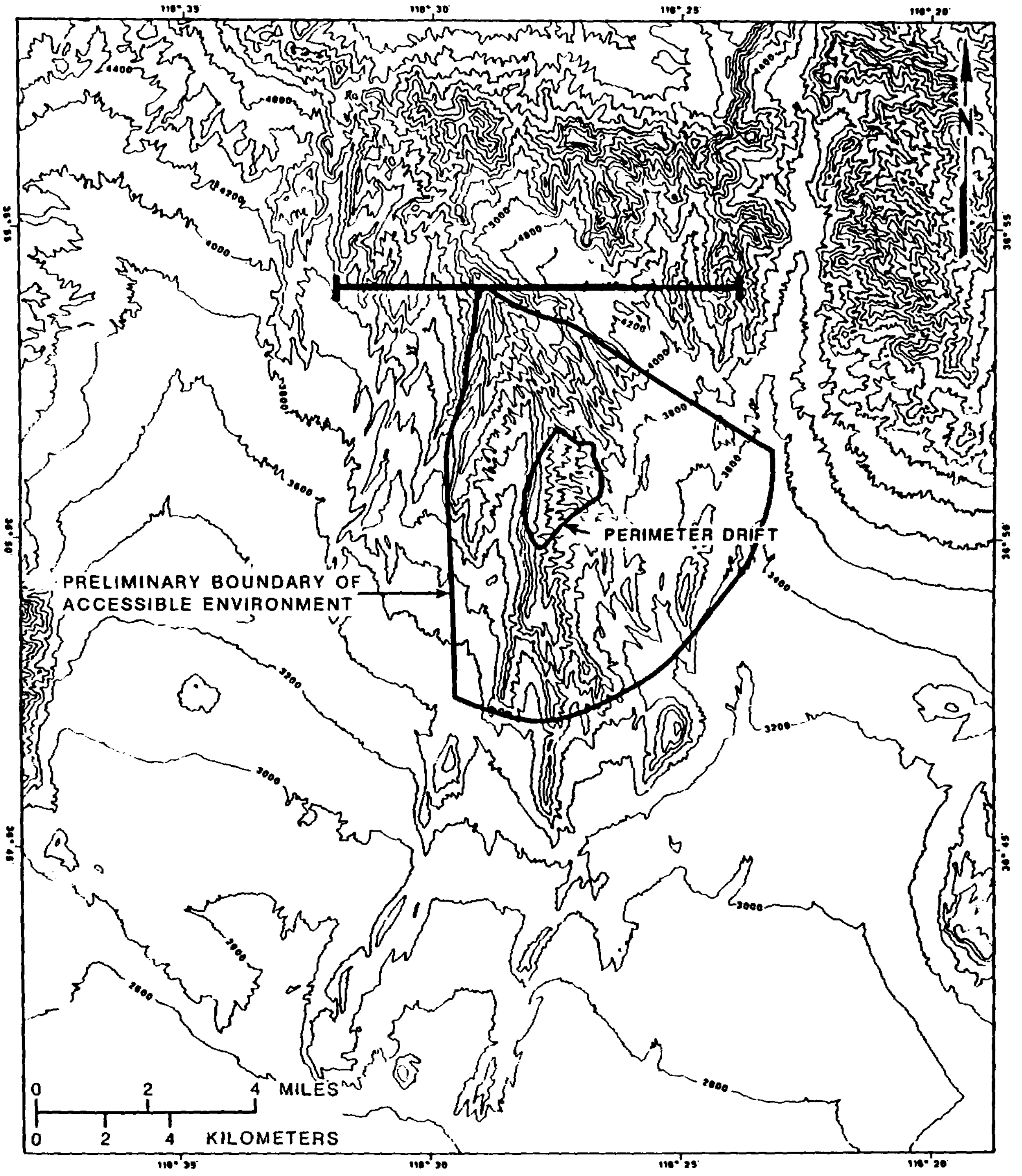


Figure 8.3.1.4-7. Approximate location of proposed seismic refraction survey across Yucca Wash.

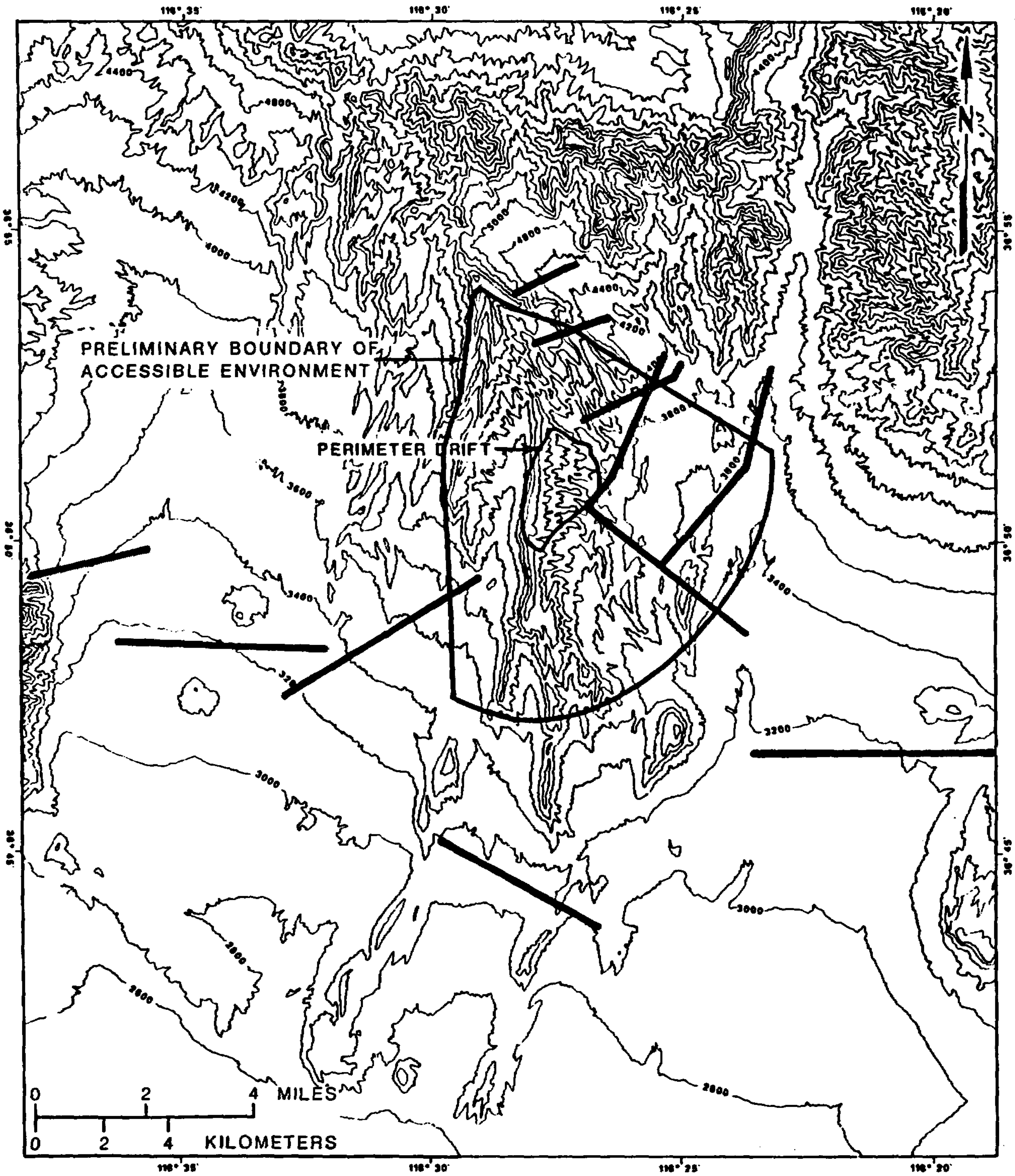


Figure 8.3.1.4-8. Approximate location of proposed seismic reflection surveys at Yucca Mountain.

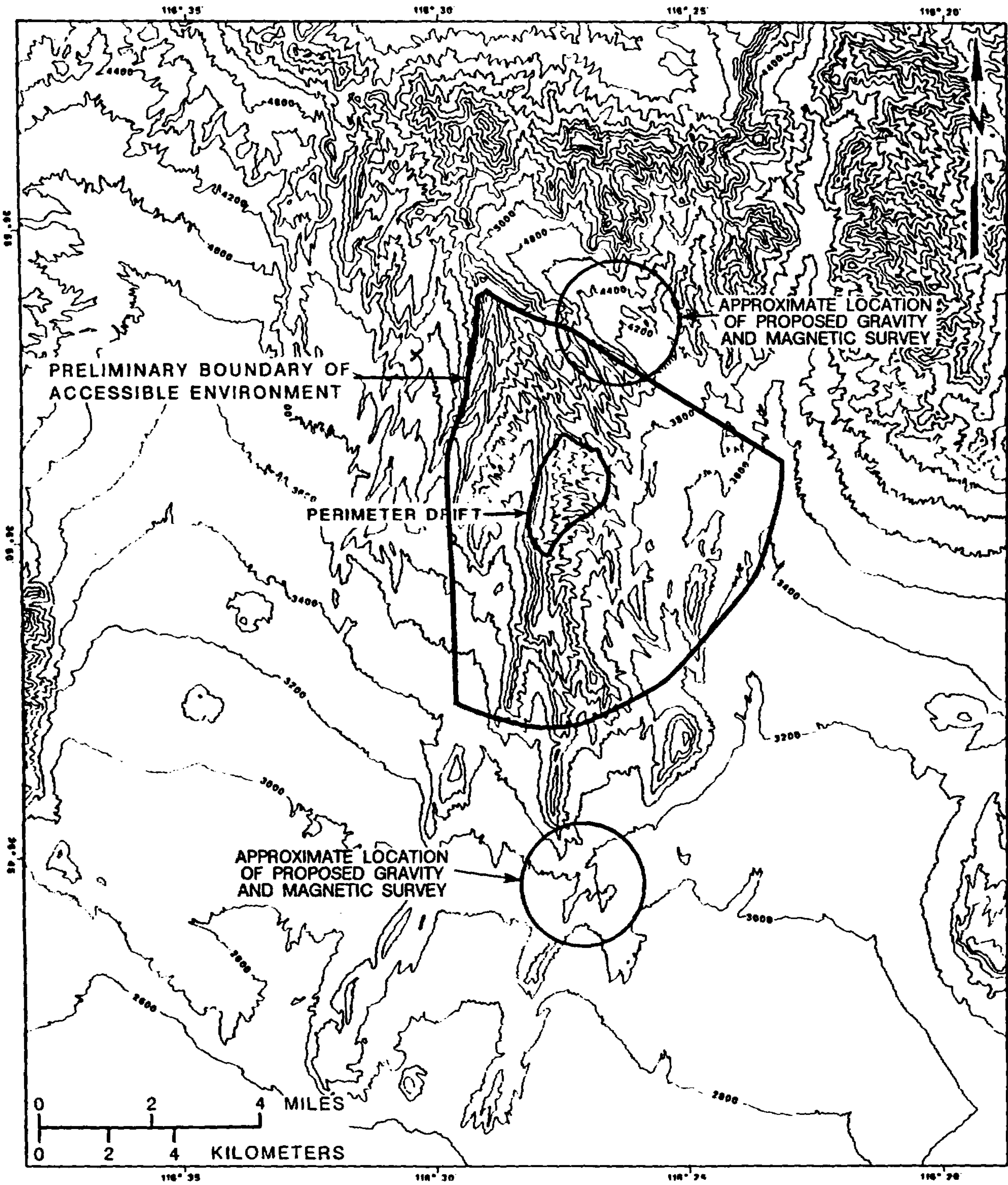


Figure 8.3.1.4-9. Approximate locations of proposed gravity and magnetic surveys near proposed coreholes.

surveys are more completely described in Activities 8.3.1.17.4.4.1 and 8.3.1.17.4.4.4. In addition, a program of intermediate seismic reflection in the vicinity of Yucca Mountain is planned in Activity 8.3.1.17.4.7.1, using such sources as vibrators, explosives, and air guns. The locations of these seismic lines will be determined after further acquisition and analysis of tectonic data using criteria that will include obtaining the requisite stratigraphic information needed to input to the geologic model of the site.

Gravity and magnetic data will be acquired at 500-ft intervals along the same surface profiles as the intermediate seismic data and shallow seismic surveys. In addition, a site gravity map at a scale of 1:24,000 is proposed (Activity 8.3.1.17.4.7.2), for which as many as 7,500 gravity stations would be required. The stations would be located at 200-ft intervals along lines spaced about 500 ft apart. An aeromagnetic survey is proposed which would produce a higher resolution map (1:24,000 scale) than previous surveys (Bath and Jahren, 1984; Kane and Bracken, 1983; Jansma et al., 1982; Bath et al., 1982), but over a smaller region. Additional gravity and ground magnetic surveys may be performed to investigate aeromagnetic anomalies, the location of proposed shafts and repository surface facilities.

Various electrical methods including airborne electromagnetic (EM) surveys, EM soundings, tensor audio magnetotellurics, telluric profiling, and direct current resistivity will be evaluated for application to tectonic, structural, and stratigraphic problems in Activity 8.3.1.17.4.7.5. In addition, radiometric (airborne gamma intensity) and remote sensing methods (thermal infrared scanner and Thematic Mapper V) will be evaluated in Activities 8.3.1.17.4.7.7 and 8.3.1.17.4.3.5 for application to 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 or fractures. Application of these electrical and remote sensing methods for site characterization will depend on the outcome of feasibility tests.

Electromagnetic surveys will be performed to investigate the thickness of the volcanic section and fault trends in Yucca Wash (near USW G-5). Alteration zones associated with fault zones will be evaluated and may provide evidence of hydraulic connectivity of the inferred fault system.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.2 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Seismic refraction surveys	SP-08, RO	Seismic study of the tectonic environment	6 June 83
	TBD[a]	Seismic refraction surveys	TBD
Seismic reflection surveys	TBD	Mini-sosie surveys	TBD
Gravity surveys	GPP-01, RO	Gravity measurement and data reduction	14 Jan 85
Magnetic surveys	TBD	Surface-based magnetic surveys	
Electromagnetic surveys	GPP-18, RO	Magnetotelluric measurements	27 May 86

[a]TBD = to be determined.

8.3.1.4.2.1.3 Activity: Borehole geophysical surveys

Objectives

The objectives for this activity are (1) to aid in the definition and refinement of the location and character of lithostratigraphic units and contacts between units and (2) to determine the distribution of rock properties within lithostratigraphic units.

Parameters

The parameters for this activity are the direct measurements and quantities derived from geophysical logs, statistical analysis, cross plots, and correlation with core data, including the borehole diameter, in situ bulk density, electrical conductivity, resistivity, spontaneous potential, gamma radiation intensity, temperature, induced polarization, porosity, saturation, potassium-uranium-thorium (K-U-Th) content, water content, seismic velocities, deformation moduli, magnetic susceptibility, and total magnetic field intensity.

Description

A suite of commercially available geophysical logs will be obtained in future holes drilled in the vicinity of Yucca Mountain. Additional experimental geophysical logs also will be obtained in selected boreholes. Geophysical log data will be correlated with measurements of properties such as porosity, saturation, water content, seismic velocity (in the unsaturated zone), deformation moduli, magnetic susceptibility, total magnetic field intensity, K-U-Th content, and hydraulic conductivity.

Compensated-density, induction, resistivity, and spectral-gamma logs will be used most frequently for lithologic correlations, although other logs may be used such as caliper, spontaneous potential, temperature, neutron, and induced polarization. Signatures of compensated-density logs will provide information to identify dominant lithophysal zones in boreholes where only drill bit-cutting samples will be available, or where poor resolution exists on borehole video-camera logs. Induction, resistivity, and spectral-gamma logs are expected to serve as indicators of smectite- and zeolite-rich intervals. These logs also will be used to identify key stratigraphic markers at the top and base of major ash-flow tuffs, which commonly show an increase in alteration.

Borehole samples, borehole video-camera logs, and geophysical logs will be correlated to help determine the vertical and lateral continuity of the lithostratigraphic units. Geophysical log data will provide rock property data for the unsaturated and saturated zone hydrology models and mechanical and thermal models of the host rock and surrounding units.

Borehole gravimetry will be used in available boreholes to obtain bulk density and structural information for the region around each hole. In addition, data from this technique will be used to study lithophysal zones, and to model the Tertiary-Paleozoic surface at the site. Gravimeter logs have been obtained for several holes (UE-25p#1, UE-25c#1, and USW H-1) including several which were continuously cored (USW G-3 and G-4). Additional logs will be acquired from as many as 15 of the existing and proposed water table holes which are nearest the site, existing deep holes as available, and all of the proposed holes which penetrate the base of the Topopah Spring Member.

Large spacing electromagnetic (EM) and resistivity logging will be tested and evaluated to determine applicability for studying fracture and lithophysal zones, and for interpreting anomalies detected by means of other borehole and surface geophysical methods. The application of these methods to acquisition of site characterization data will depend on the outcome of preliminary testing.

<u>Methods and technical procedures</u>

The methods and technical procedures for Activity 8.3.1.4.2.1.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Borehole geophysical surveys and logging	GP-02, RO	Subsurface investigations	1 Mar 83
	GPP-12, RO	Borehole gravity measurement and data reduction	20 Mar 85
	GPP-14, RO	Induced polarization borehole logging operations	27 May 86
	TBD[a]	NNWSI Project logging procedures	TBD
	TBD	Statistical analysis of borehole geophysical log data	TBD

[a]TBD = to be determined.

8.3.1.4.2.1.4 Activity: Petrophysical properties testing

Objectives

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.

Parameters

The parameters for this activity are

1. Electrical resistivity and bulk density of core samples containing in situ pore waters.

2. Electrical resistivity, induced polarization, bulk density, grain density, porosity, seismic velocities, and hydraulic conductivity on resaturated samples.

Description

Rock property testing will provide data for use in the interpretation of surface and borehole geophysical surveys (Activities 8.3.1.4.1.1.2 and

8.3.1.4.1.1.3). Laboratory measurements will be made on core samples obtained from boreholes drilled in the area of interest. Mechanical and thermal properties determined by those testing activities described in Investigation 8.3.1.15.1 and other activities under Investigation 8.3.1.4.2 will also be used in interpretation of geophysical surveys.

This activity will provide data on (1) the degree of water saturation within the rock above the static water level, (2) the moisture flux through the rock matrix, (3) preferential paths for water flow, (4) the potential for contaminant transport by means of diffusion processes, (5) concentrations of clays and zeolites within the measured stratigraphic section, (6) statistical relationships of various rock properties to provide information on the degree of welding, alteration, and compositional uniformity, and (7) rock property variation for integration in a three-dimensional geophysical model of the site.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.4 are given in the following table.

	Technical procedure		
Method	Number	Title	Date
	(NWM-USGS-)		
Laboratory measurements of rock properties	GPP-10, RO	Rock properties analysis of Yucca Mountain core samples	16 Jan 85

8.3.1.4.2.1.5 Activity: Magnetic properties and stratigraphic correlations

Objectives

The objectives of this activity are to

1. Provide magnetic property data to aid the interpretation of volcanic stratigraphy and structure of rock units within the Yucca Mountain site area.

2. Use paleomagnetic directions to provide orientations for drill core segments.

3. Assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

Parameters

Three categories of parameters are required for this activity.

Measured magnetic parameters:

1. Orientation and magnitude of remanent magnetism.
2. Magnetic susceptibility.
3. Curie temperature.

Measured properties of flow units:

1. Textural variations across boundaries.
2. Grain size variations.
3. Pumice clast concentrations.
4. Locations of lithic-rich subzones.
5. Nature of contacts between flow units.

Inferred properties of flow units:

1. Locations of deposition breaks.
2. Thicknesses of individual flow units.

Description

Natural remanent magnetization (NRM) and magnetic susceptibility exhibit systematic variation that correlates with depositional breaks within several major ash-flow tuffs. Data will be collected to help understand the observed mineralogical variations that produce the observed changes in magnetic susceptibility and remnant magnetization. Empirical relationships will be developed between depositional breaks and variations in these magnetic properties to provide information for the three-dimensional geologic model.

Lithologic relationships will be developed based on observations of the following rock properties: (1) measurement of NRM, (2) measurement of anhysteritic remanent magnetization (ARM), (3) measurement of isothermal remanent magnetization (IRM), (4) measurement of saturation magnetization (M_{sat}), (5) measurement of magnetic susceptibility, (6) alternating field demagnetization, (7) thermal demagnetization, and (8) curie temperature determination.

Oriented samples for rock magnetic properties testing will be collected from surface outcrops in the vicinity of Yucca Mountain. Sampling sites will be selected where geologic evidence indicates that the area is relatively undisturbed and the identity of the unit sampled is well known. These sites are used to establish reference paleomagnetic directions for geologic units. Other sites will be selected where rotations of the geologic structure will be evaluated. Data from these sites will be used to assess the magnitudes of the rotations.

Samples have been collected from drill core segments at 3-m intervals from throughout drillholes USW G-1, USW G-2, USW GU-3, and USW G-3. Samples also have been collected from throughout the sections penetrated by two drillholes located on Crater Flat (VH-1 and VH-2). Further sampling from drill core will be obtained from oriented core segments.

Variations in magnetic properties determined in the laboratory will be used to select intervals of core from drillholes USW G-1, USW G-2, USW GU-3, and USW G-3 for detailed petrographic studies. Studies will focus on identifying subtle variations across contacts that separate subunits of major ashflow tuffs. These features include textural changes, localized concentrations of pumice clasts and lithic fragments, anomalous welding characteristics, and subtle compositional changes that may correlate with abrupt changes in magnetic properties.

Measurement of NRM and remanent magnetization will be determined with a spinner magnetometer after at least one level of alternating field demagnetization. Progressive alternating field and thermal demagnetization will help assess mineralogical variations within the rock. Additional rock magnetic measurements (ARM, IRM, M_{sat}) will be used to help assess variation in the composition, relative abundance, and magnetic grain size of magnetic minerals. Selected samples are subjected to progressive thermal demagnetization in order to determine blocking temperature spectra, and to assess whether samples possess multiple components of remanent magnetization. Curie temperatures will be determined from rock chips of mineral separates to help define the magnetic minerals present in the samples.

Measurements of the relative magnitude of magnetic susceptibility will be obtained using a hand-held magnetic susceptibility meter. This meter will provide relative values, and will help limit the size of intervals of core selected for petrographic studies. If this technique proves to be successful, the instrument will be used in continuously cored holes.

To measure total intensity and magnetic susceptibility variation with depth, borehole magnetic surveys using an experimental flux-gate magnetometer, proton-spinner magnetometer, and susceptometer will be performed as described in Activity 8.3.1.4.2.1.3. These logs will be correlated with available geologic data. Geologic correlations will focus on identifying depositional units and rock characteristics changes in the Topopah Spring Member.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.1.5 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Sampling, examination and petrographic analysis of selected intervals of core and outcrop	MDP-01, R0	Identification, handling, storage, and disposition of drillhole core and samples	15 Oct 81
	GP-02, R0	Subsurface investigations	1 Mar 83
	GP-05, R0	Geologic support activities	1 Mar 83
	GP-19, R0	Procedure for the identification, handling, and disposition of drillhole core and cutting samples from the drill site to the core library	6 Mar 87
Density variation in rock mass	GP-14, R0	Measurement of dry bulk rock densities from paleomagnetic samples	25 Sept 86
Use of the hand-held magnetic susceptibility meter	GPP-06, R0	Rock and paleomagnetic investigations	1 Nov 84
Borehole magnetic surveys and logging	GPP-15, R0	Magnetic susceptibility borehole logging operation	27 May 86
	GPP-17, R0	Magnetometer borehole logging operations	27 May 86
Sampling, and paleomagnetic testing and analysis of selected intervals of core and outcrop	TBD[a]	NNWSI Project logging procedure	TBD

Method	Technical procedure Number	Title	Date
	GPP-06, RO	Rock and paleomagnetic investigations	1 Nov 84

[a]TBD = to be determined.

8.3.1.4.2.2 Study: Characterization of the structural features within the site area

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

Surface and subsurface structural studies will be performed to identify and characterize fracture-fault systems within the site area. Detailed geologic mapping of zonal features in ash-flow tuffs that crop out at the surface of Yucca Mountain will provide the necessary stratigraphic control for identifying small-scale faults. Lateral variability of fracture networks will be studied by detailed mapping and pavement analysis. Subsurface distribution and geologic characteristics of fracture-fault zones will be studied by analysis of core samples, borehole evaluations, exploratory shaft studies, and application of geophysical techniques. Results of these studies will be integrated with hydrologic study results described in Section 8.3.1.2 to provide information for the development of geologic models of the site (Study 8.3.1.4.2.3).

Geologic mapping of the exploratory shaft and drifts will include detailed fracture mapping and photogeologic recording. Borehole evaluations in the exploratory shaft facility after drilling and coring, will include video, geophysical and vertical seismic profiling surveys. Fracture-filling mineralogy studies in the shaft, drifts, and boreholes will be conducted to evaluate the chronology of fracture development.

Activities planned for this study include (1) geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000, (2) surface-fracture network studies, (3) borehole evaluation of fractures and faults, (4) geologic mapping of the exploratory shaft and drifts, and (5) vertical seismic profiling studies.

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

Objectives

The objectives of this activity are (1) to map zonal variations within exposed tuffs that will aid in the identification of structural displacements at a scale of 10 m or less, and (2) to detect subtle changes in structural styles.

Parameters

The parameters for this activity are

1. Thickness, attitudes, and lateral extent of zones within ash-flow and bedded tuff intervals, areal extent of exposed bedrock.
2. Attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones.

Description

Geologic mapping of zonal variations in ash-flow sheets and structural features that are exposed over much of the site area has been completed and published at a scale of 1:12,000. The mapped area forms an irregular pattern, the boundaries of which roughly coincide with prominent topographic features (Figure 8.3.1.4-10, Area A). The northernmost limit of the map is Prow Pass; the northeastern boundary is Yucca Wash; the eastern limit is Fortymile Wash; the southern extent is the southernmost exposure of Fran Ridge; and the western limit is Windy Wash.

Mapping will extend outward from the western and southern boundaries of the mapped area to include areas east of longitude 116° 32' and areas north of latitude 36° (Figure 8.3.1.4-10, Area B). The mapping will identify thickness, attitude, and lateral extent of zones within ash-flow tuffs and bedded tuff intervals; areal extent of exposed bedrock; and attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones. Northern, northeastern, and eastern limits of the map area will not be extended because rock units of interest are poorly exposed in those areas. The need for larger scale mapping (e.g., 1:2,400) in the immediate vicinity of the repository facilities will be assessed.

Geologic information that is initially documented on aerial photographs during field mapping will be transferred to stable topographic base maps by using high-precision photogrammetric techniques.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.1 are given in the following table.

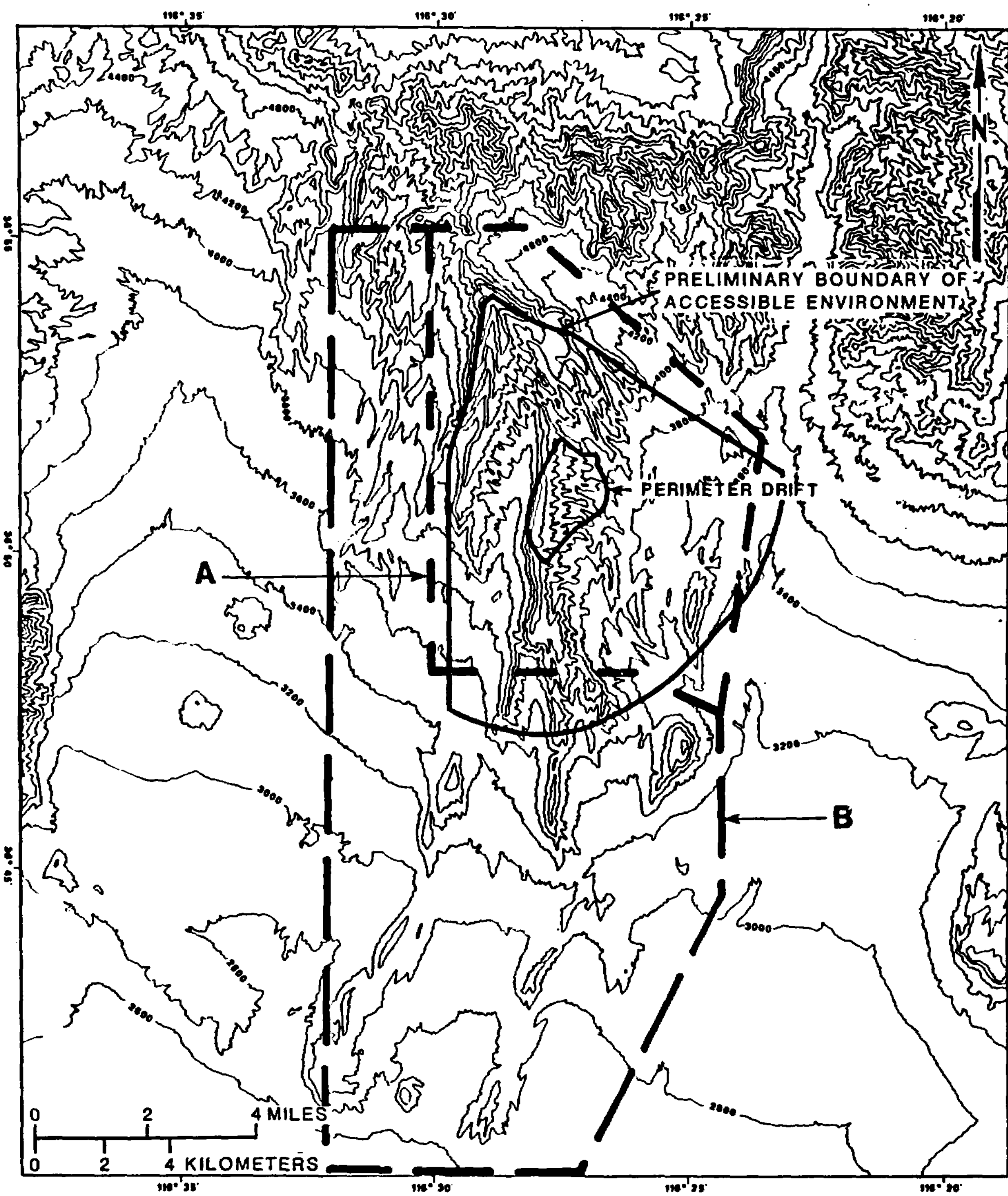


Figure 8.3.1.4-10. Approximate areal limits of mapped area (A) and area of additional mapping (B).

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Field mapping using 1:12,000-scale aerial photographs	GP-01, RO	Geologic mapping	1 Mar 83
Transfer of geologic features to topographic base maps using high-precision photogrammetric techniques	GP-01, RO	Geologic mapping	1 Mar 83

8.3.1.4.2.2.2 Activity: Surface-fracture network studies

Objectives

The objective of this activity is to provide fracture parameters and analyses in support of hydrologic modeling of potential flow paths, particularly in the unsaturated zone. The analyses will provide quantitative approaches to determining spatial distribution of fractures, chronology of fracture development, and parametric characteristics of fractures. Applications are expected to aid development of tectonic models and possibly to aid determination of the bulk response of fractured rock in the context of excavation and loading.

Parameters

The parameters for this activity are fracture orientation, aperture, roughness, trace length, spatial distribution, interconnectedness, and fracture-filling mineralogy.

Description

The characterizations of fracture networks on the surface of Yucca Mountain will be carried out through a phased program of detailed studies of natural outcrops. Because analyses of fractures in drillholes (Activity 8.3.1.4.1.2.3), and exposed in the exploratory shaft (Activity 8.3.1.4.1.2.4) are based on relatively small samples that emphasize the vertical dimension, analyses based on surface exposures of fractures provide a unique opportunity to understand the character of fracture networks and spatial distribution. Preliminary work indicates that most fractures are strata-bound. Therefore, fluid flow paths through fractures depend to a large degree on the intersections of fracture networks at the strata boundaries. The outcrops which provide two-dimensional surfaces through three-dimensional fracture networks, will be selected to obtain the most effective samples of as many subunits as possible of the Paintbrush Tuff. Analyses will proceed only if sample areas continue to be representative of the stratigraphic sequence in the repository block.

The exposures will be mapped in the field on aerial photographs at a scale of approximately 1:50. Only fractures longer than 0.20 m will be mapped. After the exposures are mapped in detail, a fracture data base will be constructed from measurements and descriptions of the following fracture characteristics: (1) orientation, (2) aperture, (3) roughness, (4) trace length, (5) interconnectivity, and (6) fracture-filling material.

A fractal analysis of each exposure will be performed to quantify the spatial distribution of fracture traces, and fracture trace intersections. The utility of fractal description is based partly on the capability to describe geometric observations on different scales, using an approach that is independent of scale. Fractal descriptions may also serve as a means to identify and study spatial variation in network geometry. Fractal analysis offers the best available technique to characterize the complex three-dimensional fracture systems in the repository block, given the sparse observational data that can be obtained. Other analysis methods will be applied to the fracture data base where appropriate.

The data collected on the other parameters listed previously will be analyzed in various ways. Fracture orientations (strike and dip) of each network will be plotted onto lower hemisphere equal-area projections and examined for groupings into preferred sets. Fracture trace-lengths, aperture, and roughness frequency distributions will be plotted and characterized for each fracture network.

Photogeologic mapping of fracture traces will be investigated as a technique for documenting local fracture patterns and determining the degree of variation among them. Fracture traces will be mapped from black and white 1:2,400-scale aerial photographs by means of a Kern PG-2 mechanical stereo-plotter. Data are traced directly onto a topographic base sheet oriented to the aerial photographs. The area covered by the photogeologic map will be determined by the areal coverage of the photograph set and the areas on the photographs where fracture traces are visible. Measurements from the photogeologic map will be limited to measuring the bearing of the fracture trace, measured directly from the base sheet.

Field work will be initiated as a means of checking the validity of fracture trace orientations measured from the photogeologic map. Areas selected on the photogeologic map will be located in the field. The number of areas selected will be based on the number determined to be representative of the photogeologic traces. Bearings of all exposed fracture traces are recorded from each area.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.2 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Mapping of fracture traces from low-altitude aerial photography	TBD[a]	Surface-fracture trace mapping on aerial photographs	TBD
Outcrop studies	GP-12, R1	Mapping fractures on pavement outcrops and along traverses	6 Mar 87
Fracture mapping of hydraulically exposed pavements and natural washout strips	GP-12, R1	Mapping fractures on pavement outcrops and along traverses	6 Mar 87
Statistical analysis of data, including fractals	GP-12, R1	Mapping fractures on pavement outcrops and along traverses	6 Mar 87

[a]TBD = to be determined.

8.3.1.4.2.2.3 Activity: Borehole evaluation of faults and fractures

Objectives

The objectives of this activity are to

1. Assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution.

2. Determine vertical and lateral variability and characteristics of subsurface fractures.

3. Identify subsurface characteristics of fault zones.

Parameters

The parameters for this activity are

1. Fracture location, dimension, type, orientation, relative chronology, aperture, degree of mineralization, mineralogy of fillings, surface profile, roughness coefficient, and apparent frequency.

2. Lateral variability in apparent fracture frequencies and strike directions of fractures within lithostratigraphic units, and subsurface fracturing closely associated with fault zones.

Description

Analysis and interpretation of subsurface characteristics of faults and fractures in the site area will, in part, be based upon (1) core sampling and fracture logging, (2) borehole video camera logging, (3) acoustic televiewer surveys and logging.

Fracture and fault studies in continuous core will help determine the relative spatial relationships of these features. Measurements will include maximum dimension, relative chronology, apertures, and fracture surface characteristics (such as surface profile and roughness coefficient), degree of mineralization, and mineralogy of fillings. Attitudes of fractures and faults will be obtained by analysis of oriented cores and by orienting segments of core based on reorientation using paleomagnetic techniques (Activity 8.3.1.4.2.1.5).

Careful reconstruction and analysis of core segments will not eliminate many of the sampling limitations that are inherent to the study of fractures in near-vertical coreholes, particularly at Yucca Mountain where vertical fractures dominate. Characterization of fractures in core provides only one dimension of the total fracture network and will be integrated with surface studies that provide information from other sampling orientations to help understand sample bias in corehole data. The relatively small sample size of core also precludes the study of fracture dimensions. No distinction can be made between large, through-going fractures and fractures that have very short trace lengths. Future coreholes will be used to aid in planning studies in the exploratory shaft and associated drifts (Activity 8.3.1.4.2.2.4) where more accurate observations of three-dimensional fracture networks can be made.

A continuous visual display of borehole walls will be obtained in future holes drilled in the vicinity of Yucca Mountain by using an instrument assembly that includes a borehole television camera, compass, light source, and digital depth readout. Video-camera tapes will be reviewed and the location, orientation, and relative abundance of fractures will be recorded. Fracture data will be compiled to show changes in the apparent frequency of fractures as a function of depth, stratigraphic unit, and lithostratigraphic unit. Directional orientation histograms will be constructed that illustrate distribution of strike and dip directions within appropriate lithostratigraphic and stratigraphic units. These types of compilations will provide a means for estimating the degree of lateral variability in apparent fracture frequencies and strike directions of fractures within lithostratigraphic units, and provide a means for estimating subsurface fracturing closely associated with fault zones.

Acquisition of a continuous record of fractures intersecting a borehole is the primary advantage of using oriented borehole television to map fractures in the subsurface. However, several limitations of the method can be identified that limit the characterization of fracture networks. They include the following:

1. Data are biased because vertical fractures are not adequately sampled as in core studies.

2. Only one dimension of the fracture network is sampled.

3. Inaccuracies in identifying and measuring the toes and heels of fracture planes that cut the borehole limit data acquisition to strike and dip directions only; the amount of dip of fracture planes often cannot be confidently measured and, therefore, true fracture spacings cannot be obtained.

4. Important fracture parameters that are useful for characterizing fracture sets, such as trace lengths, roughness, and mineral coatings, cannot be measured.

The significance and validity of subsurface fracture analyses based on core and television camera logging will depend largely on comparison with results of fracture analyses conducted in the exploratory shaft and associated underground workings.

Acoustic televiewer logging is an additional technique that can be used to study the distribution of fractures in the saturated zone by inspection of borehole walls. The televiewer provides an oriented image of the acoustic scattering profile of the borehole, in the form of a continuous log. The borehole is displayed on the log as if it were split vertically along magnetic north and unrolled onto a vertical plane. Nonvertical fractures form distinctive sinusoidal features that can be used to measure strike and dip directions as well as the amount of dip.

Fracture attitudes will be measured from existing televiewer logs as well as from logs of future holes. Data sets will be compiled to show the vertical variations as a function of depth and lithostratigraphic units. As in the analysis of fractures from video-camera observations, data will be displayed on direction orientation histograms. This will allow comparative analyses between drillholes. Unlike the video-camera log, the amount of dip often can be calculated from the televiewer log at depths where accurate determinations of hole diameters can be made from existing caliper logs. Acquisition of these data will allow application of statistical methods such as stereonet contouring to determine the significance of any preferential spatial distributions.

Several other borehole geophysical methods, including borehole-to-borehole techniques, will be evaluated in available drillholes at the site. These methods will include borehole radar, crosshole resistivity, crosshole EM, crosshole radar, and high resolution crosshole seismic surveys (Table 8.3.1.4-4). Evaluations also will involve comparative studies of the various methods used to identify subsurface fractures. Stratigraphic intervals for which fracture data are available for several subsurface techniques will be analyzed to assess the utility of each method.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.3 are given in the following table.

Method	Technical procedure: Number	Technical procedure: Title	Technical procedure: Date
Core sampling and fracture logging, including oriented core	GP-11, R0	Logging fractures in core	15 May 85
Borehole video camera surveys and logging	GP-10, R0	Borehole video fracture logging	12 Apr 85
Acoustic televiewer surveys and logging	TBD[a]	Borehole acoustic televiewer surveys	TBD

[a]TBD = to be determined.

8.3.1.4.2.2.4 Activity: Geologic mapping of the exploratory shaft and drifts

Objectives

The objectives of this activity are to

1. Determine the vertical and horizontal variability of fracture networks in the exploratory shaft facility shaft, drifts, and boreholes.

2. Characterize major fault and fault zones in the subsurface.

3. Map the lithostratigraphic features of the subunits, and the abundance and character of lithophysal zones.

4. Assist in selection of test locations in the exploratory shaft test facility.

Parameters

Three categories of parameters are required for this activity.

Fault parameters:

1. Geometry.

2. Physical characteristics.

3. Tectonic styles of faults bounding the repository on the northeast and east, and of the Ghost Dance fault.

Fracture parameters:

1. Orientation.
2. Aperture.
3. Roughness.
4. Trace length.
5. Surface characteristics.
6. Mineralogy.
7. Age.
8. Spatial distribution.

Stratigraphic parameters:

1. Lithology and petrography of Yucca Mountain stratigraphic sequence.
2. Lateral variability of repository host horizon.

Description

Figure 8.3.1.4-11 shows a conceptual layout of the exploratory shaft facility and associated drift projections to major geologic features. The subsurface structures near the northeastern and eastern boundaries of the repository could be directly studied at the ends of northeast and southeast drifts. The character of the Ghost Dance fault within the repository could be investigated at the end of a northwest drift. Lateral variability of the lithologic character of the repository host rock will be determined. Data obtained from fracture mapping in the drifts will be combined with fracture mapping data from the shaft and surface studies to describe the three-dimensional fracture network within the exploratory shaft facility.

Mapping in the shaft and drifts can provide a detailed description of stratigraphic, lithologic, and structural features. Descriptions of fracture networks and interconnections are enhanced by continuous observation because fracture spacing and attitude commonly vary over distances of tens to hundreds of meters. Both objectives can be met in a timely way by a two-tiered approach to the mapping: analysis of stereoscopic photographs of the exposed surfaces and continuous detailed mapping along reference lines.

Stereoscopic photographs will be taken of all exposed surfaces in the exploratory shaft and walls of all drifts as mining progresses; floors and working faces will not be mapped unless anomalous geologic features are exposed. Line drawings of discontinuities such as faults, other fractures, and breccia zones exposed on the walls and roof will be prepared from mosaics of the stereoscopic-photographs using close-range geologic photogrammetry.

More thorough mapping of geologic features will be done at regular intervals between mining shifts. Close-range geologic photogrammetry will provide continuous data for all exposures in the shaft and associated drifts. The shaft will be mapped along horizontal reference lines approximately 2 m apart, only if the photomosaic backup method is used. Also, the photomosaic backup method will be used in drifts, where data will be collected along one or more reference lines in the wall or roof (the number depending on the

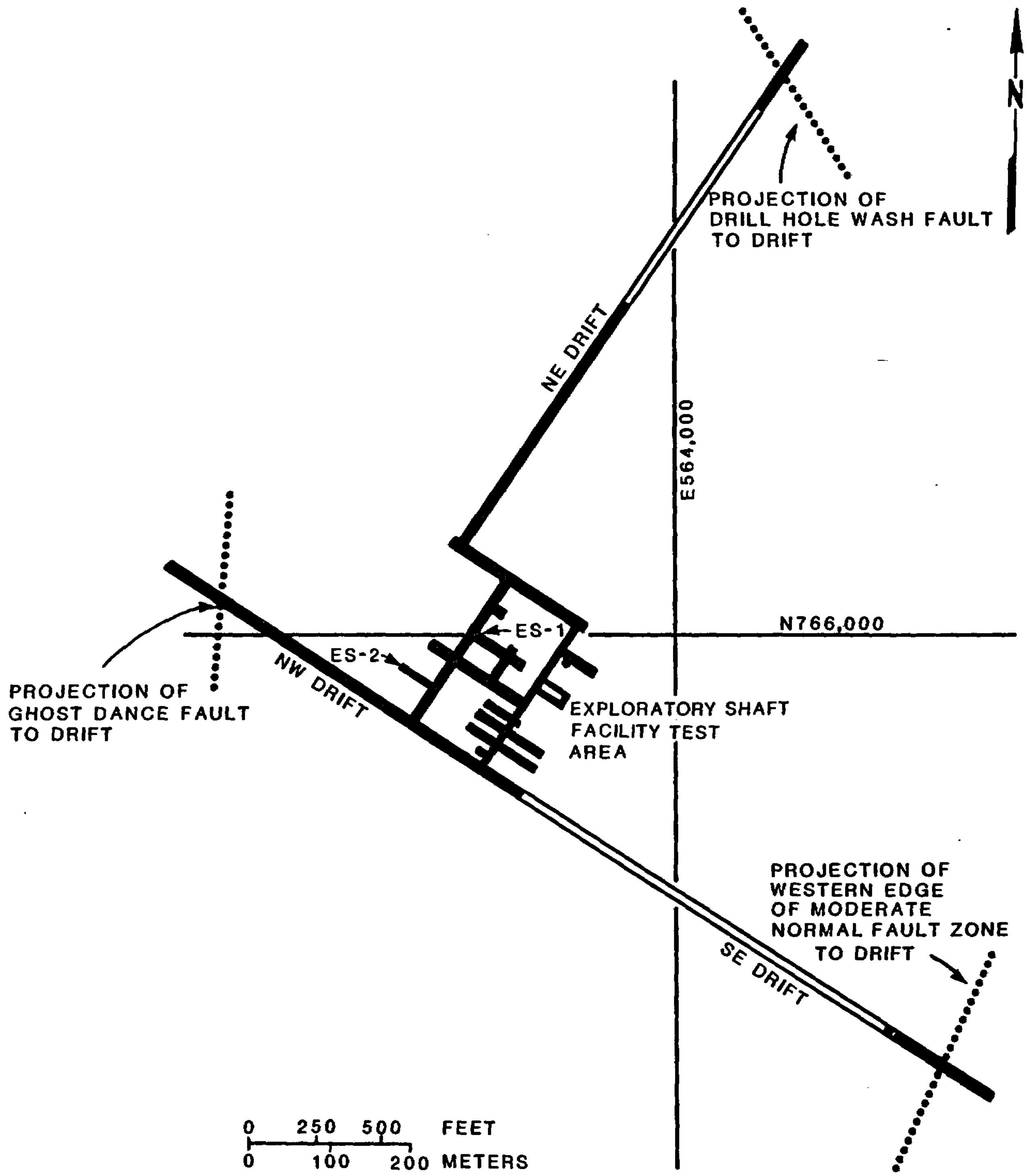


Figure 8.3.1.4-11. Proposed layout of exploratory shaft and drifts.

amount of data needed to characterize fractures and faults). Data to be recorded and samples to be collected during in situ mapping will include (1) photographs of the drift walls and roofs, (2) fracture orientation, (3) fracture aperture, (4) fracture roughness, (5) fracture-trace length, (6) evidence and attitudes of shear on fracture surfaces, (7) fracture coatings, and (8) samples of rock representative of each stratigraphic interval. Observations of lithologic and stratigraphic features will be continuous as appropriate.

Detailed mapping will be emphasized in the area adjacent to the exploratory shaft facility tests, areas near major geologic structures within the repository, and across geologic structures near the borders of the repository. In addition, investigators will make detailed maps of test rooms and will log cores from holes drilled for hydrologic, geomechanical, and geochemical tests in the ESF test area.

If unusual pockets of alteration or fracture-filling minerals are encountered, representative samples may be acquired in conjunction with geologic mapping, as appropriate for mineralogical and age determinations. The location of origin of such samples, and the observed relationships between fracture mineralization and fracture orientation, will be recorded. Sampling of the face and muck pile for uraniferous opal or manganese-rich calcite can be aided by use of an ultraviolet lamp. Petrographic and x-ray diffraction analysis, and uranium-thorium disequilibrium dating, will be performed on collected samples.

In addition to sample collection performed by geologists as described above, two 55-gal (210 L) drums of debris will be salvaged from every round and stored at the Nevada Nuclear Waste Storage Investigations (NNWSI) Project Core Storage Facility for future use of investigations within the NNWSI Project.

Because fracture coatings are more commonly preserved underground than near the surface, they are protected to a greater degree from isotopic exchange. Uranium-thorium disequilibrium dating of calcite and uraniferous opal will be performed as a part of this activity. Electron spin resonance (ESR) dating of quartz and potassium-argon dating of clay fracture coatings from subsurface samples will be performed as a part of activities of Investigation 8.3.1.3.2.

Studies of fracture-filling mineralogy will be used to determine formation of the filling minerals to help infer the ages of fracturing and to estimate rates of tectonism. This information will be used in assessments of the potential for and likely character of additional fracturing and seismic movement at Yucca Mountain. The results of these analyses will be integrated with the evaluations planned for postclosure and preclosure tectonics and repository design.

Analyses of the ages of fracture mineralogy also provide information to aid in the interpretation of past fracture hydrologic-mineralogic processes in the repository host rock and surrounding units. These studies will be integrated with fracture mineralogy evaluations in unsaturated zone hydrology and mineralogic and geochemical activities.

Products derived from this activity will include (1) photographic mosaics of the geologic features on the drift walls and roofs, (2) line drawings of fracture networks on the drift walls and roof, (3) fracture orientations and statistical distributions, (4) fracture-trace lengths and statistical distributions, (5) fracture intersection abundance, (6) fracture apertures and statistical distributions, (7) fracture roughness and statistical distributions, (8) two- or three-dimensional expression of fracture density, (9) three-dimensional estimate of fracture network characteristics and variability, (10) structural domains, (11) style of tectonism, (12) paleostress indications, as suggested by slickensides, (13) lithologic and petrographic description of stratigraphic sequence, (14) an assessment of lateral variability within the exploratory shaft drifts, and (15) archived representative rock samples.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.4 are given in the following table.

	Technical procedure		
Method	Number	Title	Date
In situ measurement of geologic features	TBD[a]	TBD	TBD
Photogeologic recording	TBD	TBD	TBD
Shaft and drift fracture mapping	TBD	TBD	TBD
Borehole drilling and coring in the exploratory shaft and drifts	TBD	TBD	TBD
Sampling and analysis of fracture filling minerals	TBD	TBD	TBD
Dating of fracture-filling minerals	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.4.2.2.5 Activity: Seismic tomography/vertical seismic profiling

Objectives

The objectives of this activity are to

1. Investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings.

2. Calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and to extrapolate the observed fracture patterns to the surrounding region.

Parameters

The parameters for this activity are travel time, amplitudes, and polarizations of the direct, reflected, and refracted compressional and shear waves (SH and SV), as well as other wave propagation characteristics identified by investigating the relationship of wave propagation characteristics to fracture properties.

Description

Tomographic vertical seismic profiling (VSP) techniques may be used to study the degree and character of fracturing of the rock mass. Feasibility studies will be performed to establish whether these techniques are applicable to the unsaturated zone at Yucca Mountain. If they are successful, then multi-offset, multisource (P, SV, and SH) VSP surveys would be conducted between the surface and existing drillholes, and between the surface and the underground excavations of the exploratory shaft facility, to detect and map spatial variation of fracture characteristics in the repository area. The objective will be to derive a series of maps of the fracture characteristics of the subsurface, to be used in development of a three-dimensional descriptive model of fracturing at Yucca Mountain. From previous VSP resolution studies, it is estimated that the spatial resolution for characterization of fracturing, in the VSP study areas at Yucca Mountain, could approach 20 m. The velocities, amplitudes, and polarizations of seismic phases recorded on three-component sensors may be used to infer fracture orientations, density, and spacing. Tomographic analysis using the travel times, amplitudes, and shear wave polarization may be used to relate seismic properties to the fracture properties. Three-component sensors will be placed in available boreholes with the compressional and shear wave sources placed at the surface. Surveys in boreholes will be calibrated by performing similar surveys in the shafts and underground workings where direct observations of fracture characteristics can be obtained. The hydrologic, geochemical, and geomechanical test results obtained in the exploratory shaft facility will be evaluated in terms of the fracture network and host-rock lithology information for the VSP surveys.

The combination of the surface geologic mapping, drillhole studies, and exploratory shaft geologic data combined with the fracture properties mapped from the VSP surveys will be used to construct a three-dimensional geologic framework for the entire repository. That is, the data gained from the VSP studies coupled with the geologic results will provide a means to extrapolate the exploratory shaft facility hydrologic, geochemical, geomechanical, and geophysical properties from specific sites (e.g., boreholes and underground workings) to the entire repository.

The following steps are proposed for the VSP work. First, structural and fracture domains with similar properties will be selected and defined in the exploratory shaft facility soon after each section of drift has been mapped. Second, appropriate sensors will be installed in drillholes into the shaft wall, providing a vertical array of sensors that can then be used to carry out the VSP work with the P- and S-wave sources at the surface. (A similar array of sensors also will be installed in the drift walls to allow additional ray path coverage.) Finally, after the instrumentation has been emplaced, the VSP survey will be conducted.

Laboratory analysis of core samples will be performed to observe and measure seismic propagation effects appropriate for interpreting the properties of the in situ rock mass. Fractured and unfractured specimens will be subjected to seismic excitation at test conditions (frequency, strain amplitude) representative of field test condition.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.2.5 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Tomographic/vertical seismic profiling surveys using P- and S-wave data for fracture and structural mapping	TBD[a]	NNWSI Project vertical seismic profiling	TBD

[a]TBD = to be determined.

8.3.1.4.2.3 Study: Three-dimensional geologic model

Objectives

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2 of Investigation 8.3.1.4.3.

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

Objectives

The objective of this activity is to develop a three-dimensional geologic model of the Yucca Mountain site that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, and design and performance assessment activities.

Parameters

The parameters of this activity fall into three categories.

Stratigraphy-lithology (Lateral and vertical variations in lithostratigraphic units):

1. Depth.
2. Thickness.
3. Attitude.
4. Welding and crystallization.
5. Alteration.
6. Petrography.
7. Lithophysal zones in Topopah Spring Member.
8. Geophysical characteristics.

Faults:

1. Distribution.
2. Displacements.
3. Orientations.
4. Age relationships.
5. Physical features.
6. Geophysical characteristics.
7. Tectonic styles.

Fractures:

1. Spatial distribution.
2. Frequencies.
3. Trace lengths.
4. Orientations.
5. Age relationships.
6. Surface characteristics.
7. Interconnectedness.
8. Aperture.
9. Mineral filling.
10. Geophysical characteristics.

Description

Geologic data that are collected from coreholes, drillholes, outcrops, and geophysical studies will be used to construct isopach maps, structural contour maps, correlation diagrams, and cross sections. These illustrations will show the distribution and lithologic variability of stratigraphic units that underlie the site and surrounding areas such as Crater Flat and Jackass Flats. Principal scales of compilations will be 1:48,000, 1:24,000, and 1:12,000.

As stratigraphic, structural, and geophysical studies progress from data collection and documentation phases into interpretation phases, important sources of information will be reviewed, assessed, and integrated into a model that describes all relevant aspects of the site geology. This descriptive model will also incorporate geologic constraints discovered during development of models of the depositional and diagenetic histories of units.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.2.3.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Synthesis of geologic and geophysical data	TBD[a]	Geologic synthesis	TBD

[a]TBD = to be determined.

8.3.1.4.2.4 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

The areas of performance assessment include the following:

Issue or information need	Subject
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment (Section 8.3.5.13.1).
1.6.1	Site information and design information needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path (Section 8.3.5.12.1)

Issue or information need	Subject
1.8	NRC siting criteria (Section 8.3.5.17)
2.4.1	Site and design information required to support retrieval (Section 8.3.5.2.1).

The areas of design include the following:

Issue or information need	Subject
1.10.4	Description of the postemplacement near-field environment (Section 8.3.4.2.4).
1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions (Section 8.3.2.2.3).
1.11.6	Predicted thermal and thermomechanical response of the host rock, surrounding strata, and ground-water system (Section 8.3.2.2.6).
1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods (Section 8.3.3.2.1).
2.7.1	Radiological protection (Section 8.3.2.3.1).
4.2.1	Site performance information needed for design (Section 8.3.2.4.1).
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1).

The areas of characterization include the following:

Investigation	Subject
8.3.1.2.2	Description of the unsaturated zone hydrologic system at the site
8.3.1.2.3	Description of the saturated zone hydrologic system at the site
8.3.1.3.2	Mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths
8.3.1.4.2	Geologic framework

Investigation	Subject
8.3.1.4.3	Three-dimensional rock characteristics model
8.3.1.8.2	Tectonic effects on waste package
8.3.1.15.1	Spatial distribution of thermal and mechanical properties
8.3.1.15.2	Spatial distribution of ambient stress and thermal conditions
8.3.1.17.2	Potential fault movements at the site

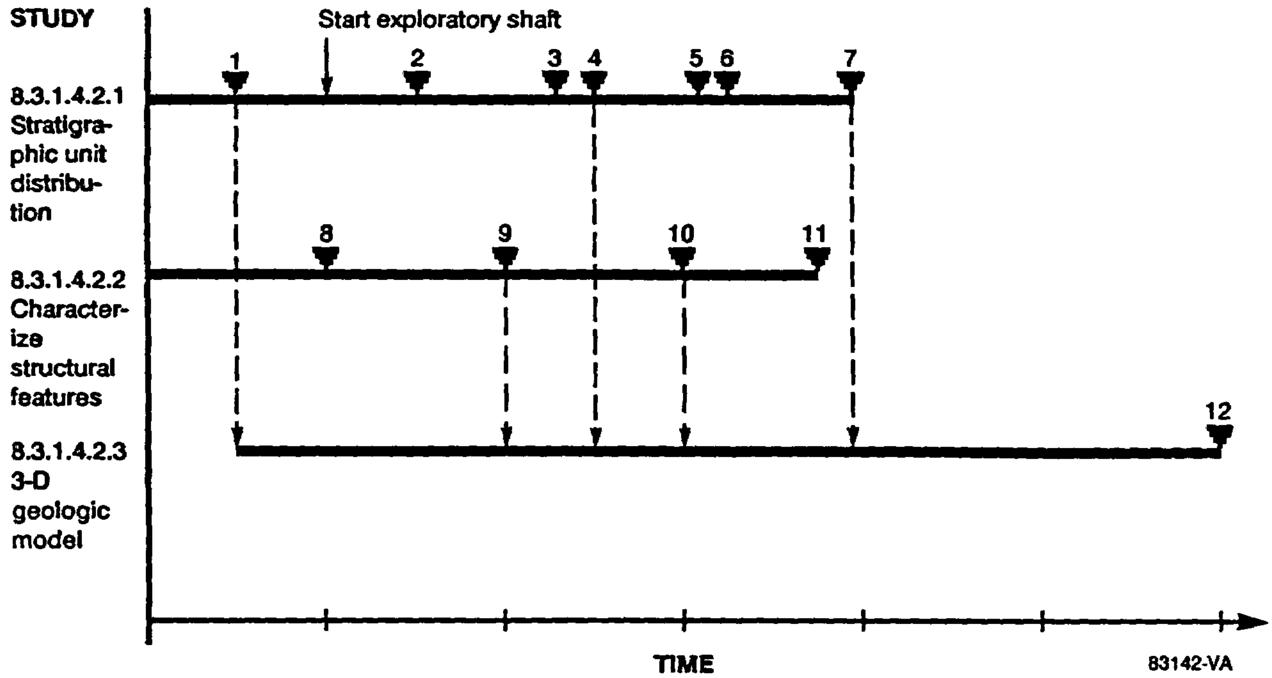
8.3.1.4.2.5 Schedule and milestones

This investigation contains three studies: 8.3.1.4.2.1 (characterizition of vertical and lateral distribution of stratigraphic units), 8.3.1.4.2.2 (characterization of structural features), and 8.3.1.4.2.3 (three-dimensional geologic model). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1. Additional schedule information for exploratory shaft activities can be found in Section 8.5.1.2.

Completion of Studies 8.3.1.4.2.1 and 8.3.1.4.2.2 is partly constrained by the start of the exploratory shaft because some of their activities involve acquisition of data from the exploratory shaft. However, each of these studies also contains activities that can be performed separately from the exploratory shaft, and these can begin after the study plan is available. Studies 8.3.1.4.2.1 and 8.3.1.4.2.3 are expected to begin within the first year of site characterization.

The studies in this investigation will acquire and evaluate data on the nature and spatial variability of the stratigraphic and structural characteristics of the site. The studies will be conducted in parallel to obtain descriptive data and will interact in an iterative fashion to produce the final three-dimensional geologic model for use in the repository license application. The geologic model will contain representations of past and present geologic processes that pertain to the performance of the site.

The study numbers and titles corresponding to the timelines are shown on the left of the figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces.



The points on the timeline are described in the following table:

Point number	Description
1	Milestone Q172. Decision whether to proceed with drillholes G-6 and G-7.
2	Milestone Z493. Complete preliminary geologic model of the site area.
3	Milestone P781. Issue report on lateral variation in stratigraphy.
4	Milestone M368. Issue report on preliminary site geologic description.
5	Milestone R757. Complete alteration and fracture mineralogy studies.
6	Milestone Q117. Complete drilling of geologic holes.
7	Issue report on compilation of structural and stratigraphic information from geologic holes.
8	Milestone P780. Issue final geologic map of Yucca Mountain.

Point number	Description
9	Milestone Z263. Complete vertical seismic profiling studies.
10	Milestone Q009. Issue report on the characterization of structural features within the Yucca Mountain site area.
11	Milestone M624. Complete geologic map of the drift walls.
12	Milestone M384. Complete final 3-D geologic model of the site area.

8.3.1.4.3 Investigation: Development of three-dimensional models of rock characteristics at the repository site

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections summarize available data relevant to the development of three-dimensional models of rock characteristics for the repository area and the immediate vicinity.

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology (summary of significant results)
1.8.1.3	Structural geology and tectonics (summary of significant results)
1.8.2.1	Relation of geology to repository design
3.6.1	Hydrogeologic units
3.10.1	Summary of significant results (hydrogeology)
4.5	Summary of significant results (geochemistry)

Parameters

The principal result of this investigation will be the development of computer-based representations of the three-dimensional distribution of physical property data. Contour maps or cross sections will show the spatial distribution of such parameters as rock compressive strength, thermal conductivity, or gas permeability. Specific parameters to be modeled include those rock characteristics parameters requested as input to design or performance assessment information needs. As an intermediate step in the three-dimensional modeling process, this investigation will provide data such as porosity, saturated hydraulic conductivity, and saturation to provide a basis for defining the detailed spatial variability of the tuff rock mass upon which all rock characteristic distributions depend. Analysis of the core obtained by this study will also provide data pertaining to the following:

1. Location of geologic contacts.

2. Basic rock descriptions including degree of welding, types of pumice or lithic fragments, abundance of lithophysae, gross mineralogy, and alteration.

3. Subsurface characteristics of faults.

4. Fracture frequencies and orientation.

5. Rock quality designation.

The core will be available for more detailed examination of lithology, fractures, faults or other geologic features by other studies and investigations (particularly Investigation Section 8.3.1.4.2, geologic framework). As additional information from detailed study of core, geophysical logs, and other investigations becomes available, the three-dimensional model will be modified to reflect the new data.

Purpose and objectives of the investigation

The purpose of developing three-dimensional, computer-based models of rock characteristics at the Yucca Mountain site is two-fold: (1) to summarize information gained during the course of Investigations 8.3.1.4.2 (geologic framework), 8.3.1.2.1 through 8.3.1.2.3 (hydrologic material properties), 8.3.1.3.2 (geochemical material properties), and Program 8.3.1.15 (thermal/mechanical properties); and (2) to provide a mechanism for transfer of this integrated information to the design and performance assessment issues.

Specifically, performance assessment and design issues have called for quantitative information regarding the spatial distribution of various rock characteristics (Table 8.3.1.4-1). Numerous investigations have been designed to acquire the basic quantitative data or to develop the geologic framework that must be considered in the development of a three-dimensional model of rock characteristics.

Technical rationale for the investigation

This investigation consists of activities that integrate information collected by numerous other investigations. These diverse types of field and laboratory data are presented in the form of three-dimensional models of rock characteristics--models that have been requested by, and that will be utilized directly by, design and performance assessment studies.

Construction of a three-dimensional block model of rock properties that represents actual rock characteristics at the Yucca Mountain site is much more than the arbitrary "plugging" of quantitative values for some rock property into the proper "box" in 3-dimensional space. Interpolation algorithms are numerous, yet application of different procedures may yield vastly differing interpretations of identical input values. The critical factor for developing a model that is representative of in situ conditions is the extent to which the quantitative determinations of some rock property value are constrained by the geologic framework (Investigation 8.3.1.4.2) of the Yucca Mountain area. A porosity model that does not respect constraints imposed by geologic knowledge of the eruptive and depositional history of the rocks involved, the general vertical and lateral variability of similar rocks elsewhere, and the observed displacement of original rock units by faulting will not be generally accepted and therefore will not be useful to a performance assessment analyst or design engineer.

The essential philosophy of model development will be to use detailed information regarding the spatial structure of selected rock characteristics (e.g., porosity, saturated hydraulic conductivity) obtained by Study 8.3.1.4.3.1 (systematic drilling program) and less abundant, quantitative rock characteristics data obtained by Investigations 8.3.1.2.1 through 8.3.1.2.3, 8.3.1.3.2 and 8.3.1.15.1 in order to determine the spatial correlation structure of the rock characteristic(s) under current consideration. Quantitative descriptions of the identified spatial structure will be compared with descriptions of the geologic framework of Yucca Mountain (Investigation 8.3.1.4.2), and major discrepancies will be resolved. The quantitative descriptive data will then be interpolated and projected using a standard mathematical algorithm to create a model of the desired property(ies) as requested by performance assessment and design issues.

8.3.1.4.3.1 Study: Systematic acquisition of site-specific subsurface information

Only one activity is planned under this study.

8.3.1.4.3.1.1 Activity: Systematic drilling program

Objectives

This activity is an example of the type and scope of drilling programs that will be assessed in Investigation 8.3.1.4.1.

The objectives of this activity will be to acquire physical rock samples, analytical data and basic descriptions of the subsurface geology of the repository site on a systematic basis from which to determine the detailed, three-dimensional distribution of rock properties underlying Yucca Mountain. Data from this study are used principally in Programs 8.3.1.2

(geohydrology), 8.3.1.3 (geochemistry), and 8.3.1.15 (thermal and mechanical rock properties) and Investigation 8.3.1.4.2 (geologic framework), which in turn provide essential data for Study 8.3.1.4.3.2 (three-dimensional rock characteristics models).

Description

The systematic drilling program that constitutes Study 8.3.1.4.3.1 is based upon the constraining requirement of data for input to the three-dimensional rock characteristics model (Study 8.3.1.4.3.2), which is systematic sampling and description of rock characteristics on a scale sufficiently detailed to allow quantitative characterization of the spatial variability. The appropriate sampling scale will depend upon the parameter of interest. Determination of adequate characterization of spatial variability will depend heavily upon geostatistical techniques and will be identified in close cooperation with the modeling efforts of Study 8.3.1.4.3.2. Stratigraphic and structural data from this study will be analyzed by Investigation 8.3.1.4.2 (geologic framework).

The data requirements specified by Study 8.3.1.4.3.2 (rock characteristics model) indicate that representative sampling of the repository site should be systematic in both horizontal and vertical dimensions. In support of this requirement, this activity proposes to drill up to 40 continuously cored holes and will provide for the basic geologic description and physical sampling of that core. The actual number and location of these holes will be determined at a later date as the drilling program matures, as described in Investigation 8.3.1.4.1. This study will also provide determinations of a small suite of parameter values (porosity, saturated hydraulic conductivity, saturation) for samples taken from this core in order to determine the spatial variability of the volcanic rock mass in detail. The logic behind this approach is that the basic spatial correlation data to be obtained are correlated statistically to the spatial distribution of other rock characteristics because these other parameters of interest are derived from the same physical rock mass. The essential correlation structure of the rock mass can be used to interpolate between more isolated data points determined through other investigations, including

1. Hydrologic properties (Investigations 8.3.1.2.1 through 8.3.1.2.3).
2. Thermal parameters (Investigation 8.3.1.15.1).
3. Mechanical parameters (Investigation 8.3.1.15.1).
4. Geochemical parameters (Investigations 8.3.1.3.2 through 8.3.1.3.3).

Holes will be located on a grid pattern (with allowance for topography, existing or other proposed site-characterization holes, the exploratory shaft drifts, etc.). The drilling program will be conducted in successive phases, allowing for evaluation of the data collected from each phase before continuing with the next stage. Information gained during each phase may, and probably will, result in a revised plan for the succeeding phase. The actual timing, locations, and phasing of these drillholes will be subject to the results of Investigation 8.3.1.4.1 (development of the integrated drilling program).

Theoretically, the first phase of drilling might consist of about 12 continuous core holes located of a grid of nominal dimensions 3,500 ft by

4,200 ft (Figure 8.3.1.4-12), which covers the entire repository area including areas proposed for extensions. Holes will be drilled to approximately 200 ft below the static water table. The second phase of drilling, if undertaken, might consist of 12 additional continuous coreholes generally located half-way between the holes of the first phase to produce a grid with nominal dimensions of 2,700 by 2,700 ft (Figure 8.3.1.4-13). Several holes may be located at closer intervals in order to provide information on small-scale variability (order of 1,000 ft). Locations of holes for a third phase of drilling are more speculative, but options include completing the remaining 2,700-ft nominal grid locations or focusing on the current repository site and completing a local grid with nominal spacing of 1,750 by 2,100 ft. Both of these options can be tailored to look at specific plans, such as expansion of the presently planned repository, or investigating specific questions that arise during performance confirmation (Figure 8.3.1.4-13). Most holes will be vertical. However, several holes angled approximately minus-60-degrees to the west may be drilled.

The sampling program will be designed to obtain statistically representative measurements of porosity, saturated hydraulic conductivity, and saturation in order to define the basic spatial variability of the rock mass (this study). After measurements of porosity, saturation, and hydraulic conductivity are completed, these samples (and other samples on an as-requested basis) will be analyzed for additional rock characteristics to support the programs in geohydrology (Program 8.3.1.2), rock characteristics (Program 8.3.1.4), and geochemistry (Program 8.3.1.3). Determination of parameters that require destructive testing will be performed last. The process of determining multiple rock properties for the same physical piece of material will form much of the basis for correlating rock characteristics data.

Figure 8.3.1.4-14 summarizes in a conceptual manner a possible method of coordinating the multiple sampling efforts for the same core segment. The actual mechanism eventually used by the Project will be determined by Project needs and coordinated through the drilling integration group (Investigation 8.3.1.4.1) and the sample overview committee.

The sampling program for sample group A (sampled for porosity, hydraulic conductivity, and saturation) is predetermined and is carried out automatically by the Sample Management Facility. Porosity and saturation are determined on samples collected every 5 ft; saturated hydraulic conductivity would be determined on every other sample, or every 10 ft. A secondary sampling program would be conducted in at least two locations within each stratigraphic unit to ensure that close-order variability is adequately represented. This secondary sampling program is represented schematically on the left-hand side of Figure 8.3.1.4-14.

Sample Group B (Figure 8.3.1.4-14) may be collected to define other rock characteristics parameters under other investigations that do not call for the same level of detail as those characteristics in Sample Group A. Sample Group C (Figure 8.3.1.4-14), would be collected for an investigation that requires a different sampling density. Sample Group D (Figure 8.3.1.4-14) represents yet a third study that obtains core samples from the systematic drilling program. Each of these sampling programs, A, B, C, and D, would be predetermined and will take place automatically. In this manner, the

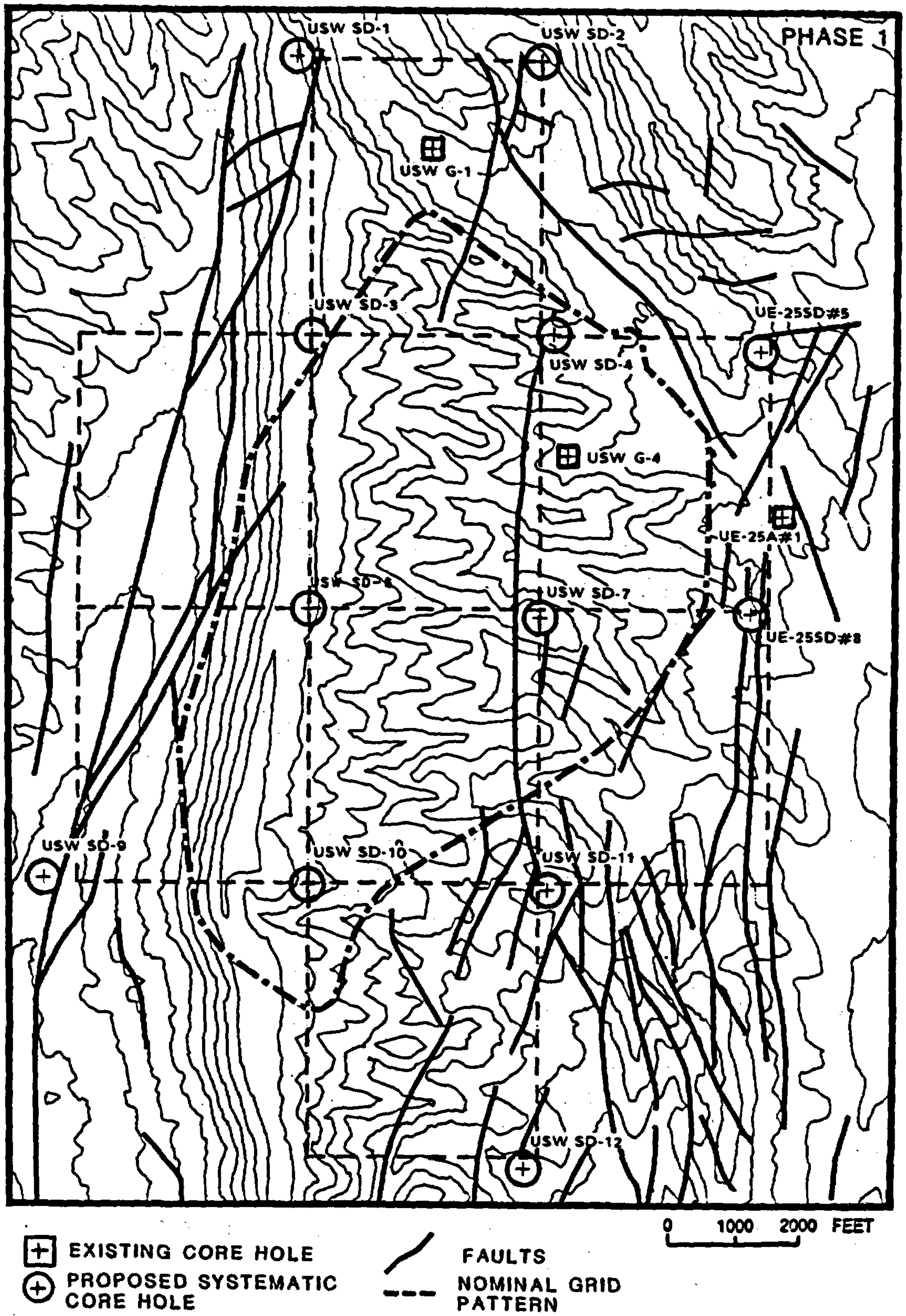


Figure 8.3.1.4-12. Distribution of proposed core holes for the first phase of systematic coring.

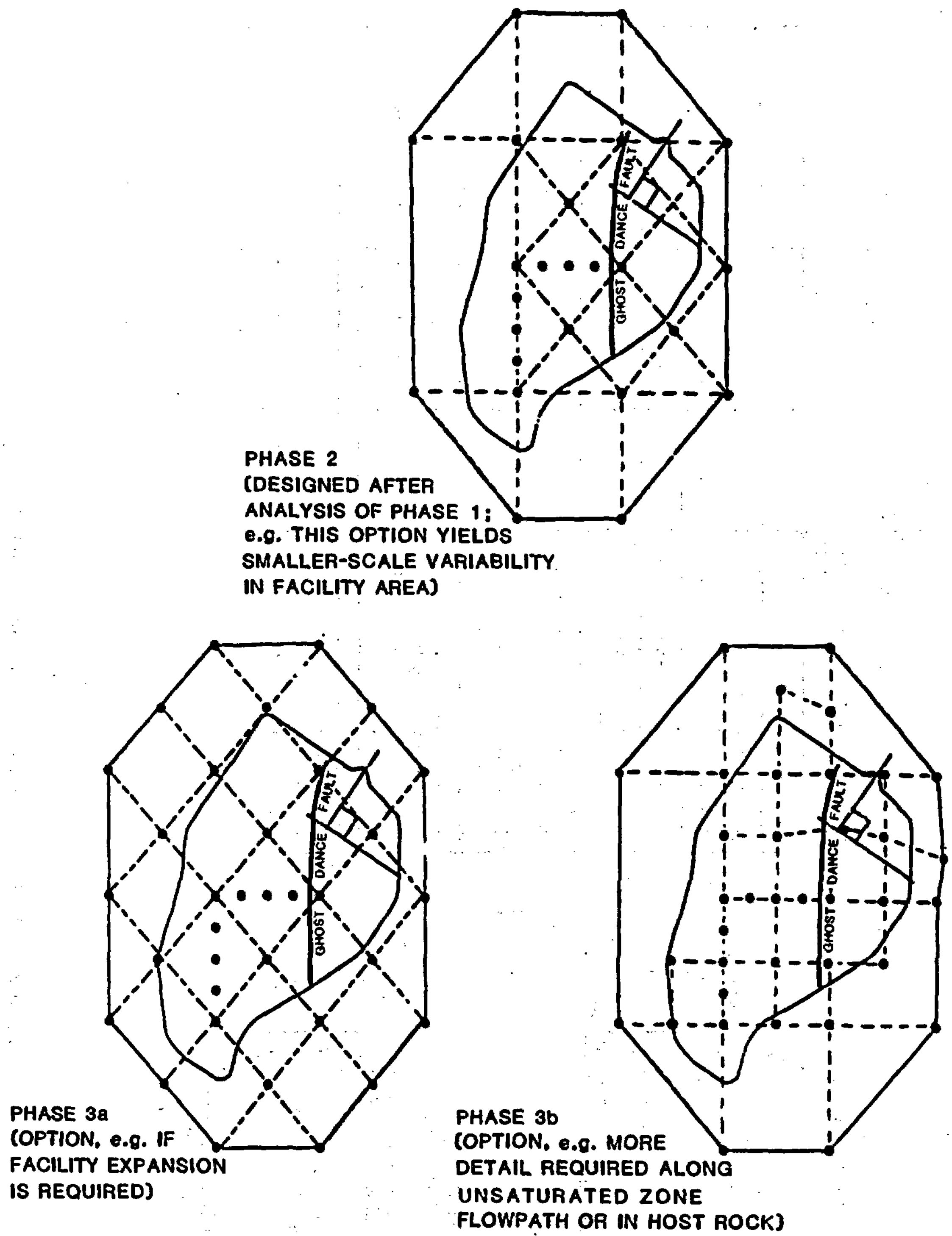


Figure 8.3.1.4-13. Conceptual example of additional phased systematic coring.

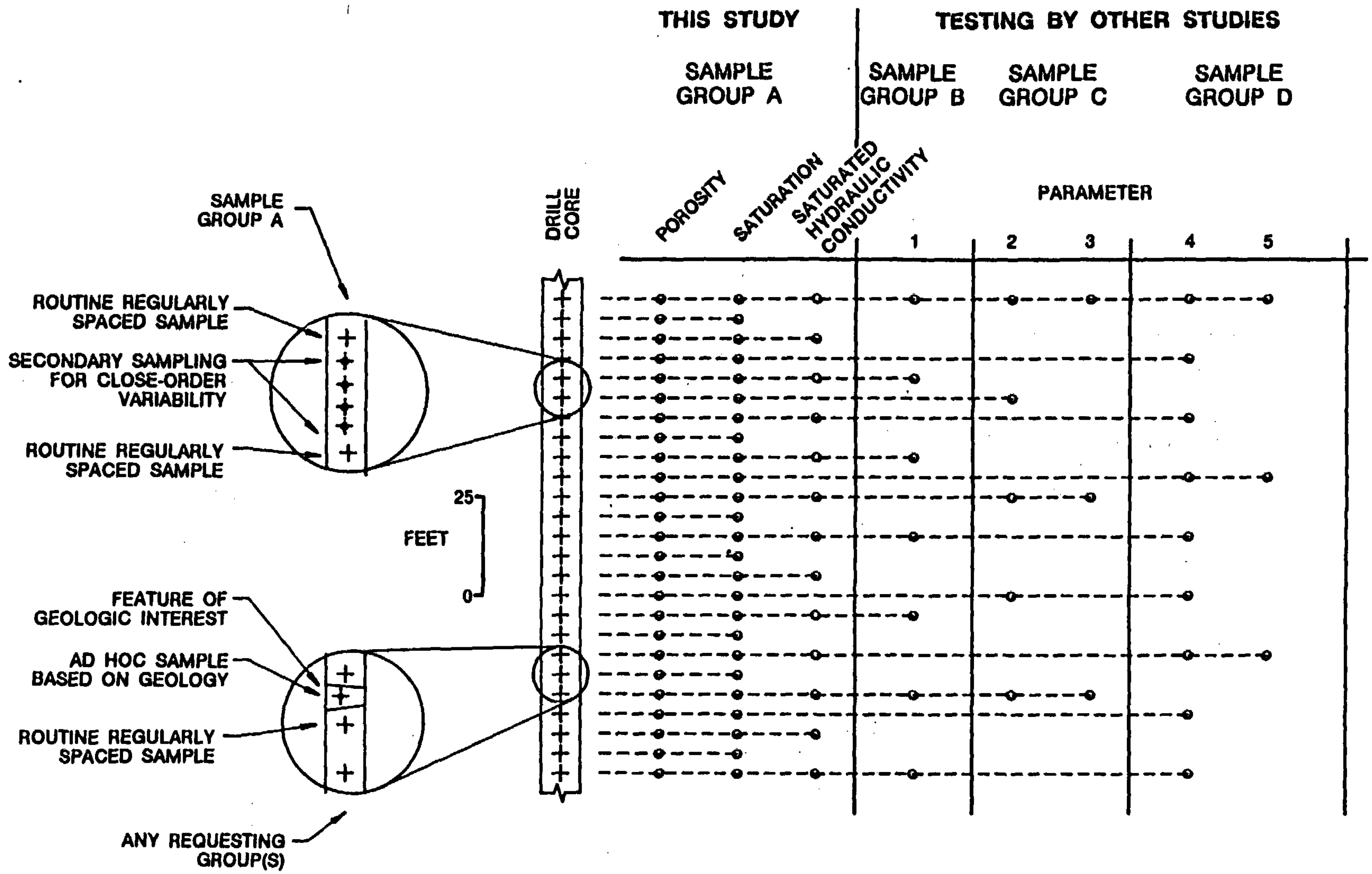


Figure 8.3.1.4-14. Possible systematic sampling program.

systematic drilling (and sampling) program would provide both for samples that are relatively unbiased and representative of the bulk rock mass and for samples of anomalies or features of interest that may occur only locally.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.4.3.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Drilling and coring	TBD[a]	Drilling and coring	TBD
Graphic logging	TBD	Graphic logging of drill core	TBD
Drillhole sampling	TBD	Routine sampling of drillholes	TBD
Sample identification, handling, and storage	TBD	Sample tracking	TBD

[a]TBD = to be determined.

8.3.1.4.3.2 Study: Three-dimensional rock characteristics models

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

Objectives

The objective of this activity is to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site (Investigation 8.3.1.4.2).

Description

This study will serve as the process whereby the majority of location-specific site characterization data describing rock characteristics is summarized and interpreted in light of a constraining geologic framework (Investigation 8.3.1.4.2) for Yucca Mountain. This study also will result in models that will be the means by which these data pass from site characterization investigations to design and performance assessment studies. Because the rock characteristics data and the geologic framework information both will be represented as three-dimensional computer-based models that are closely linked to the NNWSI Project Technical Data Base, representations of the model may take many forms depending upon the use to which the information will be put. For example, information from the model may be represented on contour (isopleth) maps, cross sections, level plans, "3-D" perspective illustrations, statistical distributions (histograms, means, variances), and as numerical data files for direct input to computer codes used for performance assessment or design analyses. The primary requirement of input data for the three-dimensional rock property models is systematic and statistically valid (unbiased) sampling at scales adequate to allow quantitative characterization of the spatial variability of the parameters of interest at Yucca Mountain. Characterization of spatial variability will depend heavily upon geostatistical techniques. Determination of sampling intervals and parameters will rely upon geostatistical analysis in conjunction with sensitivity studies conducted by the associated performance assessment or design information needs.

Much of the analysis of the spatial variability will depend upon detailed knowledge of a few selected rock characteristics (e.g., porosity, saturated hydraulic conductivity, saturation) that will be obtained as part of the integrated drilling program described by Investigation 8.3.1.4.1. These parameters will serve as surrogates in determining the spatial variability of several other parameters needed by performance assessment and design issues in preliminary stages of the analyses. Because the basic spatial distribution of properties of the rock mass at Yucca Mountain is that produced by the processes of volcanic eruption, transport, deposition, and post-depositional alteration (including welding and devitrification), the quantitative description of the distribution should correspond to parameters that derive their distribution from some part of those emplacement and alteration processes.

The measured values of parameters from which the final modeling activities will be conducted, will come largely from Site Programs 8.3.1.2 (geohydrology), 8.3.1.3 (geochemistry), and 8.3.1.15 (thermal and mechanical properties).

The models typically will be constructed as follows. First, measured values of the hydrogeologic, geochemical, or thermal/mechanical parameters of interest (from drillholes and the exploratory shaft facilities) will be mapped into their proper three-dimensional location in model space. Second, geologic framework information (the altitude of geologic contacts, fault locations and offsets, etc.), from Investigation 8.3.1.4.2 also will be mapped into three-dimensional model space. The spatial structure of the observed values (actual measurements) will be determined by geostatistical techniques (variogram or covariance analysis). The spatial structure of a group of related parameters may be further refined by study of the cross-covariances among those quantities. Conflicts between the observed spatial structure of quantitative data and the structure implied by the geologic framework will be resolved (for example, identification of a concealed fault, reinterpretation of volcanic source area or flow path, or identification of some previously unknown alteration phenomenon). Surface-based and borehole geophysical interpretations will also provide a constraint upon subsurface modeling. The geostatistical techniques of covariance analysis and kriging will be used to determine when the spatial structure of a parameter of interest is sufficient.

Hydrologic, thermal/mechanical, and geochemical rock property measurements then will be interpolated into unsampled areas constrained by the observed values at sampling points, by the faulted stratigraphy, and by the identified spatial structure. The most detailed approach to this phase of modeling involves the formulation of a three-dimensional block model, wherein the site is divided into numerous orthogonal blocks and each block is sufficiently small that the parameter of interest maybe treated as constant within the block. Once the structure of the data is determined, the values of unsampled blocks are estimated (interpolated) by kriging (or cokriging). Geostatistical techniques provide estimates of the uncertainty associated with each parameter within each block. Estimates of the probability that the true value in each block exceeds some predetermined limit or is within some range of values (specified by the corresponding performance assessment or design issue) are also possible. Geostatistics also attempts to address the question of variability of observed values for a parameter in terms of support, or the volume of material in which a determination of a parameter is made.

<u>Methods and technical procedures</u>

To be determined.

8.3.1.4.3.3 Application of results

The models and associated uncertainty information derived from this investigation will be used in the following areas of performance assessment and design.

The areas of performance assessment include the following:

Issue or information need	Subject
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment (Section 8.3.5.13.1).
1.6.1	Site information and design information needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path (Section 8.3.5.12.1).
1.8	NRC siting criteria (Section 8.3.5.17).
2.4.1	Site and design data required to support retrieval (Section 8.3.5.2.1).

The areas of design include the following:

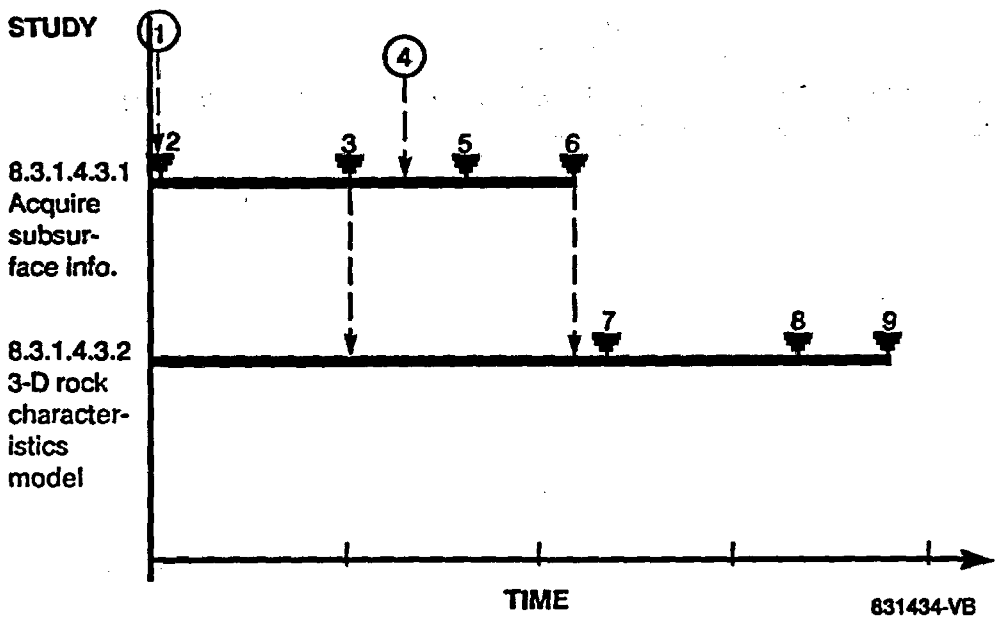
Issue or information need	Subject
1.10.4	Near-field environment (Section 8.3.4.2.4).
1.11.1	Site characteristics needed for design (Section 8.3.2.2.1).
1.12.1	Information needed for seal design and placement (Section 8.3.3.2.1).
2.7.1	Radiological protection (Section 8.3.2.3.1).
4.2.1	Site performance information needed for design (Section 8.3.2.4.1).
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1).

8.3.1.4.3.4 Schedule and milestones

This investigation, addressing three-dimensional rock characteristics models, contains two out-year studies: 8.3.1.4.3.1 (systematic acquisition of site-specific subsurface information) and 8.3.1.4.3.2 (three-dimensional rock characteristics models). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

Study 8.3.1.4.3.1 involves systematic drilling, sampling, logging, and compilation of the rock characteristics data that result from sample testing. The three-dimensional rock characteristics model of Study 8.3.1.4.3.2 will be used in design and performance assessment for the repository license application. Initiation of drilling for this study is contingent on the results from drilling integration in Study 8.3.1.4.1.3, as indicated on the figure. Successive phases of drilling are possible based on reevaluation of accumulated data and are also constrained by the results from drilling integration.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Input from integrated drilling plan for second year of site characterization (Study 8.3.1.4.1.3).
2	Milestone Q093. Begin Phase I of systematic site drilling (representative sampling) program.
3	Milestone Q101. Complete Phase I of systematic site drilling program.
4	Input from integrated drilling plan for third year of site characterization (Study 8.3.1.4.1.3).
5	Milestone Q102. Begin Phase II of systematic site drilling (representative sampling) program.
6	Milestone Q118. Complete Phase II of systematic site drilling program.
7	Milestone Z434. Issue reference model for 3-D rock characteristics of Yucca Mountain, to support advanced conceptual design.
8	Milestone Z436. Complete compilation of systematic drilling data for support of license application design.

Point number	Description
9	Milestone Q006. Complete final reference model for 3-D rock characteristics of Yucca Mountain.

DOE/RW-0160

Chapter 8

Section 8.3.1.5

M

Nuclear Waste Policy Act
(Section 113)

Consultation Draft

CLIMATE

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V

January 1988

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

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8.3.1.5 Overview of the climate program: Description of future climate conditions, required by the performance and design issues

Summary of performance and design requirements for climate information

Certain performance and design issues address requirements that climate and climate-related factors be determined for past, present, and future conditions (Investigation 8.3.1.5.1) and that the effects of future climate on hydrology be determined (Investigation 8.3.1.5.2). The results of Investigation 8.3.1.5.1 are necessary inputs to Investigation 8.3.1.5.2. Pertinent available data on recent climate, meteorology, and paleoclimate are presented in Chapter 5 along with a discussion of methods for predicting future climate. Similarly, available hydrology data pertinent to Yucca Mountain are presented in Chapter 3. The general conclusions from Chapters 3 and 5 are that more data are required than are presently available on the paleohydrology, paleoclimate, and modern climate of the Yucca Mountain area in order to adequately predict future climate and its possible effect on site hydrology relative to repository performance.

Plans for two investigations making up the climate program are given in Sections 8.3.1.5.1 and 8.3.1.5.2. Other plans for site investigations requiring climate information include those for the erosion program (Section 8.3.1.6), the geochemistry program (Section 8.3.1.3), the preclosure hydrology program (Section 8.3.1.16), and the geohydrology program (Section 8.3.1.2). The relationship between the climate program and the design and performance issues is shown in Figure 8.3.1.5-1.

The climate program consists of investigations designed to provide data on past, present, and future climate conditions and to determine the effects of climate change on surface, unsaturated-zone, and saturated-zone hydrology. Specifically, determining the effects of future climate on geohydrology helps to satisfy the following performance and design issues.

Issue	Short title	SCP section
1.1	Total system performance (the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR Part 60 and 40 CFR 191.13)	8.3.5.13
1.8	NRC siting criteria (the favorable and potentially adverse conditions of 10 CFR Part 60)	8.3.5.17
1.9a	Higher level findings (postclosure) of 10 CFR Part 960: (1) 960.4-2-1, qualifying condition for geohydrology, (2) 960.4-2-4, qualifying condition for climate	8.3.5.18

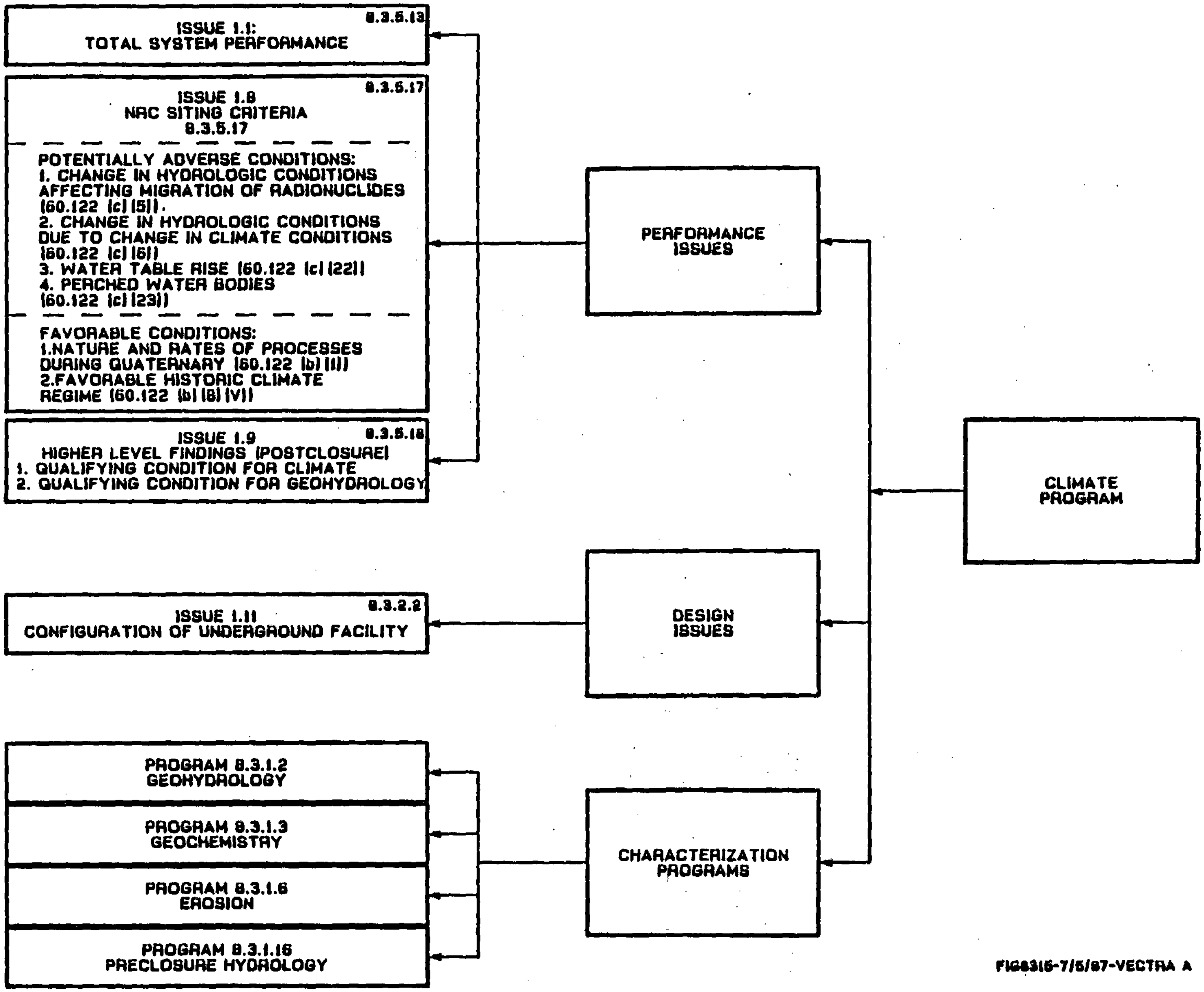


Figure 8.3.1.5-1. General logic diagram showing ties between climate program and other characterization programs, design issues, and performance issues.

Issue	Short title	SCP section
1.9b	Comparative evaluation over next 100,000 yr	8.3.5.18
1.10	Waste package characteristics (postclosure)	8.3.4.2
1.11	Configuration of underground facilities (postclosure)	8.3.2.2
1.12	Seal characteristics	8.3.3.2

For the 10,000-yr period (Issues 1.1, 1.8, 1.9a, 1.10, 1.11, and 1.12), it has been determined that information needed to satisfy Issue 1.1 will be sufficient to address Issues 1.8, 1.9a, 1.10, 1.11, and 1.12. However, to satisfy Issue 1.9b (the comparative evaluation over the next 100,000 yr), additional information is required within the climate program, including additional data and slightly different modeling strategies (Section 8.3.1.5.1.6.2).

Table 8.3.1.5-1 lists the specific repository performance scenarios related to climatic change in the "initiating event or process" column. These scenarios have been identified as being of concern to Issues 1.1 and 1.9b. Each scenario has a related performance measure, as shown in column 2. Each performance measure has two performance parameters in the third column, related to either the 10,000-yr or 100,000-yr period. Each performance measure has an additional parameter assigned as the quantitative bound on the expected magnitude of the performance parameter. Following the performance parameters are the tentative goals and corresponding confidence levels needed to meet the total system performance objectives.

The primary climatic variables that have an effect on the performance measures include magnitude and intensity of precipitation, storm types as they influence initial runoff and snow accumulation, and snowmelt and evapotranspiration. The relationship between the performance parameters and the related climate investigations is presented in the next section.

Approach to satisfy performance and design requirements

The investigations, studies, and activities within the climate program are designed to provide estimates of future climatic conditions and estimates of the effects of future climate on hydrologic conditions. Figure 8.3.1.5-2 traces the flow of information to show how data-gathering activities lead to modeling and synthesis activities to finally result in a determination of the effects of future climate on unsaturated-zone, saturated-zone, and surface-water hydrology to satisfy Performance Issues 1.1 and 1.9b (and subsequently Issues 1.8, 1.10, 1.11, and 1.12) as discussed in the previous section. This figure ties into Table 8.3.1.5-2.

Table 8.3.1.5-1. Initiating events or processes and associated performance measures (for climate program) (page 1 of 2)

Initiating event or process	Intermediate performance measures	Performance parameters	Tentative goal	Needed confidence
Climatic changes cause increase in infiltration over C-area[a]	Radionuclide transport time through UZ[b], given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of flux change due to climatic changes over next 10,000 yr (to satisfy Issue 1.1)	Show expected flux change will be < 5 mm/yr	High
		Expected magnitude of flux change due to climatic changes over 100,000 yr (to satisfy Issue 1.9b)	Show expected flux change will be < 5 mm/yr	High
Climatic changes cause an increase in altitude of water table	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level due to climatic changes over next 10,000 yr (to satisfy Issue 1.1)	Show expected magnitude of change in water-table altitude will be <+100 m	High
		Expected magnitude of change in water-table level due to climatic changes over next 100,000 yr (to satisfy Issue 1.9b)	Show expected magnitude of change in water-table altitude will be <+100 m	Moderate
Climatic change causes an increase in the gradient of the water table within the C-area	Radionuclide transport time through SZ[c], given fixed distances to accessible environment boundary	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr (to satisfy Issue 1.1)	Show change will be $< 2 \times 10^{-3}$	Moderate

Table 8.3.1.5-1. Initiating events or processes and associated performance measures (for climate program) (page 2 of 2)

Initiating event or process	Intermediate performance measures	Performance parameters	Tentative goal	Needed confidence
		Expected magnitude of change in water-table gradient due to climatic change over next 100,000 yr (to satisfy Issue 1.9b)	Show change will be $< 2 \times 10^{-3}$	Moderate
Climatic change causes appearance of surficial discharge points within C-area	Radionuclide transport time through SZ, given fixed SZ rock hydrologic and geochemical properties	Expected locations of surficial discharge points within C-zone over the next 10,000 yr; magnitudes of discharges at each location (to satisfy Issue 1.1)	Show that no significant surficial discharge points could appear within C-area, given a water-table rise <+160 m	Moderate
		Expected locations of surficial discharge points within the C-zone due to climatic change over the next 100,000 yr (to satisfy Issue 1.9b)	Show that no significant surficial discharge points could appear within C-area, given a water-table rise <+160 m	Moderate

[a] C-area = controlled area.
[b] UZ = unsaturated zone.
[c] SZ = saturated zone.

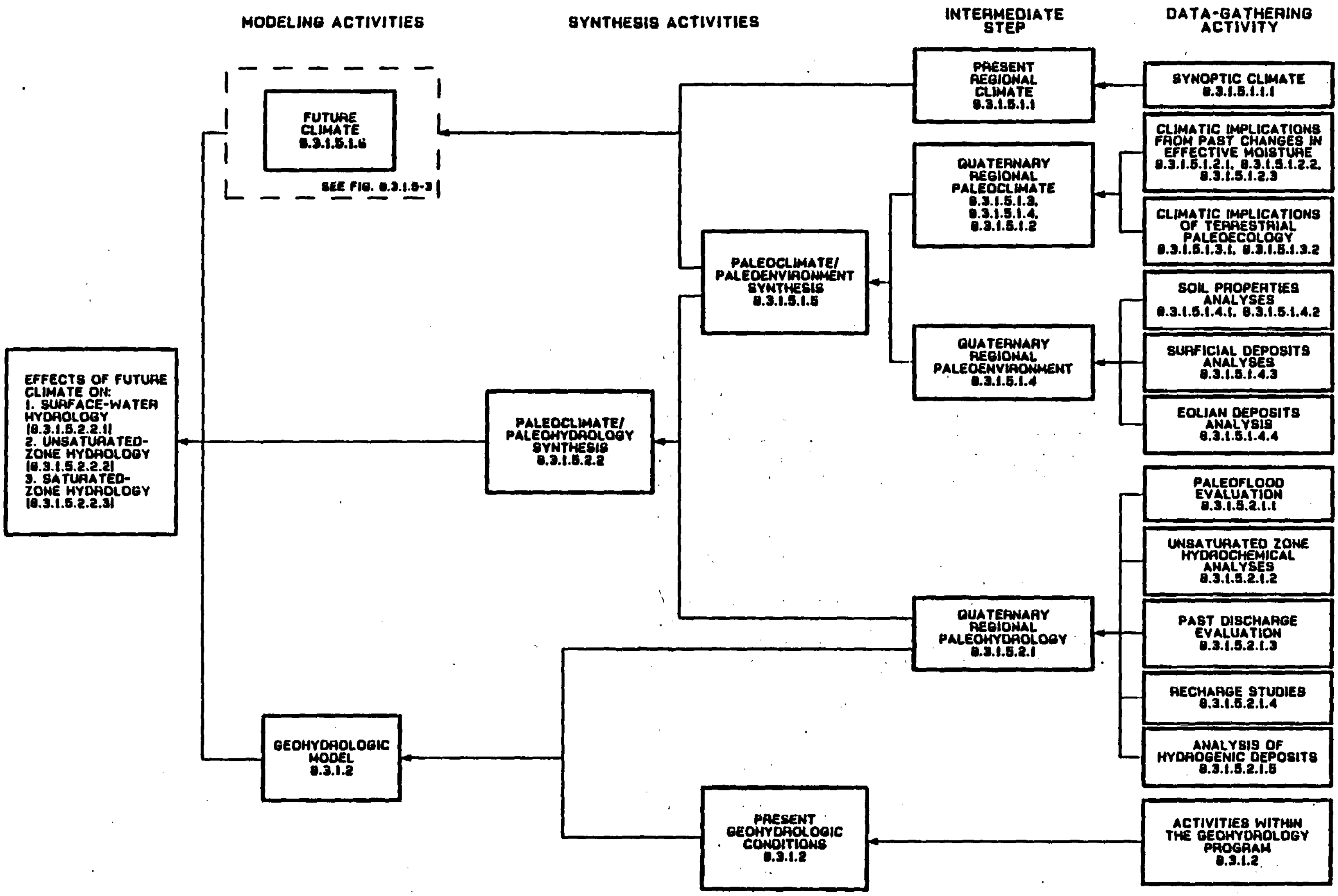


Figure 8.3.1.5-2. Logic diagram for climate program.

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 1 of 6)

Calls by performance and design issues			Response by climate characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Present regional climate	Monthly and annual values for temperature	8.3.1.5.1.1.1
			Monthly and annual values for precipitation	8.3.1.5.1.1.1
			Monthly and annual values for wind-velocity	8.3.1.5.1.1.1
			Spatial and temporal variation of precipitation	8.3.1.5.1.1.1
			Spatial and temporal variation of air temperature	8.3.1.5.1.1.1
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Quaternary regional paleoclimate	Paleontology (ostracodes, diatoms, aquatic polynomorphs, etc.) in marsh, lake and playa deposits	8.3.1.5.1.2.1
			Lithostratigraphy of marsh, lake and playa deposits	8.3.1.5.1.2.2
			Clastic sedimentology of marsh, lake and playa deposits	8.3.1.5.1.2.2
			Chemical sedimentology of marsh, lake and playa deposits	8.3.1.5.1.2.2
			Major element analyses of bulk sediments from marsh, lakes and playas	8.3.1.5.1.2.2
			Carbonate mineralogy of bulk sedi ments from lakes, marshes, and playas	8.3.1.5.1.2.3

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 2 of 6)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by climate characterization program: Activity parameter	SCP activity
1.1, 1.9.1 (continued)	8.3.5.13, 8.3.5.18.1 (continued)	Quaternary regional paleoclimate (continued)	Non-carbonate mineralogy of bulk sediments from lakes, playas, and marshes	8.3.1.5.1.2.3
			Stable isotope analyses of bulk sediments from lakes, playas, and marshes	8.3.1.5.1.2.3
			Ages of playa, lake and marsh deposits	8.3.1.5.1.2.4
			Packrat midden compositions	8.3.1.5.1.3.1
			Packrat midden distributions	8.3.1.5.1.3.1
			Packrat midden ages	8.3.1.5.1.3.1
			Pollen and spore compositions	8.3.1.5.1.3.2
			Pollen and spore distributions	8.3.1.5.1.3.2
			Pollen and spore ages	8.3.1.5.1.3.2
			Pollen-climate transfer functions	8.3.1.5.1.3.3
			Vegetation-climate and pollen-climate response surfaces	8.3.1.5.1.3.3
			Soil morphology and distribution	8.3.1.5.1.4.1
			Soil physical properties	8.3.1.5.1.4.1, 8.3.1.5.1.4.2
			Soil chemical properties	8.3.1.5.1.4.1, 8.3.1.5.1.4.2

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 3 of 6)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by climate characterization program: Activity parameter	Response by climate characterization program: SCP activity
1.1, 1.9.1 (continued)	8.3.5.13, 8.3.5.18.1 (continued)	Quaternary regional paleoclimate (continued)	Dust physical properties	8.3.1.5.1.4.1
			Dust chemical properties	8.3.1.5.1.4.1
			Soil water holding capacity	8.3.1.5.1.4.1
			Soil partial pressure of CO_2	8.3.1.5.1.4.1
			Movement of soil solutions	8.3.1.5.1.4.1
			Rates of carbonate translocation in soils	8.3.1.5.1.4.1
			Ages of soils	8.3.1.5.1.4.1
			Physical properties of surficial deposits	8.3.1.5.1.4.2, 8.3.1.5.1.4.3
			Soil mineralogical properties	8.3.1.5.1.4.2
			Ages of surficial deposits	8.3.1.5.1.4.2, 8.3.1.5.1.4.3
			Soil water chemistry	8.3.1.5.1.4.2
			Distribution of surficial deposits	8.3.1.5.1.4.3
			Thickness of surficial deposits	8.3.1.5.1.4.3
			Chemical properties of surficial deposits	8.3.1.5.1.4.3
			Mineralogical properties of surficial deposits	8.3.1.5.1.4.3
			Ages of Eolian deposits	8.3.1.5.1.4.4
			Trace element geochemicals in Eolian deposits	8.3.1.5.1.4.4
			Trace element in alluvium paleo-wind velocity	8.3.1.5.1.4.4

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 4 of 6)

Calls by performance and design issues			Response by climate characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Paleoclimate paleoenvironmental synthesis	Paleoprecipitation distributions	8.3.1.5.1.5.1
			Paleoprecipitation intensities	8.3.1.5.1.5.1
			Paleotemperature patterns	8.3.1.5.1.5.1
			Paleoevaporation rates	8.3.1.5.1.5.1
			Time series of paleoprecipitation at key locations	8.3.1.5.1.5.1
			Time series of paleoevaporation rates at key locations	8.3.1.5.1.5.1
			Time series of paleotemperature at key locations	8.3.1.5.1.5.1
			Magnitude of high paleoprecipitation	8.3.1.5.1.5.1
			Duration of high paleoprecipitation periods	8.3.1.5.1.5.1
			Occurrence of high paleosnowmelt	8.3.1.5.1.5.1
			Magnitude of low paleotemperatures	8.3.1.5.1.5.1
			Magnitude of low paleoevaporation	8.3.1.5.1.5.1
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Future climate	Future seasonal distribution and average annual rainfall	8.3.1.5.1.6.4
			Future type and intensity of storms	8.3.1.5.1.6.4
			Future distribution and average annual snowfall and rapidity of snowmelt	8.3.1.5.1.6.4
			Future evapotranspiration	8.3.1.5.1.6.4
			Future cloud cover	8.3.1.5.1.6.4
			Future temperature	8.3.1.5.1.6.4
			Future wind speed and direction	8.3.1.5.1.6.4

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 5 of 6)

Calls by performance and design issues			Response by climate characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Quaternary regional paleohydrology	Paleoflood magnitudes	8.3.1.5.2.1.1
			Paleoflood frequencies	8.3.1.5.2.1.1
			Paleoflood hydraulic characteristics	8.3.1.5.2.1.1
			Paleoflood debris movement quantities	8.3.1.5.2.1.1
			Paleoflood debris movement characteristics	8.3.1.5.2.1.1
			Travel times of Cl^{36} and C^{14}	8.3.1.5.2.1.2
			Unsaturated zone water isotopic characteristics	8.3.1.5.2.1.2
			Unsaturated zone water chemical characteristics	8.3.1.5.2.1.2
			Past evapotranspiration rate	8.3.1.5.2.1.3
			Past potentiometric head	8.3.1.5.2.1.3
			Location, type, and extent of hydrogeologic units	8.3.1.5.2.1.3
			Transmissivity	8.3.1.5.2.1.3
			Discharge of paleoseeps and paleosprings	8.3.1.5.2.1.3
			Locations of paleoseeps and paleosprings	8.3.1.5.2.1.3
			Analog infiltration rate	8.3.1.5.2.1.4
			Analog recharge rate	8.3.1.5.2.1.4
			Analog site effective moisture	8.3.1.5.2.1.4

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 6 of 6)

Calls by performance and design issues			Response by climate characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, 1.9.1 (continued)	8.3.5.13, 8.3.5.18.1 (continued)	Quaternary regional paleohydrology (continued)	Mineralogy of calcite-silica deposits	8.3.1.5.2.1.5
			Petrology of calcite-silica deposits	8.3.1.5.2.1.5
			Morphology of calcite-silica deposits	8.3.1.5.2.1.5
			Paleontology of calcite-silica deposits	8.3.1.5.2.1.5
			Chemistry of calcite-silica deposits	8.3.1.5.2.1.5
			Ages of calcite-silica deposits	8.3.1.5.2.1.5
			Isotopic concentrations of calcite-silica deposits	8.3.1.5.2.1.5
1.1, 1.9.1	8.3.5.13, 8.3.5.18.1	Paleoclimate/ paleohydrology synthesis	Relationship between climate (e.g. precipitation, temperature, evapotranspiration) and infiltration and recharge	8.3.1.5.2.1.1, 8.3.1.5.2.1.2, 8.3.1.5.2.1.3, 8.3.1.5.2.1.4, 8.3.1.5.2.1.5

Table 8.3.1.5-2 provides a direct link between the climate-related performance parameters (Table 8.3.1.5-1) and the activities in the climate characterization program by using "parameter categories." Each parameter category represents a group of activities (and the parameters to be addressed by those activities) that will be used to evaluate the climate-related performance parameters. There are seven parameter categories: present regional climate, Quaternary regional paleoclimate, Quarternary regional paleoenvironment, paleoclimate-paleoenvironmental synthesis, future climate, Quaternary regional paleohydrology, and paleoclimate-paleohydrology synthesis. From Table 8.3.1.5-1, there are essentially four types of performance parameters relating to changes in ground-water flux, changes in the elevation of the water table, changes in the gradient of the water table, and the potential for surface discharge points for ground water in the controlled area. All the parameter categories represent activities that provide information, directly or indirectly, to each of these performance parameters. The most direct link is between the future climate and the paleohydrology-paleoclimate synthesis parameter categories; however, the other categories are linked indirectly to the performance parameters through these categories.

The parameter categories listed in the table, which group the activity parameters, correspond to many of the square boxes on Figure 8.3.1.5-2. Two boxes, "present geohydrologic conditions" and "geohydrologic model," are not represented in the table because these activities do not take place within the climate program. The activity parameters represent either field or measured data or are directly calculated from field or measured data. These activity parameters are generally the output from their associated SCP activity listed in the next column. For data-gathering activities (far right on logic diagram), the associated parameter category is generally just a study-level grouping. For synthesis activities, which analyze data from multiple studies and activities, the parameter categories correspond exactly to the synthesis activities, and the associated activity parameters are the output from the synthesis activity. Modeling activities also have a direct correlation to parameter categories.

In all instances the calls by performance and design issues listed in the first column are derived from Issues 1.1 and 1.9b, and will also be used to satisfy Issues 1.8, 1.9a, 1.10, 1.11, and 1.12.

The following discussion follows the logic diagram and table and ties the climate program to the design and performance issues:

The first data-gathering activity (8.3.1.5.1.1.1) is designed to contribute to the characterization of the present regional synoptic climate along with temporal and spatial variations. This characterization is used to calibrate models of future climate as shown in the figure. The table shows the activity parameters (or data) gathered in this activity along with the parameter category associated with this study (modern regional climate).

The next two data gathering studies, 8.3.1.5.1.2 and 8.3.1.5.1.3, are designed to contribute to a chronology of paleoclimate. These studies draw upon evidence from lake, playa, and marsh sediments and terrestrial ecology (pollen and pack rat middens) to develop a qualitative interpretation of the Quaternary regional paleoclimate. The activity parameters associated with these activities are shown in the table and fall under the category "Quaternary regional paleoclimate." These studies form the basis for further activities within the climate program.

Complementing the paleoclimate history will be four data-gathering activities (8.3.1.5.1.4.1 to 8.3.1.5.1.4.4) leading in the same manner to a chronology of paleoenvironment. These activities draw upon lines of evidence from soils, surficial deposits, eolian deposits, and geomorphology. The paleoclimate and paleoenvironmental activities are to be integrated ultimately into a paleoclimate-paleoenvironmental synthesis (Activity 8.3.1.5.1.5.1). It is expected that the principal line of evidence for the synthesis will be the paleoclimate history and that the paleoenvironment history will serve to complement the paleoclimate chronology. This synthesis is necessary for the assessment of long-term variability of paleoclimate and to provide a basis for the estimation of future climatic episodes. In addition, the results of this synthesis activity will be used to determine the potential effects of future climatic conditions on hydrologic conditions. The specific output from this synthesis activity includes an assessment of paleoclimatological conditions, which will be used in the future climate modeling activities and in the paleohydrology activities.

Activities pertaining to the modeling of future climate are shown on Figure 8.3.1.5-3. Activity 8.3.1.5.1.6.1 contains the plans for global climate modeling and does not require input from any previously discussed site activities. The feasibility activity for regional numerical modeling requires information on present regional climate. The purpose of this activity is to determine if a regional numerical model is likely to provide timely and scientifically valid results. An additional empirical modeling activity (8.3.1.5.1.6.4) uses the integrated paleoclimate-paleoenvironmental chronology from Activity 8.3.1.5.1.5.1 to project past climatic episodes into the future. In the empirical modeling approach, the climatological values for past climatic regimes will provide estimates for ranges that may occur in the future. Therefore, the activity parameters listed under the category "future climate modeling" will be derived from either a linked global-regional modeling approach (8.3.1.5.1.6.3), a separate empirical modeling approach (8.3.1.5.1.6.4), or both. This model output will be used to determine the effects of future climate on geohydrology.

Five activities (8.3.1.5.2.1.1 to 8.3.1.5.2.1.5) will generate the data to be used to determine the Quaternary regional ground-water flow system. These activities include estimating severe paleorunoff and paleofloods, determining relationships between paleoinfiltration and paleorecharge, identifying areas of paleorecharge and paleodischarge in the Yucca Mountain region, and assessing the conditions and rates of recharge in that region. The specific activity-level parameters, which consist of measured or collected data, are shown in the table and are used to develop a picture of the paleohydrology at Yucca Mountain.

The data generated to determine the Quaternary regional paleohydrology will then be used along with the paleoclimate-paleoenvironmental data to determine the relationships between paleoclimate and paleohydrology. This synthesis work is not an independent study or activity but rather occurs within each of the paleohydrology activities. The parameter category,

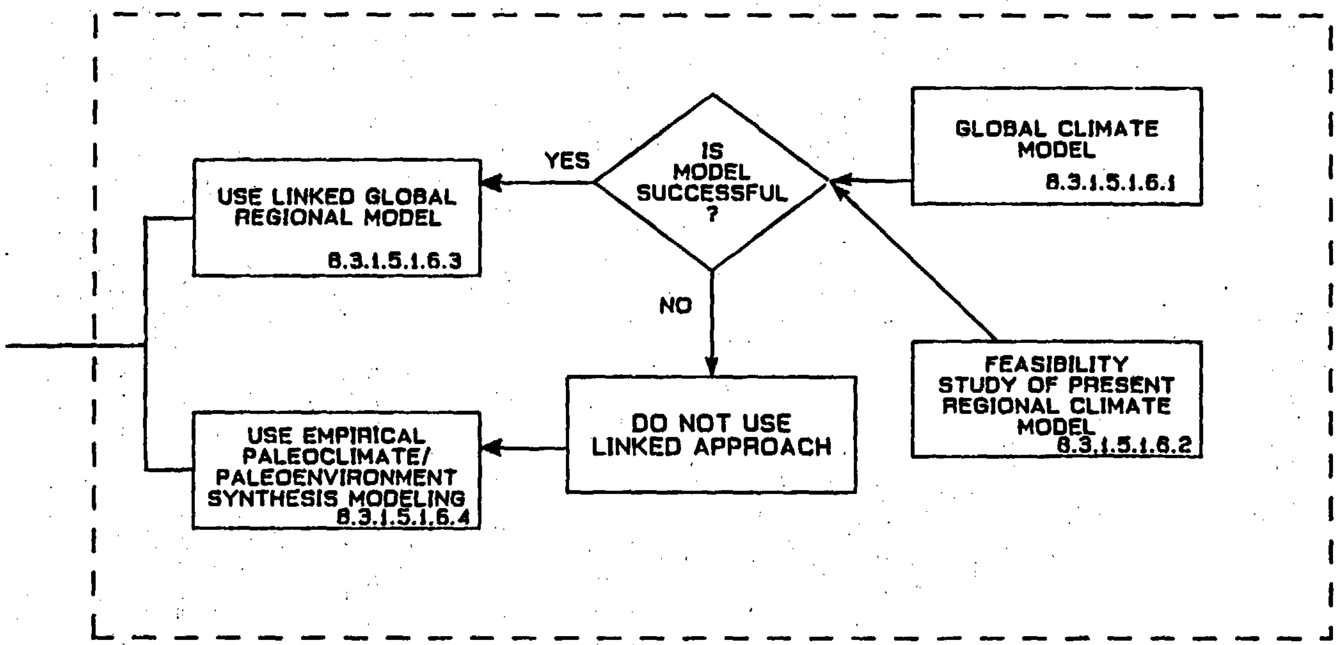


Figure 8.3.1.5-3. Detail of the climate model step (Study 8.3.1.5.1.6) in logic diagram.

"paleoclimate-paleohydrology," contains one activity parameter, "relationships between paleoclimate and paleoinfiltration and paleorecharge," that is an additional output from each paleohydrology activity.

Activities within the geohydrology program (8.3.1.2) will proceed in parallel with the above mentioned climate program activities. Specifically, studies addressing the unsaturated- and saturated-zone hydrologic system (8.3.1.2.2.10 and 8.3.1.2.3.2) will be used to develop models of the flow systems in both the unsaturated and saturated zones. These models will be used to assist in the evaluation of baseline hydrologic conditions.

At this point, information will be available (1) on future climatic conditions, (2) on the relationships between paleohydrology and paleoclimate, and (3) from the geohydrology program (models of flow systems of the unsaturated and saturated zones and the surface water system) as shown in Figure 8.3.1.5-2. These three sources of information will be used by climate program Study 8.3.1.5.2.2 to characterize future regional hydrologic conditions based on the estimated climatic changes. The result of this study will be an estimate of the impact of future climate changes on the overall hydrologic system. The first activity (analysis of future surface hydrology) will result in a determination of future precipitation-runoff relationships to be used by the erosion program (8.3.1.6). The next activity (analysis of future unsaturated-zone hydrology) will provide quantitative estimates of future infiltration, percolation, and saturation of the unsaturated zone due to climatic changes, which are essentially some of the performance parameters listed in Table 8.3.1.5-1 used to satisfy the performance objectives of Issues 1.1 and 1.9b. The final activity will provide estimates of future water-table altitude, ground-water flow rates, and ground-water velocity, corresponding to other performance parameters listed in Table 8.3.1.5-1. The performance parameters listed in Table 8.3.1.5-1 will address the performance objectives of Issues 1.1 and 1.9b and therefore Issues 1.8, 1.9a, 1.10, 1.11, and 1.12.

The information presented in Table 8.3.1.5-2 is a step toward the development of "characterization parameters" for the climate program. Characterization parameters will be a specific limited set of parameters for which quantitative testing bases will be established. These testing bases will express, through parameter goals or degree of accuracy, how well a particular parameter important to the climate program needs to be understood. Characterization parameters will be developed from the individual activity parameters in the following parameter categories: paleoclimate-paleoenvironment synthesis, future climate, and paleoclimate-paleohydrology synthesis. An example of one such characterization parameter is future precipitation. Initial sensitivity analyses performed on the hydrologic models will provide an idea as to how well future precipitation is needed to be known and what ranges of values are significant. This process will help to guide the future climate modelers as to how well they need to determine future precipitation and aid in prioritizing the activities within the climate testing program.

Interrelationships of climate investigations

Investigation 8.3.1.5.1 is designed to address the data, parameters, and processes that can be used to derive a model of future climatic change. This model is needed to predict potential future climatic changes that may (through the hydrologic regime) alter the long-term waste isolation capability of the Yucca Mountain site.

Data will be collected to characterize the present regional climate (Study 8.3.1.5.1.1) including the spatial and temporal variation. A study of the climatic inferences from paleolake, playa, and marsh sediments (Study 8.3.1.5.1.2) will draw upon the paleontology, stratigraphy, sedimentology, geochemistry, and chronology of these deposits. A study of the climatic implications of terrestrial paleoecology (Study 8.3.1.5.1.3) will draw upon evidence from pack rat midden macrofossils, palynology, and vegetation-climate relations. A paleoenvironmental study of the Yucca Mountain site (Study 8.3.1.5.1.4) will draw upon investigations into rates and conditions of soil development, distribution and geomorphology of surficial deposits, and the eolian history of the region. The paleoclimate history (from Studies 8.3.1.5.1.1 through 8.3.1.5.1.3) and the paleoenvironment history (8.3.1.5.1.4) will cross-check and complement each other and will be combined to create a final paleoclimate-paleoenvironment synthesis (Study 8.3.1.5.1.5), an integrated chronology, and a description of paleoclimate episodes at Yucca Mountain and environs.

The chronology produced in Study 8.3.1.5.1.5 will serve as the data base for the culmination of Investigation 8.3.1.5.1, modeling of future climates (Study 8.3.1.5.1.6). This study will employ a parallel approach of empirical modeling and numerical modeling to describe the timing and meteorology of future climate scenarios. This output will be used in Investigation 8.3.1.5.2 to estimate responses of the hydrologic regime to future climate.

Investigation 8.3.1.5.2 is designed to address the potential effects of future climatic conditions on hydrologic conditions. The characterization of Quaternary regional hydrology (Study 8.3.1.5.2.1) has the overall objective of defining relations between paleohydrology and paleoclimate, in order to understand how the hydrologic regime will respond to future climatic conditions. The study is planned to evaluate regional paleoflooding (Activity 8.3.1.5.2.1.1) and to assess both infiltration and percolation in the unsaturated zone and also ground-water potentiometric levels during the Quaternary (Activity 8.3.1.5.2.1.2). Isotopic composition and chemistry of water in the unsaturated zone will be analyzed to assess the Quaternary infiltration and recharge history of Yucca Mountain. An evaluation of paleodischarge areas and an evaluation of past water levels in carbonate caverns (Activity 8.3.1.5.2.1.3) will be completed to determine past discharge areas and regional ground-water levels. Potential modern analogs to pluvial climates at Yucca Mountain will be studied (Activity 8.3.1.5.2.1.4) to estimate conditions and rates of ground-water recharge at Yucca Mountain during the Quaternary. The hydrologic origin and significance of calcite and silica deposits in faults and fractures in the vicinity of Yucca Mountain (Activity 8.3.1.5.2.1.5) will be factored into this evaluation.

A study is planned to characterize the future regional hydrology taking into account future climatic changes (Study 8.3.1.5.2.2). A precipitation-runoff model is planned to simulate paleoconditions of precipitation and runoff (Activity 8.3.1.5.2.2.1). The model will then be used to estimate future precipitation-runoff conditions from scenarios for future climatic change. In addition, the unsaturated zone hydrologic model will be used to predict the potential changes in infiltration, percolation, and the degree of saturation due to future climatic change (Activity 8.3.1.5.2.2.2).

Finally, a synthesis of future hydrologic characteristics due to climatic changes will be completed (Activity 8.3.1.5.2.2.3). The objective of this study will be to integrate data on paleoclimatic and paleohydrologic conditions to complete a reconstruction of paleoclimatic conditions. The paleoclimatic reconstruction will be used, together with the meteorology of future climate scenarios and models of the present ground-water regime from Section 8.3.1.2 (geohydrology program), to predict the impacts of future climatic change on the unsaturated and saturated zone hydrologic system at Yucca Mountain. This study will involve incorporating paleohydrologic data into models to estimate potential changes in the altitude and gradient of the water table caused by future climatic change.

The schedule information provided for investigations in this section includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.1.5.1 Investigation: Studies to provide the information required on nature and rates of change in climatic conditions to predict future climates

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this information need:

SCP section	Subject
5.1	Recent climate and meteorology
5.2.1.1	Quaternary global paleoclimate
5.2.1.2	Quaternary regional paleoclimate
5.2.2.1	Components of the climate system
5.2.2.2	Climatic variations
5.2.2.3	Climate prediction methods
5.2.3	Site paleoclimatic investigations
5.3.1	Significant results

Parameters

The following parameters will be collected, measured, or calculated as a result of the site studies planned as part of this investigation:

1. Recent meteorological data.

2. Great Basin historical climatic data--spatial and temporal variability of precipitation, wind, temperature, cloud cover.

3. Selected Great Basin hydrologic data--stream discharge, lake level.

4. Age, fossil content, sedimentary characteristics, mineral content, chemical content, and magnetic properties of lake, playa, and marsh sediments.

5. Age and paleontologic characteristics of pack rat midden macrofossil assemblages.

6. Vegetation-climate calibrations--response surfaces, transfer functions.

7. Prehistoric variation in lake levels over the Quaternary.

8. Synoptic "snapshots" of prehistoric climate extremes.

9. Analysis of Quaternary soil and surficial deposit properties, and Quaternary geomorphic characteristics of surfaces and drainages.

10. Forecasts (a general estimation, not a specific parameter or variable) of climatic variables for the next 100,000 yr in southern Nevada.

Other site studies that supply information to support the determination of the previous parameters are as follows:

Study	Subject
8.3.1.12.1.1	Characterization of the regional meteorology
8.3.1.2.2.1	Characterization of unsaturated zone infiltration
8.3.1.5.2.1	Characterization of Quaternary regional hydrology
8.3.1.6.1.1	Distribution and characteristics of past erosion

Purpose and objectives of the investigation

Investigation 8.3.1.5.1 provides information to help satisfy performance and design Issues 1.1, 1.8, 1.9a and b, 1.10, 1.11, and 1.12. Recent meteorological data and Great Basin historical climate data will be used to calibrate (using present conditions) and validate (using past conditions) models of future climate. A paleoclimate-paleoenvironment synthesis will be derived from lake, playa, and marsh sediments, pack rat middens, vegetation calibrations, and soil and surficial deposits. This synthesis will provide time-sequential reconstructions for the modeling activities as well as for Investigation 8.3.1.5.2. These models will attempt to forecast climatic variables for the next 100,000 yr to determine climatic conditions.

Technical rationale for the investigation

The arid climate of the southern Great Basin is one of several factors making Yucca Mountain potentially attractive for the long-term disposal and isolation of radioactive waste. The persistence of arid conditions (and an accompanying thick unsaturated zone) in the region through the postclosure period would be advantageous to waste isolation. However, paleoclimatic studies in the surrounding region indicate that the modern degree of aridity is atypical of the past few hundreds of thousands of years. Shallow ground-water recharge occurred in southern Nevada between 20,000 and 10,000 yr ago (Claassen, 1985), when major climatic changes created vast lakes in many of the valleys of Nevada, Utah, and eastern California (Section 5.2). Although such high magnitude events may be cyclic on a time scale of 100,000 yr, most of the intervening periods appear to have been wetter than today (Smith, G.I., 1983).

When viewed on a scale of hundreds to thousands of years, climate is constantly changing, and future climatic fluctuations may significantly affect the hydrologic regime and erosion rates at Yucca Mountain. Thus, climate change must be considered when evaluating the suitability of the repository site.

If data are discovered within the Quaternary geologic period that document the above objectives, they will be studied. The exact studied time interval will be flexible depending upon the completeness of the recovered stratigraphic data. However, the late Quaternary will be emphasized.

Climatic scenarios of concern. Our present understanding of past climates suggests that there are primarily two recurring large-scale circulation patterns which may result in higher levels of effective moisture in southern Nevada. The future occurrence of either pattern could have a negative impact on the proposed repository. The first pattern is associated with the growth of continental ice sheets during glacial periods. Under modern conditions, the westerlies and the associated jet stream are strongest and in their most southerly position during winter, when cold arctic air is in close proximity to warm tropical air. During glacial periods, arctic air masses reached farther south than today in all seasons, but tropical air did not contract towards the equator to any significant degree (because orbitally induced variations in insolation have little effect in low latitudes). Thus, polar and tropical air masses would interact with each other year round in a region farther south than today, thereby potentially increasing frontal activity (storminess) and precipitation in the NTS region. An increase in frontal activity through the year would increase precipitation and reduce evaporation, factors that have the potential to increase recharge.

The second pattern involves an orbitally induced variation in insolation that results in higher than modern summer temperatures over land in the middle and high latitudes of the northern hemisphere. Under such conditions about 9,000 yr ago, the increased temperature contrast between land and sea brought moist tropical air masses (monsoons) into North Africa and the Indian subcontinent. The resulting increased rainfall and reduced evaporation turned now desert areas into savannas and woodlands (Kutzbach and Otto-Bleisner, 1982). Similar changes have been postulated to have occurred in the NTS region (Spaulding and Graumlich, 1986) and may occur again in modified form if future increases in atmospheric CO_2 concentrations cause a "greenhouse effect" on global climate.

In addition to the two patterns described above, both associated with extremes in glacial and solar insolation boundary conditions, it appears that other, more moderate, configurations of boundary conditions may result in high levels of effective moisture in the region of southern Nevada. For example, within 150 km of Yucca Mountain moderate to high lake levels were maintained for much of the period between the last interglacial (about 125,000 yr before present) and the last glacial maximum (about 20,000 yr before present) (G. I. Smith, 1983).

Paleoclimatic studies at Yucca Mountain will attempt to determine the past frequency and timing of occurrences of the scenarios listed above and to identify other patterns of past climatic circulation that led to high levels of effective moisture. Future climatic studies will attempt to estimate the probability of occurrences of these and other scenarios over the next 10,000 to 100,000 yr.

Paleoclimatic studies. The primary objectives of the paleoclimatic studies are to

1. Determine the magnitude, duration, and timing of past major periods effectively wetter than modern conditions in and near southern Nevada.

2. Provide data to establish the relationships between paleoclimate change and corresponding paleohydrologic responses.

3. Establish, where possible, the relationships between past climatic changes near Yucca Mountain and predictable elements of larger scale (global or northern hemispheric) climatic changes, such as those induced by changes in the earth's orbit.

4. Provide the basis for the validation of numerical climate models.

Constituent studies. The studies under the paleoclimatic investigation are

1. Study 8.3.1.5.1.1--Characterization of modern regional climate. The modern climate is the baseline for establishing the relationships between climatic variables (such as precipitation or temperature) and the various proxy data (such as plant distributions or lake size or chemistry). Thus, understanding modern climate is essential to reconstructing the past and predicting the future.

2. Study 8.3.1.5.1.2--Paleoclimate study: lake, playa, marsh deposits. Paleontological, stratigraphic-sedimentologic, and geochemical indicators preserved in lacustrine sediments provide the principal record of paleohydroenvironments, which for most shallow water systems are also sensitive paleoclimate records and the only available long records of climate change. These records will provide relative

estimates of climate properties and in some instances may provide quantitative estimates of climate.

3. Study 8.3.1.5.1.3--Climatic implications of terrestrial paleoecology. Plant macrofossil assemblages from pack rat middens and fossil pollen spectra from stratigraphic deposits will provide the basis for reconstructing vegetation change near Yucca Mountain and in the surrounding region. Numerical methods (response surfaces, transfer functions) will translate these vegetation records into quantitative estimates of past changes in precipitation, temperature, and other climatic variables.

4. Study 8.3.1.5.1.4--Paleoenvironmental history. Investigations of soils and surficial deposits at Yucca Mountain are necessary to define the responses of local depositional and erosional regimes to climatic change.

5. Study 8.3.1.5.1.5--Paleoclimatic-paleoenvironmental synthesis. The various lines of evidence will be synthesized into chronologies of paleoclimatic changes in formats suitable for input into the paleohydrologic studies and the future climates studies.

Spatial scale. Investigators working within the paleoclimate program will attempt to discover any available evidence of past periods of greater than modern effective moisture in as close proximity to Yucca Mountain as possible. Data bearing on this problem that are available near the proposed repository include (1) plant assemblages from pack rat middens; (2) micropaleontological, geochemical, and sedimentological data from playa and paleomarsh sediments; (3) terrestrial pollen data; and (4) vertebrate paleontological data from outcrops, pack rat middens, and paleomarsh sediments. (Refer to Tables 5-13 and 5-14 and Figure 5-24 for an analysis of currently available data.) In addition to these data, the age and nature of surficial deposits and soil development will be assessed, as appropriate, to develop an understanding of the paleoclimatic record at Yucca Mountain.

The characteristics of local playa and marsh records are planned to be evaluated in terms of climatic sensitivity, sediment accumulation rates, and preservation of paleontologic and mineralogic climatic indicators.

These records

1. Represent available aquatic record of Quaternary climatic and hydrologic events near Yucca Mountain.

2. Have direct bearing on hydrologic models and the tie between regional climatic change and local hydrologic changes.

3. Can be related to regional framework of climatic and hydrologic changes developed through regional paleoclimatic studies (discussed below). In this light, local aquatic records will provide evidence on climatic episodes that have resulted in significant hydrologic responses in this area but are of much less importance regionally.

Climate is operative on a regional scale, and no single station or paleoclimatic site can provide an adequate record of past variability or be representative of the climate over the entire recharge area. The same characteristic applies to paleoclimatic records, which, on a regional scale, are necessary to provide a check on the continuity of the local records thereby reducing the uncertainty involved in identifying major past periods of higher effective moisture. Regional records, especially from extant lakes and wet playas, should provide thicker stratigraphic sections and greater temporal resolution for dating past periods of major recharge. The potential for missing portions of the record through deflation, etc. will be minimized by studying such sites. Regional scale data are also necessary for describing variations in past storm track positions, for the validation of climatic models, and for testing hypotheses on temporal and spatial patterns of climatic change. These aspects would require a spatial network of sites for key time periods in the past. The sources of paleoclimatic proxy data available on a regional scale are the same as on the local scale, with the notable addition of permanent lakes as sources of micropaleontological, geochemical, and sedimentological data.

Temporal scale. Over the last 50,000 yr, the climate of the Northern Hemisphere has changed from "interstadial glacial" (about 65,000 to 35,000 yr before present), to "full-glacial" conditions (about 20,000 to 18,000 yr before present), to conditions warmer than today (about 9,000 to 6,000 yr before present), to modern conditions. This period thus offers examples of extreme configurations of global climatic boundary conditions, and the effects of these changes in southern Nevada are planned to be studied in detail. Available techniques for dating paleoclimatic changes are also most precise over this period and "synoptic snapshots" of paleoclimatic conditions at appropriate times in southern Nevada can be constructed for numerical model validation.

The global climates of the next 10,000 to 100,000 yr may include a transition from the current interglacial, to moderate glacial, to full-glacial conditions. To understand the ramifications of this change, the last 200,000 yr are planned to be studied in moderate detail to provide examples of the climatic effects of such global changes on the Yucca Mountain region.

Over the last 500,000 to 1,000,000 yr, climatic conditions have varied enough to allow boreal small mammals such as the bog-lemming to live in wet seeps on Yucca Mountain. Some knowledge of these seemingly very different conditions is required to predict the possible magnitudes of future wet episodes at Yucca Mountain.

Future climate investigations. Forecasts of future climatic conditions at Yucca Mountain will be made primarily through numerical models of the climate system. A general circulation model (GCM) of global climate will be used to describe the expected responses of global climate to future variations in glacial ice extent, orbital parameters (which affect the distribution of incoming solar radiation on the earth's surface), atmospheric chemistry, and other climatic boundary conditions. A regional-scale mesoscale model will be linked to the GCM to provide the spatial resolution necessary for forecasting the future climatic conditions at Yucca Mountain.

Before numerical models can be used to forecast future climatic conditions, they must incorporate evidence of past climatic change as reconstructed from paleoclimatic proxy data in the region on time scales commensurate with the periodicity of earth-sun orbital relations. This refinement is necessary because of the effects of complicated feedback systems, lag times, and topographic barriers on climate. It is performed by comparing paleoclimate records with model results and by improving the model so that it simulates known past climates more accurately.

The models will be calibrated and checked using present-day and historical data sets that will be validated in simulations of climates of key historic times such as periods of high lake stands, desiccation, vegetative change, or ground-water recharge.

Following successful model validation exercises, scenarios will be developed that include boundary conditions to account for inputs from natural and human activities to the atmosphere. The possible effects of volcanic dust, aerosol, and carbon dioxide on future climate conditions will be examined.

8.3.1.5.1.1 Study: Characterization of modern regional climate

The objective of this study is to provide a baseline and a background for the interpretation of climatic variation. Characterization of the synoptic climate will result in the determination of modern spatial and temporal variations in precipitation, air temperature, cloud cover, and other meteorological variables. These data will be used in the development of modern vegetation-climate calibration relationships, in the assessment of lake-climate relationships, and in the development and testing of climate circulation models and in specifying relationships between global-scale circulation patterns and the regional and local climate features of relevance to site performance coordinated by the overview activity in Section 8.3.1.12.1.2.1.

In cooperation with Meteorology Program 8.3.1.12 and Geohydrology Program 8.3.1.2, efforts will be made to relate modern storms (and their trajectories) to the isotopic signatures of infiltrating ground water. This analysis will be assisted by modeling of the carbon isotope systematics in ground water. These data may provide insight into past air-mass trajectories and will be available to the climatology program.

8.3.1.5.1.1.1 Activity: Synoptic characterization of regional climate

Objectives

The objectives of this activity are to

1. Provide the basis for developing vegetation-climate relationships, lake-climate relationships, and climate-circulation models (meteorological data).

2. Provide an understanding of spatial and temporal variation in climate (synoptic climate).

3. Determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs (isotopic data).

Parameters

The parameters for this activity are

1. Meteorological data, such as monthly and annual values for temperature, precipitation, wind-velocity, from a regional network of sites.

2. Synoptic climate, such as spatial and temporal variation of precipitation, air temperature, cloud cover, and wind velocity.

Description

Meteorological data will be compiled from U.S. Weather Service stations from the southern Great Basin and surrounding region. The synoptic climate of the Great Basin region will be determined through statistical correlations with larger scale climate information. These correlations will include the longest usable climatic record, including possible use of tree ring data if applicable, and will be used to identify patterns of specific weather system development and to determine how the systems affect areas of particular interest within the Great Basin.

A network of weather stations will be set up in the region, in cooperation with meteorology program 8.3.1.12 and geohydrology program 8.3.1.2. Each station will include a precipitation collector for oxygen-18 and deuterium samples, a tipping bucket, and a temperature probe connected to a data logger. Temperature data will be collected every 15 to 20 minutes; water samples will be collected whenever possible within 24 hours of a storm event. The data will be statistically analyzed to determine the relation of oxygen-18 to deuterium to storm track, air temperature, altitude, and season. Results of the analysis will be used in Study 8.3.1.5.1.2 (paleolacustrine studies) to assist in estimating the source and seasonality of recharge that occurred in the Quaternary in the Yucca Mountain region and in Activity 8.3.1.5.2.1.2 (Quaternary unsaturated zone hydrochemical analysis).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.1.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Collection, tabulation, and statistical analysis of historical climate data sets	TBD[a]	Historical climate data sets	TBD
Collection and preservation of atmospheric precipitation samples for isotope analysis	HP-16, R1	Collection and preservation of atmospheric precipitation samples of isotope analysis	14 Aug 84
Stable isotope sampling analysis	TBD (in preparation)	Stable isotope analysis of solid samples	TBD
CHEMTRAN modeling of carbon cycle during recharge to ground-water system	TBD (in preparation)	CHEMTRAN software	TBD

[a]TBD = to be determined.

8.3.1.5.1.2 Study: Paleoclimate study: lake, playa, marsh deposits

This study will establish the nature, timing, duration, and amplitude of paleoclimate changes based on analyses of paleontologic, geochemical, and stratigraphic-sedimentologic data obtained from lacustrine sediments in or near southern Nevada (Figure 8.3.1.5-4). Planned locations of the marsh, playa, and lake sampling sites may change as data are collected and analyzed. Any such changes will be reported in study plans and SCP progress reports. In addition, information will be collected on paleolake levels and sizes to identify the timing and extent of paleoclimate events. These analyses will provide estimates of past changes in precipitation, temperature, relative moisture balance, and other climatic parameters. These estimates, when integrated regionally for particular climatic episodes, will aid in identifying the particular pattern of atmospheric circulation (air-mass interactions) responsible for the observed variations. Moreover, these estimates will provide the basic data to be used for analyzing past climatic periodicity and for validating climate models.

Because climate variability may contribute significantly to the hydrologic system, especially in terms of recharge and discharge, the results of this study will also be central to the paleohydrologic studies of this area

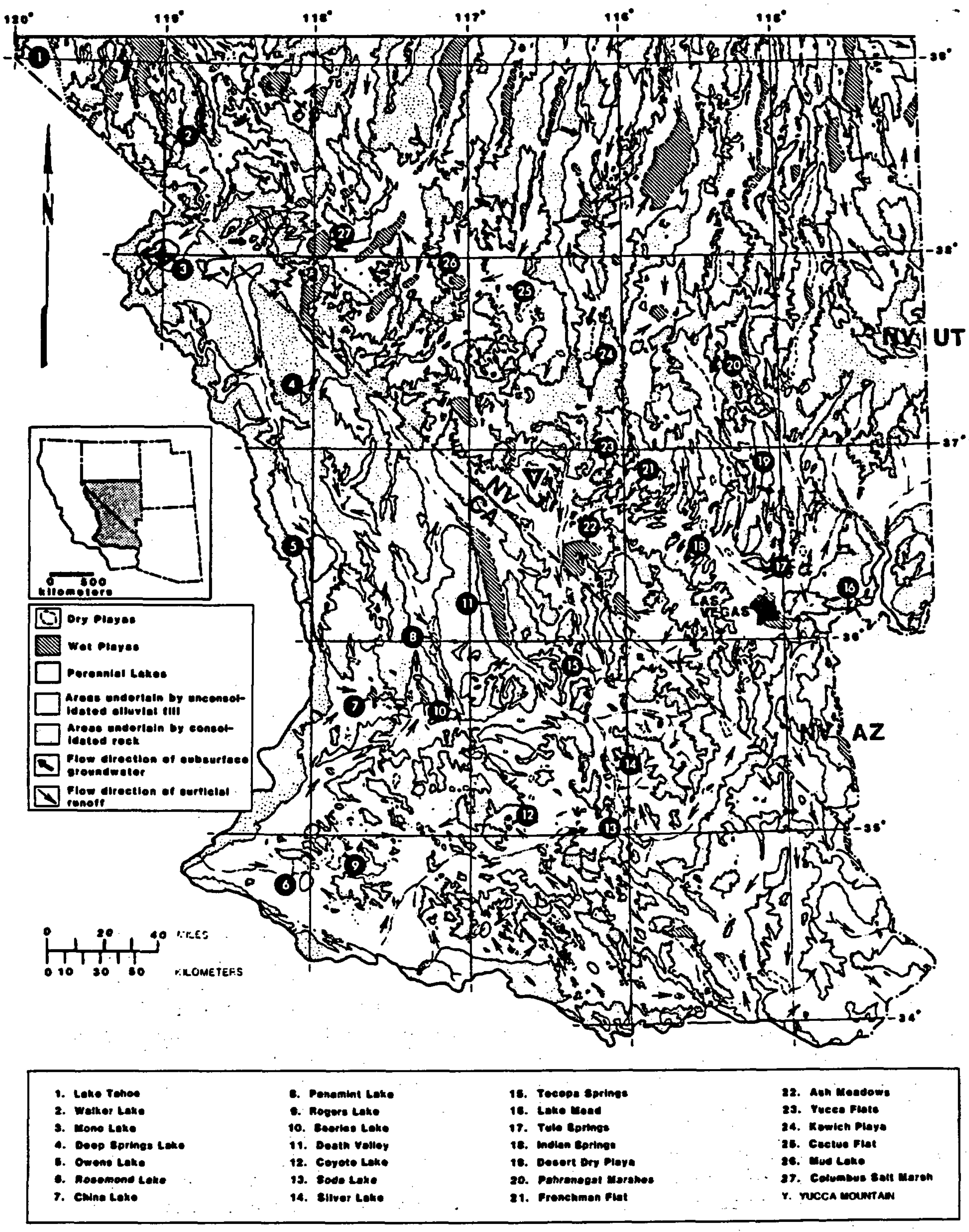


Figure 8.3.1.5-4. Possible sampling sites for paleoclimate studies. Modified from Bedinger et al. (1984).

(Section 8.3.1.5.2). The degree to which past climatic and past hydrologic changes are linked will provide a basis for comparing or linking the outputs of models that predict future climatic and hydrologic variability.

8.3.1.5.1.2.1 Activity: Paleontologic analyses

Objectives

The objective of this activity will be to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions. This record will involve collection, identification, enumeration, and interpretation of paleontologic data that emphasizes the past 50,000 yr in great detail, the past 200,000 yr in moderate detail, and the past 1,000,000 yr in some detail. Calcareous fossils will also be collected for geochemical and age analyses of their carbonate.

Parameters

The parameters for this activity include paleoenvironmental interpretations of ostracodes, diatoms, aquatic palynomorphs, and other paleobiotic remains.

Description

Ostracodes. Ostracodes are minute crustacea with bivalved calcite carapaces that can be identified to the generic or specific levels. They are largely benthic animals, living at or just below the sediment-water interface. Ostracode life-cycles range from about three weeks to well over a year, and their ecology is therefore centered upon annual or seasonal phenomena. Ostracodes live in virtually all oxygenated water bodies that persist for more than about a month. They attain their highest population densities in quiet or gently flowing water and are most commonly preserved in circumneutral to alkaline water.

Nonmarine ostracodes are divided into two major ecologic groups: those that live in surface waters (epigean) and those that live in ground water (hypogean). Epigean taxa may be further divided ecologically into those living in ground-water discharge environments and those that live in lacustrine environments. Both ground-water discharge and lacustrine taxa may be further subdivided into groups of taxa that only live in very particular environments such as continuously cold water (cryobionts) or continuously warm water (thermobionts), or water that is warm for at least a given period during the year (thermophilic). Ostracodes are very sensitive to water chemistry, with the distribution of some taxa determined by the major dissolved ion content of the water. Other parameters, such as turbidity, oxygen levels, and biotic factors appear to influence ostracode productivity rather than their presence or absence.

Most ostracode species have well-defined biogeographic ranges that appear to be limited by seasonal variations in water temperature and chemistry. Ostracodes are capable of entering new environments through the transport of adult ostracodes or eggs by birds, insects, or wind. Similarly, as environments change, some species will no longer be able to survive and will become locally extinct. Thus ostracodes may rapidly expand or contract their geographic ranges in response to changing hydroenvironmental and climatic conditions. Ostracodes will be collected in conjunction with Activity 8.3.1.5.2.1.3 (evaluation of past discharge areas).

Diatoms. Diatoms are single-celled algae that produce an opaline silica frustule, which provides precise taxonomic information. Various species of diatoms cover a range of aquatic habitats from the sediment-water interface to the open-water epilimnion. Diatoms are short-lived organisms and therefore can respond by increasing species abundance to environmental phenomena operating on weekly time scales.

Particular diatom species are known from all aquatic environments within the photic zone. Diatom species are especially sensitive to water quality, including parameters such as solute composition, salinity, and pH. They are also extremely sensitive to the availability of nutrients such as nitrogen, phosphorous, silica, and dissolved organic compounds.

Diatoms have an excellent fossil record, and, unlike ostracodes, diatoms are commonly preserved in acidic environments or any environment low in HCO_3 activity. Where both groups of organisms are preserved, the diatoms may provide useful information on short-term environmental phenomena that may have no obvious impact on the ostracode population. Conversely, ostracodes appear to be better suited to recognizing what may be termed the general environmental aspects of an aquatic environment such as temperature or water composition.

Aquatic palynomorphs. The pollen record of emergent or submergent macrophytes and the remains of certain algae provide important information about the chemical, and to a lesser extent thermal, properties of the water in which they lived. The response of aquatic plants to their general chemical environment is quite similar to the response of diatoms and ostracodes discussed above. In addition, aquatic macrophytes are sensitive to the stability of a water mass. For example, emergent plants such as cattails require that local water level remain within a specified range or they will drown from rising water levels or desiccate from falling levels. The stability of a water body on a seasonal to annual scale is an important hydrologic and climatic property.

Other biotic remains. Other fossils, ranging from terrestrial vertebrates to aquatic chrysophyte cysts and branchiopods, may prove vital to understanding the nature of a particular climate record. The way in which climate interpretations would be made from other kinds of fossils generally follows the format given above for ostracodes, diatoms, and pollen. Other types of fossils can be used to evaluate and refine the climatic interpretations derived from the principal organisms and may offer information not available from these organisms. For example, the occurrence of branchiopod fossils together with ostracodes implies a wet-playa hydrology whereas the presence of branchiopods without ostracodes implies a dry-playa hydrology. The recognition of a wet and dry playa record from cores in the modern day dry playas near Yucca Mountain would have climatic significance.

Paleoclimatic interpretations of aquatic records. The ecologies of ostracodes, diatoms, and other aquatic organisms are necessarily related to the properties of the water in which they live. To extract climatic information from the fossil record of aquatic organisms, a relationship between aquatic parameters and climate parameters must be established.

Shallow wet-playa lakes, marsh ponds, and spring pools from shallow aquifers are surface-water features that are common today and were common in the past in southern Nevada. The water columns in each of these environments will typically be thermally coupled to the daily or weekly changes in air temperature over the water body (Forester, 1987). Furthermore, the water temperature of spring vents from shallow aquifers provide good estimates of mean annual air temperature. The seasonal variability in water temperature of standing bodies or the constant value of spring vents provides a thermal habitat that determines occurrence and abundance of all aquatic organisms, but especially ostracodes. New taxa appear as the thermal habitat changes with changing climate, while others become locally extinct. Thus knowledge about the thermal ecology and biogeography of aquatic taxa provides direct information about water temperature that may then be interpreted in terms of air temperature. These interpretations may be qualitative, based on empirical observations; semiquantitative, based on multivariate analyses techniques; or quantitative, based on statistical analyses and organism physiology.

Climate may play an important role in determining water chemistry when water with a given input composition is evaporatively coupled to the atmosphere over the basin. Wet periods result in dilution or flushing of dissolved salts from the basin. Dry periods result in concentration and solute evolution due to selective mineral precipitation and other processes. The chemistry of the surface water body is thus coupled to the atmospheric moisture balance over the water body. The chemical character of the water establishes a chemical habitat that determines organism occurrence and abundance. As the chemical habitat changes with changing climate, new taxa appear or become locally extinct and thus provide a record of the paleochemistry. Thus knowledge about the chemical ecology of aquatic taxa, especially diatoms and ostracodes, provides direct information about paleohydrochemistry that may be interpreted in terms of moisture balance. As with paleotemperature, these interpretations may be qualitative, semiquantitative, or quantitative.

The response of water chemistry to climate is operative on all time scales and for basins of all sizes whereas the response of water temperature to climate may be most sensitive in shallow water bodies that remain thermally mixed in all seasons. Aquatic records, whether they provide only hydrologic or both hydrologic and climatic information, are important to any study that seeks to understand past climate, because they are integrating climate processes that are operating on seasonal or annual scales rather than the much coarser scales common to other records.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.1.2.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Palynological and paleo-ecological analyses	HP-76, RO	Diatom enumeration studies	08 Apr 85
	HP-78, RO	Ostracode sample preparation and data aquisition procedures	08 Apr 85
	TBD	Analyses of other fossils	TBD
	TBD	Pollen analysis	TBD

[a]TBD = to be determined.

8.3.1.5.1.2.2 Activity: Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits

Objectives

The objectives of this activity are to

1. Identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores. This information will provide a physical and relative temporal framework within which various paleoenvironmental studies will be made.

2. Determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology.

Parameters

The parameters for this activity are

1. Lithostratigraphy of marsh, lacustrine, and playa deposits.

2. Clastic and chemical sedimentology of marsh, lacustrine, and playa deposits.

Description

Reconnaissance coring, trenching, and seismic techniques will provide information about sample sites, access to sediments that cannot be sampled in outcrop, and general information about subsurface stratigraphy for all forms of analyses. This will minimize needed samples and maximize the climatic information obtained from the samples.

Lithostratigraphy involves the lithologic characterization of sedimentary units in order to define sedimentary units and to place these units in space and time. Investigations will describe sediment thickness, color, grain size, texture, bedding, magnetic susceptibility, bulk elements, mineralogy, and other properties deemed necessary for accomplishing this task.

Clastic and chemical sedimentology involves identifying and describing the chemical and physical nature of the sedimentary units identified by lithostratigraphy in order to define the nature of the depositional environment. Properties such as grain size, composition, bedforms, nature of contacts between sediment units or other properties that will aid in interpreting deposition environment will be investigated. Sedimentologic data provide general paleoclimatic information together with general environmental boundary conditions for other studies.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.1.2.2 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Coring, trenching, and sampling of lake, playa, and marsh sediments.	GCP-02, R1	Labeling, identification, and control of geochronology samples and separates	20 Jan 87
	GP-07, RO	Geologic trenching studies	15 June 81
	HP-37, RO	Preliminary procedure for drilling and coring of wet and dry lake sediments	14 Aug 84

8.3.1.5.1.2.3 Activity: Geochemical analyses of lake, marsh, and playa deposits

Objectives

The objective of this activity is to provide a detailed chemical and mineralogic characterization of all sediments to provide information about the chemistry of the water from which the minerals precipitated and to determine sediment provenance.

Parameters

The parameters for this activity are

1. Element analyses of bulk sediments.
2. Carbonate mineralogy.
3. Noncarbonate mineralogy.
4. Stable isotope analyses.
5. Other chemical parameters.

Description

Element analyses of bulk sediments. Element analyses of bulk sediments involves determining the kind and quantity of elements present in sediment samples taken as a time series from a core. These data are subjected to a variety of multivariate analyses to characterize the data set in terms of origins of particular element groups. This information provides important insights into chemical processes (endogenic and authigenic (diagenetic)) operating within the local environment as well as processes (allogenic) that contribute materials from the surrounding region. These types of data are important for characterizing past climate because the endogenic-authigenic processes provide information about water chemistry that may be related to moisture balance whereas the allogenic record provides information about stream input and other factors that may characterize wet periods.

Carbonate mineralogy. Endogenic carbonate mineralogy is related to the Mg/Ca ratio of the water from which the carbonate precipitated. As lake water evaporates, the Mg/Ca ratio increases or conversely, as lake water is diluted or flushed, the ratio decreases resulting in a different suite of carbonate minerals. The expected mineral sequence from dilute water to concentrated water is low-Mg calcite, high-Mg calcite, aragonite (or dolomite), and monohydrocalcite. Thus, knowledge about the carbonate mineral sequence through a sedimentary deposit may provide evidence for wet and dry cycles. Moreover, biogenic carbonate, principally the shells of ostracodes or snails, may provide information about the temperature and salinity of the water in which the carbonate was precipitated. The Mg/Ca ratio of biogenic calcite is known to be closely related to the temperature at which the carbonate precipitated, whereas the Sr/Ca ratio appears to be related to the salinity of the water. Temperature and salinity are important climate indicators in climatically sensitive aquatic environments.

Noncarbonate mineralogy. Noncarbonate minerals such as salts and silica minerals (opals, clays) provide information about the composition of the parent body of water, about the diagenetic postdepositional environment, or both. The former provides information about moisture balance, whereas the latter provides an indication of the degree of alteration of a sedimentary unit.

Stable isotopes. Stable isotopes, principally of oxygen and carbon, but also of strontium, sulfur, deuterium/hydrogen, provide information about the source/temperature of precipitation, water salinity, water temperature, and other forms of environmental information. This information, as with aquatic microfossils, provides a means of evaluating the moisture balance or temperature of the atmosphere over the water body.

Other chemical parameters. Other types of geochemical analyses may prove necessary in some situations. Marsh sediments, for example, may be especially rich in organic compounds or other components not common in playas.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.1.2.3 are given in the following table.

Method	Technical procedure Number	Title	Date
Carbonate mineral analysis	TBD[a] (in preparation)	Quantitative x-ray diffraction analysis of carbonate minerals and quartz	TBD
Analyses of organics in lake, playa, and marsh sediments	TBD (in preparation)	A program to develop detailed technical procedures for for the USGS quality assurance program of the NNWSI Project, to characterize and quantify organic matter biomarker contents of lake sediment samples	TBD
Textural and mineralogic analyses	TBD	Mineralogy of sediment samples	TBD
	TBD (in preparation)	Procedures for sedimentologic description of sediment cores	TBD
	TBD (in preparation)	Grain size analysis of sediment core samples	TBD

Method	Technical procedure Number	Title	Date
	TBD	Element analyses of bulk sediments	TBD
	TBD	Stable isotope analyses	TBD

[a]TBD = to be determined.

8.3.1.5.1.2.4 Activity: Chronologic analyses of lake, playa, and marsh deposits

Objectives

The objective of this activity is to obtain an accurate, precise chronologic framework for the paleoclimatic information acquired in this study. Moreover, all age information should, whenever possible, be tested with other techniques to reduce uncertainties.

Parameters

The parameters for this activity are ages of biostratigraphic indicators and sediments using the following techniques: carbon-14, amino acid, thermoluminescent dates, uranium-series, uranium-trend, paleomagnetism, tephrachronology, fossils, and others.

Description

Carbon-14. Radiocarbon analyses will be conducted on organic rich sediments, on terrestrial organic matter deposited in aquatic sediments, or on biogenic carbonate using conventional or tandem accelerator methodologies. Radiocarbon can provide age information in the age range from modern to 50,000 yr before present, but is subject to decreasing confidence with decreasing sample size, increasing age, and errors due to contamination.

Amino acids. Amino acid analyses may be applied to well-preserved mollusc or ostracode shells. Particular amino acids are known to change from one state to another as a function of time and temperature. Thus when temperature is known to have been relatively constant, amino acid analyses may provide age, but when thermal histories are variable amino acid data may be used for relative age or as a correlation tool.

Thermoluminescent dating. This technique is in the experimental stage at this time, but may prove useful for dating aquatic sediments in the age range of 2,000 to 250,000 yr before present. The value of this method over most others is that it is usually not dependent on local geochemistry.

Uranium-series. Uranium-series analyses are conducted largely on inorganic or biogenic carbonates. This method is useful for obtaining ages on materials that incorporate uranium but no thorium at the time of crystallization, and remain closed to uranium and its daughter products throughout their history. The age range of this method is from about 5,000 to approximately 350,000 yr before present.

Uranium-trend. Uranium-trend analyses will be conducted largely on surface sediments such as marsh outcrop or soil sequences. It may be applicable to playa cores under some circumstances. This method is an open-system dating method based on uranium-series decay and the migration of daughter products of U-238 through a soil or sediment column. The method is most effective on samples in the range of 60,000 to 600,000 yr.

Paleomagnetism. Paleomagnetic analyses will be applied to core and trench sediments to establish the remanent magnetism. Except for geologically short intervals, the past 700,000 yr has exhibited normal polarity. In most instances, the discovery of reversed polarity sediments indicates they were deposited before this date.

Tephrachronology. This method involves the comparison of the chemical and physical characteristics of volcanic ashes with those of ashes of known ages.

Fossils. The geologic history of many terrestrial and aquatic organisms are well known so that the occurrence of these organisms provides an age range for the sediment. Moreover, the timing of the expansion or contraction of biogeographic ranges for some organisms, largely rodents, is known so that the occurrence of such taxa in a particular area offers a more refined age than the geologic range of the species.

Other chronological methods. Techniques such as stratigraphic position, sediment accumulation rates, soil development, degree of weathering, or presence of artifacts may offer needed age estimates. Moreover, some forms of isotopic analyses, such as strontium isotopes, may provide a way of recognizing sediments deposited from different waters and thus offer a relative age.

Additional records that will be utilized include tree-ring data that have been collected in central and western Nevada as discussed in Chapter 5. These data will be interpreted to determine relationships between tree-ring widths and seasonal fluctuations in climate on the scale of 10 to 1,000 yr. This interpretation will be useful in the development of paleoclimatic transfer functions.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.2.4 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Dating of lake, playa, and marsh deposits	GCP-06, R0	Potassium-argon dating	15 June 81
	GCP-01, R0	Radiometric-age data bank	15 June 81
	GCP-02, R1	Labeling, identification and control of samples for geochemistry and isotope geology	20 Jan 88
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81
Dating of lake, playa and marsh deposits	GCP-05, R0	Radium, equivalent uranium, thorium, and potassium analysis by gamma-ray spectrometry	15 June 81
	GP-08, R0	Correlation of tephra by means of chemical analyses	19 Feb 86
	TBD[a] (in preparation)	Radiocarbon dating	TBD
	TBD	Amino acid	TBD
	TBD	Thermoluminescence	TBD

[a]TBD = to be determined.

8.3.1.5.1.3 Study: Climatic implications of terrestrial paleoecology

This study will provide quantitative estimates of changes in climatic variables (e.g., precipitation and temperature) for the southern Great Basin. Plant macrofossils from pack rat middens will provide coverage for the last 50,000 yr (Activity 8.3.1.5.1.3.1), while fossil pollen from land plants recovered from cores of lacustral sediments will cover at least the last 150,000 yr (Activity 8.3.1.5.1.3.2). Transfer functions, response surfaces, or both will be developed through the statistical comparisons of modern climate to the vegetation data, and these equations will be used in the reconstructions of past climates from the paleovegetation data (Activity 8.3.1.5.1.3.3).

8.3.1.5.1.3.1 Activity: Analysis of pack rat middens

Objectives

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in plant macrofossil assemblages preserved in ancient pack rat middens.

Parameters

The parameters for this activity are

1. Macrofossil assemblages collected from pack rat middens in the southern Great Basin and surrounding region.

2. Radiocarbon age estimates.

3. Other data--vertebrates, insects, isotopic data.

Description

Pollen studies (discussed in Activity 8.3.1.5.1.3.2) are generally carried out in permanently wet environments, but pack rat midden analysis is restricted to the semiarid and arid deserts of western North America. In this method, past vegetation is reconstructed from plant remains preserved in middens deposited in rock cavities by rodents of the genus Neotoma (pack rats, wood rats, or trade rats). The plant remains can often be identified to the species level, and the assemblages are believed, based on the contents of modern middens, to represent vegetation growing within a radius of 30 m of the midden at the time of accumulation.

Pack-rat middens are collected by extracting kilogram-sized samples of material from different levels of the deposit. These are soaked in water to dissolve the cementing material and sieved to concentrate the plant remains (e.g., stems, needles, leaves, and seeds). When dry, the plant material is sorted and counted or weighed to produce a quantified record of the different plant taxa present.

Selected plant macrofossils or other materials from each midden are submitted for radiocarbon analysis. This dating method provides an estimate of the age of the midden assemblage, accurate to within a few hundred years. In instances where more precise dating is required, multiple samples from the same midden are submitted for radiocarbon dating. The paleobotanical data from the individual midden assemblages are compiled to create time series of vegetational change from a given area and vegetational setting. Replication of pack rat chronologies from sites with similar settings ensures that site-specific phenomena do not introduce bias into the interpretation of the data set.

In addition to plant macrofossils, pack rat middens are rich sources of vertebrate and insect remains, pollen, and cellulose for isotopic investigations. The data may be analyzed to elucidate certain paleoclimatic signals. This activity will be carried out in conjunction with Activity 8.3.1.5.2.1.4 (analog recharge studies).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.1.3.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Collection, analysis, and radiocarbon dating of pack rat midden macrofossil assemblages	TBD[a] (in preparation)	Pack rat midden quality assurance document	TBD

[a]TBD = to be determined.

8.3.1.5.1.3.2 Activity: Analysis of pollen samples

Objectives

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains.

Parameters

The parameters for this activity are

1. Pollen assemblages collected from lacustrine, marsh, and playa sediments (and other sedimentary deposits) in the southern Great Basin.

2. Radiocarbon dates, tephrochronology, and other chronological markers.

Description

Studies of fossil pollen in stratified deposits have been used extensively to reconstruct fluctuations in temperature and precipitation over the last 20,000 yr. The applicability of the method has been limited in the western United States by the relative scarcity of bogs and small lakes, the optimal settings for most types of pollen studies. However, paleoclimatological insights have been gained from studies of the fossil pollen contained in sediments deposited in western pluvial lakes, alpine lakes, caves, rock shelters, and alluvium. Pollen records, in general, provide quasi-continuous records of regional vegetational change. While the majority of these studies are restricted to the Holocene, palynological studies of pluvial lake, marsh, and playa sediments also provide information over the period of 10 to several hundreds of thousand years ago.

Pollen is extracted from samples by dissolving unwanted mineral and organic matter in the sample with strong acids and bases. The pollen is comparatively resistant and will remain and become concentrated after dissolution. The pollen is stained to enhance its microstructural detail and mounted on microscope slides for examination. Pollen grains of known plant taxa are identified, tabulated, and plotted stratigraphically according to absolute concentration (per gram or cubic centimeter of sediment) or relative percentages. The stratigraphic plots are interpreted in terms of increasing or decreasing amounts of plant taxa responsible for the various pollen types, taking into account the relative pollen production of individual plant groups, the ease by which pollen is distributed, and the processes by which it is incorporated into the sediment and preserved.

In some instances, pollen studies will be conducted at the same sites as those for paleolacustrine investigations (Study 8.3.1.5.1.2), because lake sediments may contain well preserved pollen and represent more or less continuous deposition. However, because of exposure and oxidation, playa deposits may be unsuitable for pollen analysis. Pack rat middens also contain pollen, particularly from the local vegetation surrounding the midden site, and its analysis can be helpful in determining the nature of the pollen rain (the pollen coming from and falling on any region) in areas where lakes and marshes are few.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.3.2 are given in the following table.

Method	Technical procedure: Number	Technical procedure: Title	Technical procedure: Date
Collection and analysis of pollen deposited in lake sediment	TBD[a] (in preparation)	A program to develop needed technical procedures for the USGS quality assurance program of the NNWSI Project for paleoclimate pollen activity	TBD

[a]TBD = to be determined.

8.3.1.5.1.3.3 Activity: Determination of vegetation-climate relationships

Objectives

The objectives of this activity are to translate the vegetational records provided by pack rat midden and palynological investigations and available dendroclimatological data into quantitative estimates of past climatic variables.

Parameters

The parameters for this activity are

1. Vegetation-climate, pollen-climate response surfaces, or both.
2. Pollen-climate transfer functions.

Description

Palynological and pack rat midden studies together provide a regional network of time series of vegetational change spanning the last few tens of thousands of years. Much of the evidence for past climatic variations comes from such paleoecological records of past vegetation. The interpretation of these paleoecological records in climatic terms requires information on the modern relationships between vegetation and climate. Given the understanding of such relationships, and with certain assumptions, it is possible to infer the nature of the climatic variations responsible for the vegetation changes recorded by the fossil evidence.

Relationships between modern vegetation and climate are also required for the validation of climate simulation models. To judge the ability of the model to simulate correctly the past climate, modern vegetation-climate relationships are used to transform model simulations of past climates into estimates of past vegetation; these can then be compared with the observed fossil record.

There are two related approaches for constructing statistical relationships between modern vegetation and climate data: (1) a transfer function approach in which individual climate variables are expressed as a function of several vegetation predictor variables (e.g., the percentages of different pollen types); and (2) a response function approach in which the relative abundances (or the presence or absence) of individual taxa are expressed as nonlinear functions of one or more environmental variables.

The transfer function approach usually makes use of a multiple regression analysis to construct a relationship between a particular climate variable and a number of predictor variables, which are generally the percentages of individual pollen types. In practice, a data set of paired observations of modern surface pollen samples and climate is required for calibration of the equation. The resulting equation is then applied to fossil pollen data to interpret them in climatic terms.

In the response function approach, the relative abundance or probability of occurrence of different taxa is expressed as a nonlinear (usually polynomial) function of one or more environmental variables. The resulting functions are usually displayed as "response surfaces" that show how the abundance or probabilities vary in the space defined by the environmental variables. For relative abundance data, the response functions are fit using linear regression, while for presence-absence data, the surfaces are fit using logistic regression.

Because response functions illustrate the environmental preferences of different taxa, they can provide guidance in the qualitative interpretation of fossil data in climatic terms. Quantitative reconstruction is possible as well, using response functions of several taxa to determine the environmental conditions necessary to give rise to a particular fossil assemblage.

Application of response functions for climate model validation is relatively straightforward. The relative abundance or the presence or absence of different taxa can be simulated by applying response functions to the values of climate variables simulated by climate models. The simulated vegetation variables can then be compared with the observed. In a typical example, the climate model would be set up to simulate some specific paleoclimate, and the simulated vegetation would be compared with the observed fossil record.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.3.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Translation of paleobotanic data into a climate signal using statistical techniques: transfer functions and response surfaces from lake and playa sediment data	TBD[a]	Transfer functions and response surfaces	TBD
Preparation of "synoptic snapshots" of climate extremes	TBD (in preparation)	Synoptic snapshots of climate	TBD

[a]TBD = to be determined.

8.3.1.5.1.4 Study: Analysis of the paleoenvironmental history of the Yucca Mountain region

The objective of this study is to evaluate the paleoenvironmental record at Yucca Mountain and surroundings in the light of the inferred paleoclimate history of the southern Great Basin. It also provides information to distinguish between effects resulting from surficial processes, as opposed to tectonic activity, and to evaluate the age of tectonic events. The chronology of the erosional and depositional responses to climatic changes at Yucca Mountain will be used to cross-check and supplement the reconstruction of paleoclimate. A detailed paleoenvironmental history is needed to distinguish short- and long-term tectonic effects from local climatic controls on surficial processes. Therefore, dated deposits in this study will be used to constrain ages and recurrence intervals of fault movements.

The paleoenvironmental history of the Yucca Mountain region is a record consisting of surficial deposits and landforms resulting from a combination of specific climatic and tectonic conditions. Surficial processes involving weathering, water, and wind are dominantly controlled by climatic conditions. In surficial deposits with well-constrained ages, specific indicators of paleoclimate can be compared with the regional paleoclimatic history. Less specific indicators of paleoclimate at Yucca Mountain can be reconstructed from soils of different ages and from depositional environments of surficial deposits.

Although the characteristics of the diverse arid-region surficial deposits at Yucca Mountain and surroundings do not allow the precise determination of such climatic parameters as temperature and precipitation, they contain a valuable record of paleoclimate data pertinent to the site itself. The surficial deposits provide a tool for understanding how the Yucca Mountain region has responded to Quaternary climatic episodes and climatic change in the southern Great Basin, in that they suggest that the types and intensities of different erosional and depositional processes have changed throughout the Quaternary. To ascertain whether the climatic responses at Yucca Mountain have been synchronous with those of the rest of the Great Basin, it will be necessary to compare the paleoenvironmental record at Yucca Mountain (from surficial deposits data) with the regional paleoclimate history. If the responses have not been synchronous, it will be necessary to examine other factors besides regional paleoclimate to explain the history of erosional and depositional response at Yucca Mountain. Thus, the paleoenvironmental history serves as both a cross-check on the regional paleoclimate history, as well as a means by which the effect of past hydrologic and erosional episodes upon the Yucca Mountain landscape can be quantified. In addition, this history bears on assessing the influence of local and regional tectonic processes on the surficial processes operating at Yucca Mountain.

The modeling of soil properties at Yucca Mountain will result in a definition of the relation of the properties of late Holocene soils to modern climatic parameters, the comparison of paleoclimate scenarios to soil properties, and the quantification of soil development over time for use as a dating technique. Investigation of modern soils forming under soil moisture conditions similar to wetter paleoclimates at Yucca Mountain will result in the ability to characterize soil properties resulting from past pluvial conditions. Mapping of the surficial deposits of the Yucca Mountain area will aid in the evaluation of the influence of paleoclimate on their genesis and the history of erosion and landform development. Reconstruction of the eolian history of Yucca Mountain will result in an understanding of the role of eolian deposition and erosion in the paleoenvironment and aid in defining the Quaternary paleoclimates at Yucca Mountain.

8.3.1.5.1.4.1 Activity: Modeling of soil properties in the Yucca Mountain region

Objectives

The objectives of this activity are to

1. Determine the relations among properties of late Holocene soils and modern climatic parameters.

2. Compare properties of early Holocene and Pleistocene soils to paleoclimatic models that are reconstructed from other lines of evidence, such as paleolimnology and terrestrial paleoecology, as a check on these models.

3. Frame climatic scenarios as a function of the depth, distribution, and quantity of pedogenic carbonate and other soil parameters.

4. Quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements.

Parameters

The parameters for this activity are

1. Soil morphology and physical and chemical properties of Holocene and Pleistocene soils formed on a variety of parent material lithologies, under modern climates similar to Yucca Mountain at present and during the latest glacial maximum (the Pahute Mesa and Tonopah climatic analog sites).

2. The understanding of how airborne dust contributes to the development of soils on parent materials containing a high proportion of gravels.

3. Physical and chemical analyses of dust.

4. Field measurements of soil partial pressure of carbon dioxide (pCO_2) and available water-holding capacity (AWC).

5. Movement and composition of soil solutions as determined by lysimeter studies.

6. Rates of carbonate translocation in soils of known composition, texture, and pCO_2, under different climatic regimes and rates of accumulation of dust.

7. Rates of soil development from physical and chemical properties of dated soils, including field-described properties (color, texture, structure, clay content, and consistency) and laboratory measured properties (clay mineralogy, major elements, bulk density, soluble salts, carbonates, and extractable iron oxides).

8. Ages of soils at study sites (using cation ratios of rock varnish, potassium-argon, radiocarbon, uranium-trend, uranium-series, and thermoluminescence dating techniques). Experimental isotopic dating techniques such as beryllium-10 and chlorine-36, may be used if they are proved useful and reliable.

Description

An important aim of this activity will be to compare theoretical carbonate distributions, resulting from computer modeling under various simulated climatic conditions, with real carbonate distributions in sampled soils. This will result in a line of evidence that can be used as a check on paleoclimate models as reconstructed from other lines of evidence (paleolimnology and terrestrial paleoecology). Another aim of the activity is to apply the rates of soil development calculated from the physical and chemical properties of dated soils to undated soils in order to estimate the ages of undated soils. These ages will be important in the estimations of ages of Quaternary deposits and fault movements at Yucca Mountain and surroundings.

Soil properties are a function of time and climate. In particular, the distribution and concentration of calcium carbonate and other soluble salts are linked to temperature and precipitation. This relation can be quantified if other factors such as the available water-holding capacity (AWC) of the soil and the composition and influx rate of dust are known. Computer modeling of soils under various climatic regimes can simulate the distribution (depth) and concentration of carbonate in soils. This information, when compared with the movement of carbonate as measured by lysimeters and with carbonate distribution in soils of known age, will permit the evaluation and cross-checking of paleoclimate models proposed for the Yucca Mountain area from paleolimnology and terrestrial paleoecology. Paleoclimate models can be modified if the actual distribution of soil carbonates conflicts with distributions predicted by these models.

Rates of soil development will be calculated for dated surficial deposits, using measured physical and chemical properties. The result of these calculations will be the quantification of the development of some soil properties over time. Knowing the rates at which certain features of a soil develop will allow the dating of previously undated soils, through the examination and measurement of the same properties and the application of known rates. It is expected that this method of dating surficial deposits will also be applied to bracketing ages of fault movement in the Yucca Mountain area.

Backhoe trenches will be excavated in soils developed on surficial deposits of known or inferred ages. The sites will be classified according to deposit age. Soil profiles at a minimum of two sites for each age category will be sampled and described. Sites under consideration in California include Silver Lake and the Cima volcanic field. These particular sites may provide information to the soil modeling effort. They are localities that are characterized by relatively complete stratigraphic sections that contain multiple well-developed paleosols of various ages. The chronology of the paleosols at these localities is well established by radiometric age dates and may provide a relatively complete record of soil development during Quaternary time. Proposed sites in Nevada include Kyle Canyon, Beatty, Fortymile Wash, and a location near Tonopah.

A regional network of dust traps has been set up in a variety of climatic, lithologic, and geomorphic settings. The purpose of the network is to collect airborne dust in marble traps to simulate dust additions to soils developed in gravelly parent materials. Samples will be collected at least once a year. Dust-collection data are required for input for the computer modeling of carbonate translocation and are not available in the existing soils literature.

Soil and dust samples will be analyzed in the laboratory for physical and chemical properties related to climate and age. The properties that may be measured include, but are not limited to, (1) particle size distribution, (2) organic matter content, (3) carbonate and silica content, (4) soluble salts, (5) extractable chemistry, (6) major and minor element chemistry, (7) soil water, (8) density, (9) mineralogy, and (10) morphology.

Available water-holding capacity and pCO_2 is measured in gravelly desert soils of a variety of ages at various locations in the vicinity of Yucca Mountain. These data are required as input for the computer modeling of ground-water transport of carbonate and are not available in the existing soils literature. Also, the movement and composition of soil solutions in soils near Yucca Mountain will be measured by lysimeters. This data will be compared with the movement of soil solutions predicted by computer modeling.

Therefore, a computer program has been developed to model the movement of carbonates in solution through soils of varying texture and AWC under varying climatic conditions. The program will be used to simulate carbonate development in soils according to the paleoclimatic conditions developed from paleolimnologic and terrestrial paleoecologic evidence. Simulated soil conditions will be compared with real soil conditions at Yucca Mountain to evaluate the paleoclimate history and, if necessary, modify it.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.4.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Trenching, sampling, and description of soils	GP-07, R0	Geologic trenching studies	14 Aug 84
	GP-17, R0	Describing and sampling soils in the field	19 Feb 86
Dust trap sampling	TBD[a]	Dust trap sampling	TBD
Laboratory analyses of soil physical and chemical properties	TBD	Physical, chemical, and mineralogical properties of soils and surficial deposits	TBD
Field measurements of soil pCO_2 and available water-holding capacity (AWC)	TBD	Field measurements of soil pCO_2 and AWC	TBD
Development of computer model for the transport of carbonate by ground water	TBD	Computer modeling of soil carbonate translocation	TBD
Lysimeter studies of soil leachates	TBD	Lysimeter collection of soil leachates	TBD
Rates of soil development	TBD	Determination of rates of soil development	TBD
Dating of soils (cation ratio, thermoluminescence, radiocarbon, uranium-trend, uranium-series, and potassium-argon dating method techniques)	GCP-01, R0	Radiometric-age data bank	15 June 81
	GCP-02, R1	Labeling, identification and control of geochronology samples for geochemistry and isotope geology	4 Apr 81
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81
	GCP-06, R0	Potassium-argon dating	15 June 81
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Thermoluminescence	TBD

Method	Technical procedure Number	Title	Date
	TBD (in preparation)	Radiocarbon dating	TBD

[a]TBD = to be determined.

8.3.1.5.1.4.2 Activity: Soil moisture analog study

Objectives

The objective of this activity is to characterize physical, chemical, and mineralogic properties of selected soils at Pahute Mesa and areas near Tonopah, which have formed under conditions similar to those that may have existed at Yucca Mountain during pluvial conditions of Pleistocene glacial climatic cycles. Comparison of these soils with Yucca Mountain paleosols will allow inferences to be made concerning climate conditions that existed at Yucca Mountain at various times throughout the Quaternary.

Parameters

The parameters for this activity are

1. Chief characteristics of soil including profiles, color, structure, texture, stone content, secondary clay, calcium carbonate, secondary silica, consistency, and plasticity.

2. Chief physical properties of surficial deposits including lithology, stone content, texture, color, and depositional features.

3. Physical, chemical, and mineralogic properties of soils including, but not limited to, particle size distribution, calcium carbonate content, amorphous silica, amounts and types of soluble salts, clay mineralogy, amounts and types of extractable iron, bulk density, and soil water chemistry.

4. Ages of soils and surficial deposits.

Description

The modern soils of Pahute Mesa and areas near Tonopah in the Kawich Range, Toiyabe National Forest, have formed under approximately the same moisture levels as Yucca Mountain and the surrounding region during pluvial conditions of Pleistocene glacial climatic cycles. This activity is aimed at defining the physical, chemical, and mineralogic characteristics of soils in the region that are now developing under wetter conditions from those that presently exist at Yucca Mountain. Comparison of the properties of analog soils with those of similar soils at Yucca Mountain will provide a means of evaluating the paleoclimate history of the Yucca Mountain area.

Backhoe trenches will be excavated at selected sites at Pahute Mesa and near Tonopah to facilitate soil description and sampling. At each trench, the soil profile will be photographed and described, with the description focusing on the depth, form, and relative abundance of secondary calcium carbonate and amorphous silica. The amounts and forms of carbonate, amorphous silica, and soluble salts in soils and soil water are important to the interpretation of present and past soil moisture conditions on Pahute Mesa and other analog study areas.

Soil and soil water samples will be collected in the trenches. These samples will be analyzed in the laboratory to determine physical, chemical, and mineralogic properties. These properties may include, but are not limited to, (1) particle size distribution, (2) bulk density, (3) clay mineralogy, (4) abundance of secondary carbonate, (5) amount of amorphous silica, and (6) amounts and types of soluble salts and extractable iron oxides. Soil water chemistry will also be determined in the laboratory.

Dating of soils and surficial deposits, in conjunction with the calculation of soil profile summations (for carbonate, amorphous silica, secondary clay, and extractable iron oxides), will allow the determination of rates of accumulation of secondary constituents. Dating techniques will include an appropriate combination of uranium-series, uranium-trend, radiocarbon, thermoluminescence, and cation ratio dating.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.4.2 are given in the following table.

Method	Technical procedure: Number	Technical procedure: Title	Technical procedure: Date
	(NWM-USGS-)		
Description of soil morphology in trenches, collection of soil samples in trenches	GP-07, R0	Geologic trenching studies	14 Aug 84
	GP-17, R0	Describing and sampling soils in the field	19 Feb 86
Collection of soil water samples	TBD[a]	Collection of soil water	TBD
Laboratory analyses of soil physical, chemical, and mineralogic properties	TBD	Physical, chemical, and mineralogical properties of soils	TBD

Method	Technical procedure Number	Title	Date
Laboratory chemical analysis of soil water	GP-21	Chemical analysis of soil water	TBD
Dating of soils	GCP-02, R1	Labeling, identification and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Thermoluminescence	TBD
	TBD (in preparation)	Radiocarbon dating	TBD

[a]TBD = to be determined.

8.3.1.5.1.4.3 Activity: Surficial deposits mapping of the Yucca Mountain area

Objectives

The objectives of this activity are to

1. Determine the distribution, age, genesis, soil properties, and physical properties of surficial deposits at Yucca Mountain and surroundings.

2. Evaluate the influences of climate and tectonics on the genesis of surficial deposits.

3. Provide a map of surficial deposits for facility placement planning, geomorphic studies, engineering property studies, and surface infiltration studies.

Parameters

Among the parameters under consideration are the following:

1. Distribution, spatial relationships, and thicknesses of the various types of surficial deposits (e.g., fluvial, eolian, and colluvial).

2. Chief physical properties of surficial deposits, including lithology, stone content, particle size distribution, bulk density, soil moisture content, texture, color, and depositional features.

3. Chemical and mineralogical properties of surficial deposits and soils may include, but are not limited to, clay mineralogy, calcium carbonate content, amount of amorphous silica, amounts and types of soluble salts, amounts and types of extractable iron, and soil water chemistry.

4. Chief soil characteristics, including the profile, color, structure, texture, stone content, secondary clay amounts, calcium carbonate content, secondary silica content, consistency, and plasticity.

5. Ages of surficial deposits and soils.

6. Interpreted paleotemperatures during carbonate deposition.

Description

The distribution, spatial relationships, and thicknesses of the various surficial deposits of the Yucca Mountain area will be defined; the definition will be aimed at identifying the geomorphic settings of the various deposits (e.g., fluvial, eolian, and colluvial), the areal extents and proportion of each type of deposit within the region, their thicknesses, and their vertical and horizontal stratigraphic relations. The distribution of surficial deposits will be determined by mapping the deposits on aerial photographs and possibly on satellite imagery. The contacts of the deposits will be verified in the field by examining trenches and natural exposures. Field descriptions of surficial deposits and soils will focus upon characteristics and parameters that will aid in determining their age and genesis, as well as the influences of past climate and tectonics. The area of investigation is shown in Figure 8.3.1.5-5. This activity will be carried out in conjunction with Activity 8.3.1.6.1.1.1 (development of geomorphic map of Yucca Mountain). This activity will also interface and complement the work done in Section 8.3.1.14.2 (studies to provide soil and rock properties at potential locations of surface facilities).

To supplement the mapping (particularly with regard to deposit thicknesses, but more importantly for the description and sampling of the surficial deposits and soils), shallow trenches will be excavated by backhoe, bulldozer, or both at key sites. In addition to the detailed description of the stratigraphy, soil morphology, and other physical characteristics of the surficial deposits, samples will be collected for physical, chemical, and mineralogic analysis and for stable isotope analysis and dating. Another supplemental procedure for the mapping will be the compilation and interpretation of lithologic logs of previously drilled shallow drillholes to

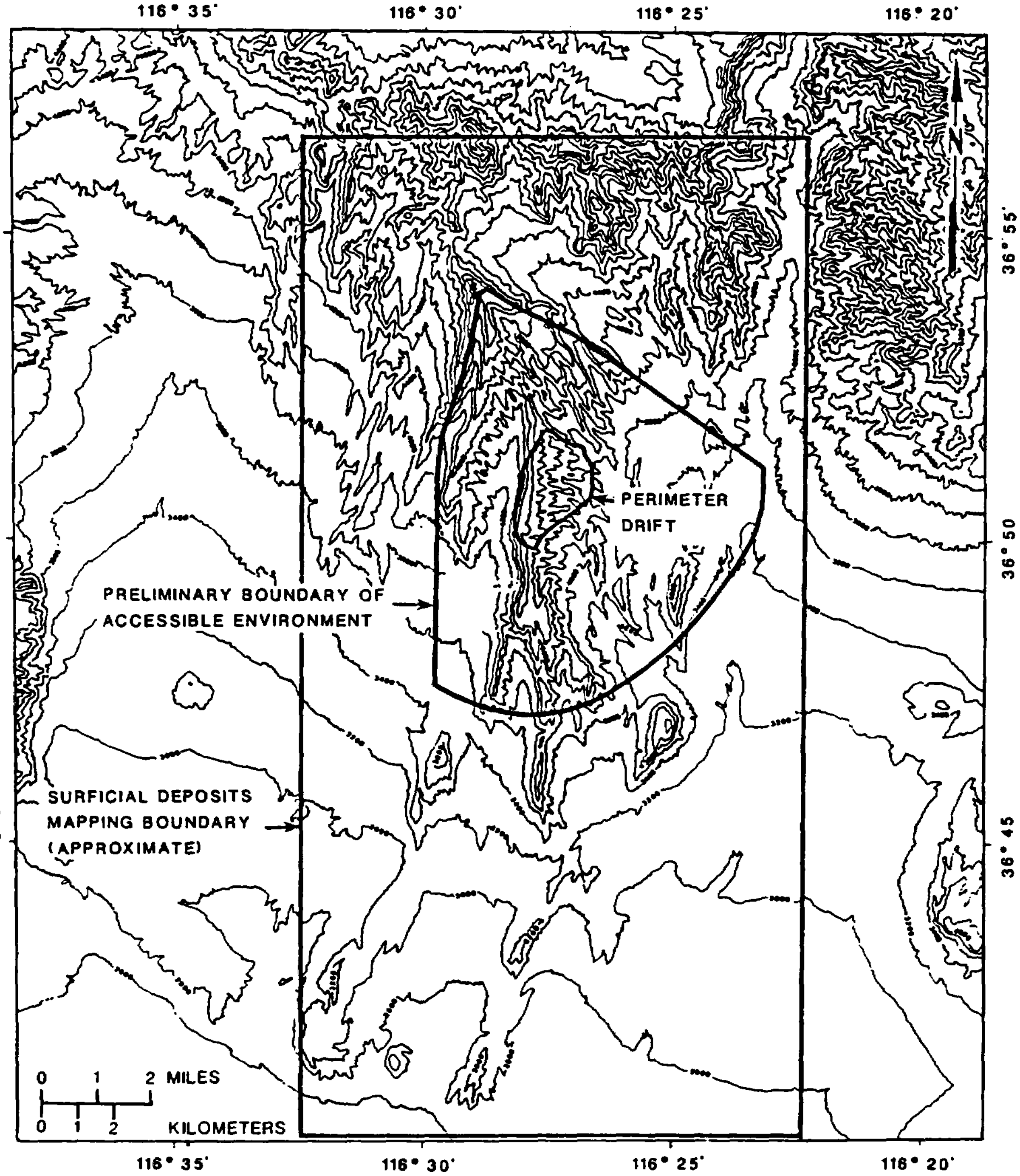


Figure 8.3.1.5-5. Approximate boundaries of Yucca Mountain surficial deposits mapping.

determine the thickness and other physical properties of surficial deposits encountered in drilling. This information will be correlated with results of the mapping and trenching procedures.

Soil water samples will be collected at selected sites for chemical analysis. Chemical data for modern soil water will aid in determining the paleoclimatic implications of the relative abundance, form, and distribution of secondary calcium carbonate and amorphous silica in the various surficial deposits. Also, this data will aid in applying the findings of the soil moisture analog study to the interpretation of paleosoil moisture conditions in the Yucca Mountain area.

Laboratory analysis of surficial deposits and soils will be conducted to determine a variety of physical, chemical, and mineralogical properties. These properties may include, but are not limited to, (1) particle size distribution, (2) bulk density, (3) soil moisture content, (4) clay mineralogy, (5) calcium carbonate content, (6) amounts of amorphous silica, and (7) amounts and types of soluble salts and extractable iron. Data from these analyses will provide a basis for characterizing key physical, chemical, and mineralogic properties of the surficial deposits and soils, and will aid in the determination of their genesis and relative ages.

The surficial deposits will also be dated to aid in correlation of depositional events with Pleistocene glacial and interglacial climatic cycles and the periods of transition between these cycles. Dating techniques will include uranium-series, uranium-trend, radiocarbon, thermoluminescence, and cation ratio dating. Dating will also contribute to the effort to correlate paleoecological evidence with the paleoenvironmental (erosional and depositional) history of Yucca Mountain area.

The uranium-series dating technique has been a useful tool in estimating the ages of crystallization of secondary carbonates. This technique can potentially be used on any materials that incorporate uranium but no thorium at the time of crystallization, and remain closed to uranium and its daughter products throughout their history (Bradley, 1985).

Preliminary analysis (Knauss, 1981) suggests that Quaternary secondary silica should be an ideal material for uranium-series disequilibrium methods. Dates on amorphous (opaline) silica would provide minimum limiting ages for their host sediments, and dates on buried opals would provide maximum limiting ages for overlying sediments. Secondary carbonates occur in a wide variety of forms in the Yucca Mountain area. Many have developed in surficial deposits; others occur as root casts in eolian-alluvial-colluvial "sand-ramp" deposits, as fracture-fill materials, and as throughflow seep deposits. Two important characteristics of these carbonates make them suitable materials for deriving paleoclimatic information: (1) they may have been deposited by meteoric waters and thus would reflect in part the temperature of crystallization in the near-surface environment, and (2) they are datable by uranium-series disequilibrium methods. Uranium is quite soluble in meteoric waters that pass through uranium-bearing minerals, especially in near-surface environments characterized by oxidizing conditions. Trace amounts of uranium are thus carried through soils, unconsolidated materials in water, or both and coprecipitated with calcium carbonate. In contrast, thorium is characterized by extreme insolubility in near-surface environments and thus does not coprecipitate with uranium because it is not leached from thorium-bearing minerals. This is significant because, with time, the amount of thorium-230 will increase by radioactive decay of uranium-234. The ratios of the activity of thorium-230 to its parent uranium-234 and its grandparent uranium-238 are used to calculate the date of crystallization of the carbonate. At present, this method is useful back to about 350,000 yr.

Uranium-trend dating is an open-system dating method based on uranium-series decay and the migration of daughter products of uranium-238 through a soil or sediment column. In the Yucca Mountain area, the uranium-trend dating method has thus far been limited mainly to alluvial deposits because they are the most extensive Quaternary sediments. Because one of the pertinent questions to be answered in geologic investigations of Yucca Mountain is the rate of hillslope erosion (Section 8.3.1.6), accurate dating of colluvial deposits is desirable. Dating of eolian sediments is also useful, because such deposits are significant from a paleoclimatic point of view. If uranium-trend dating is feasible on colluvial and eolian deposits, the derived ages should be consistent with the relative ages. Such a test is only a partial check on the suitability of the method, because consistent relative ages may result but may be incorrect in terms of absolute age. A further check is provided by the linearity of the uranium-trend plots; plots that show poor linearity indicate that the material is unsuitable for dating and little confidence can be placed in the derived absolute ages. Good linearity and consistent relative ages strongly suggest correct absolute ages. Alluvial deposits in this area generally show excellent linearity on uranium-trend plots. A final and more rigorous test of the suitability of the method would be to compare derived uranium-trend ages with independent absolute dating methods such as conventional closed-system uranium-series dates on secondary carbonates that occur in the same deposits or potassium-argon dates on volcanic rocks that underlie the deposits. This uranium-trend method is most effective on samples in the range of 60,000 to 600,000 yr (Rosholt et al., 1985).

Isotopic analyses of secondary carbonates will be performed to determine paleotemperatures from proportions of stable isotopes. The results of these analyses will include isotopic composition of secondary carbonates (oxygen-16 to oxygen-18 and carbon-13 to carbon-12 ratios), differences between crystallization temperatures of secondary carbonates and Holocene average temperatures of crystallization, and dates of crystallization of secondary carbonates. One of the primary factors controlling the oxygen isotope composition of secondary carbonates in near-surface environments is temperature of crystallization. Theoretical and empirical studies have shown that the ratio of oxygen-18 to oxygen-16 varies systematically with temperature in carbonates if the oxygen isotope compositions of the source waters are similar. Departure of carbonate crystallization temperatures from the present value can be determined using oxygen isotope compositions of Pleistocene samples in comparison with isotope composition of Holocene samples. Paleotemperatures thus determined can be very useful in testing the hypothesis that pluvial periods were caused at least in part by cooler temperatures and reduced rates of evapotranspiration. In addition, since there is a regular change in oxygen isotope composition of carbonates with temperature, the magnitude of temperature change can be estimated. Empirical studies have shown that carbon isotopic composition of soil carbonates is controlled to a great extent by the type of plant community. Because temperature is one of the controlling factors in plant geography, determination of the former vegetation type will serve as an independent, qualitative check on the paleotemperature determinations.

Erosional landforms ("nivation basins") above 2,200 m in the high mountain ranges near the Nevada Test Site reflect the past occurrence of perennial snowfields (Dohrenwend, 1984). Although the time of formation of these features is not yet known with certainty, they are presumably of Late Wisconsin age. The occurrence of perennial snowfields provides evidence on the past climate at the upper reaches of the recharge areas for Yucca Mountain. Investigations of these features will focus on their geographic and elevational distribution, their age, and the paleoclimatic inferences that can be drawn from their occurrence.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.4.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Mapping and interpretation of aerial photographs and satellite imagery; field mapping and verification	GP-01, R0	Geologic mapping	1 Mar 83
Excavation of shallow trenches at key sites for the description and sampling of surficial deposits and soils	GP-07, R0	Geologic trenching studies	14 Aug 84
Compilation and interpretation of lithologic logs of previously drilled shallow boreholes	GP-02, R0	Subsurface investigations	1 Mar 83
Collection of soil water samples	TBD[a]	Soil water collection	TBD
Laboratory analyses of surficial deposits and soils for physical, chemical, and mineralogic properties	TBD	Physical, chemical, and mineralogic properties of soils and surficial deposits	TBD

Method	Technical procedure Number	Title	Date
Laboratory chemical analysis of soil water	GP-21	Chemical analysis of soil water	TBD
Isotopic dating of surficial deposits and soil	GCP-01, R0	Radiometric-age data bank	15 June 81
	GCP-02, R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Thermoluminescence	TBD
	TBD (in preparation)	Radiocarbon dating	TBD
Stable isotope analysis	TBD (in preparation)	Stable isotope analysis	TBD
Testing of uranium-series and uranium-trend dating on new geologic materials	GCP-03, R0 GCP-04, R0	Uranium-series dating Uranium-trend dating	15 June 81 15 June 81

[a]TBD = to be determined.

8.3.1.5.1.4.4 Activity: Eolian history of the Yucca Mountain region

Objectives

The objectives of this activity are

1. Document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 yr.

2. Determine paleoenvironmental conditions during times of eolian deposition and intervening times of surface stability and soil formation.

3. Determine source areas of sand and silt.

Parameters

The parameters for this activity are

1. Age of eolian sediments and soils developed on eolian deposits by uranium-series methods, thermoluminescence, and volcanic ash identification.

2. Textural characteristics of sediments.

3. Mineralogy of sediments.

4. Paleowind directions--directly determined from faceted bedrock surfaces, or determined from cross-bedding azimuth measurements of dune deposits.

5. Paleowind velocities--indirectly determined by measuring platelet spacing on the surface of abraded quartz grains.

6. Concentrations of thorium, titanium, zirconium, yttrium, and niobium in alluvial and eolian sands and in alluvial and eolian silts.

Description

Eolian deposits are widespread in the Yucca Mountain area. Thick deposits of sand have been blown against Fran Ridge, Busted Butte, and southern parts of Yucca Mountain, and veneers of eolian silt mantle nearly all flat and gently sloping surfaces and ridge tops in the area. These deposits range in age from at least 740,000 yr to only a few thousand years old. Thus, the great spatial and temporal distribution of eolian deposition and erosion, and the intervening episodes of surface stability and soil formation, record a long history of climatically influenced conditions at Yucca Mountain. Dating of eolian deposits is also important to the reconstruction of Quaternary fault movements at Yucca Mountain, because several major north-south trending faults offset these eolian deposits.

Eolian sands will be dated primarily by identifying volcanic ashes that are interbedded in sand ramps, and by uranium-series dating of secondary carbonates in the soils developed on these deposits. Paleoenvironmental conditions that have well-constrained ages can then be compared with other paleoclimatic reconstructions, most notably the lacustrine records developed under Activity 8.3.1.5.1.2.1. Because the paleoclimate record derived from pack rat middens in the Yucca Mountain area is limited to the age range of radiocarbon dating (about 50,000 yr before present), dated eolian deposits are one of the few sensitive paleoclimatic indicators available for reconstructing paleoenvironments older than 40,000 yr.

The Bishop ash has already been observed in the sand ramps, indicating that eolian deposition in the Yucca Mountain region began before 740,000 yr before present (Izett, 1982). Volcanic ashes of Lava Creek (610,000 yr before present) and Lathrop Wells basaltic core (the late Quaternary) occur in the Yucca Mountain area and may occur in the sand ramps.

Uranium-series dating of the sand ramps is possible because these sediments contain secondary carbonates of two distinct types. The first type takes the form of rhizoliths or root casts; these features form as sheaths and casts of plant roots in sandy calcareous sediments. The presence of a plant cover implies that the sediments have been stabilized and that little or no deposition is taking place. The second type of carbonate deposit found in the sand ramps is laminar calcrete. Studies conducted elsewhere in the southwestern United States indicate that most laminar calcretes are of pedogenic origin and take a considerable amount of time to form after stabilization of the geomorphic surface (Gile et al., 1965). Uranium-series dating of rhizoliths yields a close minimum age for the time of stabilization of a sand ramp surface. Uranium-series dating of laminar calcretes yields a minimum age for the underlying sediments, but also a maximum age for overlying sediments. Thus, by dating both types of carbonates, bracketing uranium-series dates can be obtained for many of the sand ramp sediments; for the uppermost units, close minimum ages can be obtained.

Fine-grained eolian silt is an ideal geologic material for dating by thermoluminescence analysis over a time range of the last 100,000 yr. Silt-rich eolian deposits mantle gently dipping surfaces and may represent one or more episodes of eolian deposition. Preliminary thermoluminescence dating of vesicular A horizons from the Yucca Mountain area indicates that deposition of the fine silt fraction took place in the mid-Holocene (Whitney et al., 1986).

The distribution and thickness of these dated eolian deposits, both sand and silt, will be mapped to aid in the reconstruction of paleowind directions and in the identification of sediment source areas. Regional wind directions can be reconstructed from the position of dunes with respect to topographic barriers, and by regional comparison of the geometry, cross-bedding azimuths, and thickness of the deposits. Paleowind directions will also be measured from the orientation of wind-abraded bedrock surfaces on hills and mountains.

The geochemistry of immobile trace elements will be studied in eolian sediments to identify sediment source areas. Sand and silt-rich soil A horizons, typically with vesicular structure, are common surface horizons in soils of arid regions, including most soils in the Yucca Mountain area. Investigators who have studied these features in other parts of the southwestern United States have concluded that many such features are (1) primarily eolian in origin and (2) of Holocene age (McFadden et al., 1986). Particle size analyses of vesicular A horizons from the Yucca Mountain area indicate that these features have modal sizes in the fine sand and fine silt fractions, suggesting that (1) the features are probably eolian and (2) two sources of sediment may be involved, one local (fine sands) and one distant (fine silts). If the source of the fine silts can be identified, it may be possible to reconstruct the mid-Holocene paleowind pattern. The most likely candidates as distant sources for the fine silts are unvegetated playa surfaces found in the structural basins of southern Nevada. Identification of the source basin or basins is possible by analysis of playa fine silts and vesicular A horizon fine silts for immobile trace element concentrations. The term immobile here refers to elements that are usually chemically immobile under surface conditions. Such elements (thorium, titanium, zirconium, yttrium, and niobium) are not leached from crystal lattice positions under subaerial conditions and hence can serve as signatures for basins with distinctive lithologies. The five trace elements to be measured are those that have been used most extensively by igneous petrologists in classifications of volcanic rocks of different origins; their use here is appropriate because most of the basins in southern Nevada receive sediments eroded primarily from Tertiary volcanic rocks. In a similar fashion, local sources of the fine sands found in the vesicular A horizons can be identified using the same trace elements. Collectively, the data should identify the sources of sediment in soil A horizons and allow reconstruction of local and synoptic-scale paleowind patterns in the mid-Holocene.

Investigations of sand mineralogy will be performed to augment both sediment source identification and to search for volcanic ashes. Textural characteristics of the eolian deposits will be analyzed to aid in reconstructing eolian conditions and to determine how much sand has been reworked by alluvial processes. Bimodal grain-size distributions, for example, exist in the silt mantles, indicating two sources of sediment in the deposit.

Terrestrial paleoecologic studies will be done on pollen, teeth, bones, rootcasts, and burrows where such evidence is found and can be determined to indicate local paleoenvironmental conditions. Tests will be done to determine whether or not the pollen preserved in sand ramp sands and interbedded soils is of local or regional origin. This information can then be compared with paleoenvironmental information derived from macrofossil studies of local pack rat middens (Study 8.3.1.5.1.3). Soils analyses undertaken as part of the surficial deposits mapping of Yucca Mountain (see description of Activity 8.3.1.5.1.4.3) will yield paleotemperature information from oxygen isotopic analyses, and ranges of paleotemperatures and precipitation based on modeling of several soil properties (Activity 8.3.1.5.1.4.1).

Paleowind velocities will be measured indirectly by studying the surface textures of eolian quartz grains with a scanning electron microscope. The frosting of quartz grains is known to be caused by abrasion, and at the microscopic level this frosting is seen to be the formation of a series of parallel plates. The spacing between individual plates is related to the velocity of the wind that last transported the grains. Measurements of plate spacing on grains from different age deposits will allow comparison of paleowind velocities with those of present winds.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.4.4 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Dating of eolian sands by identification of volcanic ash	GP-08, RO	Correlation of tephra by means of chemical analyses	17 Feb 86
Uranium-series dating of sand ramp secondary carbonates	GCP-03, RO	Uranium-series dating	15 June 81
Thermoluminescence dating of fine eolian silt	TBD[a]	Thermolumine-scence	TBD
Mapping of distribution and thickness of eolian silt	GP-01, RO	Geologic mapping	1 Mar 83
Immobile trace element geochemistry of eolian sediments	TBD	Trace element geochemistry	TBD
Textural and mineralogic characteristics of eolian sand	TBD	Textural analyses	TBD
	TBD	Mineralogic analyses	TBD
Terrestrial paleo-ecological studies	TBD	Terrestrial paleoecology	TBD
Paleowind velocity analysis	TBD	Paleowind velocity analysis	TBD

[a]TBD = to be determined.

8.3.1.5.1.5 Study: Paleoclimate-paleoenvironmental synthesis

This study consists of one activity and will compare the paleoclimatic estimates from the various proxy data sets and provide data syntheses in the formats required for future climate and paleohydrology investigations.

8.3.1.5.1.5.1 Activity: Paleoclimate-paleoenvironmental synthesis

Objectives

The objective of this activity is to provide summaries of the paleoclimatic data in formats that can be utilized by investigations of future climatic changes and paleohydrology.

Parameters

The parameters for this activity are

1. Synoptic snapshots of climatic conditions during key time periods in the past.

2. Time series (chronologies) of changes in climatic variables (e.g., precipitation and temperature).

3. Estimates of magnitude, timing, and duration of major past periods of high effective moisture.

Description

Paleoclimatic data will be used (1) in future climate investigations to validate numerical climate models, (2) to establish the relationships between past periods of high levels of effective moisture in southern Nevada and global climate states, and (3) to provide input into paleohydrological models. The paleoclimatic estimates from paleolacustrine investigations, terrestrial paleoecology, and paleoenvironmental investigations must be compared and synthesized into the forms required by these other studies.

The numerical climate models will be constructed on the basis of modern climatic data, and paleoclimatic investigations will provide independent data for model validation. This exercise will require mapped arrays of paleoclimatic estimates (synoptic snapshots) for key time periods in the past (primarily over the last 50,000 yr). The periods will be selected to provide a range of differing boundary conditions, such as global ice maxima versus minima, and will demonstrate the validity and sensitivity of the models to changes in these conditions.

A second approach to predicting aspects of future climatic variations in southern Nevada will involve identifying the global climate states (e.g., glacials, interglacials, and interstadials) that accompanied regional periods of high effective moisture. Estimates of the characteristics, magnitudes, and durations of such periods will provide guidance in estimating the climatic infiltration parameters that would occur at Yucca Mountain, if, for example, a glacial climate occurred in the next 10,000 to 100,000 yr. Another aspect of these empirical studies will be to identify (if possible) periodic components in past climatic variations to provide a basis for estimating the timing of future changes. This approach will require time-series data of variations in climatic parameters.

Mapped summaries of paleoclimatic estimates will be compared with paleohydrologic data to establish the relationships between climatic phenomena and changes in hydrologic parameters. These maps will be similar to those required for model validations, but will be centered on Yucca Mountain and will be on finer, smaller spatial and temporal scales. Ongoing scientific work that bears directly on these modeling efforts is being carried out under the COHMAP project (Webb et al., 1987), a joint venture including Brown University, the University of Wisconsin, and the National Center for Atmospheric Research (NCAR). The COHMAP project includes mapping of general circulation model (GCM) simulated climates (from the NCAR Community Climate Model) at 3,000-yr intervals back to full glacial. The simulations are then compared with conditions inferred from paleoclimate indicators (e.g., fossil pollen). The results of the COHMAP project are expected to be extremely useful in implementing the site characterization plans, and COHMAP activities will be integrated with the SCP activities wherever appropriate.

8.3.1.5.1.6 Study: Characterization of the future regional climate and environments

The objective of this study is to estimate values for climatic parameters for the Yucca Mountain area over the next 100,000 yr, with special emphasis on the next 10,000 yr. The values for these parameters will be used in the hydrologic modeling of the ground-water regime at Yucca Mountain (Investigation 8.3.1.5.2) and in the investigation of the effects of future climate on erosion at Yucca Mountain (Investigation 8.3.1.6.2). Estimates for future precipitation, temperature, evapotranspiration, and other parameters will result from the modeling of certain climate scenarios expected to occur in the southern Great Basin over the next 100,000 yr.

Modeling of future climate requires the development of a procedure for quantitatively evaluating the characteristics of future climate scenarios. This study will employ a dual approach to modeling: a numerical approach (Activities 8.3.1.5.1.6.1 through 8.3.1.5.1.6.3) and an empirical approach (Activity 8.3.1.5.1.6.4). Both approaches first require the establishment of an integrated time series of paleoclimate change and the selection of expected future climate scenarios based on the nature and timing of climate scenarios in the Quaternary. In the numerical modeling approach, a linked global-regional numerical model will be employed to calculate the future meteorological parameters. The regional model will use boundary conditions for future scenarios as derived from a global climate model as well as from paleoclimate evidence from corresponding similar episodes in the Quaternary. In the empirical modeling approach, values of climate parameters for future scenarios will be estimated from evidence in the paleoclimate record for corresponding similar episodes in the Quaternary.

Both the numerical and the empirical approaches to modeling future climate are descriptive methods. They are two different ways of describing the meteorology of future climate scenarios, and both are based on the paleoclimate history of the region. This history will include the timing, duration, and meteorologic nature of Quaternary climatic episodes. The prehistorical record of climate must extend far enough back into the past and be dated with enough precision to allow the reconstruction of an integrated time series of paleoclimate from paleolacustrine, terrestrial paleoecologic, and paleoenvironmental evidence (Study 8.3.1.5.1.5).

As an integral part of this study, two advisory panels will be formed. These panels, made up of specialists in areas of climate modeling, will be used to assess the specific details of the two climate modeling efforts (i.e., the global modeling and the regional modeling, if the feasibility study determines that regional modeling is appropriate), with particular attention to be given to (1) the development of criteria to evaluate the different models available and the different techniques used, (2) the establishment of boundary conditions, (3) the expected and realistically attainable output from each model, and (4) the ability of the two models to interact with each other. The potential use of the advisory panels is identified in the following discussion of the activities to be conducted under this study.

8.3.1.5.1.6.1 Activity: Global climate modeling

Objectives

The objectives of this activity are to

1. Identify and estimate factors controlling global climate.

   a. Develop a sequence of "snapshots" of possible climate scenarios at intervals of up to 1,000 yr over the next 10,000 yr.

   b. Develop a set of anticipated global climate scenarios over the next 100,000 yr.

2. Compute the configuration and extent of ice sheets at regular intervals of time over the next 100,000 yr to determine the effects of such ice volume changes upon the climatic system.

3. Provide boundary conditions, including precipitation, temperature, cloud cover, evapotranspiration, and wind velocity for regional climate models through the use of general circulation models.

Parameters

The output from the global climate modeling, to be used as boundary conditions for the regional modeling includes means and ranges of the following parameters:

1. Surface temperature.
2. Cumulative precipitation rate.
3. Condensed moisture.
4. Fractional cloud amount.
5. Averaged solar flux absorbed at surface.
6. Averaged solar flux absorbed by earth and atmosphere.
7. Averaged infrared flux upward at surface.
8. Averaged longwave flux at top of atmosphere.
9. Averaged total albedo of surface and atmosphere.
10. Shortwave heating rate.
11. Longwave heating rate.

12. Convective temperature change.
13. Sensible heat flux at surface.
14. Latent heat flux at surface.
15. Wind velocity.

Description

The paleoenvironmental record for the Quaternary Period suggests that significant variations in climate have occurred in the past and are likely to occur in the future. Modeling future global and regional climate will help determine whether such variations in climate can significantly affect the proposed repository at Yucca Mountain. General circulation models (GCMs) can provide three-dimensional simulations of the atmosphere at too coarse a spatial resolution to provide meaningful results for specific sites. Regional mesoscale models are capable of disaggregating GCM output to represent explicitly the physical processes that govern the hydrologic balance. Therefore, the goal of this study is to link a GCM with a regional model to predict future climate. The details of how this is to be achieved are shown in Figure 8.3.1.5-6.

The prediction of future global climate rests largely on calculation of extreme climatic conditions (scenarios) that can be anticipated to occur in the future. A coupled ice sheet-energy balance modulus expected to be used to identify the scenarios pertinent to hydrology that are associated with repository performance. At present, the following scenarios have been identified as being of concern:

1. Natural variability under modern conditions.

2. Glacial periods that may correspond to pluvial conditions in the southern Great Basin.

3. A "super" glacial and resulting conditions in the southern Great Basin.

4. A "super" interglacial, in which increases in carbon dioxide and other trace gases lead to significant global warming.

5. A "super-long" period of changed climate, that, by virtue of its duration, could adversely affect site performance.

In addition, future climate for the next 10,000 yr will be modeled in time intervals of up to 1,000 yr in duration. Additional scenarios and time periods will be run as required by results of the energy balance model runs or other sources.

The best known changes in the global climate system during the Quaternary Period accompanied the growth and decay of major ice sheets. These glacial-interglacial cycles have been shown to correlate with the variations in orbital parameters of the earth (i.e., longitude of perihelion, obliquity, and eccentricity (Hays et al., 1976)).

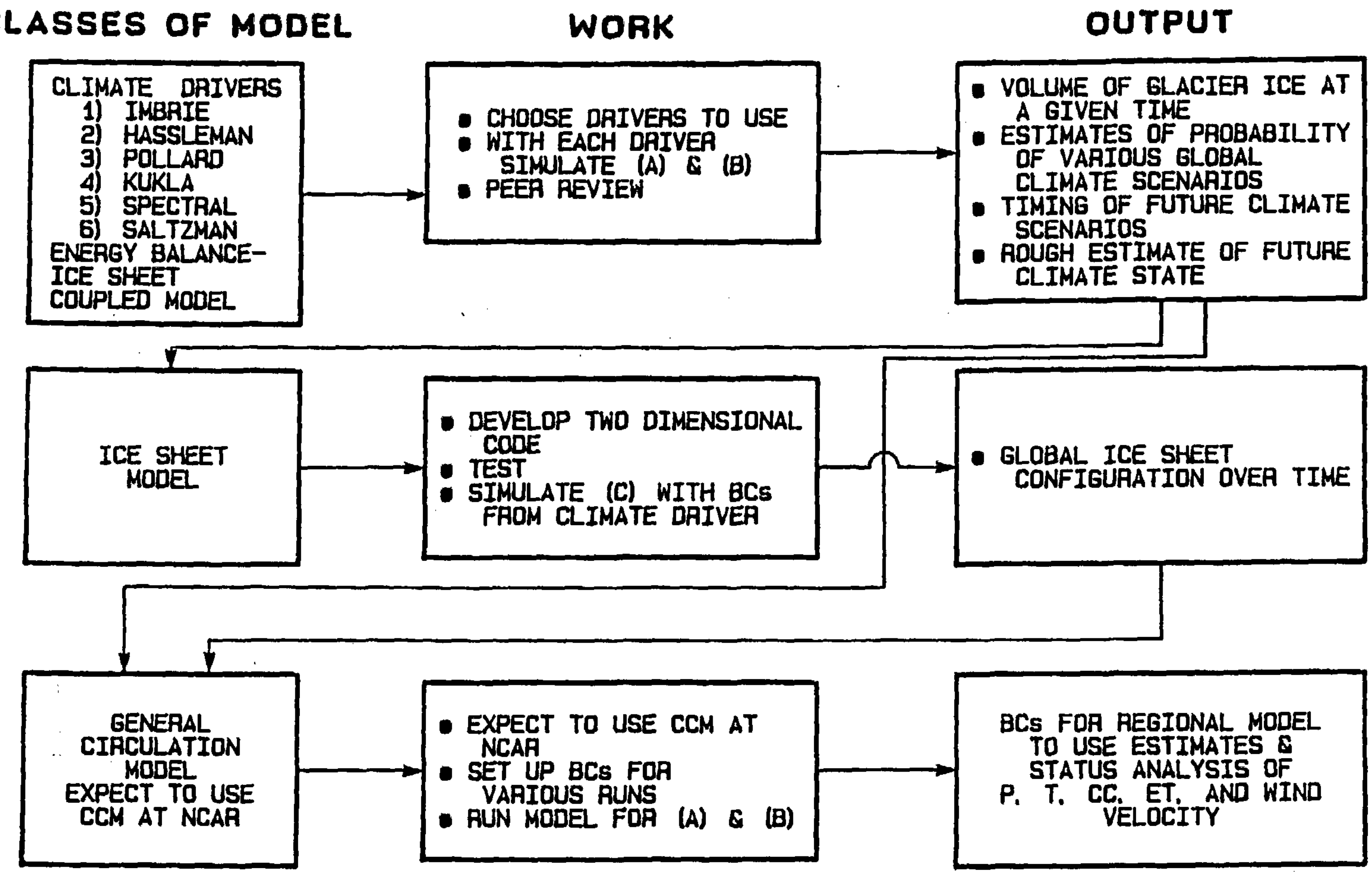
One goal of climate modeling is to demonstrate that these ice volume variations follow deductively from a simple set of mathematical statements or forcing functions. Computer codes have been developed to simulate climate change based upon these forcing functions. These climate drivers will provide (1) estimates of the probability of certain climate scenarios, (2) timing of climate scenarios of concern, and (3) rough estimates of future climate states.

The success of such a modeling effort rests upon the degree to which model output agrees with the paleoclimate record. A key output parameter from climate drivers is the volume of glacier ice present on the earth at a given time. Therefore, global ice volume will be analyzed for over the range of values believed to have occurred during the Quaternary (as discussed in Section 5.2). Validation of the climate driver simulations will be based upon oxygen isotope records (found in cores of oceanic sediments), which are considered to reflect the total volume of ice on the earth's surface at a given time.

Various climate drivers have been developed to simulate future climate states at intervals of up to 1,000 yr for the first 10,000 yr and for the four scenarios mentioned earlier. The process of selection and implementation of the drivers will be reviewed by the advisory panel chosen from specialists in the field of climate modeling (as discussed in the previous section). At a minimum, the following models will be considered: (1) the Imbrie and Imbrie (1980) global ice volume forecast based upon orbital parameters and calibrated with oxygen isotope data, (2) the Hasselmann (1976) "red noise" model of climate change which makes stochastic forecasts of global ice volume, (3) Pollard's (1983) model of ice volume linked to orbital parameters and glacio-isostatic affects, (4) the astronomical climate index model developed by Kukla et al. (1981), (5) a spectral model based upon the observed spectrum of the oxygen-isotope ratio in the Northeastern Pacific Ocean, and (6) the Saltzman (Saltzman and Sutera, 1984) physically motivated model of the integrated climate system.

The next step in the modeling activity (as shown in Figure 8.3.1.5-6) involves estimating configurations of each major ice sheet on the globe at regular intervals of time over the next 100,000 yr. Although orbital variations may induce glacial-interglacial cycles, one of the important factors helping to maintain ice ages is the extensive ice sheets which increase the albedo of the earth. Therefore, a two-dimensional ice sheet model will be developed in this activity and will be calibrated to output from the global climate drivers.

General circulation models (GCMs) are sensitive to the volume and distribution of glacial ice covering the earth as well as variations in the orbital parameters of the earth. These scenarios of interest will be determined by an expert panel after examination of the simulated evolution of boundary conditions as produced by the climate-driver models possibly augmented by an energy-balance model. The scenarios of interest may not be limited to extreme boundary conditions, but may include situations which, because of their temporal persistence or other characteristics, are potentially relevant to site performance. Therefore, output from the climate driver and ice sheet models will be used as boundary conditions for GCM runs at the time periods or for the scenarios of interest (as shown in Figure 8.3.1.5-6). Additional boundary conditions for runs of GCMs include the locations and elevations of continental areas, the locations and elevations



CCM - COMMUNITY CLIMATE MODEL
NCAR - NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
BC - BOUNDARY CONDITION
P - PRECIPITATION
T - TEMPERATURE
CC - CLOUD COVER
ET - EVAPOTRANSPIRATION

(A) SNAPSHOTS OF CLIMATE AT UP TO 1,000-yr INTERVALS FOR 10,000 yr
(B) SCENARIOS 1 - PRESENT (NATURAL VARIABILITY)
2 - GLACIAL PERIODS THAT MAY CREATE "PLUVIAL" CONDITIONS IN THE SOUTHERN GREAT BASIN
3 - SUPER GLACIAL-PLUVIAL
4 - SUPER INTERGLACIAL
5 - SUPER-LONG PERIOD OF CHANGED CLIMATE
(C) ICE SHEET CONFIGURATION AT 1,000 yr INTERVALS FOR 10,000 yr

Figure 8.3.1.5-6. Flow of information for global climate modeling activity.

of continental ice, the locations and temperature of sea ice, surface albedo, and sea-surface temperature.

Since uncertainties exist in specifying or computing factors such as CO_2 level or sea surface temperatures, the model simulations will include a sensitivity analysis of climate response to a plausible range of variables that may contribute to global climate change.

Present plans for the GCM modeling will use the CCM at the National Center for Atmospheric Research. This approach has been approved by the advisory panel mentioned earlier. A version of the CCM under development includes an oceanic circulation component and should result in documented, well-tested codes by FY 1989.

Initial model simulations are designed to determine the sensitivity of climate to uncertainties in the specified boundary conditions. These simulations will be done with fixed sea surface temperatures. Future simulations will be designed to incorporate the full seasonal cycle. Output data will include estimates of precipitation, temperature, cloud cover, evapotranspiration and wind velocity. Regional processors will be developed to manipulate the data that surrounds the Yucca Mountain site in coordination with the regional modeling activity. Input to the regional models will be in the form of boundary conditions.

Published model results (CLIMAP Project Members, 1981) for the last glacial maximum will provide a set of benchmarks in the early stages of the activity. Some examination of the validity of the model results can be obtained from the comparisons to the various time horizons represented in the geologic record.

Verification, validation, and benchmarking of all the computer codes and mathematical and numerical models will follow NRC guidelines for documentation of codes (NRC, 1983a). The basis of these efforts will be an examination of the ability of the coded procedures to reproduce accurately the modern circulation patterns and those reconstructed for the last glacial maximum and other time horizons (where data are available). All model results will be reviewed by the advisory panel at regular intervals during the characterization process.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.6.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Software development for global climate modeling	SMP-301	Determination of software classification	19 May 86

Method	Technical procedure Number	Title	Date
	SMP-302	Software development specification preparation and approval	19 May 86
	SMP-303	Final internal development review of computer code and documentation	19 May 86
	SMP-304	Computer code acceptance testing	19 May 86
	SMP-305	Computer code configuration control	19 May 86
	SMP-306	Computer code and documentation change control	19 May 86
	SMP-307	Computer code verification and/or validation	19 May 86
	SMP-308	Utility code documentation, control, testing and use	19 May 86
	SMP-309	Computer code application control	19 May 86
	SMP-310	Magnetic media protection and control	19 May 86
	SMP-311	Computer software transfer	19 May 86
	SMP-312	Control of acquired data bases	19 May 86

8.3.1.5.1.6.2 Activity: Regional climate modeling

Objectives

The objective of this activity is to establish the feasibility of using a regional scale numerical climate model for predicting future climatic conditions at Yucca Mountain. If this task is accomplished, the model will be calibrated against modern climatic data and validated with paleoclimatic data.

Parameters

The parameters for this activity are

1. Calibration of a regional-scale numerical climatic model (with historic data).

2. Validation of a regional-scale model (with paleoclimatic data).

Description

A feasibility study will be initiated to evaluate the applicability of numerical regional climate modeling in accomplishing the climate prediction requirements of the NNWSI Project within appropriate time and cost constraints. Regional numerical modeling is used to describe the meteorology of expected future climate scenarios resulting from the interpretation of the paleoclimate record. A numerical regional model is a mathematical description of the dynamics of the earth's atmospheric circulation, based upon the equations of fluid flow and specific boundary conditions. The model describes how the earth's atmosphere responds to imposed boundary conditions, with the output of the model being in the form of calculated values of meteorological parameters (precipitation, temperature, etc.) for discrete geographic areas--rectangles created by gridding the earth's surface parallel to latitude and longitude. Reducing grid size increases the spatial resolution of the model at the cost of increased computational load. The practicality of small grids will be studied.

The feasibility of a regional modeling approach would first be established by demonstrating that current climate conditions can be adequately simulated over the southern Great Basin. This validation exercise would emphasize amounts and seasonal patterning of precipitation and other surface climatological conditions. If it is successful in these simulations, the model would be tested against Quaternary paleoclimatic conditions for periods with adequate observational characterization of surface climate. If these efforts were also successful, the model would be deemed suitable for generating future climate scenarios for the proposed repository site at Yucca Mountain and would be so employed.

The development of a numerical atmospheric model will be pursued only if the proposed feasibility study indicates that the numerical modeling approach would be an effective and timely method of accomplishing the NNWSI Project climate prediction objectives. If the feasibility study does not produce encouraging results in terms of the resolution desired and computational efficiency regarding regional numerical modeling, as determined from criteria established by an expert panel, then the characterization of future regional climate and environments will be based essentially on the empirical modeling approach.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.6.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Projection of expected future climate scenarios	TBD[a]	TBD	TBD
Regional numerical modeling of future climate scenarios	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.1.6.3 Activity: Linked global-regional climate modeling

Objectives

The objectives of this activity are to

1. Formulate reasonable hypotheses for scenarios of future climate in the southern Great Basin and Yucca Mountain over the next 100,000 yr, with emphasis on the next 10,000 yr.

2. Model meteorological parameters of expected climate scenarios for the southern Great Basin.

3. Use the quantitative meteorologic descriptions resulting from the modeling of future climate scenarios to derive measurements of climate parameters to be used in hydrologic modeling of the Yucca Mountain area and in investigating the effects of climate on erosion at Yucca Mountain.

Parameters

The parameters for this activity are

1. Estimates of the nature, timing, and probability of occurrence of future climate scenarios.

2. Meteorologic parameters of expected future climate scenarios: average annual rainfall, seasonal distribution of rainfall, type and intensity of storms, average annual snowfall, distribution and duration of snow cover, rapidity of snowmelt, evapotranspiration, cloud cover, and temperature.

3. The values of meteorologic parameters over requisite time spans, to be used in the hydrologic modeling of Yucca Mountain and in erosion investigations.

Description

Following the testing period for the regional climate model, it will be decided if such a modeling approach is within the time and cost constraints of the NNWSI Project. In addition, the defensibility of the model on its own will be analyzed as well as its ability to link with the global climate model. If the regional numerical model receives approval from an expert panel, it will be linked with a GCM (Section 8.3.1.5.1.6.1) to simulate future climatic conditions at Yucca Mountain. The outputs of the global future climate modeling activity will be used as boundary conditions on regional climate model runs to simulate future climate conditions at Yucca Mountain.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.1.6.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Compilation of meteorological parameter values for input to hydrologic modeling	TBD[a]	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.1.6.4 Activity: Empirical climate modeling

Objectives

The objectives of this activity are to

1. Formulate reasonable hypotheses for scenarios of future climate in the southern Great Basin and Yucca Mountain over the next 100,000 yr, with emphasis on the next 10,000 yr.

2. Model meteorological parameters of expected climate scenarios for the southern Great Basin.

3. Use the quantitative meteorologic descriptions resulting from the modeling of future climate scenarios to derive measurements of climate parameters to be used in hydrologic modeling of the Yucca Mountain area and in investigating the effects of climate on erosion at Yucca Mountain.

Parameters

The parameters for this activity are

1. Estimates of the nature, timing, and probability of occurrence of future climate scenarios.

2. Meteorologic parameters of expected future climate scenarios over requisite time spans: average annual rainfall, seasonal distribution of rainfall, type and intensity of storms, average annual snowfall, distribution and duration of snow cover, rapidity of snowmelt, evapotranspiration, cloud cover, wind speed and direction, and temperature.

Description

The empirical approach to climate modeling will be the direct application of meteorological values estimated for paleoclimate episodes to the description of analogous scenarios expected to occur in the future. For a given scenario, values of precipitation, temperature, and other parameters would be estimated directly from the paleolacustrine, terrestrial paleoecologic, and paleoenvironmental evidence. A simplistic example would be the following: statistical examination of the paleoclimate record might show that there is a moderate-to-high probability of another period of higher-than-present precipitation and lower-than-present temperatures (a pluvial), spanning several thousand years, occurring at some time between 80,000 and 100,000 yr from the present. To characterize the meteorology of this expected episode, the values of meteorologic parameters for prior pluvial episodes are assembled from the physical evidence of the palecolimate record. The averages, seasonality, ranges, and areas of uncertainty for the parameters are synthesized in a form usable as input for hydrologic modeling. It should be noted that this approach of directly applying paleoclimate data to expected future scenarios is based directly on physical evidence, and on the assumption that climatic episodes within the next 100,000 yr in the southern Great Basin will resemble events in the Quaternary paleoclimate history of the area. The record of past climatic variations can thus provide a guide to the range of climatic conditions forseeable in the future, providing that the large-scale controls of climate remain similar to those that prevailed in the past. The increase of CO_2 concentrations in the atmosphere in the future (due to the burning of fossil fuels, etc.) makes it likely that the large-scale controls of climate in the future may differ from those experienced during the Quaternary. As a result, numerical approaches to the prediction of future climate may be required to supplement the empirical methods.

The time series of paleoclimate will then be statistically examined for possible periodic components in climatic variation, including an examination for the presence of astronomical forcing of atmospheric circulation (the influence of changes in the earth's orbital relations to the sun on global air mass circulation). The present state of our knowledge of Great Basin climate history, as evidenced by the highstands of paleolake systems, suggests periodic components in climatic episodes of higher-than-present effective moisture in the Great Basin. Should this be confirmed statistically, it will then be possible to apply this periodic forcing function to estimating the timing of possible future pluvial episodes over the next 100,000 yr. This exercise will be aided by the fact that the variations in orbital parameters (eccentricity, obliquity, and precession) governing astronomical forcing can be estimated over the next 10,000 to 100,000 yr, and thus changes in insolation in that period are predictable.

If a periodicity in the climate record can be established, a sequence of expected future climate scenarios can be formulated for the next 100,000 yr, possibly accompanied by estimates of probabilities of occurrence for different climatic scenarios over this period. Should a periodicity not be clearly established, it will become necessary to use an alternative approach to estimating the timing of future climate scenarios. Such an approach would likely be a statistical description of the probabilities of certain climate scenarios recurring over the next 100,000 yr.

Methods and technical procedures

The method and procedure for Activity 8.3.1.5.1.6.4 is given in the following table.

	Technical procedure		
Method	Number	Title	Date
Synthesis of a time series of paleoclimate history	TBD[a]	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.1.7 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

Characterization program, information need, issue or investigation	Subject
1.1.1	Site information needed for calculations (Section 8.3.5.13.1)
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3)
1.8	NRC siting criteria (Section 8.3.5.17)

Characterization program, information need, issue or investigation	Subject
1.9a	Higher level findings--postclosure (Section 8.3.5.18)
8.3.1.2.1	Regional hydrologic system
8.3.1.2.2	Site unsaturated zone hydrologic system
8.3.1.2.3	Site saturated zone hydrologic system
8.3.1.5.2	Climate effects on hydrology
8.3.1.6.2	Climate effects on erosion
8.3.1.12	Meteorology program

8.3.1.5.1.8 Schedule and milestones

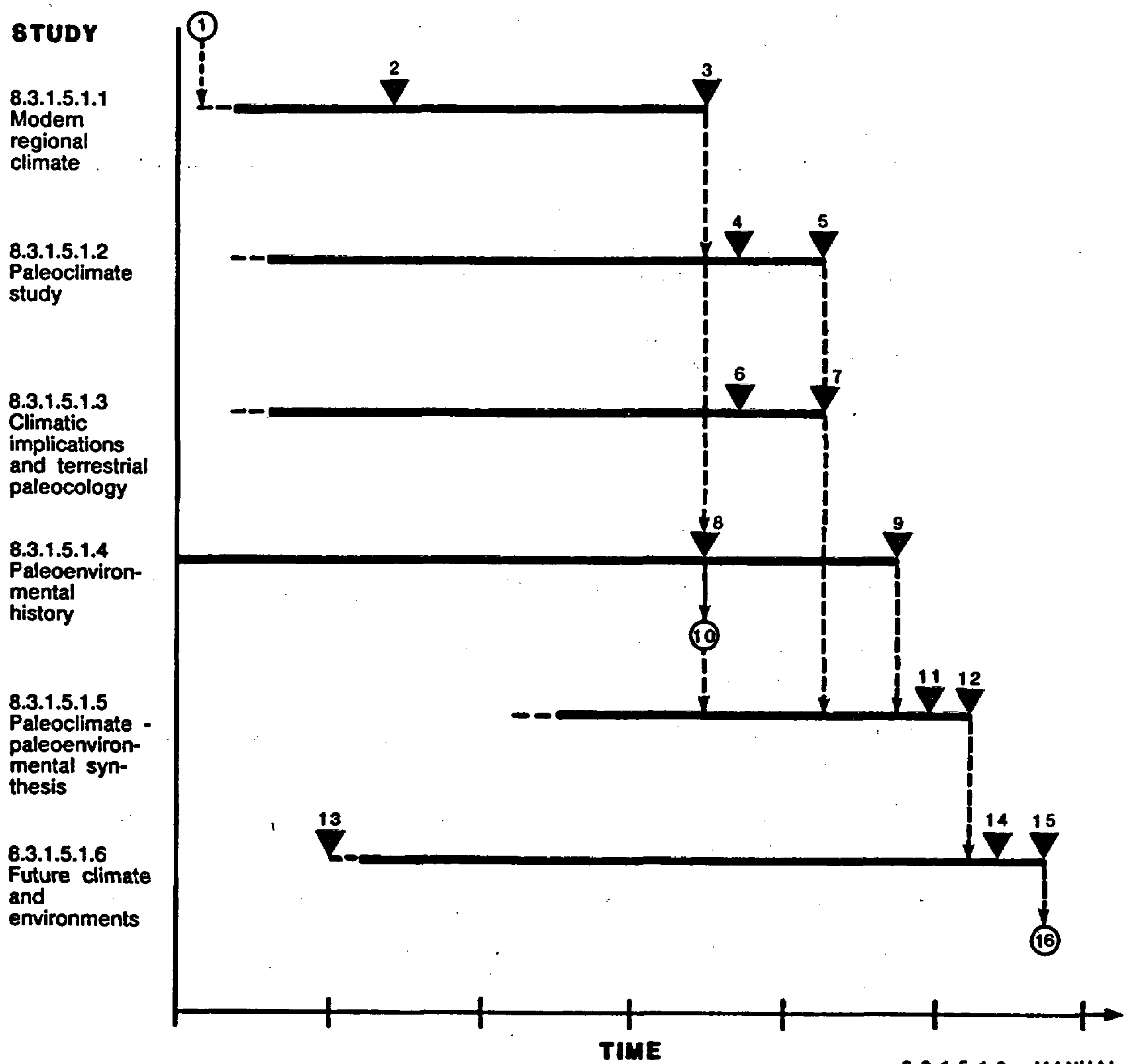
Investigation 8.3.1.5.1 contains six studies: 8.3.1.5.1.1 (characterization of modern regional climate), 8.3.1.5.1.2 (paleoclimate study: lake, playa, marsh deposits), 8.3.1.5.1.3 (climatic implications of terrestrial paleoecology), 8.3.1.5.1.4 (analysis of the paleoenvironmental history of the Yucca Mountain region), 8.3.1.5.1.5 (paleoclimate-paleoenvironmental synthesis), and 8.3.1.5.1.6 (characterization of the future regional climate and environments). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the study. Summary schedule information for this investigation can be found in Section 8.5.1.1.

One of the studies in this investigation is ongoing (8.3.1.5.1.4). Three of the studies (8.3.1.5.1.1, 8.3.1.5.1.2, and 8.3.1.5.1.3) are scheduled to begin during the first year of site characterization. The remaining two activities are scheduled to begin during the second (Study 8.3.1.5.1.6) and third (Study 8.3.1.5.1.5) years of site characterization.

The data collection, analysis, and modeling in this investigation will proceed in parallel with geohydrology, performance, and design activities and will interface with them in an iterative fashion. The characterization of future regional climate will provide input to Study 8.3.1.5.2.2 (characterization of future regional hydrology due to climatic change), as well as support the development of models of the unsaturated and saturated zones and the surface water system in the geohydrology program (Section 8.3.1.2). Future climatic changes that may alter the hydrologic regime will contribute to predictions of radionuclide transport in Issue 1.1 (total system performance evaluations of seal characteristics (Section 8.3.3.2), and evaluation of waste package characteristics (Section 8.3.4.2). This investigation also provides input to the geohydrology, erosion, surface characteristics, and preclosure hydrology programs (Sections 8.3.1.2, 8.3.1.6, 8.3.1.14, and 8.3.1.16, respectively).

The studies in this investigation are not seriously constrained by other program elements and can begin when the study plans are approved.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines represent interfaces. The data on input and output at the interfaces are shown by circles.



8.3.1.5.1.8 - MANUAL

The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Data received from meteorology program (Section 8.3.1.12) and geohydrology program (Section 8.3.1.2).
2	Milestone P725. Report available on synoptic climate of Yucca Mountain.
3	Milestone P101. Report available on characterization of the present regional climate and environment.
4	Reports available on paleontology, stratigraphy/sedimentology, geochemistry, and chronology of lake, playa, and marsh sediments near Yucca Mountain (Milestones Z265, Z266, Z267, and Z268).
5	Milestone Q039. Report available on lake, playa, and marsh sediments and their implications for paleoclimate at Yucca Mountain.
6	Milestone Z269. Report available on the evaluation of pack-rat middens in the Yucca Mountain region.
7	Milestone Q040. Report available on climatic implications of terrestrial paleoecology.
8	Milestone M698. Report available on the preliminary evaluation of paleoenvironment of Yucca Mountain.
	Milestone M892. Final 1:24,000 surface deposits map of the Yucca Mountain region available.
	Milestone P782. Final 1:12,000 scale map of site available.
9	Milestone Z272. Report on the synthesis of the paleoenvironmental history of the Yucca Mountain region.
10	Input to Study 8.3.1.17.4.6 (Quaternary faulting within the site area).
11	Milestone M395. Report available on Quaternary history of Yucca Mountain.
12	Milestone M366. Define Quaternary climate of Yucca Mountain.
13	Reports available on feasibility studies of regional climate modeling and global/regional modeling. (Milestones Z276 and Z277).

Point number	Description
14	Milestone Z278. Report available on feasibility of empirical climate modeling approach.
15	Milestone P104. Report available on future climate as predicted from models based on the nature and rates of change in climatic conditions.
16	Input available for Study 8.3.1.5.2.2 (characterization of the future regional hydrology due to climatic changes).

8.3.1.5.2 Investigation: Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
3.7.4	Paleohydrology (regional)
3.9.8	Paleohydrology (site)
5.2.1	Paleoclimatology
5.2.2	Future climatic variation
5.2.3	Site paleoclimatic investigations

Parameters

The following parameters will be measured, estimated, or calculated as a result of the site studies planned as part of this investigation:

1. Relationship between climate and infiltration.

2. Past and future surface water characteristics--locations, frequency, and hydraulic properties of past and future flood events.

3. Past and future unsaturated-zone hydrologic characteristics--hydrochemical characteristics as an indication of past hydrology and prediction of future ground-water flow conditions.

4. Past and future saturated-zone hydrologic characteristics--water table altitude, and recharge and discharge locations and rates.

Other site studies that provide information that support the determination of the previous parameters include the following:

SCP section	Study
8.3.1.2.1.2	Characterization of the regional surface water (present-day surface-water conditions)
8.3.1.2	Characterization of the regional ground-water flow system (present-day regional geohydrology)
8.3.1.2	Regional hydrologic system synthesis and modeling (present-day regional hydrology)
8.3.1.2	Characterization of unsaturated zone infiltration (present-day infiltration at the site)
8.3.1.2.2.3	Characterization of percolation in the unsaturated zone (present-day unsaturated-zone flux at the site)
8.3.1.2.2.8	Hydrochemical characterization of the unsaturated zone (present-day unsaturated-zone flux at the site
8.3.1.2.2.9	Unsaturated zone flow and transport modeling
8.3.1.2.2.10	Unsaturated zone system analysis and integration (present-day unsaturated zone geohydrology)
8.3.1.2.3.1	Characterization of the saturated zone ground-water flow system (present-day saturated zone geohydrology)
8.3.1.2.3.2	Characterization of the site saturated zone hydrochemistry
8.3.1.2.3.3	Saturated zone hydrologic system synthesis and modeling (present-day saturated zone geohydrology)
8.3.1.5.1.1	Characterization of the modern regional climate (present-day regional climatic conditions)
8.3.1.5.1.2	Regional paleolimnologic studies (past regional climatic conditions)
8.3.1.5.1.3	Regional terrestrial paleoecologic studies (past regional climatic conditions)
8.3.1.5.1.4	Analysis of paleoenvironmental history of the Yucca Mountain region (past environments at the site)
8.3.1.5.1.6	Characterization of the future regional climate and environments (future climatic conditions at the site)
8.3.1.16.1.1	Site flood and debris hazards studies (present-day flood potential at the site)

Purpose and objectives of the investigation

This investigation (8.3.1.5.2) provides information to help satisfy performance and design Issues 1.1, 1.8, 1.9a and b, and 1.10. Reconstructions from Investigation 8.3.1.5.1 along with past surface water, and unsaturated- and saturated-zone characterizations will lead to an understanding of the Quaternary regional hydrologic regime. This information along with models of future climate conditions and estimates of future meteorological conditions from Investigation 8.3.1.2.1, and models of the unsaturated and saturated zones from the geohydrology program (Section 8.3.1.2) will help determine the effects of climate change on geohydrology. This will require the development of a relationship between climate and infiltration and recharge.

Technical rationale for the investigation

Climatic, igneous, tectonic, and erosional processes may potentially change the geohydrologic setting at Yucca Mountain. The purpose of this investigation is to determine the hydrologic conditions during the Quaternary that have differed significantly from present conditions due to changes in the climatic processes. This information will be used to evaluate the likelihood of recurrence over the next 100,000 yr of episodic conditions that may affect the regional flow system. Of specific interest are (1) the maximum altitude of the water table during pluvial periods of the Pleistocene Epoch, (2) the effects of water-table rises on shortening of ground-water flow paths to discharge areas, and (3) the magnitude of increases in recharge during pluvial periods. With this information, questions such as the following can be addressed: "What is the possibility of the repository flooding due to a rising water table during a return of pluvial conditions?" and "How large an infiltration flux might move through the repository in the future?" These potential future hydrologic conditions resulting from changing climatic conditions will be predicted through the use of numerical model sensitivity analyses. These sensitivity analyses (which are discussed in detail in each appropriate activity) will involve assessing the sensitivity of flow in the unsaturated and saturated zones to variations in infiltration and recharge.

The relationship between climate and infiltration and recharge will be developed on the basis of studies conducted under this testing program. Once this relationship is developed, the results of the sensitivity analyses will be used to identify the climatic parameters needed for assessing future conditions in the unsaturated and saturated zones. This information can then be used by the future climate modeling study (Section 8.3.1.5.1.6) to simulate the necessary scenarios that describe the conditions and occurrence of significant periods of climatic variation. Subsequently, the hydrologic models will use these predicted climatic conditions to simulate future infiltration to the unsaturated zone and recharge to the saturated zone.

Recurring pluvio-glacial climate conditions could shorten the time for radionuclide transport from the repository to the accessible environment if it is shown that percolation flux is increased through the repository block. The velocity increase produced by increased infiltration will be predicted by site-scale modeling. Also of significance is the maximum water-table rise that might accompany a recurring pluvio-glacial climatic condition, travel time be shortened by reducing the thickness of unsaturated zone below the repository (Czarnecki, 1985).

The water-table altitude beneath the repository block reflects an interaction of many factors, including (1) the local recharge rate, (2) the lateral flux in the saturated zone resulting from recharge in upgradient areas, (3) vestiges from prior climatic regimes that persist because of storage effects, (4) distance to and altitude of regional discharge boundaries, and (5) especially, the distribution of conductivities and structures in the saturated zone. Computer models can functionally relate these conditions. A water-table change can be predicted due to a change of any one (or more) variable, if the model has been calibrated and checked against known conditions. Obtaining reliable predictions of water-table change will require knowledge of past changes of recharge distribution and discharge positions as well as sufficient detailed geometry and conductivities of units in the entire flow field. The studies of this investigation include (1) the interpretation of geomorphic and stratigraphic evidence of paleofloods; (2) the evaluation of analog recharge sites to estimate past, and, therefore, future, infiltration characteristics (ground-water recharge); (3) the search for hydrochemical evidence of waters that infiltrated in the past; and (4) the location of past points of ground-water discharge as evidenced by former springs, mineral vein fillings, and cave deposits recording higher water levels in the past. These studies have been formulated to provide the information required to predict the water-table fluctuations.

Paleoflooding will be investigated to improve the knowledge of severe surface runoffs during prehistoric times and to ascertain the relationships between those floods and paleoclimates. The investigation will examine alluvial deposits, debris-flow scars and deposits, severe erosion scars, and stone-stripe deposits to improve the understanding of the processes that formed them, and to determine whether these features have modern analogs that were formed or are forming under present climatic conditions. Results will provide a perspective on differences and similarities between past and present floods, and the relations to different climates. In addition, an improved understanding of the relation between paleoclimate and past floods will supplement predictions of future flooding based on rainfall-runoff modeling (Section 8.3.1.2.1.3).

The increased recharge that would occur under a return to pluvial conditions would depend upon a variety of interrelated factors. These factors include not only the amount of increase in average annual precipitation, but also the seasonal distribution and type of precipitation; the amount and rate of snowmelt; and changes in evapotranspiration, runoff characteristics, and soil and plant cover. Modern settings analogous to past climatic conditions at Yucca Mountain will be identified, instrumented, and studied to determine the infiltration versus precipitation relationships that relate to past and future climates. These modern settings, referred to as analog recharge sites, will be identified based on the rock-soil-vegetation cover, geology, topography, meteorological conditions, and hydrochemical properties of the precipitation, surface water, and soil moisture. Then, by evaluating the characteristics of each site, the conditions and rates of ground-water infiltration and recharge representative of past and future pluvial conditions will be estimated.

To gain a further understanding of the Quaternary ground-water conditions at Yucca Mountain, the discharge area of the ground-water basin will be studied for evidence of prior water-table elevation, discharge, and temperature. The potentiometric surface in the regional carbonate aquifer is gentle in slope due to the high transmissivity (Section 3.6). Provided that tectonic deformation can be ruled out, prior gradients obtained from paleospring elevations are related linearly to prior discharge. Slope extrapolation to the site and to recharge areas may provide estimates of prior potentiometric altitudes. A study of paleospring deposits and fossils contained in them will indicate altitudes of former discharge points and suggest paleodischarge rates. These studies are justified on the same basis as are efforts to interpret the fossil record and the paleohydrology of recharge areas. Both boundary conditions need to be defined for any one time modeled. Redundant and confirmatory data, such as the detailed study of zeolites for evidence of fossil saturation levels, will help substantiate the hydrologic model predictions.

Remote sensing and field survey methods will be used to locate structural features presently or formerly controlling regional flow and discharge areas. Biologic and fossil evidence will be assessed for past discharge rates and climatic implications. Carbonate deposits will be sampled in caves, where they formed at various levels reflecting different water-table elevations. Carbon and oxygen isotope ratios in such minerals reflect the age and climate of the waters that formed them; thus, cyclic history may be recorded for regional interpretation of the basin hydrology. Past discharges will also be estimated in discharge areas from measured conductivities and computed gradients.

On the basis of current knowledge of hydrogeologic properties, fluxes, hydraulic heads, and estimated recharge rates, past water-table altitudes will be calculated. To further reduce uncertainty in these results, additional information about past water tables will be sought. Hydrochemistry will be used to produce a second line of evidence for paleosaturation altitudes. Hydrochemical analyses have the potential of identifying waters of an age and oxygen-18/oxygen-16 ratio consistent with infiltration during a past pluvial period, thereby providing information on flow velocities and paths. In principle, a sufficiently refined model can then predict future fluctuations in the water table altitude if adequate boundary conditions are provided for the various climatic regimes.

8.3.1.5.2.1 Study: Characterization of the Quaternary regional hydrology

The objective of this study is to characterize the distribution of surface water, the unsaturated zone infiltration and percolation rates, and the ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain.

Activities planned for the study are (1) an evaluation of regional paleofloods, (2) an analysis of unsaturated zone hydrochemistry, (3) an evaluation of past regional discharge areas, (4) an analog recharge study, and (5) an assessment of calcite-silica vein deposits.

8.3.1.5.2.1.1 Activity: Regional paleoflood evaluation

Objectives

The objectives of this activity are to

1. Identify the locations and investigate the hydraulic characteristics of paleoflood events, and compare this evidence with the locations and characteristics of modern flooding and geomorphic processes. These findings and comparisons will improve knowledge of the relationships between climate and flooding.

2. Assess the character and severity of paleoflood and debris hazards to assess the potential of flood and debris hazards for the repository during the preclosure period.

Parameters

The parameters for this activity are

1. Magnitudes, frequencies, areal extent, and hydraulic characteristics of paleoflood flows.

2. Quantities and characteristics of debris movement during paleofloods.

Description

Two trenches have been dug in the north fork of Coyote Wash; one cross-channel trench and one T-shaped trench. These trenches have exposed deposits recording a complex sequence of debris-flow and flood-flow events that occurred during the late Quaternary Period. The trenches have been mapped and analyzed to determine the interpretable characteristics of the paleofloods. Additional trenching, mapping, and stratigraphic analyses of alluvial deposits in neighboring stream channels north and south of Coyote Wash and in the NTS vicinity will be performed to improve understanding of past flooding in the Yucca Mountain region.

Erosion scars, stone stripes, and other debris deposits will be evaluated with regard to the geomorphic processes responsible for their formation (Investigation 8.3.1.6.1). Areas and drainages of concern will be reconnoitered for erosion scars and hillslope deposits. The features that may be the products of past extreme surface-water runoffs will be examined and recorded. Attempts will be made to develop criteria for dating the features to increase the value of these data with regard to ages and frequencies of debris movement. The widespread presence of stone stripes on hillslopes at and around Yucca Mountain may be evidence of paleofloods and related landslope failures. The presence of these large deposits of cobbles and boulders over substantial areas of steeply sloping terrain poses the concern that they could become entrained in future landslope failures and become incorporated within fluvially transported debris. Improved knowledge of the age and genesis of these deposits should confirm or allay concerns regarding their potential for contributing to future debris hazards. Results will be used in analyses of flooding and debris hazards (Investigation 8.3.1.16.1).

Attempts will be made to date alluvial surfaces and unconsolidated stream-channel deposits. Much of the unconsolidated debris underlying alluvial surfaces and comprising stream-channel deposits was deposited by surface runoff. A determination of the ages of these alluvial surfaces will provide valuable knowledge of past floods. Specifically, it will date the recency of severe flooding at the sites of the deposits, and collectively, these ages may suggest whether severe runoff events of the Yucca Mountain area might be episodic or relatively continuous during recent geologic time. Relative ages of the surfaces will be determined from geomorphic mapping, and absolute ages might be determined using the newly developed technique of rock-varnish dating. A field and photo reconnaissance of areas of concern should help dictate the techniques to be applied in dating the surfaces.

The evidence of paleoflooding will be compared with the magnitudes and frequencies of historical floods. The streamflow and runoff information collected as part of the activities called "surface-water runoff monitoring" and "transport of debris by severe runoff" will be compared to assess the frequencies and magnitudes of present-day flooding in and around the NTS. Available evidence and knowledge of paleofloods will be compared with knowledge developed on current flooding to determine whether present-day flooding is more or less frequent and larger or smaller than past flooding. Modern geomorphic channel and slope processes and their resultant sediment deposits will be compared with fluvial and slope deposits of the past to determine similarities and dissimilarities between modern and paleo processes.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.2.1.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Trench, map, and analyze stream-channels deposits	TBD[a]	TBD	TBD
Stone stripes, erosion scars, and other debris deposits evaluation	TBD	TBD	TBD
Dating of alluvial surfaces and unconsolidated stream-channel deposits	TBD	TBD	TBD

Method	Technical procedure Number	Title	Date
Comparison of evidence of paleofloods with magnitude and frequency of historical floods	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.2.1.2 Activity: Quaternary unsaturated zone hydrochemical analysis

Objectives

The objectives of this activity are to

1. Determine the past and infiltration percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone.

2. Understand the past unsaturated-zone hydrologic system by modeling vadose-water hydochemistry to help predict the future hydrologic system.

Parameters

The parameters for this activity are the isotopic composition and chemistry of unsaturated zone water; travel times (chlorine-36, carbon-14, tritium), flow paths (oxygen-18/oxygen-16 ratios, deuterium/hydrogen ratios), and sources of past recharge in the unsaturated zone.

Description

The unsaturated-zone hydrology of Yucca Mountain during the Quaternary will be characterized in terms of residence times, flow paths, and sources of infiltration from the chemical and isotopic characteristics of present-day vadose water. Isotopic data of tritium, carbon-14, and chlorine-36 (Activity 8.3.1.2.2.4.2) will be used to determine infiltration and percolation rates, residence times or travel times of the water in the unsaturated zone, and serve as a check on flow paths, velocities, and travel times computed from hydraulic parameters. By analyzing the isotopic composition of water, it will be possible to estimate the climatic conditions of past recharge and flow paths and support the findings of the paleoclimate studies (Investigation 8.3.1.5.1).

The results of other investigations associated with paleohydrology and paleoclimate, from which past vadose-water movement may be inferred, will be used in conjunction with the hydraulic parameters and hydrochemical and isotopic data of surface and subsurface waters for the interpretations of the Yucca Mountain recharge history.

All pore-water samples, if enough water can be obtained, will be analyzed for (1) carbon-14, tritium, and chlorine-36 isotopic activity; (2) oxygen, hydrogen, and carbon isotope ratios; and (3) water chemistry. If perched water is encountered in boreholes or the exploratory shaft facility, water samples will also be collected for chemical and isotopic analysis. Carbon-14 and chlorine-36 activities will be determined by tandem-accelerator mass spectrometry. Tritium activity will be analyzed using low-level gas counters or liquid scintillation counters. Stable isotope ratios will be determined using isotope-ratio mass spectrometry. Water chemistry, cations and anions, will be analyzed using inductively coupled plasma and ion chromatography. These tests will be performed in conjunction with other hydrochemical tests conducted in Activity 8.3.1.2.2.4.2.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.1.2 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Collect and transport core samples	HP-12,R2	Method for collection, processing, and handling of drill cuttings from unsaturated zone boreholes at the well site, NTS	30 Mar 87
	HP-131	Method for handling and transporting samples of unsaturated core for hydrochemical analysis	TBD[a]
Extract water from core samples	HP-125	Method of extraction of pore water by triaxial compression	TBD
	HP-110	Extraction of pore waters by centrifuge methods	TBD
	HP-126	Extraction of pore waters by vacuum distillation	TBD

Method	Technical procedure Number	Title	Date
Analyze water samples	TBD	Procedure for determining the presence of tracers in pore water samples	TBD
	TBD	Data archiving, shipping and handling procedure	TBD
	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11, R0	Method for determination of radioactive substances in water	18 June 82
Analyze water samples (continued)	HP-127	Carbon-14 dating by tandem accelerator mass spectrometer	TBD
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Method for analyzing water sample for chlorine-36	TBD

[a]TBD = to be determined.

8.3.1.5.2.1.3 Activity: Evaluation of past discharge areas

Objectives

The objectives of this activity are to

1. Determine the location, type, and extent of hydrogeologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley.

2. Understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert-River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas.

3. Determine the location and hydrogeologic characteristics of paleo-spring deposits in the discharge area.

4. Determine the location and amount of discharge by evapotranspiration that has occurred at past discharge sites.

5. Understand the past and present discharge areas of the regional hydrologic system in order to predict the future saturated zone hydrologic system at Yucca Mountain.

6. Determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions.

Parameters

The parameters for this activity are

1. Past rates of evapotranspiration
2. Hydrogeologic units (location, type, and extent) in discharge areas.
3. Location of past discharge areas.
4. Past discharge of springs and seeps.
5. Past potentiometric head.

Description

Remote sensing techniques will be used to identify lineaments, fracture zones, types of vegetative cover and types of surficial units so that their hydrologic implications can be determined. The types of remote sensing techniques being considered for use include (1) Landsat multispectral scanner (MSS) and thematic mapping (TM) spectral bands; (2) high-and low-altitude aerial photography (black and white, color, and color infrared); (3) low-altitude predawn thermal data taken before, during, and after storm events; and (4) side-looking airborne radar. Remote sensing will be done in conjunction with Investigation 8.3.1.8.2. A literature search will be conducted to gather information about previous studies using these remote sensing techniques, and appropriate data bases will be collected from national agencies and private contractors. If necessary, new surveys will be run to supplement the existing information.

Linear features such as lineaments and fracture zones, will be mapped to identify areas of interaquifer connection. Existing geologic, geophysical, geochemical, hydrologic, and seismic activity data will be used to supplement the remote sensing data. Evidence of paleotectonic activity such as a facies change, and thickening or thinning of sedimentary units, will be identified from geologic data. Evidence of crystalline-basement discontinuities (structural or lithologic) will be identified by analyzing the geophysical data. Hydrologic and geochemical data will be compared with the lineament map to determine where linear structural or stratigraphic features appear to affect ground-water flow.

The characteristics of the vegetative cover and surficial units will also be identified using remote sensing techniques and categorized into units of equal infiltration-discharge capacity. Reflective and thermal-spectral characteristics will be used to identify the types, spatial distribution, and density of the vegetation and surficial units. The soil moisture content will also be evaluated using reflective and thermal scanner data. Field inspections will be made to verify the remote sensing data. The correlation between the hydrologic and spectral properties of the surficial materials will be evaluated.

Past evapotranspiration (ET) rates will be estimated by calculations using modern ET rates determined in the study area (Study 8.3.1.2.1.2). Present ET rates are a function of climate and near-surface hydrologic conditions, such as soil type, vegetative cover, and depth to water. Calculation of past ET rates will require considerable input from paleoclimate studies (Investigation 8.3.1.5.1).

The infiltration-discharge characteristics of the surficial units and the areas of interaquifer connections will be incorporated into the three-dimensional hydrologic flow model of the regional ground-water-flow system (Activity 8.3.1.5.2.2.3).

Where possible, discharge from springs and seeps will be measured. Water-level measurements will be made in existing wells, caverns, and springs in addition to those collected under Investigations 8.3.1.2.1 and 8.3.1.2.3. Approximately five sites will be selected and recorders installed to provide a record of discharge.

Carbonate caverns located in the ground-water discharge areas south of Yucca Mountain provide a convenient window to the regional carbonate aquifer. The caverns will be mapped, sampled, and analyzed. Previous studies of deposits from these caverns suggest a possible 300,000-yr record of carbon and oxygen isotope variation (Winograd et al., 1985) that may provide information about the Quaternary geohydrologic and paleoclimatologic conditions at these sites and at Yucca Mountain. Deposits on the cavern walls provide a record of water-level changes in the regional carbonate aquifer dating back through the Quaternary. Biologic evidence from the cavern deposits also provides an association with ground-water chemistry.

Where possible, several available caverns will be entered, mapped, and sampled. Approximately 50 samples of the carbonate layers that are exposed on the cavern walls will be collected. The water in these caverns will also be sampled.

The samples will be analyzed to determine mineralogic and biologic composition and age. Information such as ostracode and diatom biology will be used to provide data about mode and environment of occurrence, including water chemistry. Up to 150 thin-sections of carbonate samples will be analyzed to determine mineralogic variations that provide evidence of varying ground-water conditions. Scanning electron microscope (SEM) and x-ray techniques will also be used on up to 100 of the thin-sections to determine the microscopic structure and composition of the banded carbonate units. Chemical, physical, and isotopic analyses will be run on up to 50 samples to determine the age of the water in the aquifer.

Shallow test holes will be rotary drilled or hand augered in the ground-water discharge area south of Yucca Mountain to obtain samples of the subsurface materials. Up to 50 rock-mineral and water samples will be analyzed to determine radiometric dates. The dating method used will depend on the sample type and amount of sample available. Thin sections will be made from the collected samples and analyzed to determine the mineralogic makeup of the materials. Samples will also be analyzed using x-ray, SEM, particle induced x-ray emission (PIXE), inductively coupled plasma (spectrometer) (ICP), and chemical analyses to provide additional mineralogic information that will be used to support the chemical, geologic, and hydrologic studies. The drill cuttings and core will be evaluated for biological indicators, such as ostracodes, diatoms, and opal phytoliths, using standard methods such as screening and washing of samples and microscope analysis of residue. Samples will be analyzed to determine the species and the environmental conditions under which the biologic indicator lived.

Studies of ostracode ecology along with studies of ostracode-valve chemistry will be conducted at selected sites to provide detailed information about the thermal and chemical properties of both discharging ground-water and also of the pools, ponds, and marshes supported by that water. This modern ecologic study conducted in conjunction with Study 8.3.1.5.1.2 will use about 30 ground-water discharge environments surrounding Yucca Mountain. The selection of sites will be based upon acquiring water upwelling from the regional aquifers, water from or near recharge sites in the mountains, and water derived from perched ground water in the valleys. Site selection will emphasize thermal and chemical diversity of modern discharging ground water as well as the aquatic environments supported by the discharging ground water. The selected sites will be sampled on at least a quarterly basis and a few key sites may be sampled more frequently. Sampling at each site will include multiple samples of each local subenvironment such as spring vents, spring pools, and marshes, as well as the ground water itself at some sites. The expected sample set will be approximately 400 samples. The study and calibration of the magnesium-calcium and strontium-calcium ratios in biogenic carbonate will be based on living material collected from a limited number of sites as well as on laboratory cultures of material from those sites.

The data derived from the previous collections will be organized in two ways: (1) a record of all environmental parameters (temperature, hydrochemical) associated with a species living at the time of collection and (2) the absolute and relative abundances of all adult ostracodes found in one or more quantitative sediment samples taken from each environment. Both sets of information will be evaluated statistically as well as qualitatively and will form the baseline information needed to properly interpret any taxa found in the fossil record. The ostracode-valve chemistry data will be used to establish magnesium/calcium and strontium/calcium partitioning coefficients for common species to determine the potential temperature and salinity resolution of this method. Ecological and chemical data from the ostracodes will be correlated with the modern ground-water hydrology to establish process relationships between all ostracode environmental data and known ground-water hydrology, thereby providing the basis for evaluating the nature of past discharge areas.

Results of this activity are expected to provide estimates of the past ground-water levels in the vicinity of Yucca Mountain during the Quaternary to be used in conjunction with past ground-water level data derived from evaluations at other regional discharge areas.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.5.2.1.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Remote sensing analysis	TBD[a]	Remote sensing for lineaments, fracture zones, vegetative cover, and surficial units	TBD
Field verification of remote sensing	GP-01, RO	Geologic mapping	1 Mar 83
	TBD	Geohydrologic mapping	TBD
Spring/seep discharge measurement	HP-34, RO	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	15 May 85
	TBD	Continuous recording of spring discharge	TBD
Petrographic and biological analysis	TBD	TBD	TBD
Radiometric dating	TBD	TBD	TBD
X-ray, SEM, PIXE, ICP and chemical analysis	TBD	TBD	TBD
Field mapping and sampling	TBD	Underwater procedures	TBD
Petrographic, SEM, and X-ray analysis of carbonate samples	TBD	TBD	TBD
Water sampling and chemical analysis	HP-08, RO	Methods for determination of inorganic substances in water	6 Aug 82

Method	Technical procedure Number	Title	Date
Water sampling and chemical analysis (continued)	HP-11, R0	Methods for determination of radioactive substance in water	18 June 82
	HP-13, R0	Collection and field analysis of unsaturated zone groundwater samples	29 Aug 83
	HP-23, R0	Collection and field analysis of saturated zone groundwater samples	4 Nov 83
Drilling, coring and hand augering of wells and test holes	HP-37, R0	Preliminary procedure for drilling and coring of wet- and dry-lake sediments	14 Aug 84
	HP-83, R0 (in preparation)	Preliminary procedure for drilling and casing observation holes in sand deposits	TBD
Very high frequency (VHF) ground conductivity measurements	TBD	Use of VHF ground-conductivity measurements for mapping of water tables	TBD
Sample collection and measurements	HP-54, R0 (in preparation)	Water-flow measurements using weirs, flumes, and barrels	TBD
	HP-91, R0 (in preparation)	Collection and field analysis of surface-water samples	TBD
	TBD	Procedure for conducting well inventory	TBD
Water-level measurements	HP-01, R0	Methods for determining water levels	11 Jan 82

Method	Technical procedure Number	Title	Date
Water-level measurements (continued)	HP-25, R0 (R1 in review)	Methods for measuring water levels using the Dodge Logging Van (I-127410)	20 July 84
	GP-02	Subsurface investigation	1 Mar 83
	HP-26, R0	Method for calibrating water-level measurement equipment using the reference steel tape	14 Aug 84
	HP-39, R0 (in preparation)	Methods for determining water levels using the trailer-mounted hoist (I-134719)	TBD
	HP-71, R0 (in preparation)	Methods for monitoring water-level changes using a Campbell Scientific 21X micrologger	TBD
	HP-75, R0 (in preparation)	Method for measuring water levels in wells using reeled (2,600-ft and and 2,800-ft) steel tapes	TBD
	HP-99, R0 (in preparation)	Instructions for operation of a well sounder (M-scope) for measuring water levels	TBD
Data collection	HP-37, R0	Preliminary procedure for drilling and coring wet-and dry-lake sediments	14 Aug 84
	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83

Method	Technical procedure Number	Title	Date
Data collection (continued)	HP-76, R0	Diatom enumeration studies	8 Apr 85
	HP-78, R0	Ostracode sample preparation and data acquisition procedures	8 Apr 85
Analysis of samples	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Radiometric dating of samples using carbon, uranium, and other isotopes	TBD
	TBD	Mineralogic, chemical, and isotopic analysis of geologic samples	TBD

[a]TBD = to be determined.

8.3.1.5.2.1.4 Activity: Analog recharge studies

Objectives

The objective of this activity is to estimate the conditions and rates of ground-water recharge (infiltration) during the Quaternary in the vicinity of Yucca Mountain.

Parameters

The parameters for this activity are

1. Recharge rates of analog sites.
2. Infiltration rates of analog sites.
3. Effective moisture of analog sites.
4. Relationships between climate and infiltration and recharge.

Description

Four or five localities will be evaluated to determine if they are suitable as late Pleistocene analog recharge sites. This evaluation will consist of characterizing the rock types, vegetation types and coverage, precipitation amounts, and topography. Sites will be selected that include a range of climatic conditions postulated to have existed on Yucca Mountain during the past pluvial climatic regimes of the late Pleistocene; data will be collected and used to determine paleorecharge rates.

At each selected site, the infiltration rate will be evaluated. Water samples will be collected from the vadose-water zone to determine the local infiltration quantity and chemistry. To estimate infiltration rates from the samples, hydrochemical technique that uses the mobile chloride ion as a tracer through the hydrologic cycle will be used (Claassen et al., 1986). The plant community and its relationship to recharge and soil moisture will be studied to estimate an infiltration rate for the whole basin. Remote sensing techniques will be used to determine type, spatial distribution, and density of vegetation. Soil temperatures also will be collected on a continuous basis. Evaluation of soil characteristics to determine their hydrologic properties and effect on consumptive water use will be evaluated if needed.

The temporal and spatial variability of chloride deposition will be calculated or measured at each of the selected sites. To accomplish this task, samples of precipitation, surface water, and moisture content of soils from the vadose water zone will be collected and analyzed. The integrated precipitation samples will be collected four times per year using a bulk sampler. Surface-water samples will also be collected from creeks and springs. Soil-moisture samples will be analyzed for ionic concentrations and for hydrogen and oxygen isotope ratios. A computer code will be developed to calculate the chloride chemistry in the recharge water.

Stream gaging measurements may be made at each of the selected sites and continuous-stage recording instruments installed where appropriate when necessary. Crest-stage gages will be used to back up the peak runoff measurements made by the continuous recorders. These stream measurements will be used to aid in the development of a local basin water budget.

Field investigations will be conducted to locate and collect contemporary pack rat middens from each selected site. The contemporary plant communities and pack rat collecting habits also will be investigated in the field and by field experiments in conjunction with Activity 8.3.1.5.1.3.1 (analysis of pack rat middens). Plant macrofossil assemblages will be collected in the field and sent to the laboratory for identification. These modern biological indicators will be interpreted and compared with similar macrofossil data that were collected in the vicinity of Yucca Mountain.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.1.4 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Evaluation of potential study area	TBD[a]	Evaluation of potential study area	TBD
Meteorological measurements	TBD	Meteorological measurement	TBD
Water sampling and processing	HP-91, R0 (in preparation)	Collection and field analysis of surface-water samples	TBD
	HP-16, R1	Collection and preservation of atmospheric precipitation samples for isotope analysis	14 Aug 84
	TBD	Vadose sampling techniques	TBD
Surface water discharge measurement	TBD	Water-level measurement using a 21X datalogger and ten turn pot	TBD
	HP-54, R0 (in preparation)	Water-flow measurements using weirs, flumes, and barrels	TBD
	TBD	Intermittent surface water discharge measurement	TBD
Experimental leaching of tuffaceous rocks	TBD	Experimental leaching of of tuffaceous rocks	TBD
Evaluation of contemporary pack rat middens	TBD	Evaluation of contemporary pack rat middens	TBD
Hydrologic budget modeling	TBD	Hydrologic budget modeling	TBD
		Mass balance modeling	TBD
Analysis of samples	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82

Method	Technical procedure Number	Title	Date
Analysis of samples (continued)	TBD	Procedure for analysis of constituent stable isotopes of water	TBD
	TBD	Radiometric dating of samples using carbon, uranium, and other isotopes	TBD
	TBD	Mineralogic, chemical, and isotopic analysis of geologic samples	TBD
Soil properties and vegetative cover analysis	TBD	Soil hydrologic properties	TBD
Infiltration sampling and analysis	TBD	Vadose sampling techniques	TBD
	TBD	Chloride calculations	TBD

[a]TBD = to be determined.

8.3.1.5.2.1.5 Activity: Studies of calcite and opaline silica vein deposits

Objectives

The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Parameters

A list of possible parameters includes

1. Mineralogy--including minerals present, degree of crystallinity, and chemical composition.

2. Petrology--including textures and mineral paragenesis.

3. Morphology--including large scale structure and vertical and areal extent.

4. Paleontology--including species present and absolute and relative abundances.

5. Chemistry--including major, minor, and trace element contents of bulk samples and mineral separates.

6. Hydrology--including modeling of possible flow paths.

7. Geochronology--including uranium-series, uranium-trend, potassium-argon dating method, and fission-track ages of fracture-filling and fracture-hosting materials.

8. Isotopic compositions of hydrogen, carbon, oxygen, strontium, and lead.

Description

Cryptocrystalline calcite, with and without opaline silica, fills many faults and fractures in the vicinity of Yucca Mountain. These fillings may have originated by one or more mechanisms including pedogenic, perched-water spring, deep-seated spring, hydrothermal spring, or hydrotectonic processes similar to those described by Kopf (1982). Each possible origin may have significant implications for the paleohydrology at repository depth, and thus, knowledge of the origin is important for predicting anticipated and unanticipated events that may act on the repository in the future.

Plans for this activity are flexible because results obtained by many different methods will need to be integrated. Additionally, results from one method may either obviate or necessitate tests by other methods. Finally, before initiating the investigations, a detailed plan will be subjected to critical review by an external peer panel and will be modified according to suggestions of the review committee.

The general approach will be to gather data through a multidiscipline approach that will include field investigations, mineralogy, geochemistry, fluid-inclusion studies, geochronology, tracer-isotope, stable-isotope studies, paleontology, and hydrology. Materials that will be studied include not only fault and fracture fillings found in trenches, natural exposures, and drill cores, but also possible analog deposits such as cold spring, hydrothermal spring, and pedogenic deposits. Some of the materials collected by this broad approach are expected to have applications to other activities. For example, some data and raw sample material will likely be applicable to seismotectonic activities, and thus close cooperation with these aspects of the program will be necessary.

Field investigations of the deposits will be accomplished through a combination of trenching and drilling. Veins exposed in trench walls will be mapped in detail. Samples will be collected such that any changes in character as a function of lateral extent or vertical extent will be represented. If trenching does not expose the maximum depth of at least one vein deposit, a series of shallow vertical holes may be drilled so as to intersect the fracture containing the vein deposit at successively greater depths. If a base for the deposit is not found by a depth of 20 m, an angle hole may be drilled to an approximate depth of 80 m to attempt to ascertain the depth limit of the deposit.

Standard mapping techniques will also be used to determine the location and areal distribution of calcite and opaline silica deposits in the vicinity of Yucca Mountain. This datum will constrain possible origins for the deposits and will be a critical point for modeling of the paleo and possible future hydrologic flow systems. If field mapping locates an unfaulted calcite and opaline silica deposit at a bedrock-colluvium contact, that deposit will be thoroughly investigated as a possible analog to the fracture filling exposed in Trench 14, a trench located near the proposed surface facility site.

Fracture-filling materials, wallrock of the fractures, and samples of possible analog materials will be subjected to mineralogic study by such techniques as petrographic microscopy, x-ray diffraction, scanning electron microscopy, and standard clay-mineral analysis. Precise knowledge of mineral assemblages, degree of crystallinity of diagnostic phases, and mineral paragenesis of the fracture-filling materials may provide constraints on the origin of the deposits. In addition, alteration and reaction textures (or lack thereof) in the wallrock of the fractures may further constrain theories of origin.

Geochemical investigations will be used in support of and in conjunction with mineralogic studies. Major, minor, and trace-element compositions of whole-rock samples and of samples from specific phases from fracture filling and analog materials may prove to be diagnostic for certain possible modes of origin. The final choice of analytical methods will depend on sample sizes available, necessary precision, and detection limits. Anticipated methods include x-ray fluorescence, instrumental neutron activation analysis, and electron microprobe analysis. If any of the geochemical data reveal information of possible economic interest, samples will be referred to those investigating this aspect of the site (Section 8.3.1.9, human interference program).

Fluid inclusions (trapped samples of the liquids from which crystals grew) are common in carbonate and silicate minerals that crystallized in a variety of environments. Such inclusions, if present, will be analyzed in the fracture-filling materials as well as in samples from possible analogs. If fluid inclusions are of more than one phase, they will be heated to the homogenization temperature that represents a minimum estimate of the temperature of deposition.

Ages of fracture-filling materials will be determined by a number of different methods. These ages will be important in the understanding of sequential changes in the paleohydrology and in the determination of chronology for paleotectonics. The data will then be used to predict future hydrology and tectonics. Uraniferous calcite and opaline silica that behaved as closed systems can best be dated by uranium-series techniques. Uranium-series dating techniques on calcite and opaline silica may further constrain the age of these deposits if the uranium in these minerals behaves as a closed system. If suitable samples of volcanic ash can be obtained from within the fracture zones, potassium-argon dating will be attempted. Fission-track dating of apatite crystals separated from the wallrocks of the fractures will be attempted to see if temperatures were high enough to reset or lower apparent ages of the volcanic rocks.

The isotopic compositions of strontium and lead in the calcite-silica deposits and in samples from possible analog materials will be determined to see if these data can provide constraints on the origin of the calcite and opaline silica deposits. These isotopic compositions should be dependent on the isotopic compositions of the rocks through which the depositing fluid flowed and thus if the fluids passed through isotopically distinct units like those known to exist below Yucca Mountain, the data may identify paleohydrologic flow paths.

The isotopic compositions of oxygen, carbon, and hydrogen in the fracture-filling materials depend on temperature of deposition and isotopic compositions in the depositing fluid. If fluid inclusions can be found and analyzed, a unique temperature of deposition can be determined. Alternatively, the isotopic compositions of phases that crystallize in equilibrium with one another can be used to estimate the composition of the depositing fluid and the temperature of deposition. If the fact that equilibrium existed cannot be established, comparison of the data with data from possible analogs will at least constrain possible modes of origin.

Virtually all surface and many subsurface waters contain aquatic organisms and some of these become preserved as fossils in chemically precipitated deposits. The organisms present in a given body of water are determined by a large number of factors including temperature and chemical composition of the water. If organisms such as ostracodes are preserved within the fracture-filling material, their species and the trace-element composition of their calcareous remains can be compared with hydrologic and biologic data for present-day analogs to tightly constrain possible modes of origin.

The final phase of this activity will be to test possible modes of origin for consistency with hydrologic flow models (Section 8.3.1.2.1).

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.1.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Field work	UTP-01, R0	Hydrologic investigations	TBD[a]
	UTP-03, R0	Geologic investigations	TBD
	UTP-05, R0	Geochronologic investigations	TBD

Method	Technical procedure Number	Title	Date
	UTP-10, R0	Fenix & Scisson drill site unit task procedure	TBD
	GP-01, R0	Geologic mapping	1 Mar 83
	GP-05, R0	Geologic support activities	1 Mar 83
	GP-07, R0	Geologic trenching studies	14 Aug 84
	MDP-01, R0	Identification, handling, storage, and disposition of drillhole core and samples	
Isotope geology	GCP-02, R1	Labeling, identification, and control of samples for geochemistry and isotope geology	30 Apr 81
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81
	GCP-06, R0	Potassium-argon dating	15 June 81
	GCP-07, R0	Geochemical mineral separations	15 June 81
	GCP-08, R0	Fission-track dating	15 June 81
	GCP-09, R0	Spike calibrations	15 June 81
	TBD	Chemical separations of rubidium and strontium	TBD
	TBD	Mass-spectrometry of strontium	TBD
	TBD	Chemical separations of uranium, thorium, and lead	TBD
	TBD	Mass-spectrometry of lead	TBD
	TBD	Separation of oxygen and carbon from carbonate	TBD
	TBD	Separation of oxygen from silicate	TBD
	TBD	Separation of hydrogen from silicate	TBD
Isotope geology	TBD	Liberation and collection of fluid inclusions	TBD
	TBD	Mass-spectrometry for hydrogen	TBD

Method	Technical procedure Number	Title	Date
	TBD	Mass-spectrometry for carbon	TBD
	TBD	Mass-spectrometry for oxygen	TBD
	TBD	Alpha-spectrometry	TBD
Hydrologic studies	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	HP-11, R0	Methods for determination of radioactive substances in water	18 June 82
	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
	HP-37, R0	Preliminary procedure for drilling and coring of wet- and dry-lake sediments	14 Aug 84
Biological studies	HP-76, R0	Diatom enumeration studies	8 Apr 84
	HP-78, R0	Ostracode sample preparation and data acquisition procedures	8 Apr 84
Mineralogical and chemical studies	QP-04, R2	Handling, storage, and shipping of samples	TBD
	QP-14, R0	One-time research and development work	TBD
	DP-04, R3	Thin-section preparation	TBD
	DP-06, R2	Carbon coating of samples with DV-502 vacuum evaporator	TBD
	DP-07, R1	Microprobe operating procedure	TBD
	DP-16, R1	Siemens x-ray diffractometer procedure	TBD
	DP-19, R1	Sample preparation: rock powders	TBD
Mineralogical and chemical studies	DP-20, R1	Preparation of fused-glass beads from rock powder	TBD
	DP-24, R0	Alignment of Siemens diffractometer	TBD

Method	Technical procedure Number	Title	Date
	DP-25, R1	Clay mineral separation and preparation for x-ray diffraction	TBD
	DP-50, R0	Sputter coating with gold	TBD
	DP-51, R0	Mettler H80 sample weighing procedure	TBD
	DP-52, R0	Making fused discs with junior orbit shaker	TBD
	DP-53, R0	Pulverizing with Spex 8500 shatterbox	TBD
	DP-54, R0	Crushing with 50-ton hydraulic press	TBD
	DP-55, R0	Rock-splitting with 50-ton hydraulic press	TBD
	DP-56, R0	Brinkman automated grinding procedure	TBD
	TBD	Fluid inclusion homogenization	TBD
	TBD	Instrumental neutron activation	TBD
	TBD	X-ray fluorescence procedures	TBD

[a]TBD = to be determined.

8.3.1.5.2.2 Study: Characterization of the future regional hydrology due to climate changes

The objective of this study is to characterize the impacts of potential future climate changes on the regional and site surface-water system, the site unsaturated-zone hydrology, and the regional and site saturated-zone hydrology.

8.3.1.5.2.2.1 Activity: Analysis of future surface hydrology due to climate changes

Objectives

The objectives for this activity are to

1. Simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change.

2. Use the relationship between paleoclimate and paleo surface-water conditions to predict the impact of future climatic conditions on surface-water hydrology at the site.

Parameters

The parameters for this activity are past and future runoff and surface-water storage.

Description

Precipitation-runoff relations of modern surface-water conditions and basin characteristics will serve as the basis for the development of a present-day precipitation-runoff model (or models) for the Yucca Mountain site. Sufficient data will be collected through the current precipitation and streamflow gaging programs (Activity 8.3.1.2.1.2.1 and Section 8.3.1.12) and rainfall-runoff modeling in Fortymile Wash basin (Activity 8.3.1.2.1.3.3) to allow modeling of modern-day, precipitation-runoff relationships. The model will be run to simulate estimated paleoconditions derived from other activities such as precipitation, snowpack conditions, soil evaporation, interception of precipitation by vegetation, and transpiration. These model runs will be used to validate the model against inferred conditions derived from past proxy records. The model will be used to simulate future runoff conditions resulting from hypothesized climatic change based on results of the paleorunoff simulations.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.2.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Precipitation-runoff modeling of past and future surface-water conditions	TBD[a]	Precipitation-runoff model	TBD

[a]TBD = to be determined.

8.3.1.5.2.2.2 Activity: Analysis of future unsaturated zone hydrology due to climate changes

Objectives

The objective of this activity is to predict quantitatively the potential effects of future climatic conditions on infiltration, percolation, and the degree of saturation of the unsaturated zone at Yucca Mountain.

Parameters

The parameters for this activity are

1. Relationship between climate and infiltration.

2. Time-dependent spatial distributions of moisture potential, pore-gas pressure, saturation, and moisture flux.

Description

The unsaturated-zone hydrologic model, to be developed in Activity 8.3.1.2.2.9.2, will provide a calibrated model of present-day flow conditions and processes. The model will be calibrated using initial and boundary conditions, and geohydrologic material properties. The results of artificial infiltration studies will be incorporated into the model development (Activity 8.3.1.2.2.1.3). Sensitivity studies will be performed on a sequence of transient simulations over the next 10,000 yr during which the rate of net land-surface infiltration will be varied over time and space. These mathematical simulations will investigate the effects of scenarios chosen to represent infiltration rates resulting from probable climatic changes extrapolated from paleoclimatologic and paleohydrologic conditions. The set of simulations will delimit the sensitivity of the moisture-potential, saturation, perched-water, and moisture-flux distributions within the natural, unsaturated-zone flow system to changes in infiltration arising from climatic variations.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.2.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Unsaturated-zone hydrology model sensitivity analysis (due to climate changes)	TBD[a]	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.2.2.3 Activity: Synthesis of effects of possible future recharge due to climate changes on hydrologic characteristics of the Yucca Mountain saturated zone

Objectives

The objectives of this activity are to

1. Reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the paleoclimatic conditions reconstructed under Investigation 8.3.1.5.1 as a basis to predict the impact of future climatic conditions on the saturated-zone hydrologic system.

2. Synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine the effects that greater recharge would have on water-table altitude, ground-water flow paths, and hydraulic gradients between Yucca Mountain and the accessible environment.

Parameters

The parameters for this activity are

1. Relationship between climate and recharge.
2. Distribution of potentiometric head (past, present, and future).

Description

Records of past climates for the Yucca Mountain area indicate that conditions wetter and cooler than modern day have occurred in the past (Section 5.2.1). These conditions may have led to higher water levels in the past (Winograd and Szabo, 1986). Correlations between past climatologic and geohydrologic conditions, including past recharge rates, will be inferred using paleo-water levels determined from the study of past discharge areas and analog recharge sites. Past climate changes will be correlated with geologic and biologic evidence of paleohydrologic conditions (Activities 8.3.1.5.1.2.1 and 8.3.1.5.1.3.1).

A three-dimensional numerical ground-water flow model of the regional flow system (developed under Activity 8.3.1.2.1.4.4.) will be calibrated using modern-day conditions. The higher water levels inferred for the past will be simulated to estimate the magnitude of past recharge.

The simulation of wetter conditions will be used to assess potential changes in water-table altitude, ground-water flow rates, and ground-water flow directions. Recharge will be varied from modern conditions up to the maximum probable amount to be expected in the next 10,000 yr. Sensitivity analyses will be done to determine the appropriate time periods needed for model input.

Results of previous modeling (Study 8.3.1.2.1.4) will be the basis for future work. Recharge boundary fluxes applied to both two- and three-dimensional models for regional ground-water saturated flow (Czarnecki, 1985;

Sinton and Downey, 1986) were based on the best estimates of recharge believed to occur either as throughflow into the area or as areally distributed recharge. Principal areas where significant areally distributed recharge may occur are Pahute Mesa, Rainier Mesa, Timber Mountain, and Fortymile Wash.

New data on climatic conditions and recharge mechanisms under various scenarios (monsoon versus thunderstorm versus snowfall precipitation and corresponding vegetation changes) will be incorporated into the simulation of increased-recharge conditions.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.5.2.2.3 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Documentation of calibrated regional ground-water flow model	TBD[a]	TBD	TBD
Simulation of future ground-water conditions due to climatic change	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.5.2.3 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

Information need, issue or investigation	Subject
1.1.3	Calculational models for release scenario classes (Section 8.3.5.13.3).
1.8	NRC siting criteria (Section 8.3.5.17)
1.9a	Higher level findings (Section 8.3.5.18)
8.3.1.2.1	Regional hydrologic system.
8.3.1.5.1	Nature and rates of climate change.

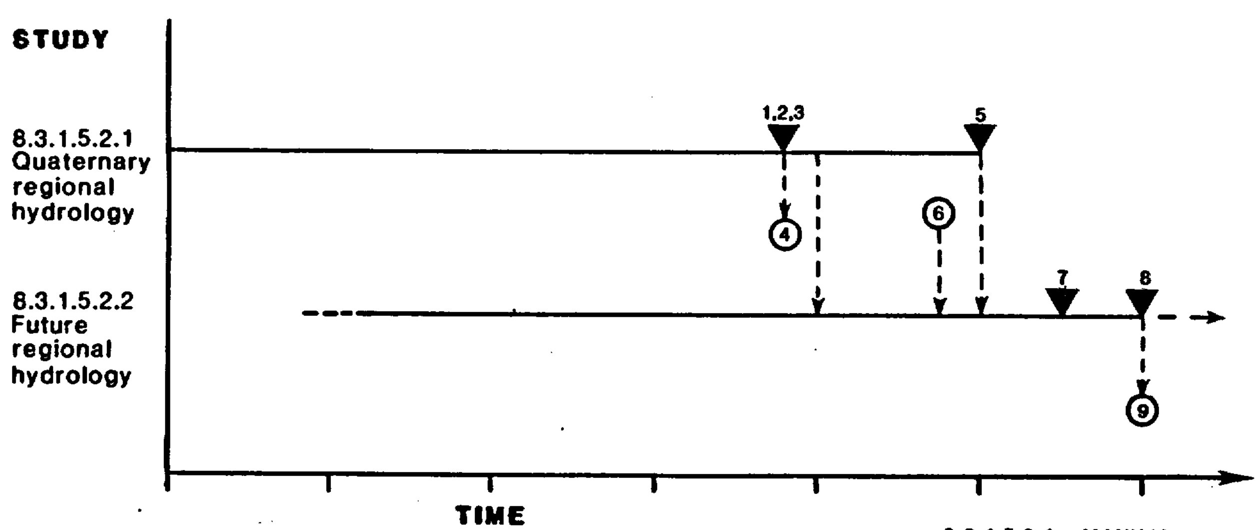
8.3.1.5.2.4 Schedules and milestones

Investigation 8.3.1.5.2 contains two studies: 8.3.1.5.2.1 (characterization of the Quaternary regional hydrology) and 8.3.1.5.2.2 (characterization of the future regional hydrology due to climatic changes). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The first study on Quaternary regional hydrology (8.3.1.5.2.1) is ongoing, while the second study on future regional hydrology (8.3.1.5.2.2) is expected to start in the second year of site characterization.

The synthesis and modeling performed in this investigation will proceed in parallel with activities in the geohydrology program and with performance and design activities and will interact with them in an iterative fashion. The impact of future climatic changes on the future regional hydrology system is needed to support the resolution of Issues 1.1 (total system performance, 1.8 (NRC siting criteria, and 1.9 (higher level findings--postclosure. This investigation will also provide data on future changes to the hydrologic system to the seal characteristics (Issue 1.12), waste package characteristics (Issue 1.10), the geohydrology program (Section 8.3.1.2), the geochemistry program (8.3.1.3), and the erosion program (8.3.1.6).

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. Points shown on the timelines represent major events or important milestones associated with this study. Solid lines represent study durations, and dashed lines represent interfaces. The data input and output at the interfaces are shown by circles. The ticks on the time scale represent one-year increments.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Milestone P690. Report available on paleodischarge areas.
2	Milestone Z280. Report available on Quaternary recharge areas.
3	Milestone Z281. Report available on hydrogenic deposits.
4	Conceptual model of calcite silica deposits available for consideration in scenario screening in Issue 1.1 (total system performance, Section 8.3.5.13) and for postclosure tectonics.
5	Milestone Q041. Report available on the characterization of Quaternary regional hydrology.
6	Final input from 8.3.1.5.1.6 (characterization of future climates and environments) available for Study 8.3.1.5.2.2).
7	Milestone Z283. Report available on future changes in unsaturated zone hydrology due to climatic change.
	Milestone P745. Report available on effects of future climate change on saturated zone hydrologic system.
8	Milestone Q162. Report available on potential effects of future climate conditions on hydrologic characteristics at Yucca Mountain.
9	Input to Issue 1.1 (total system performance) on effects of future climatic change on the hydrologic system.

DOE/RW-0160

Chapter 8

Section 8.3.1.6

Nuclear Waste Policy Act
(Section 113)

M

Consultation Draft

EROSION

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V

January 1988

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

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8.3.1.6 Overview of the erosion program: Description of the future erosional rates required by the performance and design issue

Summary of performance and design requirements for erosion information

The following summarizes the requirements for erosion data from the design and performance issues:

1. The surface characteristics program (8.3.1.14), requires information on the expected magnitude and locations of erosion, both on bedrock and alluvial-colluvial surfaces.

2. Issue 1.12 (Section 8.3.3.2, seal characteristics), requires information on the erosion potential (rates) near shafts to support the design of seals.

3. The human interference program (8.3.1.9) requires information on erosion to determine the most suitable locations for the surface markers and monuments of the warning system.

Existing regional data indicate that erosion will not affect the minimum burial depth (200 m) required by 10 CFR 960.4-2-5(b). Using the maximum erosion rates presented in Section 1.1 of 40 cm/1,000 yr, the amount of erosion that will occur over the next 10,000 yr (4 m), or even 100,000 yr (40 m), is much less than the total burial depth. Therefore, even an increase in erosion rates by a factor of two or three would have no impact on burial depth relative to the 200 m disqualifying condition.

Large-scale mass wasting (e.g., rock slides and debris flows) does not appear to pose a significant hazard to waste isolation at Yucca Mountain. Eolian processes and plans to investigate them within the climate program, are discussed in Section 8.3.1.5.1.4.4. The erosion test program concentrates on fluvial and hillslope erosion.

Approach to satisfy performance and design requirements

The general strategy used in developing the postclosure erosion program is to identify the site-specific geomorphic parameters and data that are needed to satisfy the design and performance issues and to ensure that the 200 m disqualifying condition is not exceeded. As discussed in Chapters 1, 3, and 5, the desert environment of the southern Great Basin is one of the factors that has made Yucca Mountain potentially advantageous for the long-term disposal of high-level radioactive waste. From the standpoint of waste containment, the comparative aridity of the climate and the relatively low rates of tectonic uplift (relative stability of the tectonic setting) during the Quaternary period have kept the long-term erosion rates low. The future persistence of tectonic stability coupled with the semiarid-to-arid climatic conditions would result in continued low erosion rates through the post-closure period, and assist in the isolation of the waste. Thus, erosional processes are not believed to pose a hazard to waste isolation at Yucca Mountain.

For the integrity of the repository to be at risk from erosional breaching, a combination of highly unlikely topographic, climatic, and tectonic conditions would be required. Climatic change in the postclosure period to relatively wetter semiarid conditions would result in a sustained period of higher precipitation and runoff, possibly increasing the average upland erosion rate above the present level. Although data presented in Chapter 1 indicate that Quaternary erosion rates during wetter climates were not substantially greater than present-day rates, an increase of precipitation and runoff could result in slightly higher erosion rates at Yucca Mountain. The erosion rates could also be aggravated by a period of sustained tectonic uplift, if uplift rates were to greatly exceed those estimated for the Quaternary period. It must be emphasized, however, that the probability of this hypothetical scenario occurring is extremely low. The relative vertical tectonic adjustment has been less than 3 cm/1,000 yr during the late Cenozoic (Miocene to present), and the average maximum downwasting rate was estimated to be 2 cm/1,000 yr (Section 1.1). It is highly unlikely that climatic or tectonic changes during the postclosure period will significantly change the rate of downwasting. Additionally, increased erosion of hillslope and uplands would result in increased aggradation on piedmonts and lowlands which would counterbalance local erosion rates.

Because erosion is not expected to pose a hazard to the isolation of waste at Yucca Mountain (Issue 1.1 Section 8.3.5.13), very few performance and design issues request information from the erosion program. Only Issue 1.12 (Section 8.3.3.2, seal characteristics), the surface characteristics program (Section 8.3.1.14), and the human interference program (Section 8.3.1.9), require input from the erosion program. Table 8.3.1.6-1 lists the parameters requested by these issues and programs.

Issue 1.12 (seal characteristics, Section 8.3.3), requests information on the erosion potential near specified shafts. This information will be provided through Investigation 8.3.1.6.1, which will determine the current rates of erosion at the site and through Investigations 8.3.1.6.2 and 8.3.1.6.3, which will determine the potential effects of future tectonic and climate activity on erosion at the site. The surface characteristics program (8.3.1.14) requires information on the present locations and rates of erosion. This information will be provided by Investigation 8.3.1.6.1.

The human interference program (8.3.1.9) requires information on erosion that will support the determination of the reliability and survivability of surface markers and monuments. Although erosional processes are not expected to pose a hazard to waste containment and isolation, the effects of rapid stream incision needs further study because of its potential consequences to surface markers and monuments. Markers need to be placed in areas of low erosion or deposition to aid survivability. The data obtained from studies of stream incision will be used in the design of the warning system, and will augment those studies being undertaken in support of the surface characteristics program (Section 8.3.1.14). Investigations 8.3.1.6.2 and 8.3.1.6.3 will provide information on the potential effects of future tectonic and climate activity on erosion at the site. This information will also be used to locate surface markers and monuments in areas with potential for low future erosion to enhance survivability.

Table 8.3.1.6-1. Parameters provided by the erosion program that support performance and design issues

Issue requesting parameter	SCP section number	Performance or design parameter	Tentative Goal	Desired confidence	Characterization parameter	Testing basis: Current estimate of parameter range	Testing basis: Current confidence	Testing basis: Needed confidence	Study number
1.12 (seal characteristics)	8.3.3.2	Erosion potential at exploratory shafts 1 and 2, men and materials shaft, and emplacement area exhaust shaft	< 1 m of preferential erosion of bedrock at shaft entry locations over 1,000 yr	Low	Long term erosion rates at shaft entry locations	40 cm/ 1,000 yr	Very low	Low	Study 8.3.1.6.1.1 Study 8.3.1.16.1.1
1.1 (total system performance) through human interference program	8.3.5.13, 8.3.1.9	Locations of low erosion or deposition for surface markers	Identify geomorphologically stable areas along controlled-zone boundary	Low	Long term rates of erosion, deposition at proposed marker locations	40 cm/ 1,000 yr	Very low	Low	Study 8.3.1.6.1.1 Study 8.3.1.16.1.1
4.4 (technical feasibility) through surface characteristics program	8.3.2.5, 8.3.1.14	Scour potential along Fortymile Wash at bridge locations; erosion potential along proposed roads	< 13 m of scour at bridge foundations over 100 yr; < 5 m of bed erosion in channel over 100 yr; < 1 m sheet erosion on roadways over 100 yr	Low	Rates of soil, bedrock erosion at bridge locations over 100 yr; erosion along roads and channel beds	40 cm/ 1,000 yr	Very low	Low	Study 8.3.1.6.1.1 Study 8.3.1.16.1.1

The relationship between the investigations performed under this characterization program and the issues and programs that require information on erosion locations, rates, and processes is shown in Figure 8.3.1.6-1.

Interrelationships of erosion investigations

Four investigations have been developed to provide the data required by the performance and design issues. Many of the necessary parameters have been obtained and evaluated as part of the ongoing scientific studies at the Nevada Test Site (NTS) in support of the weapons testing program. In most instances, data are not site specific and, therefore, not adequate to satisfy the performance and design issues. Studies will be carried out during site characterization to satisfy these remaining data needs.

Investigation 8.3.1.6.1 will collect site-specific data on Quaternary erosion and stream incision rates, which will be used to calculate average erosion rates on Yucca Mountain and to develop a history of the downcutting episode(s) of Fortymile Wash. Investigation 8.3.1.6.2 includes studies to assess the potential effects of future climatic changes on locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hillslope erosion rates. Local erosion data on Yucca Mountain and an evaluation of the relationship of increased runoff in Fortymile Canyon, Fortymile Wash, and their tributaries to localized stream incision rates are needed for Information Need 2.7.1 (Section 8.3.2.3.1). Investigation 8.3.1.6.3 will evaluate the effects of tectonic activity on rates of erosion.

Investigation 8.3.1.6.4 addresses the potential effects of erosion on the baseline hydrologic, geochemical, and rock characteristics at Yucca Mountain. Because the effects of erosional processes on the baseline conditions are not expected to pose any hazard to waste isolation and are not expected to affect the postclosure ground-water travel time, no further studies or activities are planned. These topics will be addressed in a topical report, which will present the discussion supporting termination of the erosion program.

Other investigations will provide data in the form of input parameters to the erosion program. Investigations 8.3.1.5.1 and 8.3.1.8.2 will provide data on the nature and extent of future climatic changes and tectonic activity, respectively. Data obtained to date on regional tectonic and climatic activity during the Quaternary Period suggest that very little change will occur in the erosional regime at Yucca Mountain during the postclosure period as a result of these processes (Chapters 1 and 5). Limited site-specific studies will be completed to determine quantitatively, on the basis of Quaternary erosion rates, the extent of potential stream incision that could result from future tectonic activity and climatic changes.

Although the long-term average upland and hillslope erosion rates have been established for the southern Great Basin, they may not be representative of actual erosion rates on Yucca Mountain or of the short-term episodes of stream incision that may occur when a critical process threshold is exceeded. Fortymile Canyon, Fortymile Wash, and their tributary channels, that are located on the eastern flanks of Yucca Mountain, may be subject to critical

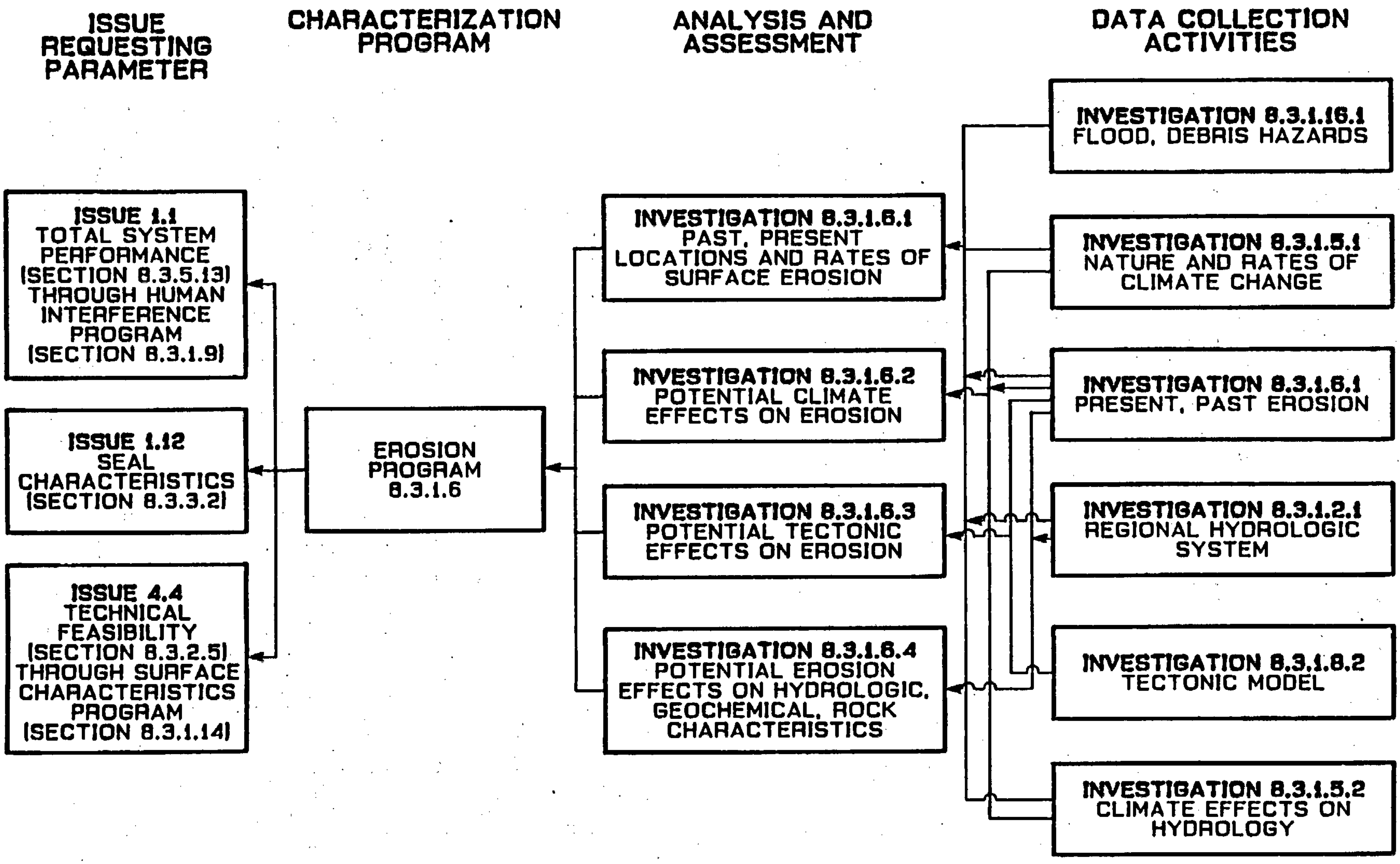


Figure 8.3.1.6-1. Relationship between erosion program and investigations.

threshold (complex) response (the reaction of a fluvial system to a disruption of the equilibrium of the system). As discussed in Chapter 1, Section 1.1.3.2, very little site-specific information is presently available that would allow for the quantification of erosional processes at Yucca Mountain. Those data needs will be satisfied during site characterization.

The schedule information provided for investigations in this section includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.1.6.1 Investigation: Studies to determine present locations and rates of surface erosion

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Sections 1.1 (geomorphology), 3.2.1 (flood history and potential for future flooding), and 5.1 (modern climate and meteorology) summarize existing data relevant to this investigation. As discussed in these sections, site-specific data are not available for rates and locations of erosion, especially along Fortymile Canyon, Fortymile Wash, and their tributaries.

Parameters

Three groups of parameters will be measured or calculated as a result of the site studies planned for this investigation:

1. A geomorphic map of Yucca Mountain that defines areas of active erosion and areas of no erosion (i.e., geomorphic stability).

2. Rates, locations, and causes of incision in Fortymile Wash and its tributaries.

3. Average rates of hillslope erosion on Yucca Mountain.

Other site studies will provide data to support the determination of these parameters. Activities in support of Investigation 8.3.1.2.1 will supply data on the regional meteorology and surface water system. Investigation 8.3.1.5.1 will provide geomorphic information on surficial deposits and geomorphic interpretation of Quaternary history. Investigation 8.3.1.5.2 will provide paleoflood evaluations. Site flood and debris hazard data will be provided from Investigation 8.3.1.16.1.

Purpose and objectives of the investigation

The objectives of this investigation are to obtain the site-specific data needed to calculate average Quaternary hillslope erosion rates and accurate average short-term erosion rates associated with episodic erosion. This investigation will perform three activities and use information from the climate (Section 8.3.1.5) and geohydrology (Section 8.3.1.2) programs to support these objectives. Figure 8.3.1.6-2 shows how these data-collection sections will support the determination of present rates and locations of surface erosion. Three kinds of data will be obtained to characterize past distribution of hillslope and alluvial deposits, and surfaces of different ages will be shown on a geomorphic map of Yucca Mountain. First, the map will show the extent to which modern erosion has affected an essentially Pleistocene landscape. Second, local stream incision rates will be calculated by dating incised stream terraces and sand ramps by uranium-trend, uranium-series, radiocarbon, and cation ratio (rock varnish) dating methods. Third, average erosion rates on hillslopes will be calculated from dated hillslope surfaces by the rock varnish dating method.

Desert geomorphic processes acting in conjunction with extensional tectonism have molded the present topography of the Yucca Mountain area, and these processes continue very slowly to modify the landscape. The predominantly semiarid-to-arid climates of the past and present have helped to preserve the landscape of the region surrounding Yucca Mountain. Weathering in arid environments proceeds more slowly than in more humid environments, and materials on most of the bedrock slopes of the mountain appear to be only slightly weathered. Available data suggest that the region surrounding Yucca Mountain has been geomorphically stable during much of the middle and late Quaternary, and that rates of geomorphic processes are likely to remain generally low during the next 10,000 yr.

The locations of modern erosion are best shown on aerial photographs and large-scale topographic maps of Yucca Mountain where the drainage networks are clearly defined. Erosion on hillslopes is visible on aerial photographs because the recently stripped slopes are much lighter in color than adjacent deposits, which are coated with dark desert varnish. The amount and distribution of modern erosion is of very limited extent when compared with the vast areas of stable Pleistocene deposits in the Yucca Mountain area. The contrast between limited areas of modern upland and hillslope erosion versus large stable areas is a strong argument for low erosion rates at the proposed repository site.

Average late Tertiary and Quaternary erosion rates for local areas of the southern Great Basin and northern Mojave Desert have been inferred from height differences between active and relict basalt-capped erosion surfaces. Estimates based on this approach for several widely separated upland areas range between 1.2 and 4.7 cm per 1,000 yr for periods of 1.1 to 10.8 million years, and the differences in these average rates show no apparent relation to regional variations in late Tertiary and Quaternary vertical tectonic activity. Degradation of upland areas in the Yucca Mountain region is relatively slow, with average downwasting rates over the last 1 to 5 million years probably between 0.5 to 2.0 cm per 1,000 yr on lower hillslopes and proximal piedmont areas and less than 0.5 cm per 1,000 yr in middle and distal piedmont areas. Thus, it would appear that the general degradation of upland areas in the region surrounding Yucca Mountain is proceeding relatively slowly.

The sporadic nature and limited areal extent of individual precipitation events are major impediments to an accurate characterization of present-day

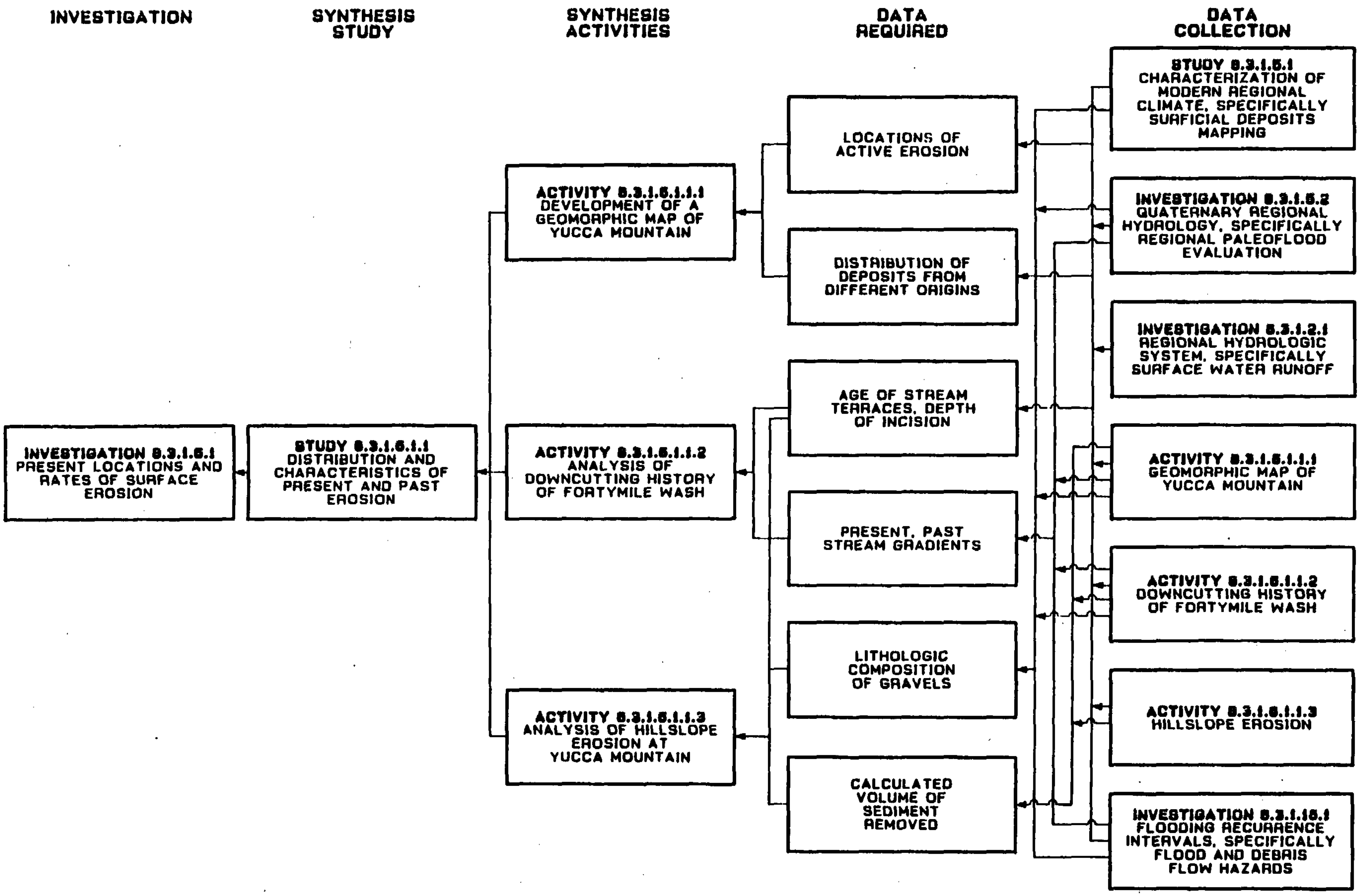


Figure 8.3.1.6-2. Logic diagram for Investigation 8.3.1.6.1.

erosion. Few data have been collected in the Great Basin to correlate individual storm events with corresponding volumes of sediment transported out of a basin with the associated storm runoff. Because the storms can be of very limited areal extent, a single storm may cause measurable hillslope erosion and flooding in one tributary, while not providing sufficient precipitation to an adjacent tributary to cause runoff. Furthermore, the next storm to cause measurable erosion on the same hillslope may occur in the same month, or not for several years or even decades. The sporadic nature of these storms causes the complex response of the fluvial systems.

Complex response is a term applied to the reaction of a fluvial system to a disruption of the equilibrium of the system. Such disruptions can be due to base-level lowering, tectonic uplift or tilting, climatic change, or human activity. The disruption of equilibrium causes a critical threshold to be exceeded (Chapter 1, Section 1.1), and the system does not respond uniformly throughout. The lower-order tributary streams of the system do not respond at the same rate as the main channel (e.g., Fortymile Wash and its tributaries). In the example of base-level lowering, a pulse of erosion along the main channel will result in rejuvenation of the tributaries. The influx of sediment from the rejuvenated tributaries can result in aggradation on the main channel, and downcutting may stop until such a time when the aggraded material has been removed. When the system has removed the aggraded material, another episode of erosion may occur. Thus, erosion is episodic and depends on the response of the entire system (Matthusen, 1986).

Direct measurement of present rates of erosion at Yucca Mountain may be difficult to obtain over the next several years of site characterization. Stream gaging equipment has been installed and more stations are planned, but there is no guarantee that a variety of storms will take place over these specific drainages during the next few years. Even if storm events do occur, the characterization of erosion locations and calculated rates of erosion may be based on limited observations and collected discharge and sediment data, and may not accurately reflect long-term erosion rates.

Indirect measurements are thus necessary to supplement direct measurements to better characterize recent hillslope erosion and floods. These measurements include the evaluation of flood and debris-flow hazards from Holocene deposits and discharge volumes of paleofloods calculated from maximum particle size and engineering analysis techniques. These activities are all included within the characterization of the regional meteorology; description of the regional surface-water system (Study 8.3.1.2.1.2), regional meteorology (Section 8.3.1.2.1.1), geomorphic information (Section 8.3.1.5.1), paleoflood evaluation (Activity 8.3.1.5.2.1.1), and site flood debris-hazards studies (Activity 1.6.1.1.1).

One study, consisting of three activities, will be performed in support of Investigation 8.3.1.6.1. The study will focus on the identification and quantification of active erosional processes. Data on these processes and stream-incision rates will be used to determine the cause of downcutting in Fortymile Wash.

8.3.1.6.1.1 Study: Distribution and characteristics of present and past erosion

The objectives of this study are to identify the erosional processes that have been operating in the Yucca Mountain area during the Quaternary, to identify the specific locations of past erosion, and to quantify the rates of the different processes and assess their relative importance.

A geomorphic map of the Yucca Mountain area will delineate erosionally active and stable areas, and will correlate the various surficial deposits with those geomorphic processes responsible for their origin. Investigation of the downcutting history of Fortymile Wash will yield ages of stream terraces, depths of stream incision, stream gradients, and lithologies of stream gravels, which will aid in identifying the controls on local stream incision.

8.3.1.6.1.1.1 Activity: Development of a geomorphic map of Yucca Mountain

Objectives

The objectives of this activity are to (1) determine the areal distribution of active erosional areas and geomorphically stable areas and (2) determine the spatial distribution of the different types of geomorphic processes and associated deposits.

Parameters

The parameters for this activity are

1. The locations of areas of active erosion.

2. The locations of geomorphically stable areas and the distribution of deposits originating from different geomorphic processes.

Description

The distribution of landforms and areas of present and past erosion at Yucca Mountain will be shown on a geomorphic map of the area. The map will show areas of modern erosion and the stable areas that are largely unaffected by modern erosion. Accurate distribution of areas of modern erosion is important for calculation of present and future erosion rates.

The geomorphic map will be a derivative map of the surficial deposits map (Activity 8.3.1.5.1.4.3). The surficial deposits map will show the types and ages of surficial deposits on the landscape. The geomorphic map will show landforms (both bedrock and surficial deposits) and the types of past and present geomorphic processes that are chiefly responsible for their formation. Ages of deposits can be used to infer the relative stability or instability of the landforms. The geomorphic map will be constructed from much of the aerial photographic interpretation and field checking of deposits and map-unit contacts that will be undertaken during preparation of the surficial deposits map (Activity 8.3.1.5.1.4.3). Dating of surficial deposits will also be accomplished in the surficial deposits map activity. The geomorphic interpretation of the surficial deposits will be primarily based upon the interpretations of origins from other paleoenvironmental studies of Yucca Mountain (Study 8.3.1.5.1.4) and reported in the synthesis of the Quaternary history of Yucca Mountain (Activity 8.3.1.5.1.5.1).

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.6.1.1.1 is given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS)		
Preparation of a geomorphic map of Yucca Mountain from the surficial deposits map	GP-01, R0	Geologic mapping	11 Mar 83

8.3.1.6.1.1.2 Activity: Analysis of the downcutting history of Fortymile Wash and its tributaries

Objectives

The objectives of this activity are to (1) determine stream-incision rates on Fortymile Wash and selected tributaries and (2) determine the cause(s) of the major downcutting episode(s) on Fortymile Wash.

Parameters

The parameters for this activity are

1. The ages of stream terraces.
2. The depths of stream incision.
3. Present and past stream gradients.
4. The lithologic composition of stream gravels.

Description

Fortymile Wash is a major geomorphic feature situated about 3 km east of the proposed repository site. The wash flows south out of the Timber Mountain caldera drainage basin, about 680 km^2 in size, and is incised 20 to 25 m into Quaternary deposits along its course east of Yucca Mountain. Dune, Sevier, and Yucca Washes are incised from 2 to 25 m into Quaternary deposits. These washes and their tributaries are incised as much as 100 m into bedrock dip slopes along the fault and fracture zones on the east side of Yucca Mountain.

Rates of stream incision are greater than surface degradation rates, and the downcutting of the Fortymile Canyon represents the highest localized erosion rates for the Yucca Mountain area. The average rate of stream incision below the main stream terrace is about 8.5 cm per 1,000 yr. However, the age of the stream terrace is based not on a direct radiometric age, but on the correlation to isotopically dated deposits with similar soil development. In this activity, all major stream terraces on Fortymile Wash will be dated by either uranium-trend, uranium-series, rock varnish (cation ratios), or radiocarbon methods. By dating all terraces, average incision rates can be refined for specific intervals of downcutting between episodes of valley aggradation and subsequent terrace formation. Terraces on Fortymile Wash tributaries will be dated in an effort to refine the youngest episodes of valley aggradation and incision. These site-specific incision rates will be used to calculate future erosion rates near the repository. This information may also be valuable for interpreting the paleoenvironmental history of Yucca Mountain (Activity 8.3.1.5.1.4).

Another aspect of this activity is to determine the cause or causes for the downcutting of Fortymile Canyon, which is unusually deep compared with other canyons in Great Basin piedmonts and basins. To identify contributing factors to this unique geomorphic feature, former stream gradients will be reconstructed from stream terrace profiles, and stream gravel lithologic compositions will be examined to identify any changes in upper basin source areas. These two activities will help in deciding if stream capture was a major factor in the formation of Fortymile Wash. Also, all relevant subsurface information, including both drillhole and geophysical data, will be examined to decide if Fortymile Wash is situated along a fault or fault zone.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.6.1.1.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS)		
Dating of major terraces on Fortymile Wash	GCP-02, R1	Labeling, identification, and control of geochronology samples and separates	20 Jan 87
	GCP-04, R0	Uranium-Trend Dating	15 June 81
	GCP-03, R0	Uranium-Series Dating	15 June 81
	TBD[a]	Cation ratio (desert varnish) dating	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS)		
	TBD (in preparation)	Radiocarbon dating	TBD
Generation of stream gradients from stream terrace profiles	TBD	Generation of stream gradients	TBD
Determination of lithologic compositions of stream gravels	GP-03, R0	Stratigraphic studies	1 Mar 83
Analysis of subsurface data to determine possibility of Fortymile Wash being situated along a fault or fault zone	GP-02, R0	Subsurface investigations	1 Mar 83

[a]TBD = to be determined.

8.3.1.6.1.1.3 Activity: An analysis of hillslope erosion at Yucca Mountain

Objectives

The objectives of this activity are to (1) determine the average rates of Quaternary hillslope erosion on Yucca Mountain in bedrock and surficial deposits and (2) determine the genesis and the rates of movement of hillslope deposits.

Parameters

The parameters that will be obtained by this activity are

1. The absolute ages of the rock varnish coatings of bedrock and surficial deposits.

2. Maximum incision depth of hillslopes and adjacent dated surfaces.

3. Descriptions of the textures, grain size distributions, and sedimentary structures of the surficial deposits.

4. The calculated volume of sediment removed from hillslopes by erosional processes.

Description

The calculation of site-specific erosion rates will be accomplished using a new rock-varnish dating technique. Rock varnish, also called desert varnish, is nearly ubiquitous in arid and semiarid regions. Rock varnish is a thin coat of ferromanganese oxides, clay minerals, and biologic materials accreted on rocks in a variety of environmental settings. Varnished deposits and surfaces can be dated because several mobile cations in the varnish are depleted with time. The ratio of mobile to immobile cations (K+Ca/Ti) decreases with time, providing a relative age sequence for varnishes in a given area (see Section 8.3.1.17.4.9.1).

Absolute age estimates have been determined by calibrating the cation-leaching curve with cation ratios from potassium-argon dated volcanic rocks in Crater Flat and uranium-trend-dated alluvial deposits along the flanks of Yucca Mountain and within the surrounding washes and canyons (Harrington and Whitney, 1987). Maximum incision parallel to the dated hillslope deposits and bedrock surfaces will be measured, and volumes of denuded sediment will be calculated where possible. Erosion rates for both bedrock and surficial deposits will be used to estimate future erosion rates during the postclosure period.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.6.1.1.3 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Rock varnish dating hillslope deposits	TBD[a]	Cation-Ratio (desert varnish) Dating	TBD
Measurement of hillslope erosion	TBD	Measurement of Hillslope Erosion	TBD
Laboratory analysis of hillslope deposits	TBD	Sediment Size Analysis	TBD

[a]TBD = to be determined.

8.3.1.6.1.2 Application of results

The information derived from the previously described activities will be used in the following areas of site characterization, repository design, and performance assessment:

SCP section	Subject
8.3.5.17	Site information needed to identify favorable and potentially adverse conditions at the site that may influence postclosure repository performance (Issue 1.8).
8.3.1.6.2	Potential effects of tectonic activity on locations and rates of erosion
8.3.1.9.1	Natural phenomena and human activities that might degrade surface markers and monuments
8.3.1.14	Surface characteristics program
8.3.3.2	Seal characteristics
8.3.2.5	Technical feasibility

8.3.1.6.1.3 Schedule and milestones

The schedule and milestone information for this investigation is given in Section 8.3.1.6.4.3, at the end of Investigation 8.3.1.6.4 (potential effects of erosion on hydrologic, geochemical, and rock characteristics).

8.3.1.6.2 Investigation: Potential effects of future climatic conditions on locations and rates of erosion

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Sections 1.1.3 and 5.2.2 of the SCP data chapters provide a technical summary of existing data relevant to this investigation. Section 1.1.3 addresses the influence of climate on geomorphic processes, average erosion rates in the region surrounding Yucca Mountain, and significant late Quaternary geomorphic processes in the Yucca Mountain area. Future climatic variations and conceptual models used to investigate future climatic variation are presented in Section 5.2.

Parameters

This investigation will synthesize the results of studies undertaken in support of Investigations 8.3.1.5.1 (nature and rates of climate change) and 8.3.1.6.1 (present locations and rates of surface erosion). Thus, the parameters themselves are the results and conclusions from these studies. The parameters that will be used as input to this investigation are (1) predicted climate of the Yucca Mountain region over the next 1,000 to 100,000 yr, including the predicted timing of climatic changes, and the nature and duration of predicted climatic episodes; (2) the present locations and rates of surface erosion; and (3) the distribution and characteristics of past erosion.

Purpose and objectives of the investigation

An estimate of the potential effects of future climate on locations and rates of erosion will be derived in this investigation from converging lines of evidence. Figure 8.3.1.6-3 shows how information from Investigation 8.3.1.5.1 and from the activities within Investigation 8.3.1.6.1 will be used to determine potential effects of future climatic conditions on locations and rates of erosion. A projected sequence of climatic episodes, including the timing for their initiation and duration, will result from the climate modeling for Investigation 8.3.1.5.1. An ancillary product of the preparation for modeling will be a correlation of the paleoclimatic history of the southern Great Basin with the paleoenvironmental history of Yucca Mountain (erosional and depositional responses to climate). From the studies for Investigation 8.3.1.6.1 will come a characterization of present and past locations and rates of erosion in the Yucca Mountain region. Fitting the projected future climate sequence with corresponding known erosion rates and past geomorphic responses will allow the quantification of erosion effects at Yucca Mountain over the next 10,000 yr.

Yucca Mountain lies within one of the warmest and driest regions of the United States, with mean annual precipitation averaging about 110 mm per year and relative humidity commonly ranging between 25 and 55 percent. The full-glacial climate in the southern Great Basin is thought to have been semiarid in the basins and lower ranges, although subhumid climates may have existed in the highest mountains. Mean annual temperatures during full glacials were probably about 7 to 10°C colder than at present; annual precipitation was less than 40 percent greater than at present. Glacial processes were probably not active in the Yucca Mountain area during most or all of the Quaternary; lacustrine processes in the Great Basin appear to have been confined to playas, and lacustrine records from the southern Great Basin do not indicate deep lakes or continuous deposition during the late Quaternary.

The semiarid to arid climates of the past and present are responsible for low rates of weathering at Yucca Mountain. Physical weathering appears to be chiefly confined to exposed bedrock hillslopes and piedmont surfaces. Modern surface flow and sediment transport are brief and intermittent.

A future episode of increased precipitation would probably cause an increase in erosion rates. An estimate for (1) the timing, duration, and probability of an expected episode of increased erosion and (2) the expected quantitative effects of the episode at different locations in the Yucca Mountain region (e.g., stream incision versus hillslope erosion) will be made. Anticipated geomorphic responses to possible predicted increases in precipitation at Yucca Mountain will be based on past erosional responses to full pluvial climates during the Quaternary (Study 8.3.1.5.1.4).

One study, consisting of one activity, will be performed in support of this investigation. The study will be a synthesis of the results from activities in support of Investigations 8.3.1.5.1 and 8.3.1.6.1.

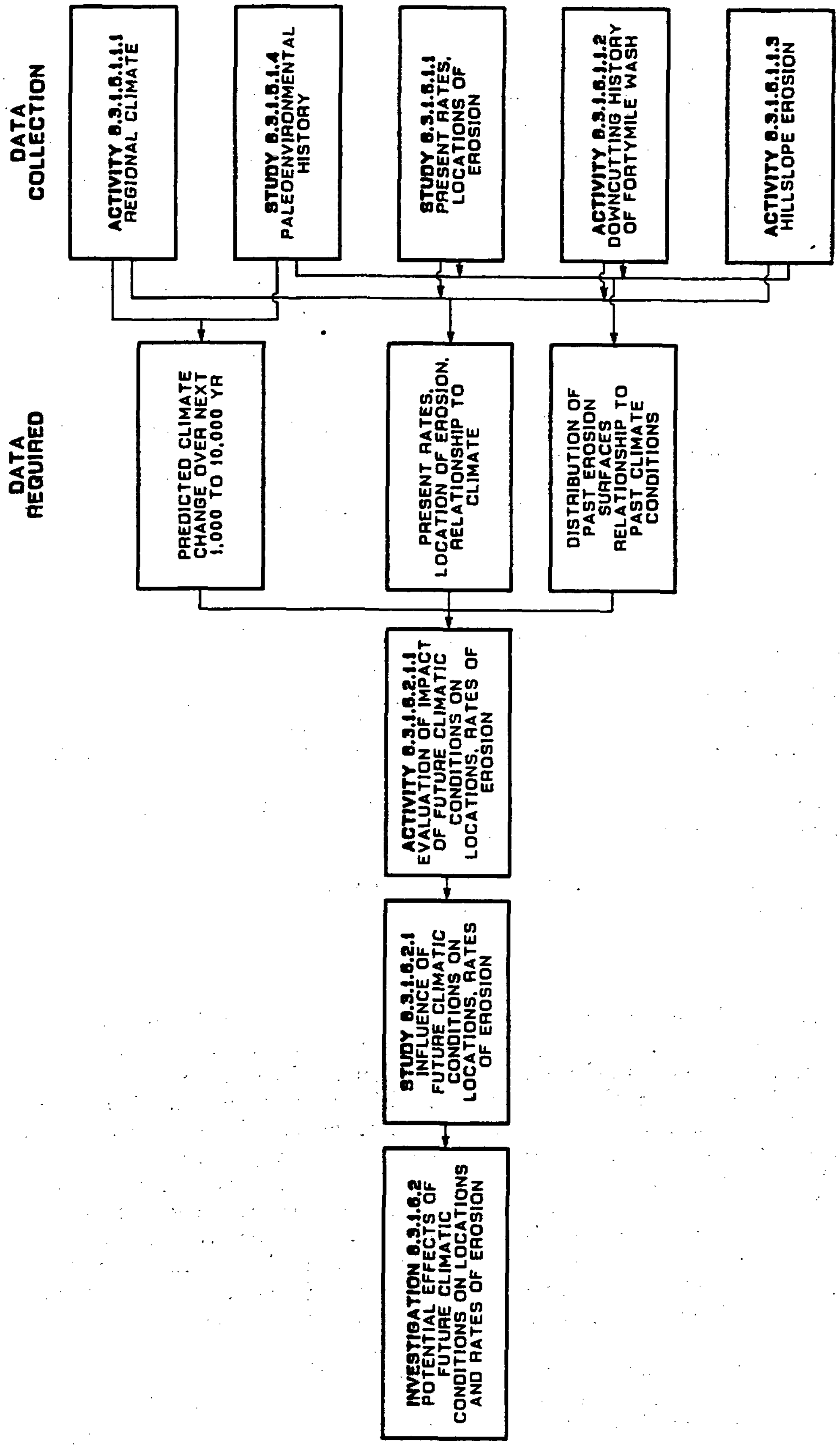


Figure 8.3.1.6-3. Logic diagram for Investigation 8.3.1.6.2.

8.3.1.6.2.1 Study: Influence of future climatic conditions on locations and rates of erosion

The objectives of this study are to determine the effects of future climatic conditions on the locations and rates of erosion. This synthesis study will use climate and erosion parameters generated by Investigations 8.3.1.5.1 and 8.3.1.6.1 to identify areas and rates of potential stream incision and increased erosion.

8.3.1.6.2.1.1 Activity: Synthesis and data evaluation of impact of future climatic conditions on locations and rates of erosion

Objectives

The objective of this activity is to integrate Quaternary climate conditions and rates of surface erosion with predicted conditions of future climate, to estimate significant changes in the character, distribution and ratio of surface erosion in the Yucca Mountain region over the next 1,000 to 100,000 yr.

Parameters

Three sets of parameters will be evaluated in this activity:

1. The predicted climate of the Yucca Mountain region over the next 1,000 to 100,000 yr, including the predicted timing for climatic changes and the nature and duration of predicted climatic episodes.

2. The present locations and rates of surface erosion and their relationship to present climatic conditions.

3. The distribution and characteristics of past erosion and their relationship to past climatic conditions.

Description

One of the expected results of Investigation 8.3.1.5.1 will be the derivation of regional climate history for the Quaternary from paleolimnologic and terrestrial paleoecologic lines of evidence (Studies 8.3.1.5.1.2 and 8.3.1.5.1.3). However, another product of this investigation will be a synthesis of the site-specific Quaternary paleoenvironmental history of Yucca Mountain and surroundings, on the basis of local surficial deposits, soils, and past geomorphic processes (Study 8.3.1.5.1.4). The paleoenvironmental evaluation will focus on the geomorphic responses to paleoclimates and climatic changes. The evaluation will also incorporate data on distribution and characteristics of past erosion. A paleoclimate-paleoenvironmental synthesis (Study 8.3.1.5.1.5) will tie the paleoclimate history (especially known episodes of temperature and precipitation extremes) to dated responses in the depositional and geomorphic record that reflect these extremes. A possible example would be correlating an episode of higher precipitation, as evidenced by the palynology of lacustrine sediments, to a period of rising base levels as reflected in a dated period of stream aggradation or reduced incision.

Thus, the paleoenvironmental history can serve as the baseline study to examine the relationship between different climatic episodes and the geomorphic responses that controlled erosion during the Quaternary. These responses can then be applied to future predicted climates, from which predicted erosion rates can be calculated.

To determine the effects of future climate on erosion, it will be necessary to integrate the results from Investigation 8.3.1.5.1 (nature and rates of climate change) with those from Investigation 8.3.1.6.1. The first important result of the latter studies will be the correlation of locations (e.g., stream incision) and rates of erosion to present climatic conditions. The second will be the determination of erosion rates and distribution of fluvial and hillslope processes during the Quaternary. By combining Quaternary erosion rates with the correlation between the regional paleoclimatic and local paleoenvironmental histories, together with the predicted future climates, it will be possible to describe expected locations and rates of erosion in response to expected future climatic episodes. If the durations of the future climatic episodes can be reasonably estimated, it will then be possible to quantify the effects of erosion at Yucca Mountain over the next 1,000 to 100,000 yr.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.6.2.1.1 is given in the following table.

Method	Technical procedure		
	Number	Title	Date
Synthesis: Evaluation of future climatic effects on locations and rates of erosion at Yucca Mountain, using results of studies and activities from Investigations 8.3.1.5.1 and 8.3.1.6.1	TBD[a]	Data synthesis	TBD

[a]TBD = to be determined.

8.3.1.6.2.2 Application of results

The information derived from the studies and activities of the plans described previously will be used in Investigation 8.3.1.9.1.

8.3.1.6.2.3 Schedule and milestones

The schedule and milestone information for this investigation is given in Section 8.3.1.6.4.3, at the end of Investigation 8.3.1.6.4 (potential effects of erosion on hydrologic, geochemical, and rock characteristics).

8.3.1.6.3 Investigation: Studies to provide the information required to determine the potential effects of future tectonic activity on locations and rates of erosion

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation. Section 1.3.2 discusses the structures and structural history of Yucca Mountain and the vertical and lateral crustal movement as they relate to tectonic activity. Section 1.1.3 examines the influence of tectonism on geomorphic processes and its effects on average erosion rates in the Yucca Mountain area and discusses significant late Quaternary geomorphic processes in the Yucca Mountain area.

Parameters

Four sets of parameters will be used in the site studies planned to obtain the needed information. This investigation is necessarily a synthesis of the results of studies undertaken to satisfy other investigations. Rates of regional uplift and subsidence, as determined from studies of tectonic geomorphology and the geodetic leveling network, will be supplied from Investigation 8.3.1.8.2. The present and past locations and rates of surface erosion will be determined from the geomorphic map. The effects of future climate on erosion will be obtained from Investigation 8.3.1.6.2.

Other site studies that provide data that support the determination of the parameters needed for this investigation include (1) a synthesis of the paleoenvironmental history of the Yucca Mountain region from Study 8.3.1.5.1.4 and (2) the tectonic model synthesis from Section 8.3.1.17.4.12.

Purpose and objectives of the investigation

Estimates of the potential effects of future tectonic activity on locations and rates of erosion will be derived in this investigation using information from Investigation 8.3.1.8.2, from Investigation 8.3.1.5.1, and from other activities performed within this program. The logic diagram for this investigation is shown in Figure 8.3.1.6-4.

Geomorphic processes in the southern Great Basin and northern Mojave Desert are determined largely by climate, existing topography, and tectonic activity, and by the spatial and temporal relations between these determinants. Late Cenozoic extensional tectonism and a predominantly semiarid-to-arid climate have combined to produce a structurally dominated landscape of high relief with narrow, rugged uplands separated by broad, gently sloping

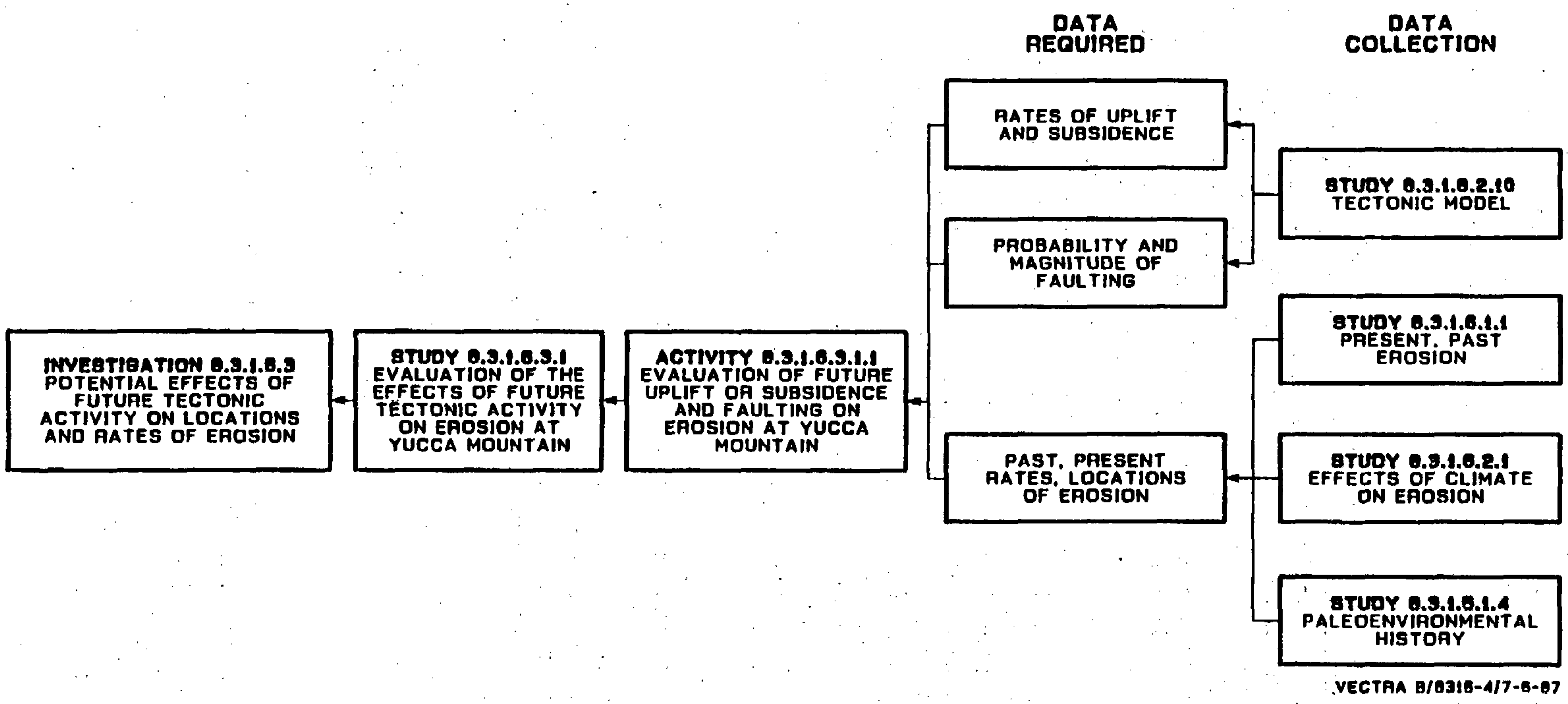


Figure 8.3.1.6-4. Logic diagram for Investigation 8.3.1.6.3.

lowland basins. Within this landscape, erosion and erosional processes are concentrated in the high, steep, and relatively moist uplands, whereas deposition and depositional processes are generally concentrated in the low, gently sloping, and relatively arid lowlands. The intervening piedmonts serve primarily as surfaces of transport between the eroding uplands and aggrading basins.

Differential vertical movement induced by regional extensional tectonism has probably been the single most important factor in the development of the landscape of the region surrounding Yucca Mountain. Essentially all landscape elements in the southern Great Basin and northern Mojave Desert are the structurally dominated products of late Cenozoic tectonism. However, with the exception of the southwest Great Basin and its bounding fault zones, tectonism appears to have played a much less significant role in regional landscape evolution during the Quaternary. For example, regional morphometric analyses indicate that large areas of the northern Mojave Desert and southern Great Basin (in particular, the eastern and southern sections of the Goldfield block of the Walker Lane belt as discussed in Chapter 1, geology) have undergone little, if any, vertical tectonic activity during the Quaternary. Local tectonic stability since latest Miocene time is documented by relations between potassium-argon-dated lava flows and relict and active erosion surfaces near the Cima volcanic field in the northeastern Mojave Desert and in the Pancake and Reveille Ranges of the central Great Basin. In the Yucca Mountain area, average rates of relative vertical tectonic adjustment during the latest Tertiary and Quaternary have been less than 3 cm per 1,000 yr. The impact of extensional tectonism on the late Quaternary landscape of Yucca Mountain has been extremely small, and the impact upon the magnitude and distribution of degradational processes in the area is very local, even in the vicinity of Quaternary faults.

If uplift rates at Yucca Mountain during the postclosure period are negligible, then (using present estimates of erosion rates) the average erosion rate of the mountain would probably be about 1 m over the next 10,000 yr. If the estimated Quaternary rate of uplift is projected over the postclosure period, even with a return to pluvial conditions, it is highly unlikely that the average rate of erosion will increase significantly. These regional erosion and uplift rates need to be verified with the site specific data from Yucca Mountain.

One study will be undertaken under Investigation 8.3.1.6.3. The study consists of one synthesis activity that will integrate data generated from tectonics investigations and from Investigations 8.3.1.6.1 and 8.3.1.6.2.

8.3.1.6.3.1 Study: Evaluation of the effects of future tectonic activity on erosion at Yucca Mountain

The objective of this study is to identify the potential effects of tectonic activity on erosion at Yucca Mountain during the postclosure period. The study is aimed at (1) defining those components of erosion that are dependent upon tectonic activity, and (2) determining how future tectonic adjustment might influence local incision rates.

8.3.1.6.3.1.1 Activity: Synthesis and data evaluation of the impact of future uplift or subsidence and faulting on erosion at Yucca Mountain and vicinity

Objectives

The objectives of this activity are to estimate (1) the effects of tectonic activity on erosion over the repository postclosure period on the basis of probable future tectonic scenarios for the Yucca Mountain region, (2) the locations and rates of present and past erosion for present climatic conditions, and (3) the effects of future climatic conditions on erosion.

Parameters

Four sets of parameters will be evaluated in this activity:

1. The rates of regional uplift and subsidence, as determined from studies of tectonic geomorphology Section 8.3.1.17.4.9, and the geodetic leveling network in Section 8.3.1.17.4.10.

2. The tectonic model synthesis, including the probability and expected magnitude of faulting in the Yucca Mountain area during the repository postclosure period from Section 8.3.1.17.2 and 8.3.1.17.4.

3. Present and past locations and rates of erosion from Investigation 8.3.1.6.1.

4. Estimated effects of future climate on erosion from Investigation 8.3.1.6.2.

Description

This synthesis activity will be aimed at identifying the magnitudes of the components of erosion rate (both local and regional) caused by Quaternary tectonic activity, and assessing the effects of probable future tectonic activity on rates of erosion expected in the Yucca Mountain region over the repository postclosure period. The tectonic data for this synthesis will be derived from Programs 8.3.1.8. and 8.3.1.17. Erosion rate data will come from Study 8.3.1.6.1.1 (distribution and characteristics of present and past erosion), Activity 8.3.1.6.1.1.3 (hillslope erosion), Activity 8.3.1.6.2.1.1 (impact of future climatic conditions on erosion), and Study 8.3.1.5.1.4 (paleoenvironmental history of Yucca Mountain region).

The apportionment of local and regional erosion rates (Quaternary through present) into components attributed to climatic and tectonic causes will be critical to this activity. Although climatic conditions are believed to be the dominant control on erosion rates, proposed studies on past erosion in the Yucca Mountain region and the reconstruction of the paleoenvironmental history will yield a quantification of the tectonic erosional component for the Quaternary. Combining local data with projected regional uplift or subsidence rates, and probable local fault movement, will result in quantitative estimates for the tectonic influences on erosion rates in the postclosure period.

Methods and technical procedures

The method and procedure for Activity 8.3.1.6.3.1.1 is given in the following table.

Method	Technical procedure Number	Title	Date
Synthesis: Estimate of the effects of tectonic activity on erosion using the results and conclusions of studies and activities for Investigations 8.3.1.5.1, 8.3.1.6.1, 8.3.1.6.2, 8.3.1.8.2	Needed	Data synthesis	TBD[a]

[a]TBD = to be determined.

8.3.1.6.3.2 Application of results

The information derived from the studies and activities in this investigation (8.3.1.6.3) will be used in Investigation 8.3.1.9.1 (degradation of markers).

8.3.1.6.3.3 Schedule and milestones

The schedule and milestone information for this investigation is given in Section 8.3.1.6.4.3, at the end of Investigation 8.3.1.6.4 (potential effects of erosion on hydrologic, geochemical, and rock characteristics).

8.3.1.6.4 Investigation: Potential effects of erosion on hydrologic, geochemical, and rock characteristics

Because existing data on the effects of erosion on hydrology, geochemistry and rock characteristics satisfy the design and performance requirements, no further studies are planned. Instead, a topical report will be prepared by the NNWSI Project to document the tentative conclusion that erosion will have a negligible effect on the hydrologic, geochemical, and rock characteristics important to waste isolation. The steps to be used in addressing this investigation are shown in Figure 8.3.1.6-5.

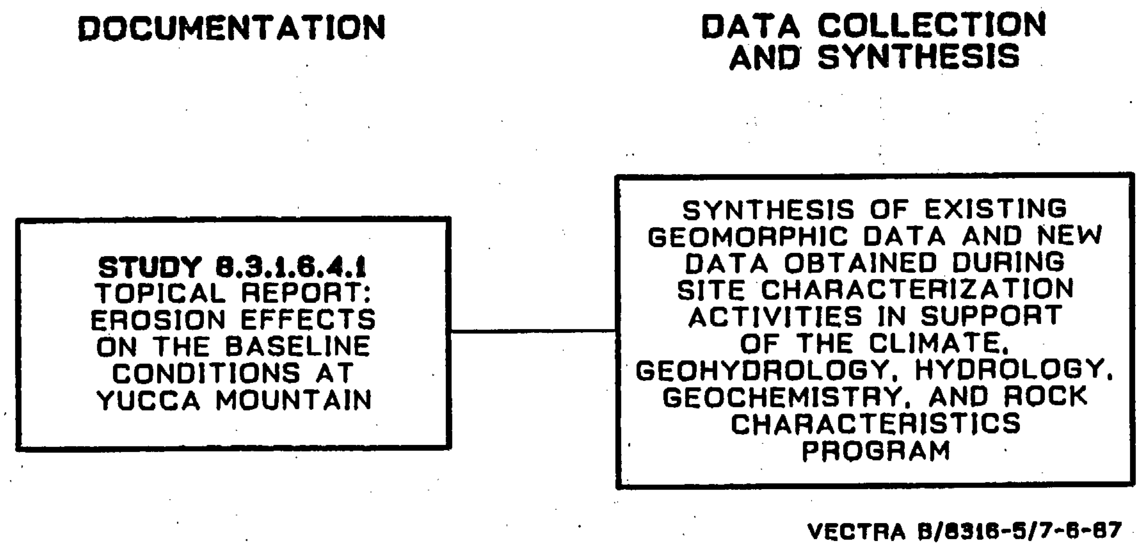


Figure 8.3.1.6-5. Logic diagram for Investigation 8.3.1.6.4.

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters summarize the information related to this investigation:

SCP section	Subject
1.1.3.2	Average erosion rates in the region surrounding Yucca Mountain
1.1.3.3	Significant late Quaternary geomorphic processes in the Yucca Mountain area
1.8.1.1.2	Discussion of significant results (geomorphology)
1.8.3.1	Information needs bearing on geomorphology
2.1, 2.2, 2.3	Mechanical properties of rock units
2.4, 2.5	Thermal and thermomechanical properties
2.6	Existing stress regime
2.7	Special geoengineering properties
2.8	Excavation characteristics
3.7.1	Areas of recharge and discharge
3.7.2	Regional ground-water flow paths
3.9.3	Conceptual model for ground-water flow system
3.9.4	Calculations of ground-water velocity and travel time
3.10	Summary Sections
4.1	Baseline geochemical characteristics at Yucca Mountain

Parameters

The parameters for this investigation are:

1. The expected effects of erosion on hydrologic, geochemical and rock characteristics during the 10,000 yr postclosure period.

2. The probability that the repository will be exhumed during the next 10,000 and 100,000 yr.

Purpose and objectives of the investigation

The product of this investigation, a topical report, will address the possibility that erosional processes at Yucca Mountain could adversely affect the potential for radionuclide releases to the accessible environment because of changes in the ground-water system, the geochemical conditions, or the rock characteristics. The likelihood of radionuclide releases because of changes in the hydrologic system is negligible. The probability that erosion will modify the surface-water regime during the postclosure period is extremely small. For erosion-induced changes in hydrologic characteristics to adversely affect waste isolation, a reduction in ground-water travel time resulting from the removal of enough rock above the water table to modify hydraulic gradients and locations of recharge or discharge near Yucca Mountain would be necessary. It is highly unlikely that expected erosion rates (even considering possible changes in climate and tectonism) will be adequate to cause the removal of sufficient overburden material necessary to change the hydrologic conditions.

Erosion-induced changes in geochemical characteristics that might adversely affect waste isolation most likely would be changes in geochemical properties along flow paths to the accessible environment. The effects of erosion on the geochemical properties along flow paths for both ground water and gases will be discussed in the topical report. Erosion is expected to have negligible effects on mechanical, thermal, or thermomechanical properties, on special geoengineering properties, or on excavation characteristics within the controlled area in ways that would affect waste isolation. Erosion may very slightly modify in situ stresses, but the expected amount of erosion within the controlled area and the corresponding change in in situ stress is so small that effects on waste isolation will be negligible.

One study, consisting of a synthesis activity and an analysis activity, will be undertaken in support of this investigation. The objective of the synthesis activity is to integrate the existing erosion data and additional erosion data that will be obtained from Investigations 8.3.1.6.1 through 8.3.1.6.3, with information on the hydrologic, geochemical, and rock characteristics. These data will be used to develop a topical report that will address the expected effects of erosion on conditions at the site needed to address the requirements of 10 CFR Part 60.

The objective of the analysis activity is to apply statistical techniques to information obtained from Investigations 8.3.1.6.1 through 8.3.1.6.3 to determine with a high level of certainty the probability that repository exhumation by erosional processes will not occur over the next 10,000 and 100,000 yr. The results of the statistical analysis will be presented in a topical report.

8.3.1.6.4.1 Study: Development of a topical report to address the effects of erosion on the hydrologic, geochemical, and rock characteristics at Yucca Mountain

Objectives

The objective of this study is to assemble data showing the expected effects of erosion on (1) the hydrologic, geochemical, and rock characteristics of the controlled area and (2) the ability of the mined geologic disposal system to effectively isolate waste over 10,000 and 100,000 yr after disposal.

Parameters

The following parameters will be considered in the topical report:

1. Rates and locations of future erosion.

2. Depth to water table in the controlled area.

3. Geochemical process along flow paths to the accessible environment.

4. Effect of erosion on retardation of radionuclides by all geochemical processes along ground-water flow paths and gaseous flow paths.

5. Effects of erosion on in situ stresses in the controlled area.

Description

Two topical reports will be prepared that will assemble and analyze existing data and data gathered during site characterization. The first report will address the expected magnitude of erosion in the controlled area and on the extent to which such erosion would reduce ground-water travel time to the accessible environment. The report will also identify and address the expected effects of erosion on the geochemical characteristics along flow paths and the expected effects of erosion on the in situ stresses in the controlled area.

In the second report, existing information and data obtained during site characterization will be used in performing statistical calculations to determine the probability that erosion of overburden materials will result in repository exhumation during 10,000 and 100,000 yr after closure.

Methods and technical procedures

There are no methods and technical procedures for Study 8.3.1.6.4.1.

8.3.1.6.4.2 Application of results

The topical report on the effects of erosion on geohydrology, rock characteristics, and geochemistry will serve as a basis for interaction with the NRC to establish that the data base on erosion is sufficient to terminate further erosion-related site studies. Additional consideration of erosion as a potentially disruptive scenario is necessary for both Issue 1.1 (total system performance, Section 8.3.5.13) and Issue 1.8 (NRC siting criteria, Section 8.3.5.17). The second topical report will present statistical analyses to support the position that the current information is sufficient to resolve all questions related to erosion effects on postclosure waste containment and isolation at the Yucca Mountain site.

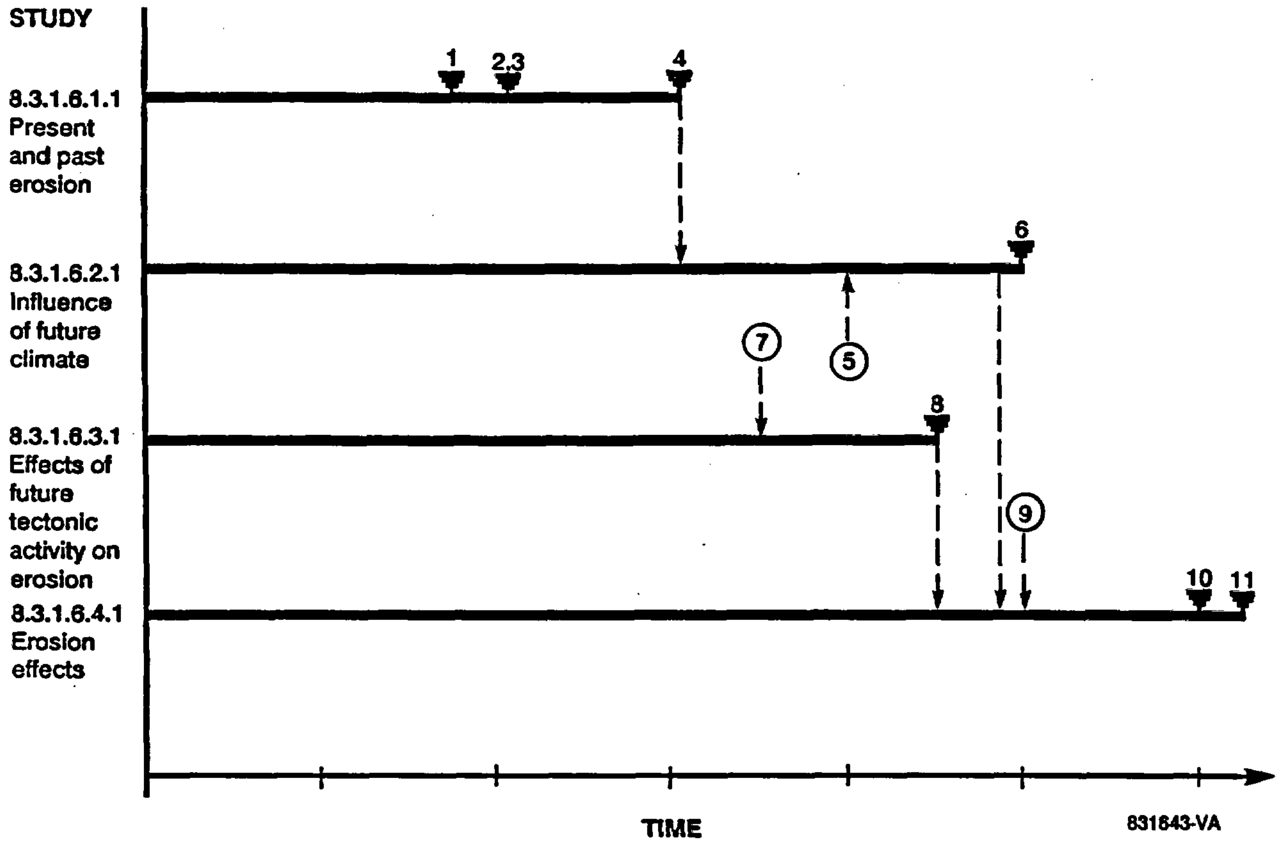
8.3.1.6.4.3 Schedule and milestones

The erosion program consists of four investigations, each of which contain one study: 8.3.1.6.1.1 (distribution and characteristics of present and past erosion), 8.3.1.6.2.1 (influence of future climatic conditions on locations and rates of erosion), 8.3.1.6.3.1 (evaluation of the effects of future tectonic activity on erosion at Yucca Mountain), and 8.3.1.6.4.1 (potential effects of erosion on hydrologic, geochemical, and rock characteristics). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from the implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for these studies can be found in Section 8.5.1.1.

The study on present and past erosion (8.3.1.6.1.1) is ongoing. The experimental and modeling work for this entire program will proceed in parallel with characterization, design, and performance activities and will interact with them in an iterative fashion. Rates and potential locations of erosion are needed to evaluate erosion potential at the shaft for Issue 1.12 (seal characteristics, Section 8.3.3.2), to identify stable locations for surface markers for the human interference program (Section 8.3.1.9), and to evaluate erosion potential at bridges and roads for the surface characteristics program (Section 8.3.1.14).

The completion of investigations in this program are constrained by needs for information from other characterization programs. Completion of the milestone reports will require information from Sections 8.3.1.2 (geohydrology program), 8.3.1.3 (geochemistry program), 8.3.1.5 (climate program), 8.3.1.16 (preclosure hydrology program), 8.3.1.8 (postclosure tectonics program), and 8.3.1.4 (rock characteristics program).

The investigation numbers and titles corresponding to the timeline are shown to the left on the following figure. The points shown on the timeline represent major events or important milestones associated with the investigation. Solid lines represent study durations, and dashed lines show interfaces. The data input or output at the interfaces are shown by circles.



The points on the timeline are described in the following table:

Point number	Description
1	Milestone Z425. Issue report on the origin of hillslope deposits.
2	Milestone Z288. Issue report on the analysis of hillslope erosion.
3	Milestone Z287. Issue report on the analysis of the downcutting history of Fortymile Wash and its tributaries.
4	Milestone Z286. Complete development of geomorphic map of Yucca Mountain.
5	Information received from climate program (Section 8.3.1.5).
6	Milestone Z290. Issue topical report on the evaluation of the impact of future climatic conditions on locations and rates of erosion.

Point number	Description
7	Information received from postclosure tectonics program (Section 8.3.1.8).
8	Milestone Z292. Issue topical report on the evaluation of the impact of future uplift/subsidence and faulting on erosion at Yucca Mountain and vicinity.
9	Information received from the geohydrology, geochemistry, and rock characteristics programs (Sections 8.3.1.2, 8.3.1.3, and 8.3.1.4).
10	Milestone Z294. Issue topical report on the evaluation of future erosion on baseline conditions at Yucca Mountain and vicinity.
11	Milestone Z498. Issue topical report on the effects of erosion on postclosure containment and isolation at Yucca Mountain.

DOE/RW-0160

Chapter 8

Section 8.3.1.7

M

Nuclear Waste Policy Act
(Section 113)

Consultation Draft

ROCK DISSOLUTION

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V

January 1988

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

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8.3.1.7 Overview of rock dissolution program: Description of rock dissolution required by the performance and design issues

Because the findings made for the Yucca Mountain environmental assessment (EA) (DOE, 1986b) are adequate to meet the requirements of Issue 1.8 (Section 8.3.5.17, NRC siting critieria) and 1.9 (Section 8.3.5.18, higher level findings-- postclosure system and technical guidelines) no additional studies are specifically planned to resolve this issue. Further work related to chemical and mineralogical changes in the post-emplacement environment are discussed in Section 8.3.4.2.4.1.

8.3.1.7.1 Investigation: Rates of dissolution of crystalline and noncrystalline components in tuff

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.1	Mineralogy and petrology
4.1.1.3.1	The potential host rock
4.1.1.4	Mineral stability
4.1.2	Ground-water chemistry

Parameters

For this investigation, parameters are not applicable.

Purpose and objectives of the investigation

For this investigation, purpose and objectives are not applicable.

Technical rationale for the investigation

This investigation has been satisfied by information presented in the Yucca Mountain EA (DOE, 1986b). The conclusions in the EA were as follows:

1. No evidence of Quaternary dissolution fronts or other dissolution features has been found.

2. None of the minerals in the host rock are considered soluble under expected repository conditions.

3. There is no evidence of past or potential future significant dissolution that would provide a hydraulic interconnection between the host rock and any immediately surrounding geohydrologic unit.

4. The minerals that compose the rock in and around Yucca Mountain are considered insoluble, and significant subsurface rock dissolution is not a credible process leading to radionuclide releases greater than those allowable under the requirements of 10 CFR Part 960 and 10 CFR Part 60.

Because the findings made for the EA are adequate to meet the higher level findings of 10 CFR Part 960 and 10 CFR Part 60, no additional studies are specifically planned to address this issue. Studies on mineral stability are described in Section 8.3.1.3 (Geochemistry Program). These studies are being done to assess geochemical retardation along flow paths to support the assessments made in Issue 1.1 (total system performance, Section 8.3.5.13).

8.3.1.7.1.1 Application of results

The information generated in this investigation will be used to address higher level findings concerning dissolution (Issue 1.9, Section 8.3.5.18) and the requirements of the NRC siting criteria (Issue 1.8, Section 8.3.5.17).

8.3.1.7.1.2 Schedule and milestones

Investigation 8.3.1.7.1 (dissolution rates) has been satisfied and, therefore, no schedule and milestone information is required.

Chapter 8

Nuclear Waste Policy Act
(Section 113)

Section 8.3.1.8

M

Consultation Draft

POSTCLOSURE TECTONICS

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V

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8.3.1.8 Overview of the postclosure tectonics program: Description of future tectonic processes and events required by the performance and design issues

Summary of performance and design requirements for postclosure tectonics information

The flow of data through the postclosure tectonics program is shown in Figure 8.3.1.8-1. The performance and design requirements that the postclosure tectonics program must address are to supply data on the probability and effects of tectonic "initiating events" that may alter existing conditions at Yucca Mountain and adversely affect repository performance. These requirements for tectonic information can be summarized as follows:

1. Data on the probability and effects of potentially significant tectonic release-scenario classes addressing both anticipated and unanticipated conditions that are needed for performance assessment calculations of radionuclide releases to the accessible environment (Issue 1.1, Section 8.3.5.13, total system performance).

2. Data required to perform the analysis to determine the degree to which each of the favorable and potentially adverse conditions listed in 10 CFR 60.122 contributes to or detracts from isolation (Issue 1.8, Section 8.3.5.17, NRC siting criteria).

3. Data needed to accommodate requirements for knowledge of site-specific tectonic conditions in design concepts for the geometry, layout, and emplacement borehole locations of the underground facility (Issue 1.11, Section 8.3.2.2, configuration of underground facilities (postclosure)).

4. Data required so that the higher level findings of 10 CFR Part 960 can be evaluated (Issue 1.9a, Section 8.3.5.18, higher level findings (postclosure)).

Four investigations in the postclosure tectonics program provide the analysis and assessment of data necessary to meet these requirements (Figure 8.3.1.8-1). These four investigations have been designed to parallel the intermediate performance measures and initiating events defined in Sections 8.3.5.13 and 8.3.2.2. Investigation 8.3.1.8.3 (tectonic effects on hydrology) has been further subdivided into three separate intermediate performance measures because of the number of performance parameters that have been identified by Issue 1.1 in this investigation. The final column of Figure 8.3.1.8-1 identifies the investigations that will provide data required by Investigations 8.3.1.8.1 through 8.3.1.8.4 in order to complete their analysis and assessment for the postclosure tectonics program. These data collection investigations include Investigation 8.3.1.8.5 which will house the data collecting studies and activities specific to the postclosure tectonics program and investigations from several other programs that provide important data for the analysis and assessment investigations.

Tables 8.3.1.8-1 through 8.3.1.8-6 list the favorable and potentially adverse conditions on which data are required for the resolution of Issue 1.8 and the performance measures, intermediate performance measures and

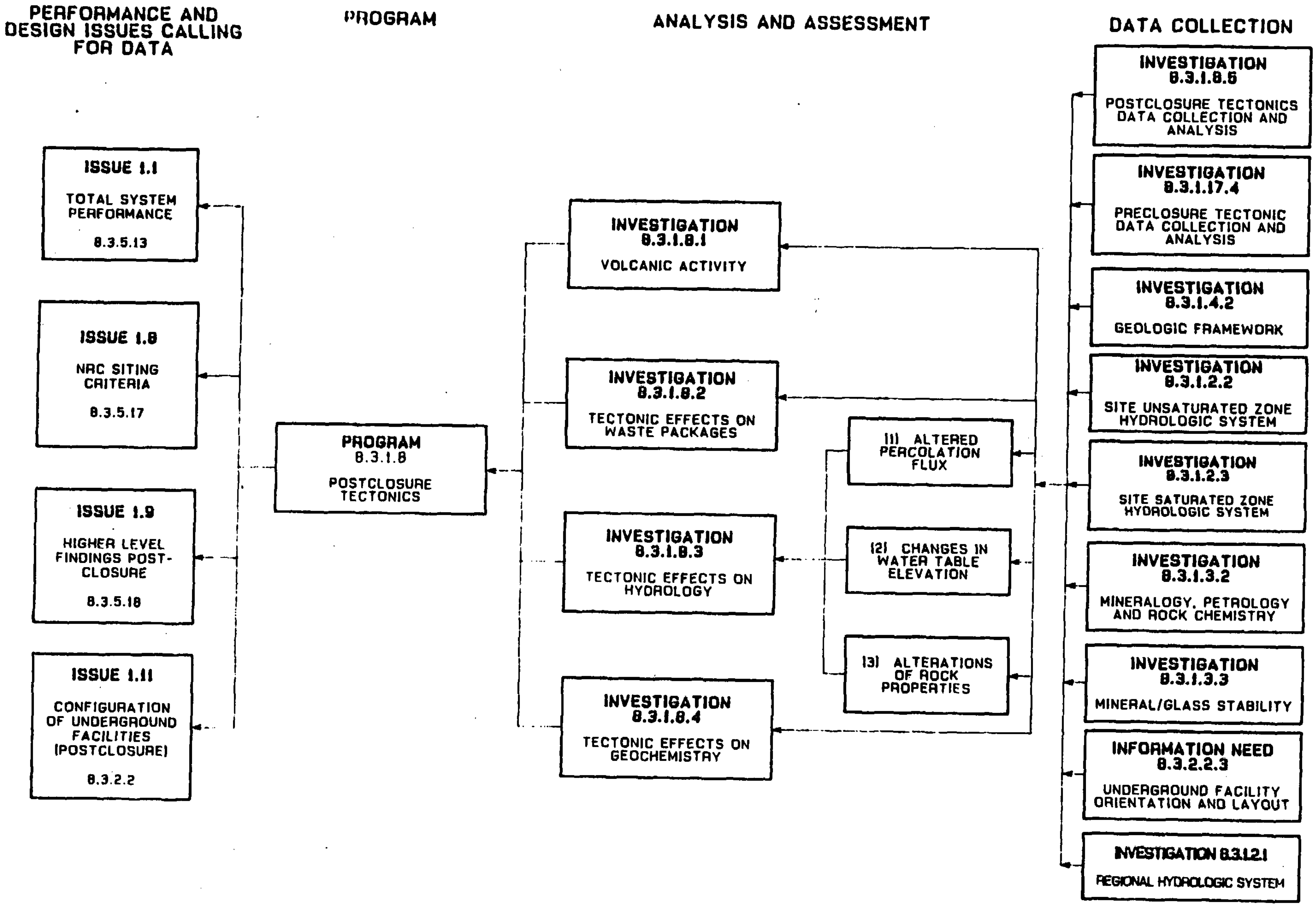


Figure 8.3.1.8-1. Relationships between the postclosure tectonics program, investigations, and performance design issues.

CONSULTATION DRAFT

Table 8.3.1.8-1(a). Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Tentative goal	Intermediate performance parameter	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance)	15	1	Volcanic eruption penetrates repository and causes direct releases to the accessible environment.	EPPM[a]	<<1	Not applicable	--	Annual probability of volcanic eruption that penetrates the repository
8.3.5.17 (Issue 1.8, NRC siting criteria)								Effects of volcanic eruption penetrating repository, including area of repository disrupted
8.3.5.18 (Issue 1.9, higher level findings-postclosure)								

[a]EPPM = expected partial performance measure (Section 8.3.5.13).

Table 8.3.1.8-1(b). Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of volcanic eruption that penetrates the repository	$< 10^{-6}$ per yr	High	Location and timing of volcanic events	See Section 1.3.2.1.2	Moderate	High	8.3.1.8.5	8.3.1.8.5.1.1 - Volcanism drillholes 8.3.1.8.5.1.2 - Geochronology studies 8.3.1.8.5.1.3 - Field geologic studies 8.3.1.8.5.1.4 - Geochemistry of scoria sequences
			Evaluation of structural controls on volcanism	See Section 1.3.2.1	Low	Moderate	8.3.1.8.1	8.3.1.8.1.1.1 - Location and timing of volcanic events
							8.3.1.8.5	8.3.1.8.5.1.3 - Field geologic studies 8.3.1.8.5.1.5 - Regional geochemical evolution of the DV-PRVZ
							8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Presence of magma bodies in the vicinity of the site	See Section 1.3.2.1	Low	Moderate	8.3.1.17.4	8.3.1.17.4.7 - Subsurface geometry of Quaternary faults at Yucca Mountain
							8.3.1.8.5	8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain
							8.3.1.17.4	8.3.1.8.4.1.2 - Monitor current seismicity 8.3.1.17.4.3.1 - Evaluate crustal structure and subsurface expression of Quaternary faults

Table 8.3.1.8-1(b). Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Effects of volcanic eruption penetrating repository, including area of repository disrupted, and confidence bounds of estimate	Show that < 0.1% of repository area is disrupted with a conditional probability of <0.1 of being exceeded in 10,000 yr, should such an intrusion occur	Moderate	Effects of Strombolian eruptions	< 0.05% of repository area disrupted	Moderate	Moderate	None planne (See Sections 1.3.2.1 and 1.5.1	
			Effects of hydrovolcanic eruptions	Data not available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.1.3 - Field geologic studies

Table 8.3.1.8-2(a). Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Tentative goal	Intermediate performance measure	Performance parameter
8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.2.2 (Issue 1.11, configuration of underground facilities-postclosure)	15	1	Igneous intrusion penetrating repository resulting in failure of waste packages	Usable area: is usable area adequate for 70,000 MTU of waste?	Probability < 0.1 in 1,000 yr that > 0.5% of waste packages will be ruptured by tectonic processes or events	Not applicable	Probability of igneous intrusion penetrating repository Effects of igneous intrusion penetrating repository
8.3.5.18 (Issue 1.9, higher level findings-postclosure)	11	1	Offset of one or more faults intersect waste packages and cause failure	Same as above	Same as above	Same as above	Number of waste packages affected by fault penetrating repository Probability of faulting with displacement over 5 cm in repository
	12 13 14	1	Ground motion causes spalling or failure and closes air gap around waste package	Same as above	Placement of waste packages in zones with rock properties that will not lead to failure during expected ground motions	Same as above	Expected ground motion at emplacement boreholes in 1,000-yr period
	11	1	Folding or distributed shear causes waste emplacement borehole deformation and results in waste package failure	Same as above	Probability < 0.1 in 1,000 yr that >0.5% of waste packages will be ruptured by tectonic processes or events	Same as above	Rate of deformation due to folding or distributed shearing in repository horizon

Table 8.3.1.8-2(b). Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of igneous intrusion penetrating repository	Annual probability less than 10^{-6}	High	Characterization parameters identical to Investigation 1.10.1	10^{-8} to 10^{-10}	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of igneous intrusion penetrating repository	Less than 0.5% of waste packages disrupted	Low	Number of waste packages disrupted by intrusion	1 to 10	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - *Effects* of Strombolian eruptions
							8.3.2.2.3	8.3.2.2.3 - Design concepts for the underground facility
Number of waste packages affected by fault penetrating repository	Less than 0.5% of waste packages intersected by a single fault with a 95% level of confidence	High	Width of Quaternary fault zones in and near site in which faulting exceeds 5 cm in a single event	< 5 m	Low	Moderate	8.3.1.17.4	8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
			Orientation of faults in and near the repository block	N.25.W-N.25.E	Moderate	Moderate	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4	8.3.1.4.2.3.1 - Development of 3-D geologic model of the site area
							8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Repository layout of waste packages and fault slip rates	See Section 6.2.6; < 0.01 mm/yr	Moderate	High	8.3.2.2.3	8.3.2.2.3 - Design concepts for the underground facility
							8.3.1.17.4	8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

CONSULTATION DRAFT

Table 8.3.1.8-2(b). Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of faulting with displacement over 5 cm in repository	Annual probability less than 10^{-4} of faulting with displacement over 5 cm	Moderate	Characteristics of faults that penetrate the repository with total offset > 10 m				8.3.1.17.4	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff 8.3.1.2.3.1 - Development of 3-D geologic model of the site area
			Density Length Total Offset	See Section 1.3.2.2.2 < 3000 m 10-50 m	Low Moderate Moderate	Moderate High High	8.3.1.4.2	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Age and recurrence of movement on suspected and known Quaternary faults
			Characteristics of Quaternary faults in and near site with slip rates > 0.001 mm/yr				8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Age and recurrence of movement on suspected and known Quaternary faults
			Location Slip rate Length Total offset	See Figure 1-36 < 0.01 mm/yr < 35 km 200-500 m	Moderate Moderate Low Low	High High Moderate High		8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
Expected ground motion at emplacement boreholes in 1,000-yr period	Probability of exceeding ground motion values < 0.1 in 1,000-yr	Moderate	Characterization parameters identical to Investigation 8.3.1.17.3	Expected PGA[a] (10,000 yr return period) 0.5-0.7g	Low-moderate	Moderate	8.3.1.17.3	8.3.1.17.3.5.2 - Characterize ground motion from the controlling seismic events 8.3.1.17.3.6.2 - Evaluate ground motion probabilities
Rate of deformation due to folding or distributed shearing in repository horizon	Waste emplacement boreholes will be subject to < 0.005 shear strain in 1,000 yrs as a result of folding or deformation	Low	Nature and age of folding in the repository horizon	No detectable folding in 10 million yr	Moderate	High	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of 3-D geologic model of the site area
							8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
							8.3.1.8.2	8.3.1.8.2.1.2 - Calculation of the number of waste packages intersected by a fault

[a]PGA = Peak Ground Acceleration.

Table 8.3.1.8-3(a). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 1 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	3, 15	1, 8(i)	Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	EPTM[a]	<< 1	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties and geochemical properties	Tectonic processes and events will not adversely alter the average percolation flux at the top of the Topopah Spring welded unit by more than a factor of 2. The probability of exceeding the goal will be <0.1 in 10,000 yr	Annual probability of volcanic events within the controlled area Effects of a volcanic event on topography and flux rates
			Igneous intrusion, such as a sill, that could result in a significant change in average flux	Same as above	Same as above	Same as above	Same as above	Annual probability of significant igneous intrusion in the controlled area Effects of an igneous intrusion on flux rates
	3, 4, 11	1, 8(i)	Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds, thereby significantly changing average flux	Same as above	Same as above	Same as above	Same as above	Probability of offset > 2 m on a fault in the controlled area in 10,000 yr Probability of changing dip by by > 2° in 10,000 yr by faulting Effect of faulting on flux rates

Table 8.3.1.8-3(a). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 2 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
	3, 4, 11	1, 8(i)	Folding changes dip of tuff beds controlled area thereby significantly changing average flux	EPPM	$\ll 1$	Same as above	Same as above	Probability of changing dip by > 2° in 10,000 yr by folding
	3, 4, 11, 16	1, 8(i)	Uplift or subsidence changes topography or drainage thereby significantly changing average flux	Same as above	Same as above	Same as above	Same as above	Probability of exceeding 30 m elevation change in 10,000 yr

[a]EPPM = expected partial performance measure (see Section 8.3.5.13).

Table 8.3.1.8-3(b). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of volcanic events within the controlled area	$< 10^{-5}$ per yr	High	Probability calculation for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of a volcanic event on topography and flux rates	Show topographic changes are not great enough to significantly affect flux	Low	Data on topographic changes caused by an eruption	See Section 1.5.1.2.2	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - Effects of Strombolian eruptions 8.3.1.8.1.2.2 - Effects of hydrovolcanic eruptions
			Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling
Annual probability of significant igneous intrusion in the controlled area	$< 10^{-5}$ per yr	High	Probability calculation for igneous events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of an igneous intrusion on flux rates	Show igneous intrusion will not significantly affect flux because of depth, location, and extent of intrusion	Low	Orientation and dimensions of possible intrusions at the site	≈ N.30.E; < 4 km x 0.3-4 m	Moderate	Moderate	No new activities planned	--
			Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling
Probability of offset > 2 m on a fault in the controlled area in 10,000 yr	$< 10^{-1}$ per 10,000 yr	Moderate	Vertical slip rate and recurrence interval on Quaternary faults in and near the site	Slip rate < 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.4.3 - Evaluate Stagecoach Road fault zone
							8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

Table 8.3.1.8-3(b). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of changing dip by > 2° in 10,000 yr by faulting	< 10^{-4} per 10,000 yr	Low	Vertical slip rate on Quaternary faults in and near the site and rate of tilting	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
							8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area
Effect of faulting on flux rates	Show faulting will not significantly affect flux because of low slip rate	Moderate	Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling
Probability of changing dip by > 2° in 10,000 yr by folding	< 10^{-4} per 10,000 yr	Low	Rate of folding in the unsaturated zone section	No detectable folding in 10 million yr	Moderate	High	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4.3	8.3.1.4.2.2.4 - Geologic mapping of the exploratory shaft and drifts
Probability of exceeding 30 m elevation change in 10,000 yr	< 10^{-4} per 10,000 yr	Low	Rate of uplift or subsidence at site	< 3×10^{-2} mm per yr	Moderate	Moderate	8.3.1.17.4	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area 8.3.1.17.4.9.2 - Evaluate extent of Quaternary uplift and subsidence at and near Yucca Mountain 8.3.1.17.4.10 - Geodetic leveling

Table 8.3.1.8-4(a). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water table elevation) (page 1 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings - postclosure)	5, 15, 22, 23	1, 8(ii)	Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	EPPM[a]	<< 1	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Water table will not rise to within 100 m of emplaced waste in 10,000 yr	Annual probability of a significant igneous intrustion within 0.5 km of controlled area boundary
							No discharge points created in the controlled area	Barrier-to-flow effects of igneous intrusions on water-table levels
							Perched aquifers will not be created within 100 m of emplaced waste	Thermal effects of igneous intrusions on water-table levels
							The probability of exceeding the goals will be < 0.1 in 10,000 yr	
	4, 5, 11, 22, 23	1, 8(ii)	Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Same as above	Same as above	Same as above	Same as above	Probability that strain-induced changes increased to potentiometric level to > 850 m mean sea level

Table 8.3.1.8-4(a). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water table elevation) (page 2 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
	4, 5, 11, 22, 23	1, 8(ii)	Folding, uplift, or subsidence lowers repository with respect to water table	Same as above	Same as above	Same as above	Same as above	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr
	4, 5, 11, 22, 23	1, 8(ii)	Offset on fault juxtaposes transmissive and nontransmissive units resulting in either the creation of a perched aquifer or a rise in the water table	Same as above	Same as above	Same as above	Same as above	Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary Effects of fault offset on water-table levels

[a]EPPM = expected partial performance measure (see Section 8.3.5.13).

Table 8.3.1.8-4(b). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water-table elevation) (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of a significant igneous intrusion within 0.5 km of controlled area boundary	$< 10^{-6}$ per yr	Moderate	Probability calculation for volcanic events	10^{-7} to 10^{-8} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.4 - Probability calculations and assessment
Barrier-to-flow effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	Low	Orientation and dimensions of possible intrusions at the site	Orientation: N.20°-40°E. Length: 400-4000 m	Moderate	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Thermal effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,0000 yr	Low	Model thermal effects around a dike	400°C at 2 m distance after 40 days	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - Effects of Strombolian eruptions 8.3.1.8.1.1.3 - Presence of magma bodies in vicinity of site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Probability that strain-induced changes increase potentiometric level to > 850 m MSL	$< 10^{-5}$ per yr	Low	Strain rates and strain changes due to faulting	See Section 1.3.2.3	Low	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$< 10^{-4}$ per 10,000 yr	Low	Folding, uplift, and subsidence rates in site area	$< 3 \times 10^{-2}$ mm per yr	Moderate	Moderate	8.3.1.17.4	8.3.1.17.4.9.2 - Evaluate extent of Quaternary uplift and subsidence at and near Yucca Mountain 8.3.1.17.4.10 - Geodetic leveling
							8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff 8.3.1.4.2.2.4 - Geologic mapping of exploratory shaft and drifts
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area

Table 8.3.1.8-4(b). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water-table elevation) (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary	< 10^{-1} per 10,000 yr	Low	Slip rates on Quaternary faults in and near site	< 0.01 mm/yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.4.3 - Evaluate Stagecoach Road fault zone 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Effects of fault offset on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	High	Orientation and length of faulting	N.25°E. - N.25°W. 10-20 km	Moderate	Moderate	8.3.1.17.3	8.3.1.17.3.1 - Relevant earthquake sources
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
			Hydrologic model of unsaturated flow system	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling
			Evidence of higher water levels in Quaternary due to faulting	See Section 1.2.2.2.10	Low	Moderate	8.3.1.5.2	8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits

Table 8.3.1.8-5(a). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 3; alteration of rock properties along significant travel paths)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	5, 15, 24	1, 8(i)	Igneous intrusion causes changes in hydrologic properties	EPPM[a]	<< 1	Radionuclide transport time through UZ, given fixed thickness of UZ	The localized flux along travel paths from the repository to the accessible environment will not be significantly increased for distances that are a significant part of the travel path over 10,000 yr	Annual probability of significant igneous intrusions within 0.5 km of controlled area boundary Effects of igneous intrusions on local fracture permeabilities and effective porosities
	4, 5, 11, 24	1, 8(i)	Episodic offset on faulting causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, creating barriers to flow, or creating new conduits for drainage	Same as above	Same as above	Same as above	Same as above	Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary Effects of fault motion on local fracture permeabilities and effective porosities
	4, 5, 11, 24	1, 8(i)	Changes in stress or strain in the controlled area resulting from episodic faulting, folding, or uplift causes changes in the hydrologic properties of the rock mass	Same as above	Same as above	Same as above	Same as above	Effects of changes of stress or strain on hydrologic properties of the rock mass

[a]EPPM = expected partial performance measure (Section 8.3.5.13).

Table 8.3.1.8-5(b). Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 3; alteration of rock properties along significant travel paths)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of significant igneous intrusions within 0.5 km of controlled area boundary	$< 10^{-6}$ per yr	Moderate	Probability calculation for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.4 - Probability calculations and assessment
Effects of igneous intrusions on local fracture permeabilities and effective porosities	Show no significant changes in rock hydrologic properties	Low	Evidence of change in rock properties around dikes in the region	No data available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.2.2 - Chemical and physical changes around dikes
Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary	Show $< 10^{-4}$ per yr for each fault	High	Location of Quaternary faults in and near site	See Figure 1-36	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Slip rate and recurrence interval for Quaternary faults in and near site	Slip rate < 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Effects of fault motion on local fracture permeabilities and effective porosities	Show change in fracture permeability is < a factor of 2, and that fracture porosity increases	High	Evidence of episodic rock property changes along faults	See Section 1.3.2.2.2	Low	Moderate	8.3.1.4.2	8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures 8.3.1.4.2.2.4 - Geologic mapping of exploratory shaft and drifts 8.3.1.3.2.1.3 - Fracture mineralogy
Effects of changes of stress or strain on hydrologic properties of the rock mass	Show changes in conductivity and porosity of rock mass are < a factor of 2	Low	Potential stress and strain changes in the rock mass due to faulting or other tectonic processes	See Section 1.3.2.3	Low	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic models of flow in the saturated and unsaturated zone	See Sections 3.9.2.1 and 3.9.3.2.2	Low	Moderate	8.3.1.2.2 8.3.1.2.3	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling 8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models

Table 8.3.1.8-6(a). Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	8, 15, 24	1, 3	Igneous intrusion causes changes in rock geochemical properties	EPPM[a]	<< 1	Radionuclide transport time through UZ, given fixed thickness of UZ	For radionuclides with travel times less than 10,000 yr, the change in K_ds will not be more than a factor of 2 in 10,000 yr with a high level of confidence	Annual probability of igneous intrusions within 0.5 km of the controlled area boundary Effects of intrusions on local rock geochemical properties
	8, 11, 24	1, 3	Offset on a fault causes changes in movement of ground water that result in mineralogical changes along fault zone	Same as above	Same as above	Same as above	Same as above	Probability of movement and location of Quaternary faults in controlled area Degree of mineral changes in fault zone in 10,000 yr
	8, 11, 24	1, 3	Offset on a fault changes travel pathway to one with different geochemical properties	Same as above	Same as above	Same as above	Same as above	Probability of total offsets > 2.0 m in 10,000 yr on a fault within 0.5 km of controlled area boundary Effects of fault offset on travel pathway
	8, 11, 24	1, 3	Tectonic processes cause changes in ground-water table or movement that results in mineral changes in controlled area	Same as above	Same as above	Same as above	Same as above	Degree of mineral change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr

[a]EPPM = expected partial performance measure (Section 8.3.5.13).

Table 8.3.1.8-6(b). Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of significant igneous intrusions within 0.5 km of the controlled area boundary	$< 10^{-5}$ per yr	Moderate	Probability calculations for volcanic events	10^{-7} to 10^{-8} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.4 - Probability calculations and assessment
Effects of intrusions on local rock geochemical properties	Show potential changes in mineralogy will not be extensive	Low	Evidence of change in geochemical properties around dikes in the region	Data not available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.2.2. - Chemical and physical changes around dikes
Probability of movement within 2 km of surface and location of Quaternary faults in controlled area	$< 10^{-4}$ per yr for each fault	Moderate	Location of Quaternary faults in controlled area	See Figure 1-36	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Slip rate and recurrence intervals for Quaternary faults in the controlled area	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Degree of mineralogic change in fault zone in 10,000 yr	Show adverse changes in mineralogy will not occur	Moderate	Nature and age of mineralogic changes on faults in the controlled area	See Section 1.3.2.3	Low	Moderate	8.3.1.4.2	8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures 8.3.1.4.2.2.4 - Geologic mapping of shafts and drifts 8.3.1.3.2.1.3 - Fracture mineralogy 8.3.1.3.2.2 - History of mineralogic and geochemical alteration of Yucca Mountain
Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary	$< 10^{-1}$ per 10,000 yr	Moderate	Slip rates on Quaternary faults in and near site	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.4.3 - Evaluate Stagecoach Road fault zone 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

Table 8.3.1.8-6(b). Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Effects of fault offset on travel pathway	Show significant changes will not occur	Moderate	Hydrologic models of unsaturated and saturated zone flow	See Sections 3.9.3.2.1 and 3.9.3.2.2	Moderate	High	8.3.1.2.2 8.3.1.2.3	8.3.1.2.2.9 - Unsaturated zone flow and transport modeling 8.3.1.8.3.3.1 - Conceptualization of saturated zone flow models
Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr	Show adverse changes in mineralogy will not occur	Low	Probability and magnitude of hydrologic changes	Data not available	Low	Moderate	8.3.1.8.3	8.3.1.8.3.2.2 - Assessment of the effects of igneous intrusion on water-table elevations 8.3.1.8.3.2.3 - Assessment of the effect of strain changes on water-table elevation 8.3.1.8.3.2.4 - Assessment of the effect of folding, uplift, or subsidence on water-table elevation 8.3.1.8.3.2.6 - Assessment of the effect of faulting on water-table elevation

performance parameters on which data are required by Issue 1.1 and Issue 1.11. Each table is linked to a specific performance or intermediate performance measure identified by Issue 1.1 or 1.11 and a specific post-closure tectonics program investigation. The first column in Part A of the tables identifies the performance or design issue that has requested information from the postclosure tectonics program. The second and third columns identify the potentially adverse and favorable conditions from Issue 1.8 that will be addressed by each initiating event.

The fourth column lists the initiating events identified by Issues 1.1 or 1.11 that are related to the performance measure or intermediate performance measure. Initiating events are tectonic events or processes that, if they should occur during the period of interest, could directly or indirectly lead to releases or adversely affect estimates of release at the accessible environment boundary. An example of an initiating event that could directly lead to releases is the penetration of the repository by a volcanic event. Most initiating events only indirectly affect estimates of release by potentially altering another parameter (such as average percolation flux rates) that, if changed, could adversely affect estimates of releases at the accessible environment boundary.

The fifth and sixth columns identify a performance measure and associated goal. Performance measures are high level measures of total system performance and are described in more detail in Section 8.3.5.13 (Issue 1.1) and Section 8.3.2.2 (Issue 1.11). The seventh and eighth columns describe an intermediate performance measure and associated goal that is related to a significant component of the radionuclide release calculation (e.g., average percolation flux rates) that could be altered by tectonic processes or events. The goal for the intermediate performance measure is not intended to indicate the expected value that will result from the analysis of the tectonics program or the value at which the site would fail to meet the system performance objective. Instead, the goal provides an estimate of when the initiating event may start to become significant in performance calculations and is intended to provide guidance to the tectonics program on the level of accuracy or precision required in the program's analyses. The intermediate performance measures and the scenario classes to which they belong are further described in Section 8.3.5.13 for Issue 1.1 or in Section 8.3.2.2 for Issue 1.11.

The final column in Part A describes the performance parameters that have been related by Issue 1.1 or Issue 1.11 to each initiating event. For each initiating event in the tectonics program there are usually two performance parameters. The first performance parameter provides the probability that the tectonic event described in the initiating event will occur during the period of interest. In many instances, estimating probabilities for a tectonic initiating event over 10,000 yr may be difficult. Evaluation of these probabilities are subject to considerable uncertainty, but these uncertainties are quantifiable using available data and judgment. The second performance parameter provides a description of the effects of the event on the concern described in the intermediate performance measure should such an event actually occur. The specific requirements of 10 CFR Part 960 are not explicitly addressed in the tables because it has been determined that no additional data are needed to make the higher level findings of 10 CFR Part 960 over that required to resolve Issue 1.1 (total system performance, Section 8.3.5.13) and Issue 1.8 (10 CFR Part 60, NRC siting criteria, Section 8.3.5.17). Detailed discussion of the 10 CFR Part 960 higher level findings can be found in Section 8.3.5.18 (higher level findings--postclosure).

Part A of Tables 8.3.1.8-1 through 8.3.1.8-6 basically repeats the information called for in Tables 8.3.5.13-9 through 8.3.5.13-16 in Issue 1.1 and the requirements of Issue 1.11 (Section 8.3.2.2). Part B of the tables indicates the data that will be used and the activities supplying the data necessary in addressing the performance parameters. The first column of Part B repeats the performance parameters from Part A to provide a link between the two parts of the table. The second column provides a tentative parameter goal for the performance parameter. Like the goals for intermediate performance measure, performance parameter goals are intended to provide guidance on the level of accuracy or precision required in addressing the performance parameter rather than indicating anticipated results or levels at which total system performance objectives would not be met. The third column presents a subjective judgment on the needed level of confidence and relative importance of the performance parameters in order to demonstrate that the goals for the performance measure and intermediate performance measure are satisfied. These judgments combine a consideration of the level of detail that can reasonably be achieved in addressing the parameter, the probability of the initiating event having a significant impact on the component of the system performance calculation being considered, and the probability of the initiating event occurring. The information in this column is intended to provide guidance to the data gathering activities on the relative amount of effort that should be expended in addressing each performance parameter.

The fourth column identifies the characterization parameters associated with each performance parameter. A characterization parameter is an item of information necessary to prepare the analysis called for in the performance parameter. Characterization parameters are frequently higher level parameters themselves in that data supplied by other activities must generally be compiled and synthesized to supply the necessary information. The fifth column provides the current estimate of the characterization parameter. These estimates are based on the data presented in Chapter 1, the references supporting Chapter 1, and the technical judgments based on these data. The sixth and seventh columns provide a judgment of the confidence in the current estimate of the characterization parameter and a judgment of the confidence needed at the end of site characterization in the characterization parameter. These two columns are intended to provide guidance to the data collecting activities on the amount of additional effort that is required to complete the program. The final two columns in Part B identify the investigation number, and number and short title of the specific studies or activities that are called upon to supply data to satisfy the characterization parameter.

The approach used in this program to satisfy the data needs listed in the performance parameters is to have one activity associated with each initiating event whose role is to prepare a report that provides an assessment of that event. The assessment will address the performance parameters associated with the initiating event and provide an overview of the probability of significant changes in existing conditions that could affect radionuclide release rates resulting from the tectonic process being considered. The report will provide the basis for deciding how the initiating event will be treated in repository performance assessment calculations. The data presented in Chapters 1 and 4 indicate that several of the initiating events (e.g., those related to uplift, folding, and geochemical changes) can be considered as non-credible in repository release calculations. In these cases, the reports prepared by this program will document this conclusion using existing data or bounding calculations, and little or no additional data will be gathered to directly address these initiating events.

Approach to satisfy performance and design requirements

Both the NRC technical criteria (10 CFR 60.122) and the DOE siting guidelines (10 CFR 960.4-2-7) require that prediction of future tectonic processes and events be determined from projections based on an examination of these processes and events during the Quaternary. The NNWSI Project, therefore, intends to base its analysis of performance measures on a projection of Quaternary rates of tectonic processes on geologic structures at and proximal to the site.

This program also supplies data for the resolution of Issue 1.8 (Section 8.3.5.17): analyses to determine the degree to which each of the favorable and potentially adverse conditions, if present, has been characterized and the extent to which it contributes to or detracts from isolation. Specific guidance on the scopes of these analyses is provided in 10 CFR 60.21(c)(1)(ii)(B): "For the purpose of determining the presence of the potentially adverse conditions, investigations shall extend from the surface to a depth sufficient to determine critical pathways for radionuclide migration from the underground facility to the accessible environment. Potentially adverse conditions shall be investigated outside of the controlled area if they affect isolation within the controlled area."

The data identified in the first four investigations will provide the additional detail necessary to accurately characterize the effects of tectonic processes operating at or near the site and to measure the rates at which they operated during the Quaternary. This information will then be used to provide the projection of future rates necessary to satisfy the performance parameters. Before each data gathering activity begins, the related performance parameters will be evaluated to determine if currently available data are sufficient to satisfy the parameter with the required level of confidence. If the performance parameter has been satisfied, then further studies will not be undertaken (Figure 8.3.1.8-2). If the parameter has not been satisfied, then the feasibility of planned or potential activities will be evaluated to determine if the activities will reasonably increase the level of confidence in the parameters that describe the process or not. If it is not feasible to increase the level of confidence, then no additional studies will be performed and the site performance will be evaluated on the basis of available data. The data gathering activities identified in the analysis and assessment investigations will be undertaken if they are found to provide the additional data or confidence necessary to resolve the performance parameter.

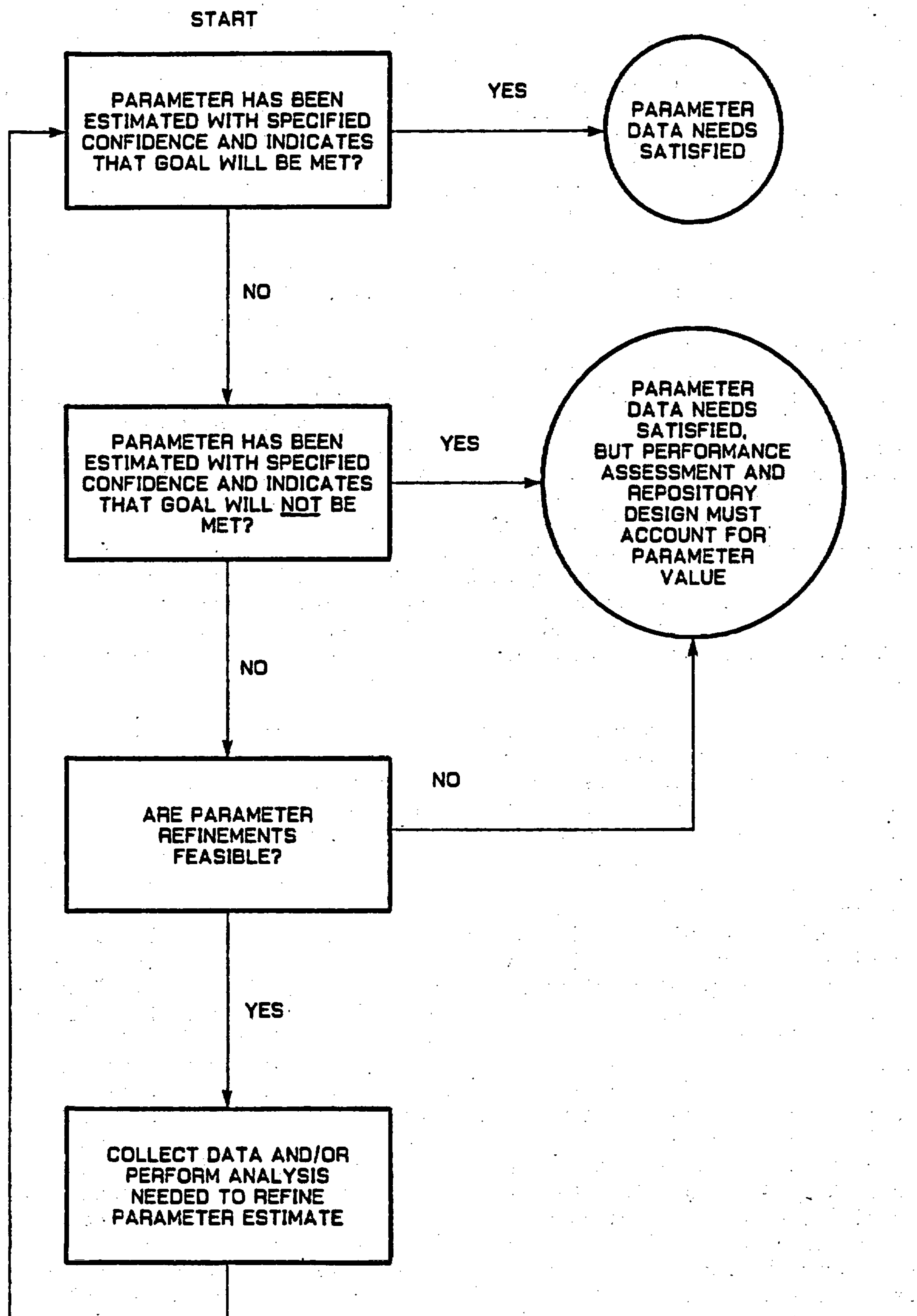


Figure 8.3.1.8-2. Parameter analysis

Various data are used to make the projections of tectonic processes and events into the future, including earthquake observations, fault measurements, geologic mapping, drilling, gravity and magnetic surveys, and other geophysical data. Alternative interpretations of the data will be explored and evaluated with respect to implications for repository performance. These multiple interpretations will be refined to the extent necessary to establish the degree of confidence in the parameter characterization that is specified by the intermediate performance measure goals and performance parameter goals (Tables 8.3.1.8-1 through 8.3.1.8-6).

Five investigations have been identified under the postclosure tectonics program. The first four investigations are related to the six intermediate performance measures in Tables 8.3.1.8-1 through 8.3.1.8-6. The studies and activities connected with these investigations provide the analysis and interpretation necessary to evaluate the site against the performance parameter. These analysis activities also identify the type and level of detail of the data necessary for the resolution of the performance parameter. Because the analysis and interpretation activities for different performance parameters repeatedly call for the same type of data, data gathering activities are grouped separately under a fifth investigation that feeds data as required to the analysis activities associated with the performance and characterization parameters. The interrelationships among the investigations in this program are shown in Figure 8.3.1.8-1. Much of the data required to resolve this issue will be collected by activities associated with other programs. These activities and the data they are required to provide are identified in the investigation descriptions and in their accompanying logic diagrams.

Studies for Investigation 8.3.1.8.1 will provide the analyses to satisfy the performance parameters related to direct releases resulting from volcanic activity. These performance parameters address the initiating event related to the direct intrusion of magma into the repository or potential explosive episodes (hydrovolcanism) that may result from such intrusions which could directly result in releases to the accessible environment. As discussed in Sections 1.3 and 1.5, basaltic volcanism is considered the only credible scenario for igneous intrusion in the controlled area during the postclosure time period. Preliminary calculations of the probability of basaltic volcanism (Section 1.5.1.2.3) indicate that this type of igneous activity may fall into the range of unanticipated events (between 10^{-5} and 10^{-8} annual probability). The performance goal assumes that annual probabilities of occurrence for this type of event are independent of time (Poisson recurrence model) and sets for a goal that this type of event will remain unanticipated with a high level of confidence (10^{-6} annual probability or 99 percent level of confidence that the event will not occur in 10,000 yr). The strategy used in this investigation is to gather more refined data on the age, occurrence, and relation to geologic structure of basaltic volcanism in the site area and to use these data to calculate more detailed probabilistic assessments of the potential for basaltic volcanism intersecting the repository or occurring in the controlled area. The possibility that the occurrence of volcanism is not random over the region, but controlled by geologic structures or other factors will also be considered in the assessment. A second part of the strategy will be an assessment of the effects on a repository of Strombolian or hydrovolcanic eruptions that penetrate the repository.

Investigation 8.3.1.8.2 will provide the analyses to resolve the performance measure related to the failure of waste packages due to tectonic events. Structural deformation resulting from tectonic processes such as faulting (including detachment faulting), uplift, subsidence, or folding could adversely affect the effective lifetime of the waste packages in containing the waste. If deformation was found to be significant enough that the requirements for waste package performance could not be met, the changes required in repository geometry may be such that the repository would no longer be able to accommodate the specified volume of waste (70,000 MTU). The goal (Table 8.3.1.8-2) for the performance measure is derived from the considerations discussed in Section 8.3.4.2. Section 8.3.4.2 sets design goals for rock-induced loads to the waste package. One goal states that less than 0.5% of the waste packages will be breached by anticipated tectonic processes and events that may occur during the first 1,000 yr. This level is designed to be compatible with the overall goal for waste package performance from all modes of failure of less than 5 percent in 300 yr and less than 20 percent in 1,000 yr. (Section 8.3.5.9). The level of confidence for the performance goal was set so that exceedance of the goal would be an unanticipated event.

The first initiating event considered under this intermediate performance measure is the possibility of igneous activity such as the intrusion of a dike or an explosive hydrovolcanic event which could lead to waste package failure (Table 8.3.1.8-2). The number of waste packages affected by a disruptive event such as a hydrovolcanic eruption has not been estimated. The performance parameter goal was set to have the penetration of the repository in 1,000 yr by igneous intrusions be an unanticipated event because waste package disruption scenarios only need to consider anticipated events.

The second initiating event considers the effect of fault displacement on waste package integrity. A value of 5 cm was selected as the performance parameter at which fault displacement becomes significant over a 1,000-yr period because at this value it is estimated that the 7.6-cm air gap around the waste package (Sections 6.2.6.2 and 7.3.1.3) would be substantially closed and any additional displacement might result in waste package failure.

The strategy for demonstrating that faulting will not lead to significant waste package failure in 1,000 yr will be to locate and characterize Quaternary faults in and proximal to the controlled area. Because these faults (such as Windy Wash and Paintbrush Canyon (Section 1.3.2.2.2)) have very low slip rates, it is anticipated that the demonstration can be made that the occurrence of 5 cm of displacement in 1,000 yr on even these longer, more significant faults is a very low probability event. The characteristics of the known Quaternary faults in the area will be compared to those of the faults that penetrate the repository block to demonstrate that these smaller faults are much less likely to support a slip rate comparable to the larger faults in the area. A second part of the strategy will be to estimate the number of waste packages a throughgoing fault would intersect in the repository. Using the formula of Link et al. (1982) to estimate the hazard posed by faulting, a randomly oriented fault would intersect about ten waste packages out of an inventory of 18,000 waste packages in a 510 ha repository. This type of analysis will be used to demonstrate that significant displacement would have to occur on several faults to create failures on more than 0.5 percent of the waste package inventory.

The third initiating event considers the possibility that high rates of folding operating over a 1,000-yr period could result in sufficient waste-emplacement borehole deformation to lead to waste package failure. The performance parameter goal was selected so that, if the goal is met, then bending of waste emplacement boreholes by folding or deformation due to distributed shear of more than 5 cm will not be a credible event (less than 10^{-8} annual probability). The value of 5 cm for the goal for borehole deformation was also selected on the basis of a substantially reduced air gap around the waste package. The strategy for demonstrating compliance with the performance parameter goal will be to demonstrate the absence of significant folding in the repository horizon during the last 10 million yr.

Regional uplift and subsidence are not considered credible processes that could lead to waste package failure. The only conceivable mechanism by which uplift could lead to waste package failure is for extreme uplift rates to occur, which could lead to the exposure of waste packages to erosional processes. This initiating event is considered separately in Investigation 8.3.1.6.3.

Investigation 8.3.1.8.3 addresses the effects tectonic processes may have on hydrologic characteristics in the controlled area. A set of three intermediate performance measures have been identified as the significant hydrologic factors that could be adversely affected by tectonic processes and events. The three intermediate performance measures are alteration of average percolation flux, changes in water-table elevation, and alteration of rock properties along significant potential travel paths (Tables 8.3.1.8-3 to 8.3.1.8-5 and Section 8.3.5.13).

The initiating events identified for the intermediate performance measure that addresses the alteration of average percolation flux are concerned with tectonic processes that could alter flux rates such as (1) the creation of impoundments due to volcanic flows or the formation of fault scarps, (2) the diversion of drainage due to volcanic activity, faulting, uplift, or subsidence, (3) the creation of perched aquifers above the repository due to faulting, (4) the creation of impermeable zones such as the injection of a sill, and (5) a change in dip of the repository rock due to faulting or folding. The basic strategy in addressing this intermediate performance measure will be to measure the Quaternary rate of igneous activity and tectonic deformation due to faulting, folding, uplift, and subsidence in the repository area and demonstrate that these rates are low enough that the performance parameter goal would not be exceeded in a 10,000-yr period.

The intermediate performance measure concerned with changes in water table elevation (Table 8.3.1.8-4) considers the possibility that tectonic events or processes could result in rises in the water table, changes in the potentiometric level of confined aquifers, or the creation of perched aquifers. Such changes could result in the shortening of the ground-water travel pathway in the unsaturated zone and altered radionuclide release rates to the accessible environment. Changes in water-table elevation may also affect hydraulic gradients and the location of discharge points. The distance from the repository horizon to the water table is currently about 250 m. The intermediate performance measure goal was set at a distance of greater than 100 m because it is estimated that the reduction in unsaturated zone release rates would become significant at this point.

The effects of tectonic initiating events considered as possible causes for these changes in the length of the unsaturated zone pathway in Table 8.3.1.8-4 include (1) the creation of barriers to ground-water flow as a result of the formation of igneous dikes, (2) offsets that juxtapose units with differing hydrologic properties due to movement on a fault, (3) the change in elevation of the repository with respect to the water table due to folding or subsidence, and (4) the change in water-table elevation or potentiometric level that might result from strain changes through the faulting cycle.

The intermediate performance measure addressing the alteration of rock properties along significant potential travel paths is concerned with possible changes in rock properties due to tectonic processes that could result in changes in the hydrologic flow properties of the rocks in the controlled area. The effects of initiating events considered are (1) changes in rock properties due to an igneous intrusion, (2) change in rock properties along a fault due to fault movement that results in the creation or destruction of barriers to lateral flow or the creation of conduits of increased vertical flow, and (3) changes in the hydrologic properties of the rock mass due to episodic changes in strain due to faulting or folding (Table 8.3.1.8-5). This intermediate performance measure will also consider the effects that changes in rock properties could have on the movement of gaseous decay products in the unsaturated zone. The strategy for evaluating the magnitude of such changes will be to estimate the rate of tectonic activity in the area and estimate the impact of tectonic processes through hydrologic modeling.

Investigation 8.3.1.8.4 addresses the possibility that geochemical characteristics could be changed in the controlled area as a result of tectonic processes and events. This investigation addresses the concerns of the intermediate performance measure that addresses the possible changes in rock geochemical properties or ground-water chemistry resulting from tectonic processes and events (Table 8.3.1.8-6). The goal for this intermediate performance measure was set so that tectonic processes would not adversely affect the radionuclide release rate due to changes in the distribution coefficient (K_ds) of the rock by more than a factor of 2 in 10,000 yr for those radionuclides with expected travel times of less than 10,000 yr with a high level of confidence. The effects of initiating events that are considered for this intermediate performance measure are (1) alteration of the country rock caused by an igneous intrusion, (2) changes in the mineralogy along a fault zone due to changes in ground water flow paths caused by faulting, (3) changes in travel paths due to faulting, and (4) mineralogic changes caused by fluctuations in water level due to tectonic events. The principal strategy in addressing this intermediate performance measure will be to investigate the nature and extent of mineralogic changes that have occurred in the past around dikes and faults in the area around the site.

The studies and activities that provide the data for the analyses of the intermediate performance measures are collected under Investigation 8.3.1.8.5. The data-gathering studies and activities are aggregated separately from the investigations addressing the intermediate performance measures because each of the intermediate performance measures tends to call on the same data to analyze its initiating events. The separation of data-analysis activities from data-gathering activities by placing them in different investigations is believed to improve and clarify the logic flow in the investigations related to the analysis of the intermediate performance measures and to identify more clearly the nature and level of detail of data that must be collected. The activities collected under Investigation 8.3.1.8.5 for this tectonics program are few because most of the data necessary for the resolving of the intermediate performance measures are supplied by activities in other programs. The data that are being supplied by activities in other programs are identified in Tables 8.3.1.8-1 to 8.3.1.8-6 and in the investigation descriptions.

Interrelationships of postclosure tectonics investigations

The interrelationship among issues, programs, investigations, favorable conditions, and potentially adverse conditions is shown in Tables 8.3.1.8-1 to 8.3.1.8-6, Figure 8.3.1.8-1, and in the logic diagrams accompanying the investigation descriptions.

The assessment of potential igneous activity in Investigation 8.3.1.8.1 will require an improved data base on the nature and rate of past activity in order to prepare a probabilistic calculation on the possibility of future igneous activity. The assessment will also include a consideration of possible structural controls on igneous activity and an evaluation of the possibility of magma sources underlying the site. A second study will evaluate the disruptive effects of Strombolian and hydrovolcanic eruptions should they occur at the repository.

Investigation 8.3.1.8.2 is composed of one study that will assess the likelihood and effects of each of the four initiating events on waste package integrity. Data for the assessment of waste package rupture due to igneous activity will come from Investigation 8.3.1.8.1. The assessment of waste package rupture due to faulting will use (1) data on the number of waste packages that could be intersected by a throughgoing fault and (2) data on the slip rate, recurrence interval and displacement of individual events, length, sense of movement, and width of zone of Quaternary deformation for the north-trending normal faults found in and near the controlled area from Investigations 8.3.1.17.4 and 8.3.1.4.2.

The performance parameter goals for folding indicate levels of significance that are so high in relation to natural rates that existing data and data from Investigation 8.3.1.4.2 are sufficient to make an assessment. Only minor studies to gather additional data on folding in the region are planned.

Investigation 8.3.1.8.3 will use data on the nature and rates of igneous activity, faulting, folding, uplift, and subsidence collected by the investigations listed in Tables 8.3.1.8-3 to 8.3.1.8-6 to perform an assessment of the amount of change that could be expected over the next 10,000 yr for the three hydrologic concerns discussed in the intermediate performance measures. In each instance, this assessment will have two parts and will be an iterative process. The first part will be an estimation of the probability of occurrence of tectonic processes that could affect hydrologic properties and a characterization of the type of changes that could occur and the volume of rock affected. The second part of the assessment will be hydrologic modeling of potentially significant changes in model parameters due to tectonic processes to determine the expected amount of change in the hydrologic intermediate performance measures. This investigation therefore supplies the interface point needed for the integration of data between the geohydrology and postclosure tectonics program staff.

Investigation 8.3.1.8.4 will provide the analysis necessary to address the intermediate performance measure concerning changes in rock geochemical properties resulting from tectonic processes. The data necessary to perform the analysis will be supplied by activities in Investigations 8.3.1.17.4, 8.3.1.2.2, 8.3.1.2.3, and 8.3.1.4.2 (Table 8.3.1.8-6). The analysis will use data on mineral changes around dikes and faults in the area surrounding the site to project the amount of expected change in the next 10,000 yr. Other studies and activities will evaluate the probability of the initiating events and evaluate the potential mineral changes that could result from the occurrence of those events.

Investigation 8.3.1.8.5 will house the data-gathering studies and activities that are called for by the analysis activities. The studies contained in this investigation are related to the probability and effects of volcanic events and folding in region surrounding the repository. All other required data will be collected by investigations related to other programs.

8.3.1.8.1 <u>Investigation: Studies to provide information required on direct releases resulting from volcanic activity</u>

<u>Technical basis for obtaining the information</u>

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.5.1	Volcanism
1.8.1.3.1, 1.8.1.3.2	Significant results (structural geology and tectonics), discussion of significant results
1.8.1.5.1	Significant results (long-term regional stability)

Parameters

The following performance parameters (Table 8.3.1.8-1 and Section 8.3.5.13) will be measured or calculated as a result of the studies planned to satisfy this investigation:

1. Annual probability of a volcanic eruption that penetrates the repository.

2. Effects of a volcanic eruption penetrating the repository including area of repository disrupted and confidence bounds of estimate.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the data required for an assessment of repository performance with respect to the possibility of direct releases resulting from volcanic events. The two performance parameters for this investigation have been identified by Issue 1.1 (Section 8.3.5.13 and Table 8.3.1.8-1). The evaluation of these two performance parameters is the subject of the two studies in this investigation (Figure 8.3.1.8-3). The two studies in this investigation will also supply the data required by Issue 1.8 (Section 8.3.5.17) to address the favorable and potentially adverse conditions of 10 CFR 60.122 listed in Table 8.3.1.8-1. Investigations 8.3.1.8.2 through 8.3.1.8.4 will also use the results of this investigation in their analyses of other intermediate performance measures.

Technical rationale for the investigation

This investigation considers the single initiating event of a volcanic eruption penetrating the repository and resulting in direct releases to the atmosphere or land surface. As discussed in Sections 1.3.2.1 and 1.5.1, basaltic volcanism is considered to be the only credible type of activity to have a possibility of occurrence in the next 10,000 yr. Releases could occur as the result of a dike that feeds a volcanic vent intersecting the repository and entraining some waste. The waste could be ejected in a Strombolian eruption as pyroclasts and incorporated in an ash fall and cinder cone. As an alternative, if the ascending magma intersects a body of ground water, a hydrovolcanic explosion could occur at depths great enough to cause disruption of the repository. This hydrovolcanic type of eruption might result in the ejection of waste fragments as a result of the explosions from a tuff-ring or maar volcano. Hydrovolcanic eruptions may change in time to a Strombolian eruption resulting in the formation of a cinder cone.

Study 8.3.1.8.1.1 correlates to the first performance parameter listed in the previous section. This study will analyze the data collected by the program and estimate the probability of a volcanic event intersecting the repository. The logic flow for the four activities contained in the study is shown in Figure 8.3.1.8-3. The probability calculations will be refined versions of the estimates presented in Section 1.5.1.2 and will assume that the occurrence of basaltic volcanism in the region is independent of time and location (Poisson recurrence model). It is possible that the occurrence of volcanism is not actually a completely random process but that the location of volcanic vents and the probability of their occurrence can be affected by regional structural trends, local structures, and even topography. The influence of regional structural trends was factored into the area ratio (area of repository/area to which volcanic event rate applies) of the probability calculations (Section 1.5.1.2.3). The possibility of local structural controls will be assessed by evaluating the location of late Cenozoic basaltic vents in relation to known structures and aeromagnetic, gravity, and seismic data. The results of these analyses will be incorporated into the final volcanic probability assessment as appropriate. Geophysical evidence will also be evaluated for indications that magma bodies

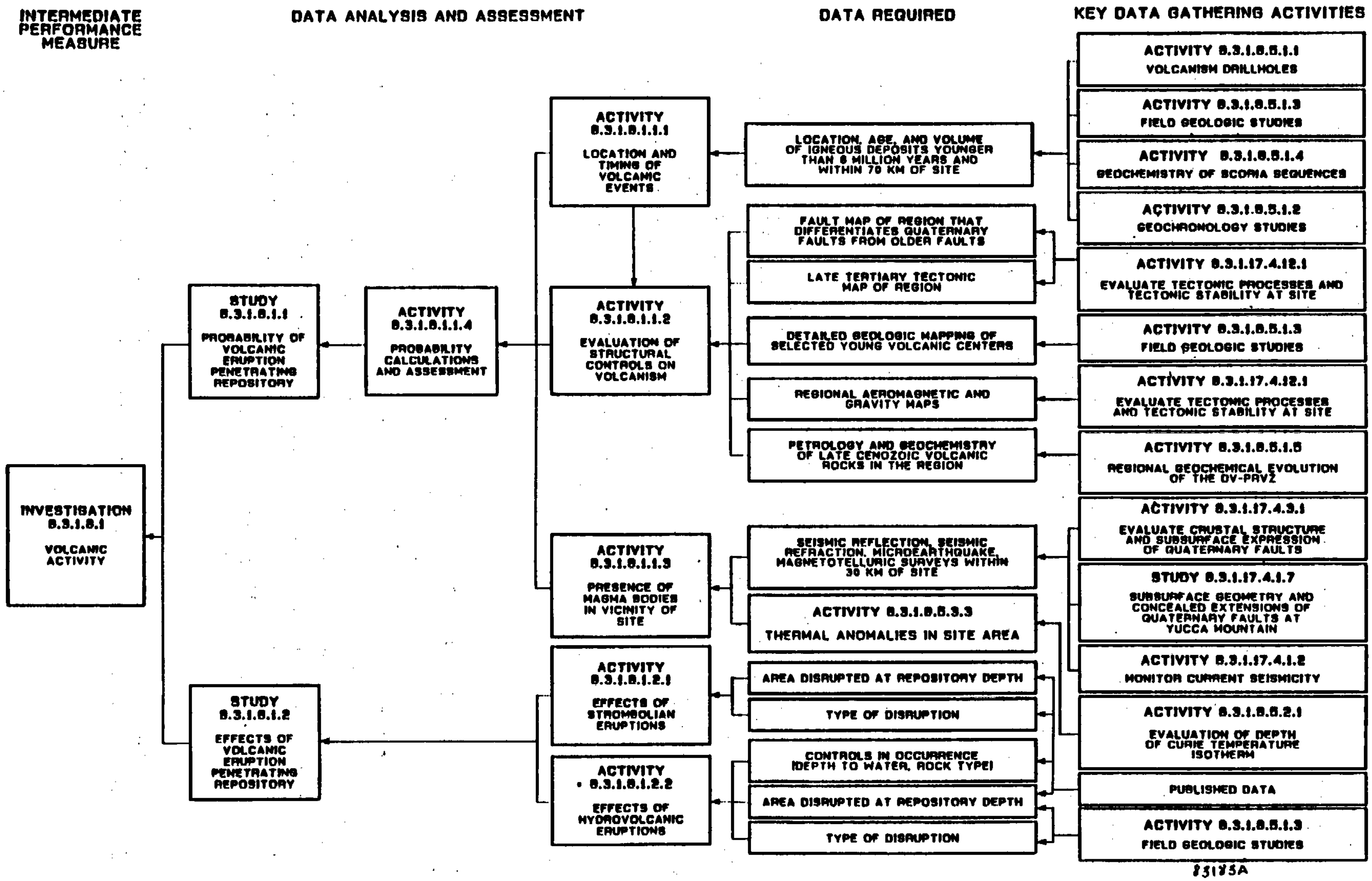


Figure 8.3.1.8-3. Logic diagram for Investigation 8.3.1.8.1 (volcanic activity).

may be present in the vicinity of the site. The evidence for the presence or absence of magma bodies will also be factored into the probabilistic estimates.

Study 8.3.1.8.1.2 correlates with the second performance parameter listed in the previous section and will consider the effects a basaltic eruption could have on repository performance if such an event should occur. Two types of eruptions have been found to be characteristic of past activity in the region: Strombolian and hydrovolcanic (Section 1.3.2.1.2 and 1.5.1.2). Sufficient data have been collected on the effects of Strombolian eruptions for an analysis of repository performance so no additional field data gathering is planned. Additional data are needed on the effects of and controls of hydrovolcanic eruptions. This study will integrate current and newly acquired data into a format that can be used for repository performance assessment.

8.3.1.8.1.1 Study: Probability of a volcanic eruption penetrating the repository

The purpose of this study is to assess the probability of future volcanic activity with respect to siting of a repository for storage of high-level radioactive waste at Yucca Mountain. The probability assessment will be completed through a combination of studies and the results of these studies will be compared for consistency (Crowe et al., 1983a). The probability that volcanic activity could intersect the repository will be estimated from the analysis of a variety of data on the location and timing of volcanic events during the last 4 to 8 million yr, magma generation rates, structural controls on the location of volcanic activity, and geophysical data on the locations of potential magma bodies that could be the sources for future events.

8.3.1.8.1.1.1 Activity: Location and timing of volcanic events

Objectives

The objective of this activity is to synthesize the data collected by other activities (Figure 8.3.1.8-3) on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site. These additional data will be used by Activity 8.3.1.8.1.4 to produce revised probability estimates of the disruption of the repository by volcanic events.

Parameters

The parameters for this activity are the location, age, and volume of volcanic deposits within 70 km of the site and younger than 8 million yr.

Description

Data from the literature, previously completed studies and the planned studies in Investigation 8.3.1.8.5 will be compiled and synthesized to produce maps showing the age, location of vents, and distribution and volume of lava and pyroclastic deposits erupted from the vents. The resulting maps will be interpreted to determine eruptive patterns of volcanic activity during the last 8 million years. Magma volumes will be calculated as dense rock equivalents versus time and vent counts will be calculated to provide data for forecasting future rates of volcanic activity for probability calculations (Crowe et al., 1982). The data and analyses produced by this activity will be used to calculate the probability of volcanic eruptions (Activity 8.3.1.8.1.1.4) and in the evaluation of possible structural controls on volcanic activity (Activity 8.3.1.8.1.1.2).

Methods and technical procedures

Activity 8.3.1.8.1.1.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82

8.3.1.8.1.1.2 Activity: Evaluation of the structural controls of basaltic volcanic activity

Objectives

The time-space distribution of basaltic volcanic activity may not be completely random across the site area. This activity will investigate the time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future volcanic centers at and adjacent to Yucca Mountain. Statistical evaluation of geophysical data will be undertaken to assess the significance of possible local and regional structures on the area ratio of the probability calculation.

Parameters

The data gathered from other activities that are needed for this work are

1. A tectonic model for the Yucca Mountain region (including fault map of the region that differentiates Quaternary faults from older

faults and a late Cenozoic tectonic map of the region; Activity 8.3.1.17.4.12.2: evaluate tectonic models).

2. Aeromagnetic, gravity and seismic data for the Yucca Mountain region.

3. Field mapping of young volcanic centers (< 4 million years old) in the Yucca Mountain region (Activity 8.3.1.8.5.1.3: field geologic studies).

4. Geochronology measurements for young volcanic rocks (< 4.0 million years old; Activity 8.3.1.8.5.1.2: geochronology studies).

5. Petrologic cycles of volcanic rocks in the Yucca Mountain area (< 8.0 million years old) and from other basaltic volcanic fields of the southern Great Basin (Activity 8.3.1.8.5.1.5: petrologic cycles of basaltic volcanic fields).

The data to be gathered by this activity are

1. Cluster analysis of aeromagnetic data.

Description

The time-space patterns of basaltic volcanic activity will be examined for the Yucca Mountain region. Current data support a progressive southwesterly stepping of areas of volcanic activity through time. The youngest activity is concentrated in the Crater Flat area at, and northeast of, the intersection of the Bare Mountain fault system with the Mine Mountain-Spotted Range structural zone. Preliminary evidence suggests the Bare Mountain fault is no longer a structural boundary for the localization of sites of basaltic activity. This interpretation implies that future volcanic activity should occur southwest of the Crater Flat area, between the Bare Mountain and the Death Valley fault zones and that the peak of basaltic volcanic activity has passed from the Crater Flat area. Geologic and geophysical evidence will be evaluated for this volcanic/tectonic model and the model will be integrated with tectonic models developed in Investigation 8.3.1.17.4.

Three important lines of evidence will be evaluated for the volcanic/tectonic structural studies. First, plots of magma volume versus time for volcanic activity of the Yucca Mountain area show declining rates of magma production through time. This interpretation must be tested using refined data for the age of volcanic activity from Activity 8.3.1.8.5.1.2 (geochronology studies), and for the volume of volcanic activity from Activity 8.3.1.8.5.1.3 (field geologic studies). Second, geochemistry studies of the Crater Flat area (Vaniman et al., 1982; Crowe et al., 1983b, 1986) show distinct petrologic trends through time. The oldest basalts of the Crater Flat area are hypersthene-normative hawaiite and the youngest basalts are nepheline-normative hawaiite or basanite. These same trends have been observed, but not documented in detail, at other basaltic volcanic fields of the Basin and Range province (Lunar Crater and Cima volcanic fields). Further work is required to determine if the transition to nepheline-normative basalt is indicative of the waning or termination of volcanic activity at a field. Third, the transition from hypersthene- to nepheline-normative basalt in the Crater Flat area is accompanied by a decrease in the volume of eruptive products and an increase in the frequency of eruptions. This observation, if valid, may affect assumptions used for forecasting future rates of volcanic activity. It must be tested by studying time variations in the petrology and volume of basaltic activity at other volcanic fields in the Yucca Mountain vicinity.

The three topics, magma volume/time, petrologic patterns through time, and the decreased volume/increased eruptive frequency through time all are important observations that affect assumptions used for calculating the probability of future volcanic activity at Yucca Mountain. It is important that these concepts be tested at other volcanic fields in the region, particularly fields that have a more voluminous record of eruptive activity, to test the implications of conclusions for the Yucca Mountain area (Activity 8.3.1.8.5.1.5).

The second topic to be examined for this activity is the local structural controls for sites of volcanic activity in the Yucca Mountain area. Cluster analyses routines will be used to assess spatial patterns of aeromagnetic data in the Yucca Mountain area. Identified patterns will be correlated with known structures in the Yucca Mountain area and the location of volcanic centers to identify what structural features control the location of volcanic vents. This information will be used to test for the presence of potential structural features in the Yucca Mountain exploration block that could provide pathways for the localization of future volcanic activity. The results of this analysis will be factored into the volcanic probability calculations (Activity 8.3.1.8.1.1.4).

Methods and technical procedures

Activity 8.3.1.8.1.1.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure		
	Number	Title	Date
Analysis of data	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82
Cluster analysis routines	TBD[a]	TBD	FY 1988

[a]TBD = to be determined.

8.3.1.8.1.1.3 Activity: Presence of magma bodies in the vicinity of the site

Objectives

The objective of this activity is to review geophysical data collected in the vicinity of the site to assess whether any indications of midcrustal magma bodies are present that might be the source for future volcanic events.

Parameters

The parameters for this activity are seismic refraction, seismic reflection, Curie temperature isotherm, heat flow, gravity, magnetotelluric and microearthquake data collected within 30 km of the site.

Description

The geophysical and microearthquake data collected at the site and in surrounding areas, such as Crater Flat, by Studies 8.3.1.17.4.1, 8.3.1.17.4.3, and 8.3.1.17.4.7 will be analyzed to determine if there are indications of a magma body in close proximity to the site. The magma bodies that would be associated with the Strombolian eruptions that have occurred in the region during the Quaternary probably occur at depths of 20 km or more. Magma bodies of this type have been found in Death Valley (de Voogd et al., 1986) and the Rio Grande rift (Brown et al., 1979; Jiracek et al., 1979; Rinehart et al., 1979) at depths of about 20 km using geophysical and microearthquake techniques. The regional depth to the Curie temperature isotherm and heat flow data will also be investigated for indications of possible temperature anomalies related to magmatism. This activity will consist of an interpretation of data collected by other activities only. No new data will be collected for this activity.

Methods and technical procedures

The methods and technical procedures for this activity are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Analysis of data	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82
Analysis of geophysical data	TBD[a]	TBD	TBD

[a]TBD = to be determined.

8.3.1.8.1.1.4 Activity: Probability calculations and assessment

Objectives

The objective of this activity is to revise the estimates of the probability of volcanic disruption of a repository site at Yucca Mountain (Crowe et al., 1982) incorporating newly acquired data on the age, location, and volume of volcanic centers in the NTS region and the results from activities investigating the possibility of structural controls of sites of volcanic activity and the presence of magma bodies in the Yucca Mountain area. These data may result in modifications of the area ratio and the rate of volcanic activity used in the probability formula.

Parameters

The parameters for this activity are

1. Maps showing the location and age of volcanic vents within 70 km of the site.

2. Magma generation rates within 70 km of the site.

3. Structural controls on volcanism.

4. Evidence for the presence of magma bodies in the vicinity of the site.

Description

Data from parameters 1 through 4 are used for probability calculations. The probability of disruption of a repository by basaltic magma is formulated as a case of conditional probability

$$Pr = \{E2 \text{ given } E1\} \qquad (8.3.1.8\text{-}1)$$

where Pr is the probability of repository disruption, E1 is the rate of occurrence of volcanic events, and E2 is the probability of intersection of a repository by magma given E1. This probability is expressed as (Crowe et al., 1982)

$$Pr\ [\text{no disruptive event before time } t] = e^{-\lambda tp} \qquad (8.3.1.8\text{-}2)$$

where λ is the rate of volcanic activity and p is the probability that an event is disruptive. The most difficult parameter to estimate for the calculations is λ. The NNWSI Project has defined the parameter λ in two ways using data for the Yucca Mountain region: (1) cone counts through time and (2) calculations of magma volume through time (rate of magma production). Alternative models are possible but are difficult to test with the limited data from the Yucca Mountain region. Much more comprehensive data will be obtained from high cone-density volcanic fields. These data will be used to test existing methods for calculating volcanic rates and developing additional alternative methods. If new methods are developed, they will be tested using the Yucca Mountain data set. Further work will be undertaken to attempt to revise the probability of repository disruption (p). Cluster analysis of the aeromagnetic and gravity data will be used to attempt to correlate spatial trends with sites of surface volcanic activity. If these correlations are successful, the disruption ratio will be revised for the probability calculations. Ongoing work described in Chapter 1 has shown that there has been a progressive southwest migration of sites of basaltic volcanic activity through time. These data lead to the conclusion that the Yucca Mountain region has passed the peak of the most intense volcanic activity. This interpretation will be tested using information on time-space patterns of basaltic volcanism from Activity 8.3.1.8.1.1.1. The results of the revised probability calculation and assessment will be summarized in a report that includes the following:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment on the probability of volcanic events.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

The method and technical procedure for this activity are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Probability modeling	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82

8.3.1.8.1.2 Study: Effects of a volcanic eruption penetrating the repository

The purpose of this study is to gather data on the effects of a potential volcanic eruption should such an eruption penetrate the site. The data will be used by Issue 1.1 and the other investigations in this program to assess the consequences of such an eruption on repository performance.

8.3.1.8.1.2.1 Activity: Effects of Strombolian eruptions

Objectives

The objective of this activity is to summarize the effects of a

Strombolian eruption on a repository. The summary will be available for use in consequence analyses of possible radiological releases.

Parameters

The parameters for this activity are representative eruption parameters for Strombolian eruptions including area of repository disrupted and confidence bounds of estimate.

Description

The published literature and completed Project reports (e.g., Link et al., 1982) provide sufficient data for the completion of this activity. This activity will compile and summarize those data for use in consequence analyses.

The data used will include the area of the repository that could potentially be disrupted, characteristics and dimensions of intrusions (dikes and sills) associated with an eruption, thickness and extent of flows and ashfalls, temperatures of magma, and duration of eruptions. The data summarized by this activity will also be used in Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4.

Methods and technical procedures

The method and technical procedure for this activity are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Analysis of data	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82

8.3.1.8.1.2.2 Activity: Effects of hydrovolcanic eruptions

Objectives

The objective of this activity is to obtain geologic parameters for the disruption of a repository by magmatic activity accompanied by hydrovolcanic (magma-water) explosions. Critical parameters controlling the hydrovolcanic explosions will be identified and information obtained on these parameters will be used for calculations of the radiological release levels for performance assessment.

Parameters

The parameters for this activity are the representative eruption parameters for hydrovolcanic eruptions including the area of repository disrupted and the confidence bounds of the estimate.

Description

Eruption parameters will be defined for an eruption scenario involving an initial hydrovolcanic eruption changing in time to a Strombolian eruption. Parameters for a Strombolian eruption without a hydrovolcanic component have been completed (Link et al., 1982). There are two important categories of evidence related to the possibility of hydrovolcanic activity at Yucca Mountain: (1) theoretical models of magma/water interaction show that hydrovolcanic explosions are possible in the Yucca Mountain setting, and (2) geologic evidence suggests that the likelihood of a hydrovolcanic explosion decreases with increasing depth of the water source (Crowe et al., 1986). Consequence studies of the area of the repository disrupted by a basaltic eruption need to be repeated with a modified eruption scenario that includes hydrovolcanic explosions. Two topics require further studies for these modifications. First, likely scenarios for hydrovolcanic eruptions need to be identified based on information obtained from field studies of basalt centers that exhibited hydrovolcanic activity (Activity 8.3.1.8.5.1.3) and a review of the literature should be conducted. Second, data on key geologic parameters need to be obtained from the scenarios. The data needed will be used to predict (1) whether an ascending magma body will intersect water at a depth to cause an explosive fuel-coolant type reaction between magma and water, and (2) whether that reaction will be of sufficient magnitude to cause an explosive eruption that will disrupt the repository, possibly breach waste canisters, and cause the release of radioactive waste at the surface.

Methods and technical procedures

The method and procedure for this activity are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82

8.3.1.8.1.3 Application of results

The information derived from the studies and activities described above will be used in the following issues and investigations.

Issue or investigation	Subject
1.1	Total system performance (Section 8.3.5.13)
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings-postclosure (Section 8.3.5.18)
8.3.1.8.2	Tectonic effects on waste package
8.3.1.8.3	Tectonic effects on hydrology
8.3.1.8.4	Tectonic effects on geochemistry
8.3.1.9.1	Degradation of markers
8.3.1.17.1	Volcanic activity

Additionally, Investigation 8.3.1.8.1 will provide information to Investigation 8.3.1.17.4, which will be used to develop working models of the tectonic framework of the Yucca Mountain region. It is important that models of the tectonic setting of volcanism are consistent with the models of the tectonic framework.

8.3.1.8.1.4 Schedule and milestones

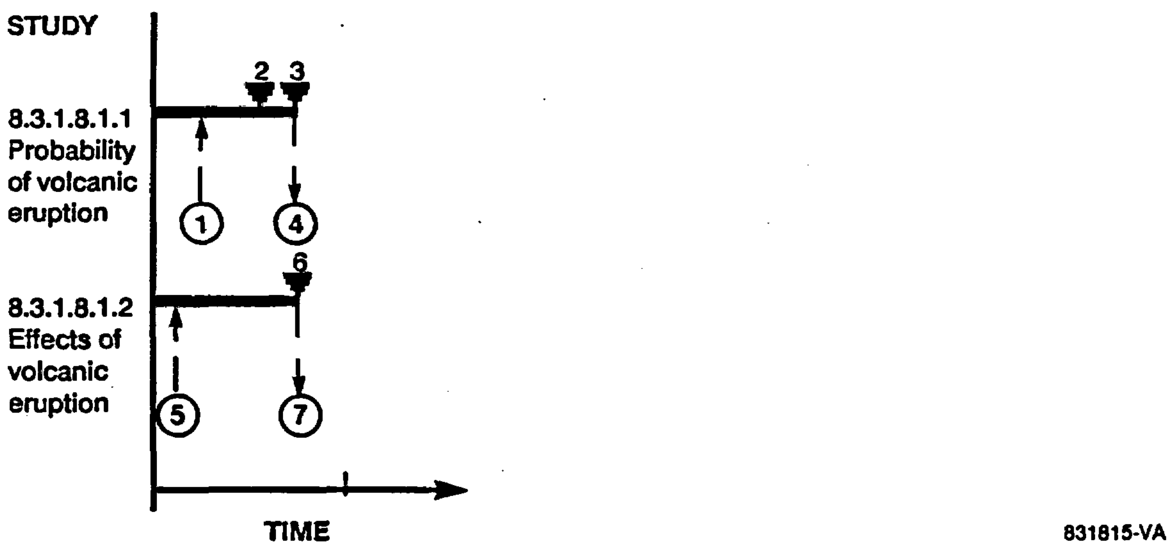
This investigation, addressing postclosure volcanic activity, contains two studies: 8.3.1.8.1.1 (probability of a volcanic eruption penetrating the repository) and 8.3.1.8.1.2 (effects of a volcanic eruption penetrating the repository). Both of these studies are ongoing.

In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information of this investigation can be found in Section 8.5.1.1.

The activities of this entire investigation are planned to progress in parallel with performance and design activities in an iterative fashion. The results of these studies will be used to resolve Issue 1.1 (total system performance) and to support advanced conceptual and license application designs.

The studies in this investigation are constrained by other program elements, as follows: Study 8.3.1.8.1.1 depends on the characterization of volcanic and igneous intrusive features (Studies 8.3.1.8.5.1 and 8.3.1.8.5.2). Study 8.3.1.8.1.2 depends upon data on the nature of hydrovolcanic eruptions from Study 8.3.1.8.5.1.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Data available on dating, location, and volume of flows; geochemical patterns of volcanism in the Great Basin; and anomalies that indicate the presence of magma bodies from Studies 8.3.1.8.5.1 and 8.3.1.8.5.2.
2	Milestone Z001. Final report available on volcanic chronol _y for volcanic risk assessment. Available for use by Issue 1.1 (total system performance).
3	Probability calculations for risk assessment completed.
4	Input to Issue 1.1 on results of study.
5	Data available from Study 8.3.1.8.5.1 on the nature of hydrovolcanic eruptions in the site region

Point number	Description
6	Milestone Z378. Summary report available on effects of igneous and volcanic effects.
7	Results of Study 8.3.1.8.1.2 input to Issue 1.1.

8.3.1.8.2 Investigation: Studies to provide information required on rupture of waste packages due to tectonic events

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.4.1.5	Seismic hazard within the southern Great Basin
1.5.1	Volcanism
1.5.2	Faulting

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Probability of igneous intrusion penetrating repository.

2. Effects of igneous intrusion penetrating repository.

3. Effects on waste packages of a fault penetrating the repository.

4. Probability of faulting with displacement over 5 cm in repository.

5. Expected ground motion at emplacement boreholes in 1,000-yr period.

6. Rate of deformation due to folding or distributed faulting in repository horizon.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the data necessary for an analysis and assessment of repository performance with respect to the possibility of tectonic processes and events affecting the lifetime of waste packages. The six performance parameters listed in the previous section have been defined to address the performance measure identified by Issue 1.11 (Section 8.3.2.2). The types of tectonic initiating events that may affect waste package performance and that will be considered in this analysis are listed in Table 8.3.1.8-2. The study and activities in this investigation will take data gathered by field studies in this and other programs and provide an analysis of the probability of the initiating events and their effects on waste package performance for use by Issue 1.11 (Section 8.3.2.2) in assessing layout and design of the underground facilities.

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed in Table 8.3.1.8-2.

Parameter 5 indicates the need for data on the ground motion that would be expected during the waste package lifetime. This parameter and its related initiating event respond to the need identified in Issue 1.11 (Section 8.3.2.2, configuration of underground facilities (postclosure)) for such data. Issue 1.11 will use the ground motion data to evaluate the design of emplacement drifts and boreholes in order to assess their postclosure stability.

Technical rationale for the investigation

The flow of data and interconnections between activities is shown on Figure 8.3.1.8-4. The first initiating event considered in this program is the possibility that igneous intrusions penetrating the repository could adversely affect waste package performance. This initiating event is similar to the one considered in Investigation 8.3.1.8.1, but assumes that the basaltic dikes or sills that might penetrate the repository do not feed a volcanic vent and do not directly result in releases at the ground surface. Activity 8.3.1.8.2.1.1 will address this initiating event and satisfy parameters 1 and 2. The assessment of this initiating event will be similar to that in Investigation 8.3.1.8.1 and will use the data analyzed in that investigation to calculate the probability of igneous intrusions penetrating the repository. The number of waste packages that an intrusion might intersect will also be calculated using data on the probable length, width, and orientation of intrusions and current repository design concepts.

The second initiating event considers the possibility that failure of waste packages could occur due to a fault that intersects waste packages and experiences offset that is great enough to cause failure through shearing. Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4 will assess this initiating event and satisfy parameters 3 and 4. This assessment will include calculating (1) the probability that faulting with offset great enough to cause waste package failure would occur in the repository and (2) the number of waste packages that a through going fault might intersect. These activities will organize and assess data collected by Programs 8.3.1.17 and 8.3.1.4 to characterize the nature and Quaternary activity of faults that penetrate the repository and those faults in and near the controlled area. Because of the scarcity of Quaternary deposits on Yucca Mountain, it may not be possible to directly demonstrate the degree of Quaternary activity present on all the faults that potentially penetrate the repository. It is therefore probable that the assessment of the probability and amount of movement on these faults will be characterized by comparison with the known Quaternary

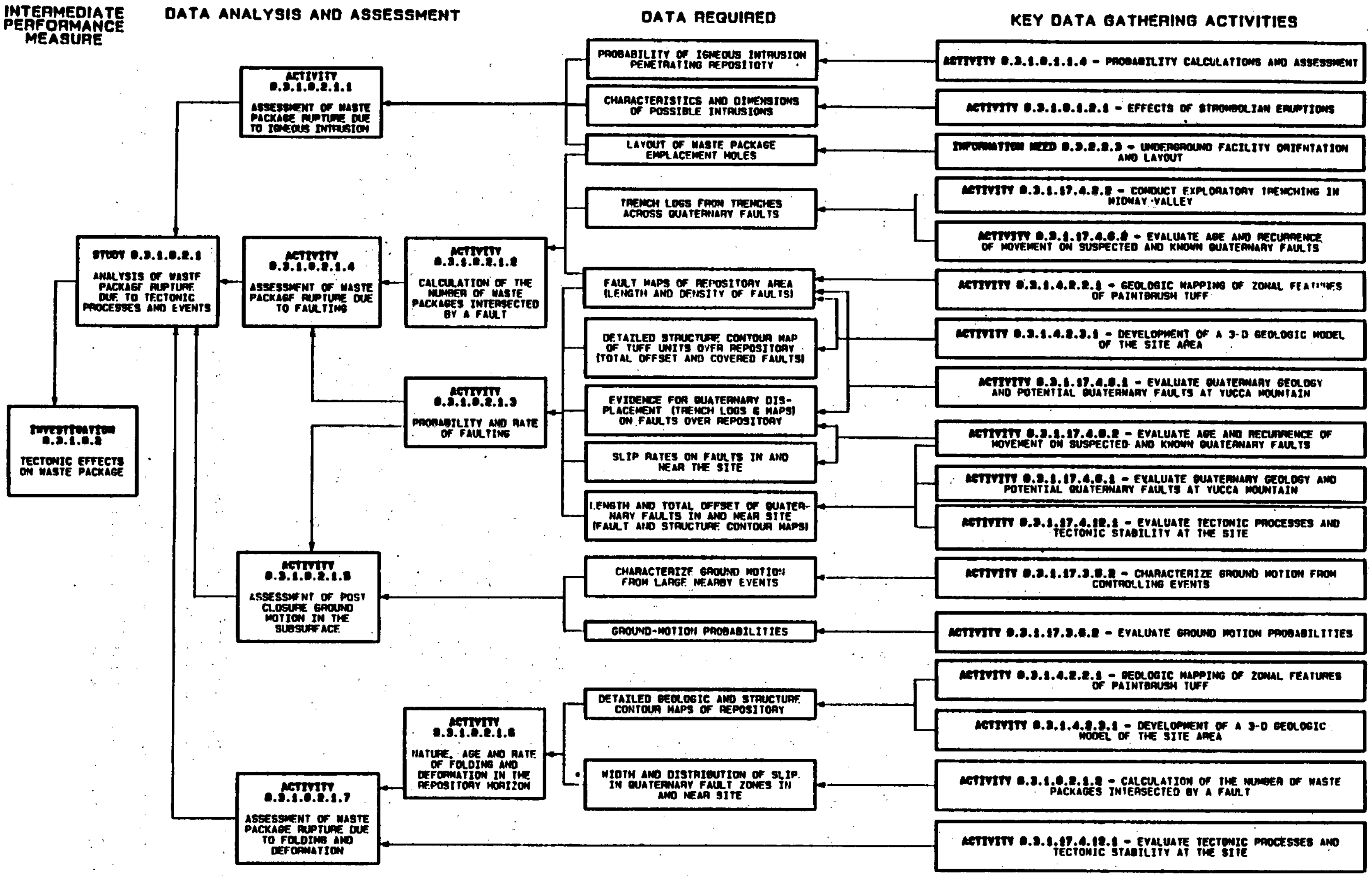


Figure 8.3.1.8-4. Logic diagram for Investigation 8.3.1.8.2 (tectonic effects on waste package).

faults in the vicinity of the site that have a similar trend and sense of movement. Faults such as the Paintbrush Canyon, Solitario Canyon, and Windy Wash traverse areas underlain by Quaternary deposits of a variety of ages (Sections 1.2.2.3 and 1.3.2.2.2) that can be used to determine the nature and rate of Quaternary activity. The comparison of the faulting potential of these larger faults with faults penetrating the repository will incorporate a consideration of the differences in length and total displacement between the two classes of faults. When all these data are collected and coordinated, an annual probability of fault displacement exceeding 5 cm will be calculated for faults that may penetrate the repository.

The second part of the assessment will be a calculation of the number of waste packages that a fault might intersect should a faulting event, with sufficient offset to rupture waste packages, occur. Data will be compiled on the length and width of fault zones, and then calculations similar to those in Link et al. (1982) will be carried out using current repository designs to estimate the number of waste packages that might be affected.

The third initiating event considers the possibility that ground motion occurring during the postclosure period could cause spalling or failure in the underground workings that would result in corrosion or mechanical failure of waste packages due to closure of the air gap around them. Activity 8.3.1.8.2.1.5 will partially address this initiating event and address parameter 5 by calculating expected ground motion values in the repository during the lifetime of the waste packages. The performance of underground excavations under these ground motion conditions will be evaluated separately in Issue 1.11 (Section 8.3.2.2). In this investigation, the ground motion estimates for preclosure design in Investigation 8.3.1.17.3 will be reviewed. Appropriate ground motion parameters for the postclosure time period will then be calculated on the basis of this data.

The fourth initiating event considers the possibility that folding, or fault offset distributed across a broad zone of minor shearing, could sufficiently deform the waste-emplacement boreholes through a closure of the air gap surrounding the waste packages such that the waste packages would fail through bending. Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 will address this initiating event and satisfy parameter 6. These activities will collect data on rates and amount of post-Miocene folding in the repository horizon by reviewing the detailed geologic and structure contour maps of the repository horizon generated by Program 8.3.1.4. Rates of deformation will then be calculated using these data, and a probability of significant waste package failure due to deformation processes calculated.

8.3.1.8.2.1 Study: Analysis of waste package rupture due to tectonic processes and events

The assessment of the probability and effects of all tectonic processes and events that could result in adverse effects on waste package lifetime are aggregated under this study.

8.3.1.8.2.1.1 Activity: Assessment of waste package rupture due to igneous intrusion

Objectives

The objective of this activity is to review and organize supporting field data collected by other activities, and to use this data to calculate the probability of an igneous intrusion penetrating the repository and the number of waste packages that would be affected by such an event.

Parameters

The parameters for this activity are

1. Probability of an igneous intrusion penetrating the repository.
2. Number of waste packages affected by an igneous intrusion.

Description

This activity will use the data and probability calculations in Activity 8.3.1.8.1.1.4 as the basis for estimating the probability that an igneous intrusion may penetrate the repository. The results of Link et al. (1982) will be reviewed and compared with current repository designs and the results of Activity 8.3.1.8.1.2.1 to calculate the number of waste packages that might be intersected by an igneous intrusion. These previous estimates will be revised as necessary to incorporate current data and designs. A report will be prepared that

1. Organizes and summarizes the data on which calculations are based.

2. Presents the theory and calculations used to estimate the probability of igneous intrusion and the number of waste packages affected.

3. Presents a discussion and assessment of the assumptions and uncertainties of the data and the calculations.

Methods and technical procedures

Activity 8.3.1.8.2.1.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.2 Activity: Calculation of the number of waste packages intersected by a fault

Objectives

The objective of this activity is to collect and summarize the relevant data from other activities and calculate the number of waste packages that a fault penetrating the repository would intersect.

Parameters

The parameter for this activity is the number of waste packages affected by a fault penetrating the repository.

Description

This activity will review data collected by trenching and geologic mapping activities in and around the site by Programs 8.3.1.4 and 8.3.1.17. The data on the length, width, and orientation of known Quaternary fault ruptures will be summarized. Representative values for these fault characteristics will be selected for use in calculations. Current repository designs will be reviewed to collect data on the layout and emplacement mode of waste packages. These data will be used to calculate the number of waste packages that a fault might intersect in the repository. The calculation method will be similar to that used by Link et al. (1982) for volcanic events and will result in a probability distribution of possible effects.

Methods and technical procedures

Activity 8.3.1.8.2.1.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.3 Activity: Probability and rate of faulting

Objectives

The objective of this activity is to summarize and evaluate the available data on slip rates and recurrence intervals on faults in and near the controlled area.

Parameters

The parameters for this activity are

1. Evidence of Quaternary activity on faults penetrating the repository.

2. Density, length and total displacement of faults penetrating the repository.

3. Slip rates and recurrence intervals of faults with Quaternary activity in and near the controlled area.

4. Location, length, and total displacement of faults with Quaternary activity in and near the controlled area.

Description

This activity will collect and summarize data on the length, total displacement, and Quaternary activity of faults that are mapped in and near the controlled area and can be projected downward or laterally to intersect the repository. The data will be gathered by several activities in Programs 8.3.1.4 and 8.3.1.17 (Figure 8.3.1.8-4). The data will consist of detailed bedrock geologic maps, structure contour maps, Quaternary deposits maps, remote sensing and geomorphic analyses, and trench logs. The various types of data available will be analyzed and compared with each other to generate a summary of the characteristics of these faults.

Data will also be collected and summarized on the length, total displacement, slip rate, and recurrence interval of Quaternary faults such as the Paintbrush Canyon, Solitario Canyon, and Windy Wash that are in and near the controlled area. These data will come from trenching and mapping studies carried out mainly by Activities 8.3.1.17.4.6.1 and 8.3.1.17.4.6.2. The analyses and data summaries will be used by Activity 8.3.1.8.2.1.4 to assess the probability of significant effects on waste package lifetime due to faulting.

Methods and technical procedures

Activity 8.3.1.8.2.1.3 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.4 Activity: Assessment of waste package rupture due to faulting

Objectives

The objective of this activity is to complete an assessment of the probability of faulting in waste emplacement boreholes and effects of faulting on waste package lifetime.

Parameters

The parameters for this activity are

1. Effects on waste packages of a fault penetrating the repository.

2. Probability of faulting with a displacement over 5 cm in the repository.

Description

This activity will take the data summarized and compiled by Activities 8.3.1.8.2.1.2 and 8.3.1.8.2.1.3 and prepare an assessment of the hazard posed by fault displacement to waste package lifetime. The results of this assessment will be contained in a report that includes the following topics:

1. A summary of data on the characteristics of the faults projected to intersect the repository.

2. A summary of data on the characteristics of the Quaternary faults in and near the controlled area.

3. The calculation of the probability of a cumulative 5-cm displacement occurring in 1,000 yr on a known Quaternary fault in and near the controlled area using slip rates or recurrence intervals and including the type of analysis presented in URS/Blume (1987).

4. A comparison of the characteristics of known Quaternary faults in and near the controlled area with the characteristics of faults projected to intersect the repository and an estimation of the probability of a cumulative 5-cm displacement occurring in 1,000 yr on a fault intersecting the repository.

5. An evaluation of the number of faults penetrating the repository on which cumulative displacements greater than 5 cm could occur during a 1,000 yr period and the interrelationship of events on different faults.

6. The calculation of the number of waste packages that a fault penetrating the repository would intersect.

7. An analysis of the assumptions and uncertainties contained in the data and calculations used for the assessment.

Methods and technical procedures

Activity 8.3.1.8.2.1.4 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86

Method	Technical procedure Number	Title	Date
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.5 Activity: Assessment of postclosure ground motion in the subsurface

Objectives ?

The objective of this activity is to provide an assessment of expected ground motion at the repository horizon in a 1,000-yr period.

Parameters

The parameter for this activity is the expected ground motion at emplacement boreholes in 1,000-yr period.

Description

This activity will supply data that will be used by Issue 1.11 (Section 8.3.2.2) to analyze the postclosure performance of the underground workings under earthquake loading conditions. Data from Studies 8.3.1.17.3.5 and 8.3.1.17.3.6 will be used to characterize ground motions that have a probability of less than 0.1 of being exceeded in the 1,000-yr waste package lifetime. Time histories representative of the estimated ground motions at the repository horizon will be prepared for use in the engineering evaluations. A report will be prepared that

1. Summarizes the data used in the analysis.

2. Discusses the methods used to estimate expected ground motion levels.

3. Analyzes the assumptions and uncertainties in the data and estimation methods.

4. Provides time histories and other data characterizing expected ground motion parameters for use in engineering analysis.

Methods and technical procedures

Activity 8.3.1.8.2.1.5 will only synthesize and compile data collected by other activities and will use the methods and technical procedures in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.6 Activity: Nature, age, and rate of folding and deformation in the repository horizon

Objectives

The objective of this activity is to provide an estimate of the rate of folding or deformation in the repository horizon during Quaternary time.

Parameters

The parameters for this activity are

1. Wavelength and amplitude of folds in the Miocene rocks of the repository horizon.

2. Amount and nature of deformation resulting from faulting in the repository horizon.

Description

This activity will collect and analyze data from Program 8.3.1.4 (rock characteristics) to characterize folding in the repository horizon. The data evaluated will include geologic maps, detailed structure contour maps, and maps of the shafts and drifts. Data on the wavelength and amplitude of any folds found in the area of the repository will be summarized. The site data will also be reviewed for evidence of warping, distributed shear or faulting. Data on the width of Quaternary zones of deformation around faults in the area will also be taken from Activity 8.3.1.8.2.1.2. All the data will be used by Activity 8.3.1.8.2.1.7 in its evaluation of the rate of folding and deformation in the repository and its effect on waste package integrity.

Methods and technical procedures

Activity 8.3.1.8.2.1.6 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.1.7 Activity: Assessment of waste package rupture due to folding and deformation

Objectives

The objective of this activity is to provide an assessment of the hazard resulting from folding and deformation to waste package integrity.

Parameters

The parameter for this activity is the rate of deformation due to folding or faulting in the repository horizon.

Description

This activity will use the data generated by Activity 8.3.1.8.2.1.6 and data on the rate and changes in deformation in the Neogene from Study 8.3.1.17.4.12 to estimate the rate of folding or deformation in the repository horizon and describe the effects such folding may have on waste package integrity. This activity will result in a report that will include

1. The data used in making the assessment.

2. The methods used to calculate or estimate Quaternary folding rates.

3. Quaternary folding rates and an assessment of the impact on waste package integrity.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.2.1.7 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.2.2 Application of results

The information derived from the study and activities described above will be used in the following issues and investigations:

Issue or investigation	Subject
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings - Postclosure (Section 8.3.5.18)
1.11	Configuration of underground facilities (postclosure) (Section 8.3.2.2)
8.3.1.8.3	Tectonic effects on hydrology
8.3.1.8.4	Tectonic effects on geochemistry

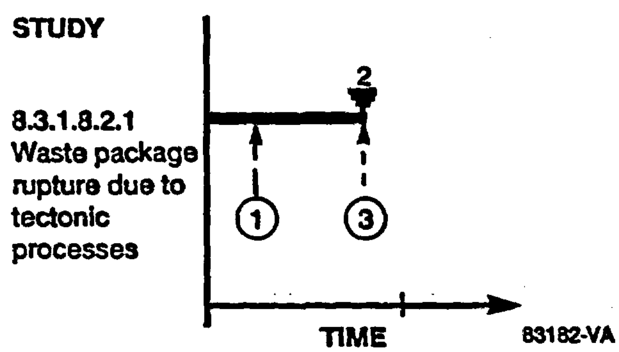
8.3.1.8.2.3 Schedule and milestones

This investigation addresses postclosure tectonic effects on the waste package and contains one out-year study: 8.3.1.8.2.1 (analysis of waste package rupture due to tectonic processes and events). In the figure that follows, the schedule information for this study is presented in the form of a timeline. The timeline extends from implementation of the approved study plan to the issuance of the final product associated with the study. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The activities of this entire investigation are planned to progress in parallel with performance and design activities in an iterative fashion. The results of this study will be used to resolve Issue 1.11 (configuration of underground facilities (postclosure)), and to support advanced conceptual and license application designs, and waste package performance evaluation and design.

Completion of this study is constrained by the availability of data on the probability and dimensions of igneous intrusions from Investigation 8.3.1.8.1, underground design data from Information Need 8.3.2.2.3, exploratory trench data from Investigation 8.3.1.17.4, detailed geologic and structure contour maps from Investigation 8.3.1.4.2, and data on expected ground motions from Investigation 8.3.1.17.3.

The study number and title corresponding to the timeline are shown on the left of the following figure. The points shown on the timeline represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Data available from Investigations 8.3.1.8.1 (volcanic activity), 8.3.1.17.3 (vibratory ground motion), 8.3.1.17.4 (preclosure tectonic data collection analysis), and 8.3.1.4.2 (geologic framework), and Information Need 8.3.2.2.3 (underground facility orientation and layout).
2	Milestones Z379, Z380, and Z382. A series of reports to be available for use by Issue 1.11 (configuration of underground facilities (postclosure)), assessing the effects on waste package integrity resulting from faulting, folding, deformation, and igneous intrusive processes, and on expected repository ground motions during the postclosure period (Milestone Z381).
3	Data input to Issue 1.11 from reports assessing the effects of faulting, folding, deformation and igneous intrusive processes on waste package performance.

8.3.1.8.3 Investigation: Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.3.2.3	Existing stress regime
1.5.1.2	Basaltic volcanism
1.5.2	Faulting
3.6	Regional hydrogeologic reconnaissance of candidate area and site
3.9	Site hydrogeologic system

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Annual probability of volcanic events within the controlled area.
2. Effects of a volcanic event on topography and average flux rates.
3. Annual probability of significant igneous intrusion within 0.5 km of the controlled area.
4. Effects of an igneous intrusion on average flux rates.
5. Probability of offset more than 2 m on a fault in the controlled area in 10,000 yr.
6. Probability of changing dip by greater than 2 degrees in 10,000 yr by faulting.
7. Effect of faulting on average flux rates.
8. Probability of changing dip by greater than 2 degrees in 10,000 yr by folding.
9. Probability of exceeding 30 m of elevation change in 10,000 yr.
10. Barrier-to-flow effects of igneous intrusions on water-table levels and hydraulic gradients.
11. Thermal effects of igneous intrusions on water-table levels and hydraulic gradients
12. Probability that strain-induced changes will increase potentiometric level to greater than 850 m mean sea level (MSL).
13. Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr.
14. Probability of total offsets more than 2.0 m in 10,000 yr on a fault within 0.5 km of controlled area boundary.
15. Effects of fault offset on water-table levels and hydraulic gradient.
16. Effects of igneous intrusions on local fracture permeabilities and effective porosities.
17. Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary.
18. Effects of fault motion on local fracture permeabilities and effective porosities.

19. Effects of changes of stress or strain on hydrologic properties of the rock mass.

Purpose and objectives of the investigation

The 19 performance parameters listed above have been identified by Issue 1.1 (Section 8.3.5.13 and Tables 8.3.1.8-3 to 8.3.1.8-5) to address the possibility that tectonic processes and events could produce the following changes in existing hydrologic conditions:

1. Alteration of average percolation flux over the repository.

2. Changes in water table elevation that affect the length of the unsaturated zone travel path or hydraulic gradients.

3. Alteration of rock hydrologic properties along significant travel paths.

The three studies in this investigation will provide assessments of the likelihood and magnitude of these hydrologic changes for use by Issue 1.1 in analyzing total system performance of the repository in limiting radionuclide releases to the accessible environment. Several of the initiating events considered in this investigation probably will have no significant impact on repository performance because of the very low rates at which the related tectonic processes operate at Yucca Mountain (e.g., folding, uplifting, and subsidence). It is anticipated that little or no additional data will be required to complete the assessments of the initiating events related to these tectonic processes. The level of effort for the activities related to these initiating events is therefore anticipated to be low and to consist primarily of organizing and presenting existing data in order to provide the basis for eliminating these initiating events from consideration during performance assessment evaluations.

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed on Tables 8.3.1.8-3 to 8.3.1.8-5.

Technical rationale for the investigation

The flow of data and interconnections between activities in each study are shown on Figures 8.3.1.8-5 to 8.3.1.8-7. Study 8.3.1.8.3.1 considers the initiating events that may affect the average percolation flux over the repository. The first initiating event considered in this study is the possibility that volcanic events may alter topography as a result of the extrusion of volcanic flows or other effects and create impoundments or diversions of drainage that could adversely affect average percolation flux rates. The second initiating event considers the possibility that an igneous intrusion such as a sill intruded above the repository horizon could divert downward percolating waters to the area above the repository and thereby increase average percolation flux rates. The first two activities in the study address these initiating events and will satisfy parameters 1 to 4. Activity 8.3.1.8.3.1.1 will use data from Activity 8.3.1.8.1.1.4 to calculate

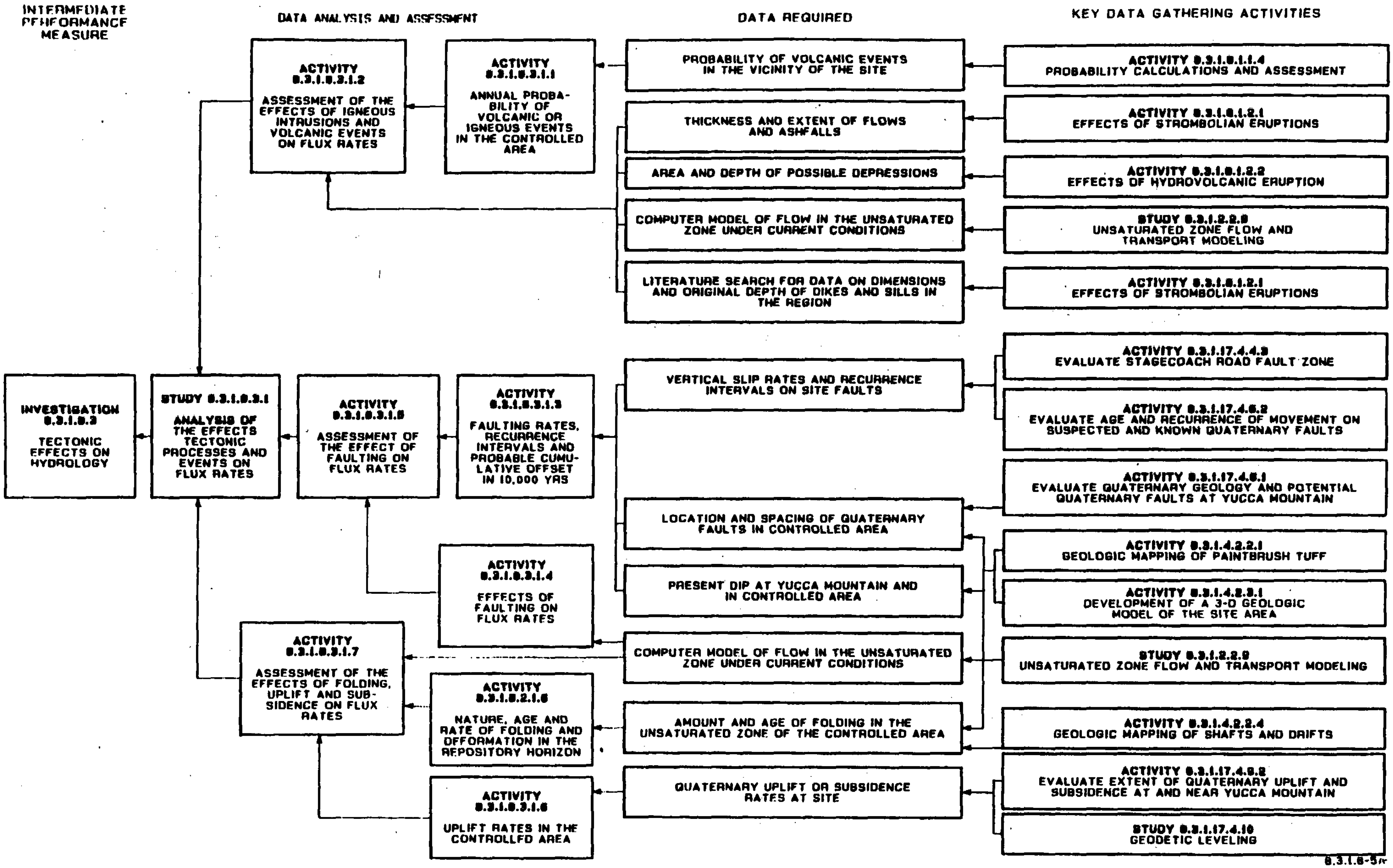


Figure 8.3.1.8-5. Logic diagram for Study 8.3.1.8.3.1 (analysis of the effects of tectonic processes and events on flux rates).

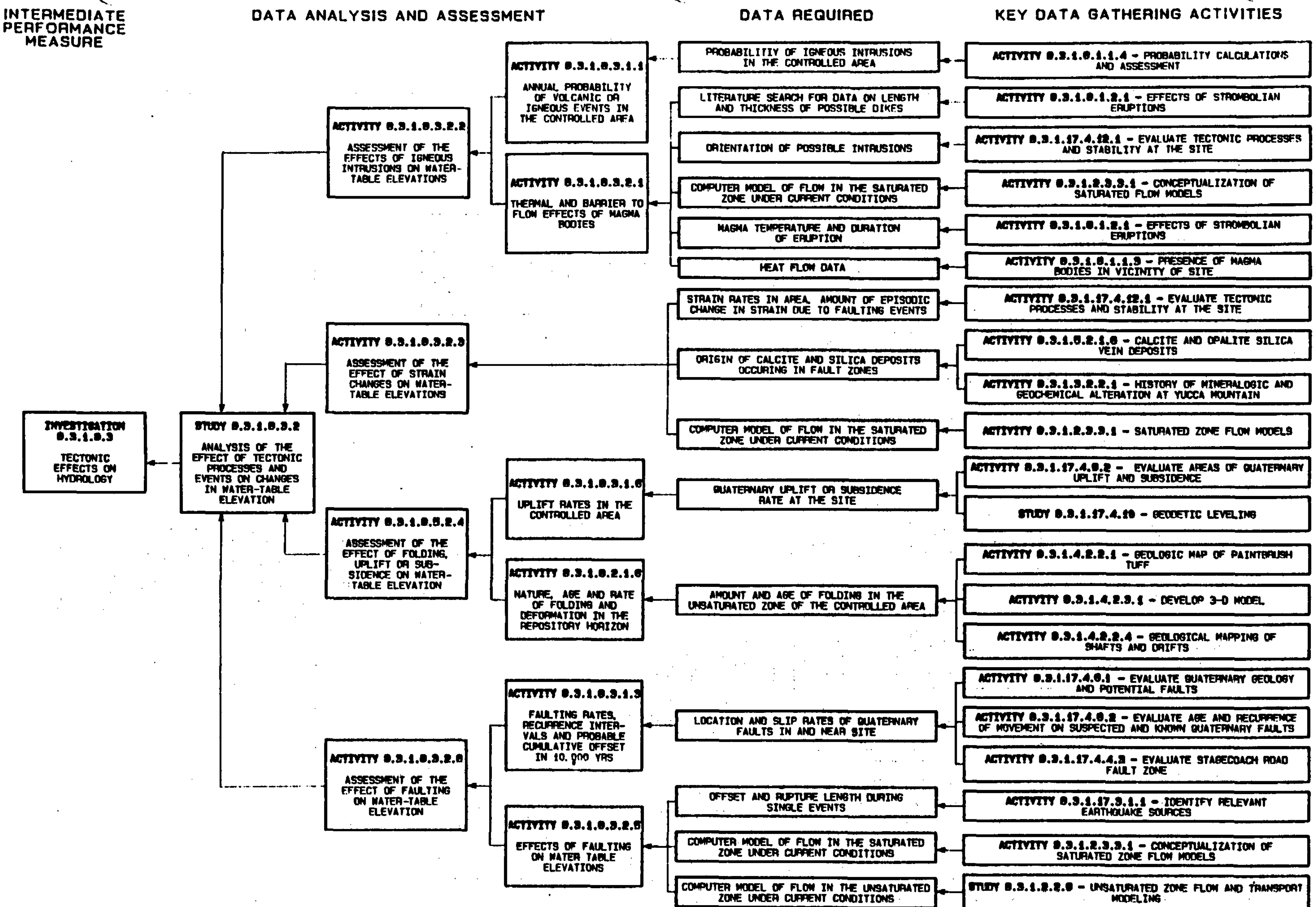


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Figure 8.3.1.8-6. Logic diagram for Study 8.3.1.8.3.2 (analysis of effects of tectonic processes and events on changes in water-table elevation).

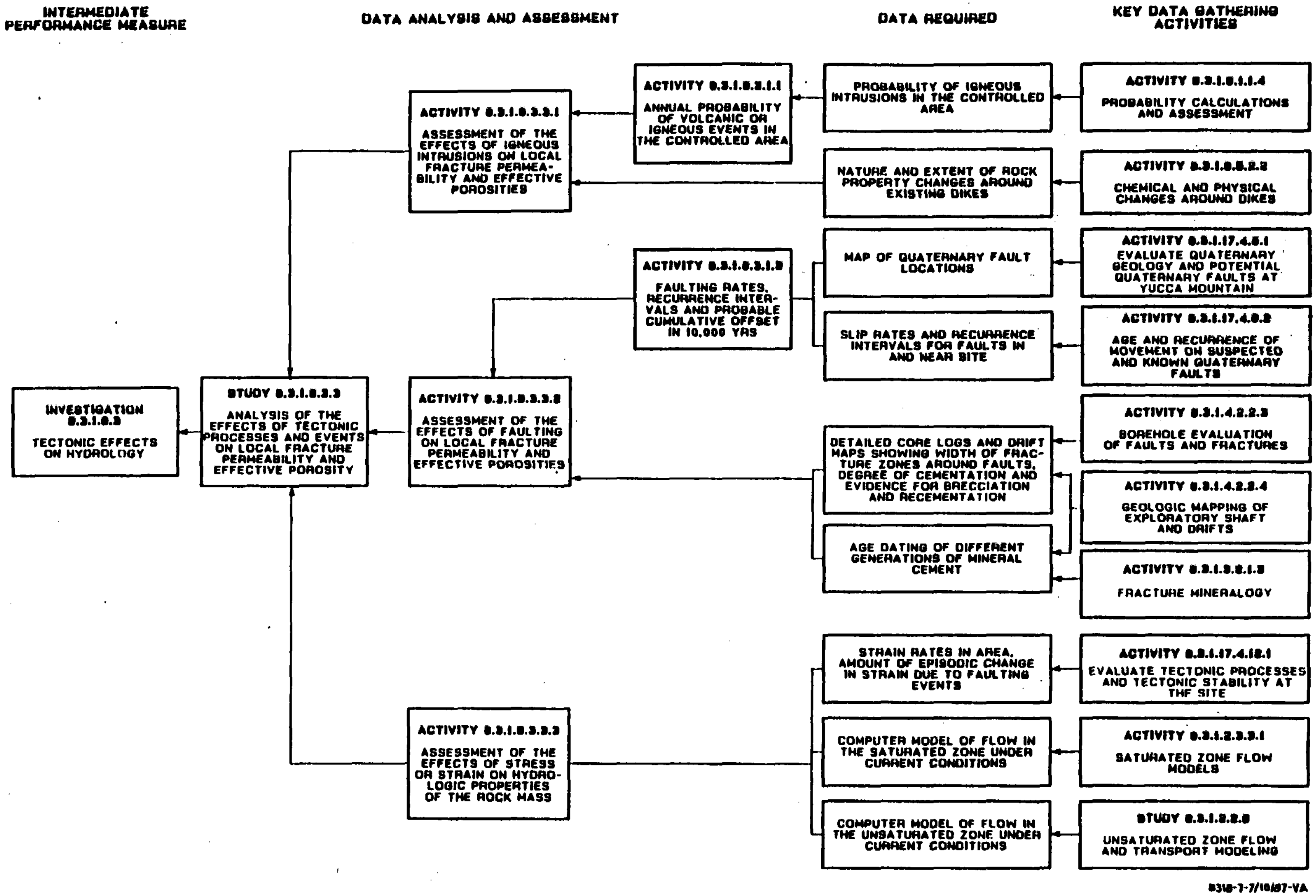


Figure 8.3.1.8-7. Logic diagram for Study 8.3.1.8.3.3 (effects of faulting on local fracture permeability and effective porosity).

the probability of igneous events occurring in the larger area encompassing the controlled area and a buffer zone. Activity 8.3.1.8.3.1.2 will summarize the available data on the size and location of volcanic and igneous features that could occur in the area. This activity will also perform modeling studies to estimate the amount of change in flux rates that could occur as a result of an igneous event. The activity will then use this data and the data from Activity 8.3.1.8.3.1.1 to (1) provide an assessment of the possibility that significant changes could result from these initiating events and (2) prepare a report.

The third initiating event considered by Study 8.3.1.8.3.1 is the possibility that fault offset could affect average percolation flux rates. Effects to be considered include surface topographic changes such as the creation of a scarp that could create impoundments or divert drainage; and subsurface changes, such as the juxtaposition of units of different hydrologic properties or change in the dip of beds that could create perched aquifers or divert subsurface drainage toward the repository. Activity 8.3.1.8.3.1.3 will collect and summarize field data gathered by other activities and calculate slip rates, recurrence intervals and probable cumulative offset in 10,000 yr for faults in and near the controlled area. Activity 8.3.1.8.3.1.4 will perform hydrologic modeling studies to estimate the effect of faulting on flux rates. Activity 8.3.1.8.3.1.5 will use the data generated by the previous two activities to (1) generate an assessment of the effect of probable fault movement on flux rates that will satisfy parameters 5 to 7 and (2) prepare a report.

The fourth initiating event considers the possibility that folding processes could change the dip of beds in the repository area sufficiently to alter flux rates. This could occur where downward percolating waters are diverted laterally at the contact with a low permeability unit. The laterally moving waters at the contact could be diverted toward the repository by folding, thereby increasing repository flux rates. The fifth initiating event considers the possibility that rapid rates of area-wide uplift or subsidence could alter drainage patterns or gradients sufficiently to affect flux rates. These initiating events and parameters 8 and 9 associated with them will be addressed by Activities 8.3.1.8.3.1.6 and 8.3.1.8.3.1.7. Activity 8.3.1.8.3.1.6 will collect and summarize field data from other activities and calculate uplift and subsidence rates for the area including the site. Activity 8.3.1.8.3.1.7 will use these rates and rates of folding calculated by other activities to estimate the amount of folding uplift and subsidence expected in 10,000 yr. The activity will then (1) perform an assessment of the effect of these changes on average percolation flux rates using hydrologic modeling techniques and (2) summarize the assessment in a report.

Study 8.3.1.8.3.2 will analyze the possibility that tectonic processes and events could cause changes in the elevation of the water table or the potentiometric surface of confined aquifers. Rises in the water table would shorten the length of the unsaturated zone travel path and affect release rates. Such rises could also change the hydraulic gradient, alter the location of discharge points, or create perched aquifers in the area of the site. These effects could affect ground-water travel times or place locally saturated zones in close proximity to the waste. Four initiating events have been identified in connection with this study (Table 8.3.1.8-4).

The first initiating event considers the possibility that igneous intrusions could affect water table elevations by creating barriers to flow such as a dike or creating thermally driven circulation systems that could cause water to rise to repository levels as the result of an intrusion or volcanic event. Activity 8.3.1.8.3.2.1 will collect and summarize data from other activities (Figure 8.3.1.8-6) on the dimensions and orientations of probable intrusions and the thermal effects around such intrusions. Hydrologic models of existing conditions at Yucca Mountain will then be used to estimate the magnitude of the changes that could result from igneous events. Activity 8.3.1.8.3.2.2 will take the results of this activity and combine them with data on the probability of such intrusions (Activity 8.3.1.8.3.1.1) to produce an assessment of the effects igneous intrusions would have on water table levels and will satisfy parameters 10 and 11. This activity will also prepare a report summarizing the results of the assessment.

The second initiating event considers the possibility that episodic movement on faults could result in variations in stress and strain levels in the rock mass that produce relatively short-lived fluctuations in water-table or potentiometric levels. If these fluctuations are great enough, these episodic changes could result in the periodic saturation of the repository horizon due to a general rise in the water table or water moving upward along a conduit such as a fault from a confined aquifer. Activity 8.3.1.8.3.2.3 will provide an assessment of the probability and magnitude of these effects and satisfy parameter 12. The activity will collect data on strain rates in the region and calculate the amount and nature of expected changes during a faulting event. Modeling studies will then be performed to analyze the amount of water table fluctuation that could be expected. The assessment will also include a consideration of the field evidence that significant water-table or potentiometric surface fluctuations have occurred in the past near Yucca Mountain and an evaluation of reports of water table occurring in connection with earthquakes at other locations. The activity will also prepare a report summarizing the assessment and the supporting data.

The third initiating event considers the possibility that folding, uplift, or subsidence could significantly change the position of the repository with respect to the water table in 10,000 yr. Activity 8.3.1.8.3.2.4 will review the data collected by other activities on the rates of folding, uplift, and subsidence in the area to provide an assessment of the probability of significant changes of this type and satisfy parameter 13.

The fourth initiating event considers the possibility that offset on faults could be great enough to juxtapose lithologic units of differing hydrologic properties and produce changes in ground-water flow that result in rises in the water table or the creation of perched aquifers. Activity 8.3.1.8.3.2.5 will conduct a hydrologic modeling study to estimate the amount of change in water-table levels that could be expected for a range of displacements. Activity 8.3.1.8.3.2.6 will combine this data with data on the probability of significant offsets (Activity 8.3.1.8.3.1.3) to produce an assessment of the probability of significant changes in water levels in a 10,000-yr period and satisfy parameters 14 and 15. The activity will also produce a report summarizing the data and the results of the assessment.

Study 8.3.1.8.3.3 will consider the possibility that tectonic processes and events could alter the rock properties governing ground-water flow along significant travel paths. The initiating events are related to events or processes that could produce local changes in the saturated fracture permeability or fracture effective porosity. If such changes were to occur, they could result in the formation of barriers to ground-water flow or the creation of conduits to enhanced flow that could adversely affect the containment or transport rate of wastes. Three initiating events have been identified under this study (Table 8.3.1.8-5).

The first initiating event considers the possibility that an igneous intrusion could cause changes in the physical properties of the surrounding rocks. Activity 8.3.1.8.3.3.1 will collect and summarize data from the literature and field data gathering activities on the effects of the intrusion of dikes and sills in tuffs (Figure 8.3.1.8-7). This data will be combined with data on the probability of such intrusions in the controlled area (Activity 8.3.1.8.3.1.1) to produce an assessment that satisfies parameter 16 on the expected changes in local fracture permeability and fracture effective porosity resulting from igneous intrusions. The activity will result in a report summarizing the data and the results of the assessment.

The second initiating event considers the possibility that periodic offset on Quaternary faults in and near the controlled area could cause temporary changes in physical properties along the fault. These changes could result in the fault becoming a barrier to lateral ground-water flow or a conduit to vertical flow until mineralization or other processes return conditions to present values. Activity 8.3.1.8.3.3.2 will collect and summarize data from other activities on the width of fracturing around fault zones and evidence of significant fracturing and recementation along faults. These data will then be used to predict the variation in physical properties that can occur along faults through the faulting cycle. This information will then be combined with data on the probability of faulting events in the controlled area (Activity 8.3.1.8.3.1.3) to produce an assessment of the effects of the initiating event and satisfy parameters 17 and 18. The activity will also produce a report summarizing the data and the results of the assessment.

The third initiating event considers the possibility that episodic faulting, folding, uplift, or subsidence could result in cyclic changes in the physical properties of the rock mass because of changes in the stress and strain regime. Activity 8.3.1.8.3.3.3 will address this possibility and satisfy parameter 19 by summarizing data on strain rates in the area and modeling the changes in rock fracture permeability and porosity that could result. The activity will also produce a report summarizing the data and the results of the assessment.

8.3.1.8.3.1 Study: Analysis of the effects of tectonic processes events on average percolation flux rates over the repository

This study will produce analyses and assessments of the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

8.3.1.8.3.1.1 Activity: Annual probability of volcanic or igneous events in the controlled area

Objectives

The objective of this activity is to calculate the annual probability of igneous and volcanic events within 0.5 km of the controlled area boundary.

Parameters

The parameters for this activity are

1. Annual probability of volcanic events within the controlled area.

2. Annual probability of significant igneous intrusion within 0.5 km of the controlled area boundary.

Description

This activity will take the data developed in Activity 8.3.1.8.1.1.4 on the probability of volcanic and igneous events penetrating the repository and expand that analysis to calculate probabilities for the area within 0.5 km of the controlled area boundary. Special attention will be paid to the possibility that the influence of structural controls on igneous activity may be different for this larger area than for the repository. The data supplied by this activity will be used by Activity 8.3.1.8.3.1.2 and in other studies in this investigation as part of the assessments of the effects of igneous activity in producing possible changes in hydrologic characteristics.

Methods and technical procedures

Activity 8.3.1.8.3.1.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.1.2 Activity: Assessment of the effects of igneous intrusions and volcanic events on flux rates

Objectives

The objective of this activity is to produce an assessment of the possibility that volcanic or igneous events could cause significant changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

Parameters

The parameters for this activity are

1. The effects of a volcanic event on topography and average flux rates.

2. The effects of an igneous intrusion on average flux rates.

Description

This activity will collect and summarize data from the literature and other activities on the thickness and extent of lava flows and ash falls and the dimensions of Strombolian cones or hydrovolcanic maars that are possible in the site area. The data on these features will be reviewed to determine whether the appearance of such features could substantially alter average flux rates through changes in drainage and topography. This activity will also compile data and complete an estimate on the length, depth, and orientation of possible dikes and sills in the area. These data will then be used in computer modeling of the hydrologic flow system to determine the effect of intrusions on flux rates. The results of this analysis will be combined with the probability of such igneous events occurring calculated by Activity 8.3.1.8.3.1.1 into an assessment of the probability of significant changes in flux due to igneous events. The activity will prepare a report that will address the following topics:

1. A summary of the data used in the assessment.

2. A discussion of the methods and models used in the analysis.

3. The results of the assessment.

4. A discussion of the assumptions and uncertainties in the data and the methods of analysis.

Methods and technical procedures

Activity 8.3.1.8.3.1.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.1.3 Activity: Faulting rates, recurrence intervals, and probable cumulative offset in 10,000 yr

Objectives

The objective of this activity is to provide estimates of the slip rates, recurrence intervals, and probable cumulative offset in 10,000 yr on Quaternary faults in and near the controlled area.

Parameters

The parameters for this activity are

1. Location and spacing of Quaternary faults in and near the controlled area.

2. Slip rates on Quaternary faults in and near the controlled area.

3. Recurrence intervals on Quaternary faults in and near the controlled area.

4. Present dip of tuff beds at Yucca Mountain in and near the controlled area.

Description

This activity will collect and summarize data from a number of field data gathering activities and synthesize that data to provide estimates of the parameters listed above. The data to be reviewed and summarized include detailed bedrock geologic mapping, mapping of Quaternary deposits and faults, detailed structure contour maps, and logs of trenches across Quaternary faults. Figure 8.3.1.8-5 indicates the key data gathering activities that will be supplying this data. The bedrock and Quaternary geologic maps and the structure contour maps will be used to define the location, length, and orientation of Quaternary faults in the area of the repository. Data on the amount and age of displacement from trench logs, detailed structure contour maps, and detailed geologic maps will be used to calculate slip rates and recurrence intervals. Slip rates for time intervals extending from the present to the Miocene will be calculated in order to determine Quaternary slip rates and to analyze the changes that have occurred in slip rates over the last 15 million yr. The detailed structure contour maps will also be used to determine the range of possible down-dip fault geometries that need to be considered in the depth range that is significant in calculating the effects of faulting on hydrologic properties. These structure contour maps will incorporate data obtained from the geophysical, drilling, and mapping activities. The information generated by this activity will be used by Activity 8.3.1.8.3.1.5 and the other studies in this investigation to satisfy the performance parameters.

Methods and technical procedures

Activity 8.3.1.8.3.1.3 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.1.4 Activity: Effects of faulting on average flux rates

Objectives

The objective of this activity is to estimate the effects that the creation of scarps, the diversion of drainage, the change in the dip of beds, or the juxtaposition of beds due to fault offset would have on average percolation flux at the top of the Topopah Spring welded unit.

Parameters

The parameters for this activity are models of average flux rate change resulting from a range of faulting conditions.

Description

This activity will generate models that can be used by Activity 8.3.1.8.3.1.5 to analyze the probability of significant changes in average percolation flux rates due to fault activity. These models will be based on the models of present conditions that control flux rates in Study 8.3.1.2.2.9. This activity will consider the perturbations to current conditions resulting from the offset or tilting of beds and changes to topography that a faulting event may cause. Various amounts and locations of offset will be modeled to determine the point at which fault offset could become a significant factor in controlling flux rates.

Methods and technical procedures

Activity 8.3.1.8.3.1.4 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.1.5 Activity: Assessment of the effects of faulting on flux rates

Objectives

The objective of this activity is to provide an assessment of the probability that average percolation flux rates at the top of the Topopah Spring welded unit at Yucca Mountain would be significantly affected by future fault activity.

Parameters

The parameters for this activity are

1. Probability of offset more than 2 m on faults in the controlled area in 10,000 yr.

2. Probability of changing dip by greater than 2 degrees in 10,000 yr.

3. Effect of faulting on average flux rates.

Description

This activity will use the data and models generated by the two previous activities to prepare an assessment of the probability that faulting will significantly affect flux rates at Yucca Mountain. The data on slip rates and recurrence intervals will be used to calculate the probability that faulting events will occur during a 10,000-yr period. These data will also be used to calculate the amount of expected offset in single events, the cumulative offset in 10,000 yr, and the probability of significantly large offsets (>2 m) occurring. The data on the present dips at the site, location and spacing of Quaternary faults, and slip rates will be analyzed to estimate the amount of change in dip that could result from fault displacement in 10,000 yr and the probability of significant changes (>2°) occurring. The models from Activity 8.3.1.8.3.1.4 will then be used to estimate the effects of expected faulting conditions on flux rates. A report that contains the results of the assessment will be prepared that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.1.5 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.1.6 Activity: Uplift rates in the controlled area

Objectives

The objective of this activity is to calculate the rate of uplift or subsidence in and around the controlled area.

Parameters

The parameter for this activity is the uplift or subsidence rates in and around the controlled area.

Description

This activity will compile and summarize data collected by other field data-gathering activities that can be used to calculate the rates of uplift and subsidence affecting the controlled area. Data such as geodetic leveling and the geomorphic and geologic indicators of Quaternary uplift and subsidence will be used in the calculation. The rates estimated by this activity will be used by Activity 8.3.1.8.3.1.7 and the other studies in this investigation to assess the effect of uplift and subsidence on hydrologic conditions.

Methods and technical procedures

Activity 8.3.1.8.3.1.6 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.1.7 Activity: Assessment of the effects of folding, uplift, and subsidence on flux rates

Objectives

The objective of this activity is to assess the probability that folding, uplift, or subsidence will significantly alter average percolation flux rates at the top of the Topopah Spring welded unit over the repository.

Parameters

The parameters for this activity are

1. The probability of dip changing by greater than 2 degrees in 10,000 yr by folding.

2. The probability of exceeding 30 m of altitude change in 10,000 yr.

Description

This activity will use the data generated by Activities 8.3.1.8.2.1.6 and 8.3.1.8.3.1.6 to calculate (1) the expected amount of change in dip and altitude in 10,000 yr and (2) the probability that significant changes would occur. If significant changes are considered credible, models based on the present conditions controlling flux rates in Study 8.3.1.2.2.5 will be developed to consider the perturbations to current conditions resulting from the tilting of beds and changes to topography that could occur. A report will be prepared that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.1.7 will only synthesize and compile data collected by other activities and will use the method and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.2 Study: Analysis of the effect of tectonic processes and events on changes in water-table elevation

This study will produce analyses and assessments of the probability that tectonic initiating events could result in significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area.

8.3.1.8.3.2.1 Activity: Thermal and barrier-to-flow effects of igneous intrusions on water-table elevation

Objectives

The objective of this activity is to model the effects that dikes or other intrusions would have on water-table elevation due either to the barrier to flow created by intrusion or the thermal pulse produced by the intrusion.

Parameters

The parameters for this activity are models for predicting the effects of igneous intrusions on water-table levels.

Description

This activity will produce models for use in assessing the effects of igneous intrusions on water-table levels. These models will be based on the models of present ground-water flow developed in Activity 8.3.1.2.3.3.1. The first part of the modeling activity will consider the perturbations to current conditions resulting from the barriers to flow that intrusive features such as a dike might produce. Dikes of various sizes and orientations will be modeled to estimate the range of effects and determine at what point igneous intrusions would begin to produce significant changes.

The second part of the modeling activity will consider the thermal effects of an intrusion on water levels. As discussed in Sections 1.3.2.1.2 and 1.5.1, basaltic volcanism is considered to be the only credible intrusive scenario during the postclosure period. This type of activity is characterized by the intrusion of dikes from magma bodies with depths of 20 to 30 km. Therefore, the intrusion of a dike is considered to be the only credible process by which changes in the thermal characteristics of the site could occur. Published methods (e.g., Link et al., 1982) will be used to calculate the magnitude and extent of thermal changes around a dike. The results of Activity 8.3.1.8.1.2.3 will also be reviewed to determine if there are any indications of magma bodies in the vicinity of the site with the potential for significant movement in 10,000 yr that could produce significant changes in the thermal gradient. Models will then be generated that predict the effects of thermal changes on water levels. These models will be used by Activity 8.3.1.8.3.2.2 in the assessment of the probability that igneous intrusions will cause significant changes in water-table levels.

Methods and technical procedures

Activity 8.3.1.8.3.2.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.2.2 Activity: Assessment of the effects of igneous intrusions on water-table elevations

Objectives

The objective of this activity is to produce an assessment of the probability that igneous intrusions will cause (1) significant changes in the elevation of the water table or potentiometric surface, (2) changes in the hydraulic gradient, (3) the creation of discharge points in the controlled area, or (4) the creation of perched aquifers in the controlled area.

Parameters

The parameters for this activity are

1. Barrier-to-flow effects of igneous intrusions on water-table levels and hydraulic gradients.

2. Thermal effects of igneous intrusions on water-table levels and hydraulic gradients.

Description

This activity will use the data in Activity 8.3.1.8.3.1.1 to estimate the probability of an igneous event occurring in or near the controlled area. It will also collect and summarize data from other data gathering activities (Figure 8.3.1.8-8) to estimate the length, thickness, and orientation of possible future intrusions. This data will then be used with models developed in Activity 8.3.1.8.3.2.1 to estimate the effects of expected intrusions. This activity will also review the available literature for evidence of water-table changes during volcanic events in other parts of the world that are analogous to the types of events that might occur in the vicinity of the site. All of this information will then be integrated to produce an assessment of the probability that igneous intrusions will cause significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area. The results will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.2.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.2.3 Activity: Assessment of the effect of strain changes on water-table elevation

Objectives

The objective of this activity is to estimate the probability that changes in stress or strain resulting from faulting events could significantly alter water-table levels or potentiometric surfaces in and around the controlled area.

Parameters

The parameter for this activity is the probability that strain-induced changes will increase the water-table level or the level of potentiometric surfaces to more than 850 m mean sea level (MSL).

Description

This activity will use the models of present flow in the saturated zone from Activity 8.3.1.2.3.3.1 to develop a model to predict the effects on the level of the water table or potentiometric surfaces in the vicinity of the site of changes in the present level of stress or strain caused by a faulting event. Data on the magnitude of such changes in stress and strain will be estimated using theoretical calculations and data from Activity 8.3.1.17.4.12.1. The model will be used to estimate the effects of anticipated strain changes and to determine the point at which such strain changes could become significant.

This activity will also compile and analyze data on the effects of historic earthquakes on water-table elevations. Earthquakes that have induced water-table fluctuations will be studied to determine the type of material in which changes occurred (rock or alluvium), the amount and duration of changes, and the local geologic and ground-water conditions that may influence whether or not significant changes occur. The results of this analysis will be compared with conditions present at the site to estimate whether any of these occurrences represent analogs of possible future site behavior.

Field evidence from the site will be reviewed to determine if there is any evidence of past water-table fluctuations that may be related to tectonic events. For example, the results of Activity 8.3.1.5.2.2.6 will be reviewed to determine whether or not the calcite-silica deposits that are found along some faults are episodic spring deposits that may be related to fluctuations of the water table or potentiometric surface or whether the deposits are the result of surface pedogenic processes.

The results of these studies will then be incorporated into an assessment evaluating the possibility of significant water-table fluctuations due to strain changes. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.2.3 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.2.4 Activity: Assessment of the effect of folding, uplift, or subsidence on water-table elevation

Objectives

The objective of this activity is to provide an assessment of the probability that folding, uplift, or subsidence could change the elevation of the repository with respect to the level of the water table sufficiently to significantly alter the length of the unsaturated zone travel path.

Parameters

The parameter for this activity is the probability that the repository will be lowered by 100 m through the action of folding, uplift, or subsidence in 10,000 yr.

Description

This activity will use the data generated by Activities 8.3.1.8.2.1.6 and 8.3.1.8.3.1.6 to calculate the expected amount of change in the elevation of the repository horizon over 10,000 yr caused by folding, uplift, or subsidence. This activity will also assess the probability that changes of a significant nature would occur. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.2.4 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.2.5 Activity: Effects of faulting on water-table elevation

Objectives

The objective of this activity is to produce models to analyze the potential for fault offset to change the elevation of the water table or potentiometric surface, change the hydraulic gradient, create discharge points in the controlled area, or create perched aquifers in the controlled area.

Parameters

The parameters for this activity are the models for predicting the effects of faulting on water-table levels.

Description

This activity will use the models of present flow in the saturated zone from Activity 8.3.1.2.3.3.1 and unsaturated zone from Study 8.3.1.2.2.9 to develop a model to predict the effects of a faulting event on the level of the water table or the creation of a perched aquifer. The effects of a variety of fault offsets, orientations, down-dip geometries, and locations will be calculated to estimate the point at which faulting could become significant. The models produced by this activity will be used by Activity 8.3.1.8.3.2.6 in the assessment of the effects of faulting on water-table levels.

Methods and technical procedures

Activity 8.3.1.8.3.2.5 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure		
	Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.2.6 Activity: Assessment of the effect of faulting on water-table elevation

Objectives

The objective of this activity is to prepare an assessment of the probability that fault offset will result in significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, the creation of perched aquifers in the controlled area in 10,000 yr.

Parameters

The parameters for this activity are

1. Probability of total offsets more than 2.0 m in 10,000 yr on faults within 0.5 km of the controlled area boundary.

2. Effects of fault offset on water-table levels and hydraulic gradient.

Description

This activity will use the data on slip rates and recurrence intervals on Quaternary faults in and near the controlled area from Activity 8.3.1.8.3.1.4 to calculate the expected cumulative displacement in 10,000 yr and the probability of significant cumulative offset (>2 m) occurring on any fault. These data and data on the length and location of Quaternary faults will then be used with the models produced in Activity 8.3.1.8.3.2.5 to estimate the changes that would be produced under anticipated and unanticipated conditions.

This activity will also consider the results of Activity 8.3.1.8.3.2.3 on the evidence of possible past changes in water-table levels in the site area and the effects of faulting during historic earthquakes on water-table levels. The above data will then be incorporated into an assessment of the probability of significant fault offsets occurring in 10,000 yr and the effects of fault offset on water-table elevation. The assessment will include an analysis of possible changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, the creation of perched aquifers based on the results of the modeling and probability calculations. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.2.6 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.3 Study: Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity

The activities in this study address tectonic initiating events and processes that could cause local changes in saturated fracture permeability or fracture effective porosity.

8.3.1.8.3.3.1 Activity: Assessment of the effects of igneous intrusions on local fracture permeability and effective porosities

Objectives

The objective of this activity is to assess the possibility that igneous intrusions, such as dikes or sills, could cause changes in the hydrologic flow properties of the surrounding rocks.

Parameters

The parameters for this activity are the effects of igneous intrusions on local fracture permeabilities and effective porosities.

Description

This activity will use the results of Activity 8.3.1.8.3.1.1 on the probability of igneous intrusions in and near the controlled area and Activity 8.3.1.8.5.2.3 that measures the nature and extent of physical changes around intrusions in tuff. These data will be reviewed, summarized, and combined into an assessment of the probability that igneous intrusions could result in significant changes in local saturated fracture permeability and fracture effective porosity. The assessment will also include a consideration of how probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.3.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.3.2 Activity: Assessment of the effects of faulting on local fracture permeability and effective porosities

Objectives

The objective of this activity is to assess the probability that movement on faults could result in significant local changes in saturated fracture permeability and fracture effective porosity along the fault that could affect the regional ground water flow system.

Parameters

The parameters for this activity are

1. The annual probability of faulting events on Quaternary faults within 0.5 km of the controlled area boundary.

2. The effects of fault motion on local fracture permeabilities and effective porosities.

Description

This activity will determine the nature of faulting and calculate the annual probability of faulting in and near the controlled area using the data on slip rates, recurrence intervals, down-dip geometry, and number of faults from Activity 8.3.1.8.3.1.3. Data on the width of fracture zones around faults, evidence of the possible episodic brecciation and recementation of mineral fillings along fault zones, and the age and nature of the mineral fillings will be collected and summarized after reviewing the core logs, the geologic mapping of shaft and drifts, and fracture mineralogy studies collected by other field data gathering activities (Figure 8.3.1.8-7) near Quaternary faults. These data will be analyzed to determine the nature, extent, and duration of changes in physical properties that could occur along faults in the vicinity of the site. An assessment of the probability of significant changes will then be produced by integrating all the above results. The assessment will also include a consideration of how the probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.3.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.3.3.3 Activity: Assessment of the effects of stress or strain on hydrologic properties of the rock mass

Objectives

The objective of this activity is to assess the probability that changes in stress or strain conditions around the site caused by a tectonic event could result in significant changes in the saturated fracture permeability and fracture effective porosity of the rock mass.

Parameters

The parameters for this activity are the effects of changes of stress or strain on hydrologic properties of the rock mass.

Description

This activity will use theoretical calculations and the data from Activity 8.3.1.17.4.12.1 to estimate the magnitude of stress and strain changes through the faulting cycle for the site area. Modeling studies will then be performed to estimate the effect that these changes might have on hydrologic properties. These results will then be combined with the probability of faulting events in and near the controlled area to calculate the probability that significant changes in the physical properties of the rock mass could occur. The assessment will also include a consideration of how the probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data used in the assessment.

2. A summary and discussion of the models used in the assessment and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.3.3.3 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not developed under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.3.4 Application of results

The information derived from the studies and activities described above will be used in the following issues and investigations.

Issue or investigation	Subject
1.1	Total system performance (Section 8.3.5.13)
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings--postclosure (Section 8.3.5.18)
8.3.1.8.4	Tectonic effects on geochemistry

8.3.1.8.3.5 Schedule and milestones

This investigation addresses postclosure tectonic effects on hydrology and contains three out-year studies: 8.3.1.8.3.1 (analysis of the effects of tectonic processes and events on average percolation flux rates over the repository), 8.3.1.8.3.2 (analysis of the effect of tectonic processes and events on changes in water-table elevation), and 8.3.1.8.3.3 (analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity). In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

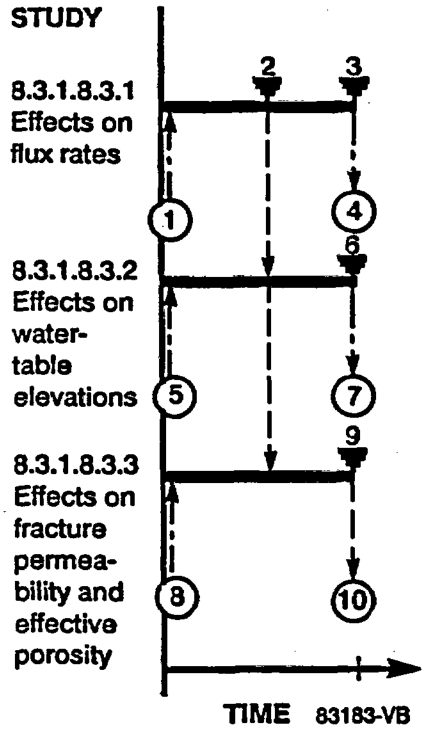
The activities of this entire investigation are planned to progress in parallel with performance and design activities in an iterative fashion. The results of these studies will be used toward the resolution of Issue 1.1 (total system performance) and to support advanced conceptual and license application designs.

Completion of the studies in this investigation are constrained by the availability of data from several other investigations. Study 8.3.1.8.3.1 requires the following data: the probability and effects of volcanic eruptions from Investigation 8.3.1.8.1, computer models of flow in the unsaturated zone from Investigation 8.3.1.2.2; fault location, spacing, displacement and recurrence from Investigation 8.3.1.17.4; and detailed geologic and structure contour maps from Investigation 8.3.1.4.2.

Completion of Study 8.3.1.8.3.2 is constrained by the following information: the probability and effects of volcanic eruptions from Investigation 8.3.1.8.1; computer models of flow in the unsaturated zone from Investigation 8.3.1.2.2; fault location, spacing, displacement and recurrence from Investigation 8.3.1.17.4; detailed geologic and structure contour maps from Investigation 8.3.1.4.2; origin of calcite-silica deposits from Investigation 8.3.1.5.2; origin, nature and age of vein fillings and rock alteration from Investigation 8.3.1.3.2; computer models of flow in the saturated zone from Investigation 8.3.1.2.3; expected amounts of rupture length and offset during single faulting events from Investigation 8.3.1.17.3; and detailed mapping of the exploratory shaft and drifts from Investigation 8.3.1.4.2.

Completion of Study 8.3.1.8.3.3 depends on the availability of the following information: the probability and effects of volcanic eruptions from Investigation 8.3.1.8.1; computer models of flow in the unsaturated zone from Investigation 8.3.1.2.2; fault location, spacing, displacement and recurrence of faulting and area strain rates from Investigation 8.3.1.17.4; computer models of flow in the saturated zone from Investigation 8.3.1.2.3; evaluation of faults and fractures mapped or logged in boreholes or the exploratory shaft and drifts from Investigation 8.3.1.4.2; age dating of different generations of mineral fillings in faults and fractures from Investigation 8.3.1.3.2; and rock property changes around dikes and sills from Investigation 8.3.1.8.5.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Data input from Investigations 8.3.1.8.1 (volcanic activity), 8.3.1.2.2 (site unsaturated zone hydrologic system), 8.3.1.17.4 (preclosure tectonics data collection analysis), and 8.3.1.4.2 (geologic framework).
2	Milestone Z297. Report available on faulting rates, recurrence intervals, and probable cumulative offset in 10,000 yr available for use by Studies 8.3.1.8.3.1, 8.3.1.8.3.2, and 8.3.1.8.3.3.
3	Milestones Z384, Z383, and Z393. A series of reports is available for use by Issue 1.1 (total system performance) assessing the effects of volcanism, faulting, folding, uplift and subsidence on flux rates.
4	Data input to Issue 1.1 from reports assessing the effects of volcanism faulting, folding, uplift and subsidence on flux rates.

Point number	Description
5	Data input from Investigations 8.3.1.5.2 (climate effects on hydrology), 8.3.1.3.2 (mineralogy, petrology, and rock chemistry), 8.3.1.2.3 (site saturated zone hydrologic system), 8.3.1.17.3 (vibratory ground motion), 8.3.1.8.1, 8.3.1.2.2, 8.3.1.17.4, and 8.3.1.4.2.
6	Milestones Z385, Z386, Z387, and Z388. A series of reports available for use by Issue 1.1 assessing the effects of igneous intrusions, strain changes, faulting, folding, uplift and subsidence on water-table elevations.
7	Data input to Issue 1.1 from reports assessing the effects of igneous intrusions, strain changes, faulting, folding, uplift and subsidence on water-table elevations.
8	Data input from Investigations 8.3.1.8.1 (volcanic activity), 8.3.1.8.5 (postclosure tectonics data collection and analysis), 8.3.1.17.4 (preclosure tectonics data collection analysis), 8.3.1.4.2 (geologic framework), 8.3.1.3.2 (mineralogy, petrology, and rock chemistry), 8.3.1.2.2 (site unsaturated zone hydrologic system), and 8.3.1.2.3 (site saturated zone hydrologic system).
9	Milestones Z389, Z390, Z391. A series of reports available for use by Issue 1.1 assessing the effects of igneous intrusions, faulting and stress and strain changes on local fracture permeability and effective porosity.
10	Data input to Issue 1.1 from reports assessing the effects of igneous intrusions, faulting, and stress and strain changes on local fracture permeability and effective porosity.

8.3.1.8.4 Investigation: Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.5.1.2	Basaltic volcanism

SCP section	Subject
1.5.2	Faulting
4.1.3.7	Geochemical retardation of the host rock and surrounding units--anticipated conditions
4.1.3.8	Geochemical retardation of the host rock and surrounding units--unanticipated conditions
4.4.2	Potential effects of natural changes

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Effects of igneous intrusions on local distribution coefficients.

2. Degree of mineralogic change in fault zones in 10,000 yr.

3. Effects of fault offset on travel pathway.

4. Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths due to tectonic processes in 10,000 yr.

Purpose and objectives of the investigation

The four performance parameters listed in the previous section have been identified by Issue 1.1 (Section 8.3.5.13, total system performance, and Table 8.3.1.8-6) to address the possibility that tectonic processes and events could produce significant changes in the geochemical properties of the rocks of the controlled area that control the rate of radionuclide movement (distribution coefficients (K_ds)). The study and activities in this investigation will address these requirements by providing assessments of the probability that the tectonic initiating events that have been recognized by Issue 1.1 could significantly alter distribution coefficients. These results will be used by Issue 1.1 to analyze total system performance of the repository in limiting radionuclide releases to the accessible environment. The initiating events considered in this investigation probably will have no significant impact on repository performance because of the very low rate at which mineral alteration occurs in the site area (see Section 4.1.1.4). It is anticipated that the data to be gathered in the geochemistry program (Section 8.3.1.3) to address other concerns will provide the data necessary to evaluate the rate of geochemical change. The level of effort for the activities related to these initiating events is therefore anticipated to be low and to consist primarily of organizing and presenting the data collected in other programs to provide the basis for evaluating the credibility of the initiating events in performance assessment activities.

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed on Table 8.3.1.8-6.

Technical rationale for the investigation

The flow of data and interconnections between activities in the single study of this investigation are shown on Figure 8.3.1.8-8. The first tectonic initiating event considered in this investigation is the possibility that an igneous intrusion could alter the mineralogy of the surrounding host rocks. Activity 8.3.1.8.4.1.1 will provide an assessment of this initiating event and satisfy parameter 1 by considering (1) the probability of an igneous intrusion occurring in the controlled area and (2) the extent and nature of mineral changes that have been found to occur around dikes and sills in tuffs during field studies. The activity will combine these data in an assessment of the probability that significant changes would occur.

The second initiating event considers the possibility that offset on a fault could result in significant mineral changes along the fault that could affect local distribution coefficients. Changes in distribution coefficients could result from the growth of mineral fillings in the fault zone itself or from the sealing effect of the mineral fillings that prevent interaction between fluids moving through the fault zone and the surrounding country rock. Activity 8.3.1.8.4.1.2 will provide an assessment of this initiating event and satisfy parameter 2 by analyzing data from core and the mapping of drifts and shafts to review the evidence of significant changes during past faulting events to determine the age, type, and extent of mineral changes that have occurred. The probability and location of faulting events will be determined from mapping and trenching activities that will provide data on slip rates, recurrence intervals, and locations of Quaternary faults. The assessment will integrate these data.

The third initiating event considers the possibility that offset on a fault could significantly affect distribution coefficients by diverting flow to pathways with significantly different mineral properties or water chemistry as a result of the juxtaposition of different lithologic units. Activity 8.3.1.8.4.1.3 will provide an assessment of this initiating event and satisfy parameter 3 by conducting modeling studies to determine the amount of offset necessary to produce significant changes. The results of the modeling activity will be combined with the probability that such offsets could occur using data on slip rates and recurrence intervals of faults in and near the controlled area as part of the assessment. The activity will summarize the results of the assessment in a report.

The fourth initiating event considers the possibility that changes in water-table levels or ground-water movement as a result of tectonic processes could produce significant mineral alteration in the formerly unsaturated rocks. Activity 8.3.1.8.4.1.4 will provide an assessment of this initiating event and partially satisfy parameter 4 by calculating the probability of significant faulting events and the nature of water-table fluctuations that could be expected from such events. Activity 8.3.1.3.7.1.2 will complete the characterization of this parameter by calculating the rate that mineral changes could occur in this environment using data on the history of mineral and geochemical alteration at Yucca Mountain and incorporating the results in

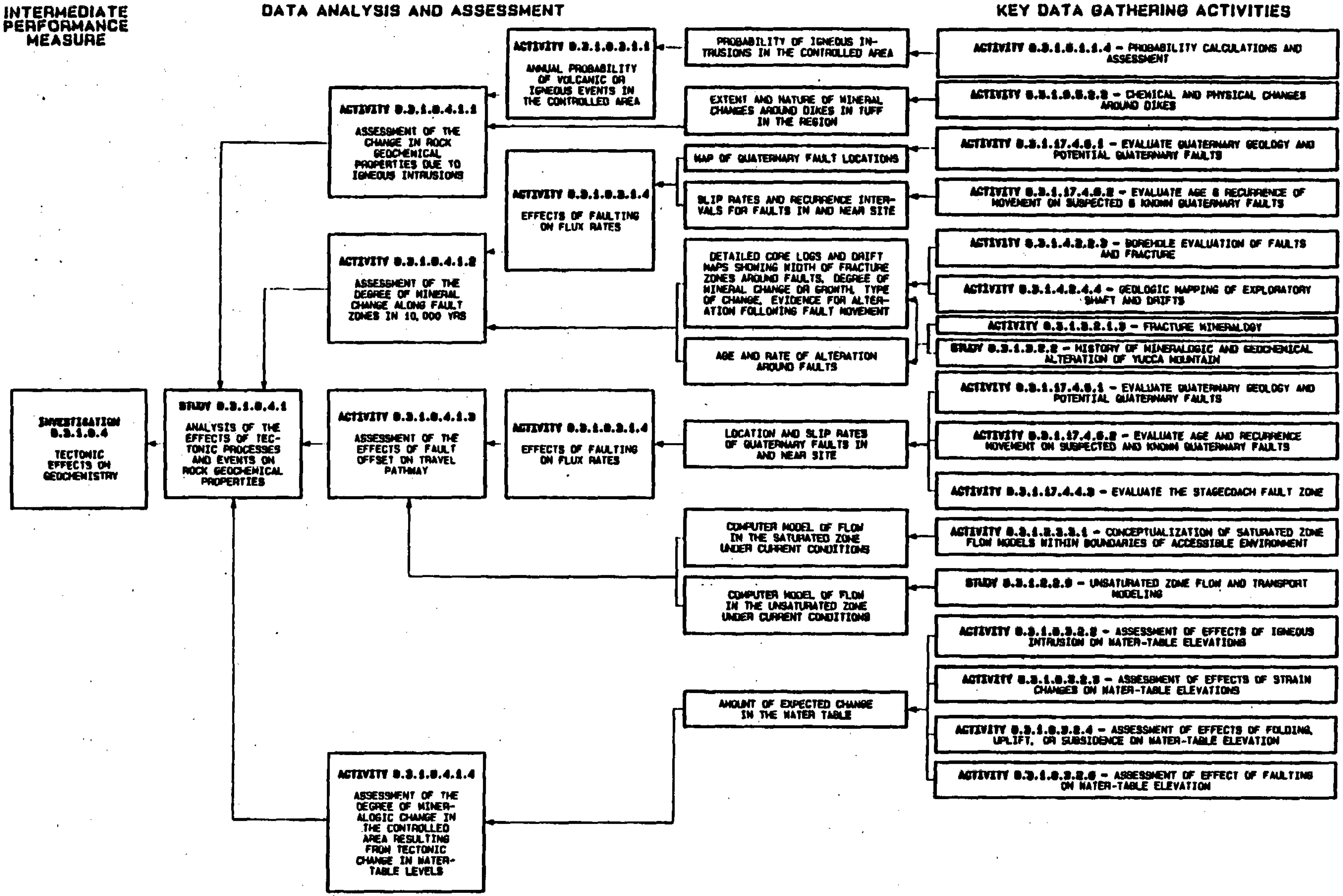


Figure 8.3.1.8-8. Logic diagram for Study 8.3.1.8.4.1 (analysis of the effects of tectonic processes on rock geochemical properties).

the integrated geochemical transport calculations. These data will be combined with the results of Study 8.3.1.8.3.2 on the probability of significant water-level changes occurring as the result of tectonic processes to complete the assessment. The activity will summarize the results of the assessment in a report.

8.3.1.8.4.1 Study: Analysis of the effects of tectonic processes and events on rock geochemical properties

The activities in this study provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

8.3.1.8.4.1.1 Activity: Assessment of the change in rock geochemical properties due to igneous intrusions

Objectives

The objective of this activity is to assess the probability that igneous intrusions will cause significant changes in local distribution coefficients in the controlled area in 10,000 yr.

Parameters

The parameters for this activity are the effects of igneous intrusions on local distribution coefficients.

Description

This activity will use the data collected by Activity 8.3.1.8.5.2.2 on the nature and extent of mineral changes occurring around dikes in tuffs to evaluate whether the observed changes would significantly alter distribution coefficients in the controlled area. The results of this evaluation will be combined with the probability of igneous intrusions occurring in the controlled area from Activity 8.3.1.8.3.1.1 to produce the assessment on the probability of significant change. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.4.1.1 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not develloped under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.4.1.2 Activity: Assessment of the degree of mineral change along fault zones in 10,000 yr

Objectives

The objective of this activity is to assess the probability that local distribution coefficients will be significantly altered along faults in 10,000 yr by displacement events.

Parameters

The parameter for this activity is the degree of mineral change along a fault zone in 10,000 yr.

Description

This activity will review and summarize the data on the nature and extent of mineralization along faults for evidence of brecciation and recementation that would result from periodic fault offset. This data will come from drilling activities that recover core from fault zones and the activities that will conduct geologic mapping of the shafts and drifts of the exploratory shaft facility. Data on the age and mineralogy of these zones will also be used in an assessment of the nature, extent, and rate of possible changes in distribution coefficients. These results will be combined with the probability of faulting events occurring in the controlled area derived from the data on slip rates and recurrence intervals in Activity 8.3.1.8.3.2.3 to complete the assessment of the probability that significant changes will occur. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.4.1.2 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not devel-loped under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.4.1.3 Activity: Assessment of the effects of fault offset on travel pathway

Objectives

The objective of this activity is to assess the possibility that offsets occurring on faults in 10,000 yr in the controlled area will divert radionuclides to travel pathways with significantly different distribution coefficients or water chemistry.

Parameters

The parameters for this activity are the effects of fault offset on travel pathway.

Description

This activity will use models based on the models of flow in the saturated and unsaturated zones under current conditions from Activity 8.3.1.2.3.3.1 and Study 8.3.1.2.2.5 to estimate the amount of offset necessary to produce significant changes in radionuclide travel pathways. To produce the assessment, these results will be combined with the probability of such displacements occurring in the controlled area derived from slip rate and recurrence interval data in Activity 8.3.1.8.3.1.4. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.4.1.3 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Title	Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not develloped under the NNWSI Project QA Plan	31 Jan 86
Validation of computer models	NNWSI-SOP-03-02	Software quality assurance	28 Feb 86
	QP 3.2	Use and control of computer programs	20 Dec 86

8.3.1.8.4.1.4 Activity: Assessment of the degree of mineral change in the controlled area resulting from tectonically induced change in water-table elevations

Objectives

The objective of this activity is to assess the probability and nature of tectonically induced changes in water-table level that might result in significant mineral changes in the newly saturated or unsaturated rock.

Parameters

The parameter for this activity is the degree of mineral change in the controlled area resulting from changes in water-table level or flow paths caused by tectonic processes in 10,000 yr.

Description

This activity will generate an assessment of the probability that faulting events could significantly alter water levels during the postclosure period and estimate the amount of these water-table fluctuations. The data for this assessment will be provided by Study 8.3.1.8.3.2. The assessment will be used by Activity 8.3.1.3.7.1.2 to complete characterization of the parameter by calculating the degree of mineral change such fluctuation could produce and the effect of these changes on the geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

Methods and technical procedures

Activity 8.3.1.8.4.1.4 will only synthesize and compile data collected by other activities and will use the methods and technical procedures given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Analysis of data	QP 3.1	Scientific investigation control and design control	20 Dec 86
Use of data from non-Project sources	NNWSI-SOP-03-03	Acceptance of data or data interpretation not devel-loped under the NNWSI Project QA Plan	31 Jan 86

8.3.1.8.4.2 Application of results

The information derived from the study and activities described above will be used in the following issues and investigations.

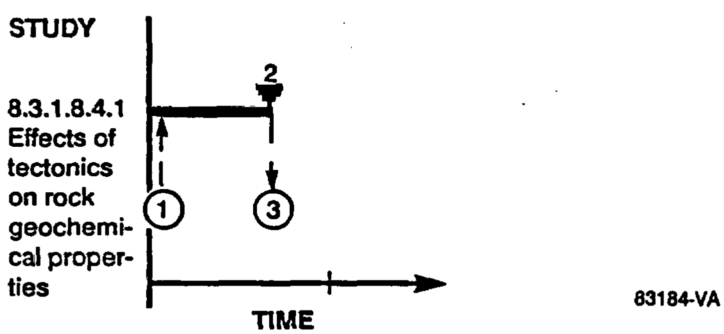
Issue or investigation	Subject
1.1	Total system performance (Section 8.3.5.13)
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings--postclosure (Section 8.3.5.18)
8.3.1.3.7	Radionuclide retardation investigation

8.3.1.8.4.3 Schedule and milestones

This investigation addresses postclosure tectonic effects on geochemistry and contains one out-year study: 8.3.1.8.4.1 (analysis of the effects of tectonic processes and events on rock geochemical properties). In the figure that follows, the schedule information for this study is presented in the form of a timeline. The timeline extends from implementation of the approved study plan to the issuance of the final products associated with the study. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The activities of this entire investigation are planned to progress in parallel with performance and design activities in an iterative fashion. The results of this study will be used toward the resolution of Issue 1.1 (total system performance) and to support advanced conceptual and license application designs.

Completion of Study 8.3.1.8.4 is constrained by the availability of the following data: the probability of igneous intrusions in the controlled area from Investigation 8.3.1.8.1; mineralogic changes around dikes and sills from Investigation 8.3.1.8.5; location, Quaternary slip rate, and recurrence interval on faults from Investigation 8.3.1.17.4;; detailed core logs and exploratory drift maps showing degree and type of mineral change around faults and fractures from Investigation 8.3.1.4.2; age and rate of mineral alteration around fractures from Investigation 8.3.1.3.2; computer models of flow in the unsaturated zone from Investigation 8.3.1.2.2; computer model of flow in the saturated zone from Investigation 8.3.1.2.3; and the amount of expected change in water-table elevation due to tectonic processes and events from Investigation 8.3.1.8.3.



The study number and title corresponding to the timeline are shown on the left of the preceding figure. The points shown on the timeline represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Data on input from Investigations 8.3.1.8.1 (volcanic activity), 8.3.1.8.5 (postclosure tectonics data collection and analysis), 8.3.1.17.4 (preclosure tectonics data collection and analysis), 8.3.1.4.2 (geologic framework), 8.3.1.3.2 (mineralogy, petrology, and rock chemistry), 8.3.1.2.2 (site unsaturated zone hydrologic system), 8.3.1.2.3 (site saturated zone hydrologic system), and 8.3.1.8.3 (tectonic effects on hydrology).
2	Milestones Q149, Z397, Z398, and Z399. A series of reports available for use by Issue 1.1 (total system performance) assessing the effects of igneous intrusions, faulting or tectonically induced changes in water-table elevation on rock geochemical properties along likely travel pathways.
3	Data input to Issue 1.1 from reports assessing the effects of igneous intrusions, faulting or tectonically induced changes in water table elevation on rock geochemical properties along likely travel pathways.

8.3.1.8.5 Investigation: Studies to provide the information required by the analysis and assessment investigations of the tectonics program

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.5.1	Volcanism

Parameters

The following parameters will be measured or calculated during the studies planned to satisfy this investigation:

1. Location, age, and volume of igneous deposits younger than 4 million yr and within 70 km of the site.

2. Detailed maps showing the relation of geologic structures to selected young volcanic centers.

3. Map showing depth to Curie isotherm.

4. Chemical and physical changes around dikes in tuff.

5. Petrology and geochemistry of late Cenozoic volcanic rocks in the region.

6. Evaluation of folding in the region and its relation to faulting or detachments.

7. Evaluation of heat-flow data.

Purpose and objectives of the investigation

The studies and activities in this investigation will collect the field data called for by the analysis and assessment activities in Investigations 8.3.1.8.1 through 8.3.1.8.4. Because most of the data required by these analysis and assessment activities are being collected by other programs, the activities in this investigation are limited to a small number providing data to support the analysis of volcanic, igneous intrusion, and folding processes. Figures 8.3.1.8-3 through 8.3.1.8-8 and Tables 8.3.1.8-1 through 8.3.1.8-6 show the relationship of the data gathering activities in this section to the analysis and assessment investigations.

Technical rationale for the investigation

One of the main requirements in the evaluation of the hazard of volcanic or igneous events is the calculation of the probability that such events would actually occur in the repository or the controlled area. Parameter 1 indicates the data required by Activities 8.3.1.8.1.1.1 and 8.3.1.8.1.1.4 to carry out this calculation. Activities 8.3.1.8.5.1.1 through 8.3.1.8.5.1.4 are designed to improve the existing data base on the age, location, and volume of young volcanic and igneous rocks in the region surrounding the site. These activities refine the dating of known occurrences using a variety of techniques, many of which have not previously been employed, and determine by drilling the nature of suspected buried deposits.

Another concern related to the probability of volcanism in the site area is that the location of any intrusion may not be entirely random across the area but controlled by structural features. To address this possibility, parameter 2 has been identified as one of the data requirements of Activity 8.3.1.8.1.1.2. Activity 8.3.1.8.5.1.3 will satisfy the requirement by completing detailed geologic mapping around selected volcanic features to clarify the relationship that might exist between the volcanic features and local structures. Parameter 5 has also been identified as a data requirement of Activity 8.3.1.8.1.1.2; this parameter will be used to address tectonic models for the time-space patterns of igneous events in the Yucca Mountain area and the structural controls for volcanic sites or future volcanic sites at or adjacent to Yucca Mountain. These data will be factored into probability calculations. Activity 8.3.1.8.5.1.5 will evaluate petrologic and volume trends of volcanic fields through time to test for indications of waning volcanism or increases in the rate of eruptive activity associated with decreasing eruption volumes.

For data on thermal anomalies in the area that might be related to magma bodies that could be sources of volcanic or igneous activity, parameters 3 and 7 have been identified as a data requirements of Activity 8.3.1.8.1.1.3. Activities 8.3.1.8.5.2.1 and 8.3.1.8.5.2.3 will satisfy the requirement by generating maps showing the depth to the Curie isotherm and heat-flow data in the area surrounding the site.

Parameter 4 has been identified as a data requirement of both Activities 8.3.1.8.3.3.1 and 8.3.1.8.4.1.1 and will provide information on the nature and extent of physical and geochemical changes around dikes and other intrusions. Activity 8.3.1.8.5.2.2 will satisfy this requirement by collecting the required data from field studies of known intrusions in the region around the site and from literature reviews.

Parameter 6 will provide general regional data on the relationship of Neogene folding in the region to faults and detachments. Activity 8.3.1.8.5.3.1 will satisfy this parameter by reviewing the available literature and possible detailed mapping in selected areas.

8.3.1.8.5.1 Study: Characterization of volcanic features

The activities under this study will provide refined data on the age, location, and volume of young volcanic rocks in the vicinity of the site. These data will be used to refine the calculations on the probability of igneous or volcanic events occurring in the controlled area and penetrating the repository. Much of the work for this study has been completed and is described in Chapter 1. The focus of this study is to summarize continuing activities that are necessary to complete risk assessment. The major activities include (1) geochronology studies to refine the ages of Quaternary basaltic activity and the youngest silicic volcanic activity in the Yucca Mountain area, (2) refining the area parameter used in probability calculations based on revised procedures to quantify the structural controls of surface volcanic centers, (3) drilling of prominent aeromagnetic anomalies in Crater Flat and the Amargosa Valley that are inferred to represent shallowly buried basaltic volcanic centers, and (4) collecting additional field data on the possibility of structural controls on volcanism in the vicinity of the site.

Other activities in this study will investigate the petrologic and geochemical cycles of volcanic fields in the region. The goals of these activities are to

1. Establish the geochemical sequence through time of the lava flows and scoria deposits at Crater Flat for correlation with basaltic ashes exposed in various trenches excavated in alluvium for the preclosure tectonic program (Study 8.3.1.17.6) and test petrologic models of polycyclic volcanism.

2. Examine and document the temporal and spatial geochemical patterns of the late Cenozoic basaltic fields of the southwest Basin and Range. These patterns will be compared in Activity 8.3.1.8.1.1.2 with patterns established from the Crater Flat data and to test tectonic models for the spatial distribution for volcanic activity at the Crater Flat volcanic field.

These data will be used in Activity 8.3.1.8.1.2 to assess the significance of petrologic patterns of the Crater Flat volcanic field and to examine, in conjunction with geophysical data, the possibility that the Death Valley-Pancake Range volcanic zone (DV-PRVZ) represents an incipient rift zone.

8.3.1.8.5.1.1 Activity: Volcanism drillholes

Objectives

The objective of this activity is to investigate the origin of four aeromagnetic anomalies found in Crater Flat and the Amargosa Valley. These anomalies are inferred to represent shallowly buried basaltic or silicic volcanic centers or intrusive bodies. The anomaly sites will be drilled and continuous core recovered from the drillholes. Data from this work will be used to refine probability calculations, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal geochemical patterns of basalts in the NTS region.

Parameters

The data gathered by other activities and needed for this activity are

1. The location and extent of aeromagnetic anomalies.

2. The potassium-argon (K-Ar) and Ar-40/Ar-39 age determinations of volcanic material recovered the drilling program. This information will be obtained from Activity 8.3.1.8.5.1.2.

The data to be gathered by this activity are

1. Core from drillholes.
2. Stratigraphy and location of core from drillholes.
3. Magnetic polarity measurements of core.
4. Major-element geochemical data of recovered volcanic materials.
5. Trace-element geochemical data of recovered volcanic materials.
6. Sr and Nd isotopic data of recovered volcanic materials.
7. Petrography of recovered volcanic materials.

Description

The inferred, buried volcanic centers may represent volcanic events that have not been documented in the geologic record. These anomalies need to be drilled, dated, and volumes obtained to apply to volcanic rate calculations used for the probability model for the Yucca Mountain area.

Four anomalies have currently been identified from aeromagnetic data for investigation using drillholes (USGS, 1978). One is located in southwest Crater Flat, the remaining three are in the Amargosa Valley (Figure 8.3.1.8-9). The anomaly sites will be drilled and core recovered from volcanic rocks encountered in the hole. Four drillholes are currently planned and each will be drilled to a depth of approximately 330 m.

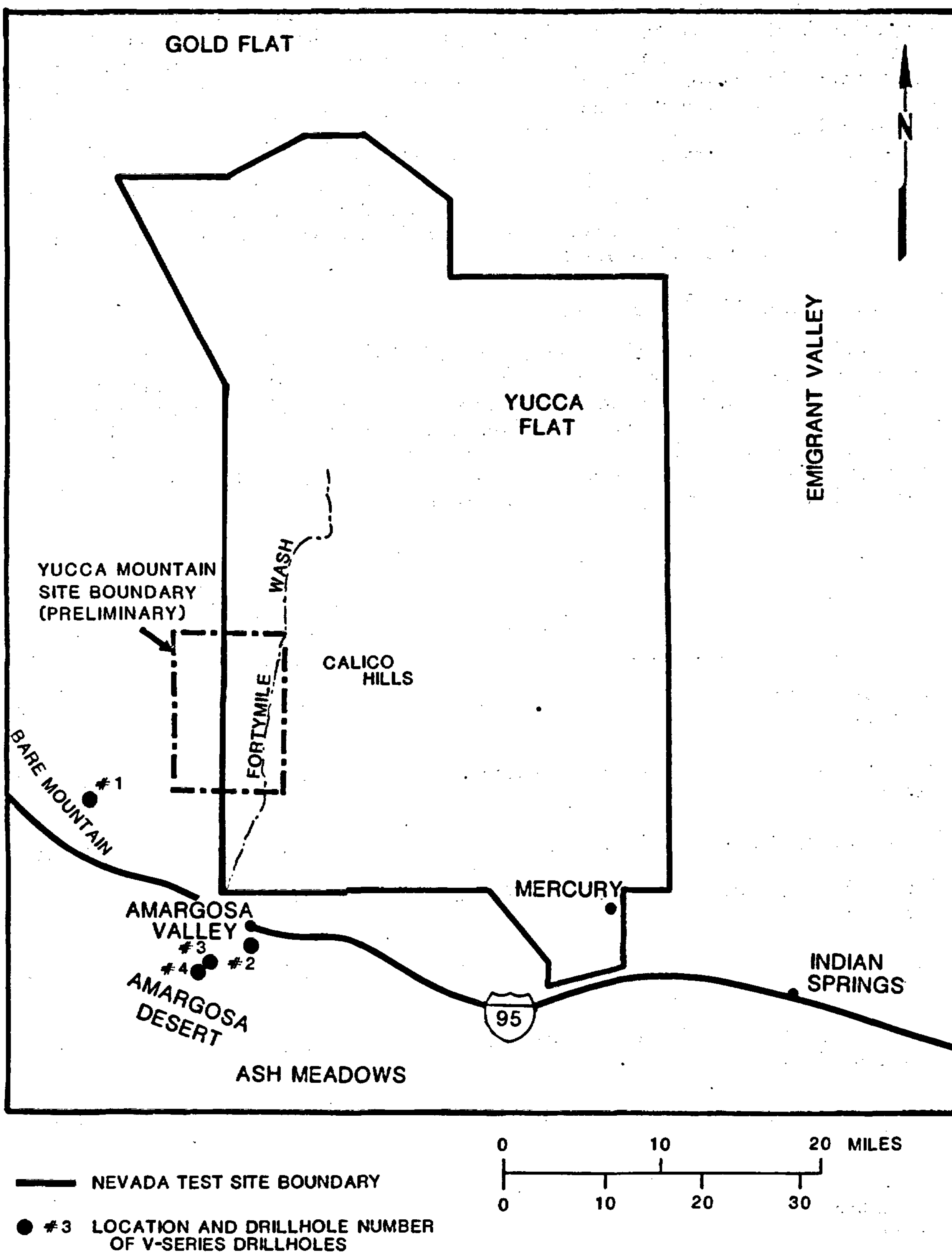


Figure 8.3.1.8-9. Map showing location of volcanism drillholes.

The anomalies may be buried surface volcanic centers or they could be intrusive bodies. If they are intrusive bodies, there are no established constraints on their age--they could be as young as the younger events in the Yucca Mountain region. The thickness of the recovered volcanic core material and the geometry of aeromagnetic anomalies will be used to estimate volumes of buried volcanic centers. This data will be combined with potassium-argon ages to refine probability calculations and establish a tectonic model of basaltic volcanic activity (Activity 8.3.1.8.1.1.4). K-Ar ages of the core will be combined with major- and trace-element data and isotopic data to test geochemical patterns of basaltic volcanism in the NTS region (Activities 8.3.1.8.5.1.4 and 8.3.1.8.5.1.5).

Methods and technical procedures

Drilling plans for the four holes will be completed in FY 1988 and drilling is scheduled to take place in FY 1989. Drilling plans for two holes (V-1 and V-2) have been completed. Procedures and the Quality Assurance program are detailed in the completed drilling plan. Major-element data will be obtained using x-ray fluorescence (XRF). Trace-element data will be obtained by instrumental neutron activation analysis (INAA) and XRF. Isotopic data for Sr and Nd are obtained by mass spectrometry.

	Technical procedure		
Method	Number	Title	Date
Magnetic polarity measurements	In preparation	TBD[a]	FY 1987
X-ray fluorescence procedures	In preparation	TBD	FY 1987
Isotopic measurements	In preparation	TBD	FY 1988
Microprobe operating procedure	TWS-ESS-DP-07, R2	TBD	Nov 82
Sample preparation: procedure	TWS-ESS-DP-04, R4	TBD	Jan 83
Sample preparation: rock powders	TWS-ESS-DP-10, R8	TBD	Nov 82
NTS core petrography procedure	TWS-ESS-DP-03	TBD	Nov 82
Volcanic hazard investigations work plan	TWS-INC-WP-12	TBD	Nov 82

Method	Technical procedure Number	Title	Date
Instrumental neutron activation analysis (INAA) procedures	In preparation	TBD	FY 1988

[a]TBD = to be determined.

8.3.1.8.5.1.2 Activity: Geochronology studies

Objectives

The objective of this activity is to establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region. These data will be used to revise the rate parameter of the volcanic probability calculations and to determine the age of cessation of silicic volcanic activity. The geochronology studies have been under way for a number of years and the chronology of older basaltic activity (> 8 million yr) has been established. Further studies are required for three topics:

1. The age of Quaternary volcanic events in the Yucca Mountain region.

2. The age of the youngest volcanic event in the Yucca Mountain area.

3. The age of the youngest silicic volcanic activity in the region with emphasis on the Black Mountain caldera or young silicic rocks that may be encountered in shallow volcanic drillholes.

Parameters

The data gathered by other activities and needed for this activity are

1. Geographic location and geologic field relations of volcanic rocks or volcanic features used for age determinations. This information will be obtained from Activity 8.3.1.8.5.1.3.

2. Core from volcanic rocks recovered from the volcanism drillholes. This material will be obtained from Activity 8.3.1.8.5.1.1.

The data to be gathered by this activity are

1. Age determinations of volcanic rocks using the potassium argon (K-Ar) and Ar-40/Ar-39 methods.

2. Age determinations of silicic volcanic rocks using a single crystal, laser-fusion method for determination of the Ar-40/Ar-39 ages.

3. U-Th disequilibrium measurements of crystals and whole rock for age calibration of basaltic volcanic rocks.

4. Measurement of the cosmogenic He-3 accumulation in basaltic volcanic rocks to obtain the surface exposure age of the rocks.

5. Measurement of the cosmogenic Cl-36 accumulation in basaltic volcanic rocks to obtain the surface exposure age of the rocks.

6. Measurement of cation element ratios in desert varnish developed on basaltic volcanic rocks to calibrate the time of surface exposure of the rocks.

7. Carbon-14 dating of desert varnish developed on basaltic volcanic rocks to determine the surface exposure age of the rocks or volcanic features.

8. Measurement of the paleomagnetic pole position of young basaltic volcanic rocks to test age constraints from crystallization and surface exposure age determinations.

9. Measurement of scoria cone and lava flow geomorphic parameters to evaluate the surface exposure age of the volcanic features.

10. Measurement of soil development for evaluation of the age of soils developed on young basaltic rocks or volcanic features.

Description

Potassium-argon (K-AR) age determinations are needed to establish the chronology of volcanic activity in the Yucca Mountain region. Previous work has established the timing of major episodes of activity in the region (Crowe et al., 1986). The focus of work for probability calculations has been based on patterns of basaltic activity during the last 4.0 million yr (Crowe et al., 1982). The age of basaltic volcanic events during this interval is a key parameter for the probability calculations. It is important, therefore, to obtain high quality age determinations for volcanic events in this age interval. Duplicate ages are needed for the volcanic centers to (1) establish the accuracy and precision of the age determinations and (2) allow statistical analysis of age data.

A second problem is the age of the youngest silicic volcanic center in the Yucca Mountain region, the Black Mountain caldera. Published ages of the Thirsty Canyon Tuff, the major outflow unit of the Black Mountain caldera, are as young as 6.5 million yr (Kistler, 1968). These age determinations were obtained from anorthoclase mineral separates. This mineral tends to lose Ar and therefore the ages are probably minimum ages and do not record the crystallization age of the mineral. Dated basalt flows that overlie individual units of the Thirsty Canyon Tuff range in age from 8.0 to 9.1 million yr and are inconsistent with the anorthoclase ages. This inconsistency needs to be resolved through additional K-Ar dating of the overlying basalt flows and determination of single-crystal Ar-40/Ar-39 ages of minerals in the Thirsty Canyon Tuff.

The final problem that requires refinement of continuing work is an evaluation of the age or ages of the Lathrop Wells volcanic center. This center was considered to be about 200,000 to 300,000 yr old as reported in the environmental assessment for Yucca Mountain (DOE, 1986b). However, new data suggest the lava flows are somewhat younger and the scoria cone is much younger than this reported age. A sufficient number of K-Ar dates will be obtained to resolve the age of the lavas through statistical analysis and to address the problem of why there has been such variability in the results of K-Ar age determinations. Dating of the scoria cone is much more difficult. To resolve this problem, a variety of techniques will be used that either provide crystallization ages of the magma that formed the cone or date the time of surface exposure of the cone. Because these techniques are developmental, multiple results will be obtained from two separate laboratories, and the results will be compared for consistency. Additionally, the measurements of paleomagnetic pole positions, the evaluation of geomorphic parameters of the cone, and the soils chronology provide cross-checking procedures for the data obtained from crystallization ages and surface exposure ages.

Methods and technical procedures

The methods and technical procedures for K-Ar measurements will follow the conventional techniques established by the University of California at Berkeley and the USGS geochronology laboratories. The USGS work is described in NWM-USGS-GCP-06, R0, Potassium-Argon Dating, effective date June 15, 1981, controlled date October 21, 1986. The procedures of U.C. Berkeley will be evaluated and necessary documentation will be provided to qualify or upgrade the procedures for the NNWSI Project Quality Assurance program.

The following work requires technique development to establish the procedures for the measurements and to evaluate whether this work will provide data that will be used in site characterization:

1. Measurement of single crystal Ar-40/Ar-39 ages in volcanic rocks using laser excitation.

2. Measurement of U-Th disequilibrium in volcanic crystals and whole rock samples.

3. Measurement of cosmogenic He-3 accumulation in basaltic volcanic rocks.

4. Measurement of cosmogenic Cl-36 accumulation in basaltic volcanic rocks.

5. Measurement of C-14 ages of desert varnish developed on basaltic volcanic rocks. This work will be covered by TWS-MSTQA-QP-14, R1, Research and Development (Experimental) Procedure, effective date May 19, 1986.

When these techniques are established and the data are judged to be of use to site characterization for the volcanic hazard studies, detailed procedures will be developed for each task.

Detailed procedures are being prepared for the cation ratio work with desert varnish. The first procedure, TWS-ESS-DP-114, Sample Collection for Rock Varnish Studies, has been completed, with an effective date of issue of April, 1987.

The detailed procedures for the measurement of paleomagnetic pole positions are in preparation.

Procedures for studies related to the calibration of geomorphic parameters for basaltic volcanic centers and the measurement of soil parameters on basaltic volcanic flows and volcanic features are in preparation.

8.3.1.8.5.1.3 Activity: Field geologic studies

Objectives

The objective of this activity is to establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region. Most of the work is completed, including reconnaissance mapping of older volcanic centers (>6 million yr) and detailed mapping of younger volcanic centers. Two problems remain:

1. Recently acquired geochronology data have shown that some small volume basalt centers may be polycyclic (i.e., formed during multiple cycles of volcanic activity separated by significant intervals of inactivity). Further geologic mapping coupled with geochronology studies are required to investigate how common polycyclic activity is at the young (<4.0 million yr) volcanic centers of the Yucca Mountain region.

2. Field studies are needed to attempt to correlate scoria sequences exposed in alluvial deposits in trenches with the scoria cone deposits in the Crater Flat area.

Parameters

The data gathered by other activities and needed for this activity are

1. The results of geochronology studies from Activity 8.3.1.8.5.1.2.

2. The results of scoria geochemistry studies from Activity 8.3.1.8.5.1.4.

The data to be gathered by this activity are

1. Contact relations and geologic maps of basaltic volcanic centers in the Yucca Mountain region.

2. Eruptive sequences of basaltic volcanic centers in the Yucca Mountain region.

3. Volumes of eruptive deposits of the basaltic centers in the Yucca Mountain region.

4. Tephra sequences and correlations among the scoria deposits of the basaltic volcanic centers of the Yucca Mountain region.

Description

A major assumption over the past several decades in geology is that small volume volcanic centers form during short periods of time (days, months, or at most years). Rock units such as separate lava flows or scoria cone clusters at basaltic volcanic centers are inferred to have formed virtually instantaneously relative to the resolving ability of conventional dating techniques. Recent geologic work using new techniques for dating the time of surface exposure of volcanic features combined with geomorphic analysis of degradation rates of volcanic features, and calibration of the time required for development of soils on young volcanic rocks has shown that some basaltic volcanic centers may be polycyclic. This means that they were formed from multiple pulses of basaltic activity with significant time intervals between events. The time interval between pulses may be sufficiently long to affect the rate parameter of probability calculations. Studies at the Lathrop Wells volcanic center suggest that it was formed by two, possibly three, pulses of basaltic magma over a period of time that may have exceeded 100,000 yr. Further geologic mapping coupled with geochronology studies are needed to evaluate the possibility of multiple eruption cycles at the Quaternary volcanic centers of the Yucca Mountain region. This work will allow refinement of constructed curves of magma volume versus time, which yields the rate of generation of magma, a key parameter for probability calculations. The second problem, correlation of tephra sequences, requires the same information base. Petrologic studies conducted to date assume the composition of lava represents the composition of the entire range of eruptions at small volume basalt centers. If these centers are polycyclic, the magma that formed separate pulses may differ in composition. Geologic mapping is required to identify the separate eruptive units, and these units will be evaluated as potential eruptive sources for tephra deposits that are interbedded with alluvium in the Yucca Mountain region.

Methods and technical procedures

This procedure has been in effect since November 24, 1982. Separate procedures will be written to cover significant parts of the Work Plan listed in the following table. A field studies procedure will be written in FY 1987.

Method	Technical procedure		
	Number	Title	Date
Geologic mapping of Quarternary volcanic centers	TWS-INC-WP-12, R0	Volcanic hazard investigations work plan	24 Nov 82

Method	Technical procedure Number	Title	Date
(field studies)	TBD[a]	TBD	FY 1987

[a]TBD = to be determined.

8.3.1.8.5.1.4 Activity: Geochemistry of scoria sequences

Objectives

The objective of this activity is to determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area. These data will be used to test and develop petrologic models of polycyclic volcanism. The models will be used to test geologic assumptions made for (1) the probability calculations and (2) the time-space tectonic model for the distribution of basaltic volcanism developed from Activity 8.3.1.8.1.1.2. In addition, the data on the geochemistry of the scoria sequences will also be used to correlate basaltic ash interbedded in trenches with their correct eruptive source.

Parameters

The data gathered by other activities and needed for this activity are

1. Field relationships of scoria sequences at the Lathrop Wells volcanic center. This information will be obtained from Activity • 8.3.1.8.5.1.3.

2. Ages of multiple scoria sequences at the Lathrop Wells center. This information will be obtained from Activity 8.3.1.8.5.1.2.

The data to be gathered by this activity are

1. Major-element data of scoria from Lathrop Wells center, and centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year sleeping Butte basalt centers.

2. Trace-element data of scoria from Lathrop Wells center, centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year Sleeping Butte basalt centers.

3. Mineral chemistry and petrography of scoria from Lathrop Wells center, centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year Sleeping Butte basalt centers.

4. Major- and trace-element chemistry of lava flows at the Lathrop Wells center the 1.1 to 1.5 million-year cycle in Crater Flat and the 0.3

million-year Sleeping Butte basalt center. Most of this information has already been obtained (Crowe et al., 1986).

Description

At least two eruptive events, separated by a significant time interval, occurred at the Lathrop Wells center. This indicates that small basaltic centers of this type may be polycyclic. The major-, trace-element, and mineral chemistry of scoria sequences, bombs, and lava flows will be determined and combined with chronologic information (Activity 8.3.1.8.5.1.2) to test petrologic models of polycyclic volcanism. An understanding of the mechanisms of polycyclic volcanism derived from this modeling will provide an important means of assessing the possibility of future eruptions at the Lathrop Wells center. The geochemistry of scoria sequences will be used to correlate eruptive events to basaltic ash deposits exposed in trenches dug for tectonic studies (Study 8.3.1.17.4.6). In addition, the geochemistry of scoria can be used to constrain the existence of discrete eruptive events where field relationships may be ambiguous.

Methods and technical procedures

Preliminary work will be required to determine if scoria geochemistry corresponds to magma geochemistry, or if scoria geochemistry is modified during or after eruption. This will be done by comparing the major, trace element, and mineral data of basalt flows and bombs with data for scoria sequences of the same eruptive episode. Developmental work will be done to determine the best method of preparing scoria for analysis to minimize the effects of post-eruption alteration or addition of foreign material. Major-element data will be obtained using x-ray fluorescence (XRF). Trace-element data will be obtained by instrumental neutron activation analysis (INAA) and XRF. Mineral chemistry will be obtained by electron microprobe analysis.

8.3.1.8.5.1.5 Activity: Geochemical cycles of basaltic volcanic fields

Objectives

The objective of this activity is to determine the time-space geochemical variations of the volcanic fields of the southern Great Basin. These patterns will be compared with the documented geochemical patterns for the volcanic fields of the Yucca Mountain area. This information will be used to test a model that associates changes in basalt composition, increases in the eruptive frequency of polycyclic eruptions, and decreases in the volume of eruptive activity with the waning or termination stages of basaltic volcanic fields. This model, if valid, supports the idea that the Yucca Mountain area has passed the peak of maximum basaltic volcanic activity. Probability calculations, which are based on the peak rate of activity, could therefore be shown to be a worst-case approach to volcanic risk assessment.

Parameters

The data gathered by other activities and needed for this activity are geologic, geochemical, and geochronologic data (geologic maps, geochemical data, and K-Ar ages) for volcanic fields of the southern Great Basin. This information will be obtained from the published literature and from Activities 8.3.1.8.5.1.2, 8.3.1.8.5.1.3, and 8.3.1.8.5.1.4.

The data to be gathered by this activity are geochemical patterns of basaltic volcanism through time for volcanic fields of the southern Great Basin.

Description

Geochemical and geochronological studies of basalt of the Yucca Mountain area have shown that there are distinct variations in these parameters with time. Early eruptions were moderately high volume (> 0.5 km^3) hypersthene hawaiite (3.7 to 1.1 million years). Subsequent eruptions were smaller volume (0.1 km^3) and the rocks are increasingly undersaturated (Vaniman et al., 1982; Crowe et al, 1986). Similar trends have been noted at the Lunar Crater and southern Death Valley volcanic fields (Crowe et al., 1986). These geochemical patterns may be indicative of the terminal stage of basaltic volcanic activity at a volcanic field. If this interpretation is valid, it supports the concepts being developed for the volcanic/tectonic model for the Crater Flat area including: (1) southwesterly migration of basaltic volcanic activity in the Yucca Mountain region, and (2) the observed decreased volume of basaltic activity in the Yucca Mountain area. Both concepts support the assumption that the calculated probability bounds for future volcanic activity at Yucca Mountain are worst-case values. If volcanism is waning for this area, rates of magma generation calculated for past volcanic activity should be higher than future rates.

These concepts need to be tested by examining the time-space geochemical trends of other basaltic fields of the southern Great Basin. Emphasis would be placed on examining the geochemical patterns of older fields where there is clear evidence that volcanic activity has ended (no basaltic volcanic activity in Quaternary time). The patterns observed for the Yucca Mountain area need to be corroborated at several volcanic fields to support the volcanic/tectonic model. A second important parameter is the apparent increased frequency of volcanic eruptions associated with the transition to small volume, under-saturated basalt. This parameter needs to be investigated to determine if the trend could result in small-scale fluctuations in rates of volcanic activity. The fluctuations could be significant in forecasting future volcanic activity.

Methods and technical procedures

Major-element data will be obtained using x-ray fluorescence (XRF). Trace-element data will be obtained by instrumental neutron activation analysis (INAA) and XRF. Mineral chemistry will be obtained by electron microprobe analysis.

The methods and technical procedures for K-Ar measurements will follow the conventional techniques established by the University of California, Berkeley, and USGS geochronology laboratories. These procedures will be evaluated for conformance to the NNWSI Project Quality Assurance Program.

Method	Technical procedure		
	Number	Title	Date
X-ray fluorescence (XRF) procedures	In preparation	TBD[a]	FY 1987
Microprobe operating procedure	TWS-ESS-DP-07	TBD	Nov 1982
Sample preparation: lab procedure	TWS-ESS-DP-04	TBD	Jan 1983
Sample preparation: rock powders	TWS-ESS-DP-10	TBD	Nov 1982
Volcanic hazard investigations work plan	TWS-INC-WP-12	TBD	Nov 1982
Instrumental neutron activation analysis (INAA) procedures	In preparation	TBD	FY 1988
Isotopic measurements	In preparation	TBD	FY 1988

[a]TBD = to be determined.

8.3.1.8.5.2 Study: Characterization of igneous intrusive features

The activities in this study will gather data concerning the presence of thermal anomalies in the area and data on the geochemical and physical effects of intrusions on the surrounding rock. The evidence for the presence or absence of thermal anomalies will be used as part of the evaluation of the presence of significant magma bodies in the area and their relation to the probability of future volcanic events. The data on the effects of intrusions on surrounding rocks will be used as part of the assessments of the probability of significant changes on local fracture permeabilities and local effective porosities (Study 8.3.1.8.3.3) and local distribution coefficients (Study 8.3.1.8.4.1).

8.3.1.8.5.2.1 Activity: Evaluation of depth of curie temperature isotherm

Objectives

The objective of this activity is to determine the depth of the curie temperature isotherm by analyses of existing magnetic survey data.

Parameters

The long wavelength attributes of magnetic survey data are the parameters for this activity.

Description

The curie temperature isotherm is the deepest level that significant crustal magnetic sources can exist; anomalies from these sources consequently have long wavelengths and very low amplitudes compared with shallower crustal sources. Hence, any method used to study the limiting depth of these sources must be capable of characterizing the long wavelength attributes of a magnetic survey. The Connard-Couch technique (Connard et al., 1983), accomplishes this characterization by dividing the survey area into overlapping rectangular cells, calculating the power spectrum of each cell, and analyzing the shape of the long wavelength part of each spectrum. All of the sources contributing to the spectrum are treated as a statistical set, or ensemble.

This method and its application to a part of the Oregon Cascade Range was described by Connard et al. (1983). Their curie temperature depths agreed approximately with published heat flow measurements, recent structural features, and surface geothermal manifestations. Couch et al. (1986) have summarized their results in the Cascade Range. They now have analyzed magnetic data over the Cascade geologic province from Mount Hood to Lassen Peak, and the agreement between their curie temperature depths and heat flow measurements is quite remarkable.

The proposed method has some limitations. Anomalies due to deep sources are difficult to separate from their dominant shallow counterparts, no matter which method is used, and particularly in Nevada, where the data are of lesser quality and the geologic situation more complex than in the Oregon Cascade Range. Finally, the method estimates the depth to the bottom of magnetic sources, which are assumed to correspond to curie temperatures.

Nevertheless, this technique offers a method for characterizing undulations of the curie temperature isotherm in Nevada, and to compare areas of shallow isotherms with areas of recent volcanism and zones of high heat flow.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.8.5.2.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Curie temperature isotherm analysis	Needed	Connard-Couch technique of magnetic data analysis	TBD[a]

[a]TBD = to be determined.

8.3.1.8.5.2.2 Activity: Chemical and physical changes around dikes

Objectives

The objective of this activity is to gather data on the nature and extent of chemical and physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills.

Parameters

The parameters for this activity are

1. The extent and nature of changes to physical properties such as fracturing and effective porosity that could affect ground-water flow in tuffs surrounding a basaltic dike or sill.

2. The extent and nature of changes to geochemical properties that could affect local distribution coefficients (K_ds) in tuffs surrounding a basaltic dike or sill.

Description

As discussed in Sections 1.3.2 and 1.5.1, basaltic volcanism is considered the only credible igneous process that could affect the site. This activity will investigate the possibility that the intrusions related to this type of activity such as dikes or sills could adversely affect the hydrologic or geochemical characteristics of the surrounding rock in a significant manner. The first phase of the activity will be a literature review of the effects of dikes and sills of the type expected in the area on tuffs and other rock types. This will be followed, as necessary, by a field investigation of selected localities in the region where dikes or sills are known to have penetrated rock types similar to those found at the site. The rocks surrounding these intrusions will be examined petrologically to describe the nature of the mineral changes caused by the intrusion and the distance that these changes extend from the intrusion. Changes in fracturing and other physical characteristics that could affect ground-water flow will also be described. These data will be used by Activities 8.3.1.8.3.3.1 and

8.3.1.8.4.1.1 as part of the assessment of the effects of igneous intrusions on hydrologic and geochemical characteristics of the site.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.8.5.2.2 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Petrologic examination of samples	GP-03, R0	Stratigraphic studies	1 Mar 83
	GCP-01, R0	Radiometric-age data bank	15 June 81
	GCP-02, R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
Description of fracturing and physical properties	GP-01, R0	Geologic mapping	1 Mar 83
	GP-03, R0	Stratigraphic investigations	1 Mar 83
	GP-04, R0	Structural studies	1 Mar 83
	GP-07, R0	Geologic trenching studies	14 Aug 84
	GP-17, R0	Describing and sampling soils in the field	19 Feb 86
	GCP-01, R0	Radiometric-age data bank	15 June 81
	GCP-02, R1	Labeling, identification, and control of samples for geochemistry and isotope geology	1 Jan 87

Method	Technical procedure Number	Title	Date
	GCP-03, R0	Uranium-series dating	15 June 81
	GCP-04, R0	Uranium-trend dating	15 June 81

8.3.1.8.5.2.3 Activity: Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies

This activity will be undertaken in cooperation with Activity 8.3.1.9.2.1.3 (assessment of geothermal resources). Both activities are aimed at characterizing the local geothermal regime as it might relate to repository performance during the postclosure period. Activity 8.3.1.9.2.1.3 will focus on assessing geothermal activity as a potential resource. This activity (8.3.1.8.5.2.3) will evaluate the local ambient heat flow and local heat flow anomalies in relation to Quaternary volcanism. Data compilation and evaluation will be carried out jointly through both activities.

Objectives

The objectives of this activity are to

1. Compile available heat flow data at and near Yucca Mountain and identify local heat flow anomalies in conjunction with activity 8.3.1.9.2.1.3. The quality of these data will be assessed under this activity in conjunction with Activity 8.3.1.9.2.1.3.

2. Compile available calcite and silicate geothermometry data from calcite and silica deposits in soils and core and along faults in the vicinity of Yucca Mountain. These data will be assessed with respect to their utility for measuring thermal and hydrothermal perturbation associated with Quaternary volcanism, such as that at the Lathrop Wells volcanic center. In addition, the utility of such data for calibrating and evaluating theoretical calculations of the thermal and hydrothermal effects of volcanism will be assessed.

3. Assess the potential value of additional heat flow and other geothermometry studies for satisfying project goals. Recommendations will be made as to the objectives, nature and scope of any additional studies that may be needed, including the collection of geothermal data from existing or planned drill holes or specific methods of drill hole construction necessary to collect the highest quality heat flow data.

Parameters

The parameters for this activity are

1. Geothermal profiles of drillholes.
2. Temperature of ground water from springs and wells.
3. Thermal conductivity of core and other samples.
4. Surface temperature.
5. Silica geothermometry of water samples.
6. Calcite geothermometry of calcite-silica deposits.

Description

Local heat flow anomalies could be associated with faults, shallow magma bodies, and (or) local areas of anomalous ground-water flow, such as segments of thermally driven ground-water convection cells. Internally consistent heat-flow calculations from drillhole UE-25a#3 in the Calico Hills yield values of as much as 3.08 to 3.34 HFU. These data are between two and three times the expected ambient values according to Sass et al. (1980), who suggest that Calico Hills is the focus of an ascending segment of a geothermal convection cell. The ambient thermal regime beneath Yucca Mountain is not known with sufficient confidence that a similar geothermal process can be ruled out there. In this activity, heat-flow calculations will be made for existing and planned drillholes where feasible. The data will be compiled onto maps and compared with other geological, hydrological, and geophysical data. Recommendations for additional heat-flow measurements will be made to evaluate local heat-flow anomalies. Such recommendations could include plans for an additional drillhole specifically constructed to acquire high quality data to evaluate regional ambient heat flow. Additional heat-flow data could also be required to evaluate tectonic or fault models, tectonic history, geothermal resource potential, regional ground-water flow, and/or calculation of ambient heat flow at and near Yucca Mountain. The silica geothermometry method used by Fournier et al. (1979) will be evaluated as to its utility in corroborative heat-flow calculations for Yucca Mountain in conjunction with Activity 8.3.1.9.2.1.3.

An understanding of the present thermal regime also is helpful to evaluate the magnitude and areal extent of the thermal perturbation due to Quaternary igneous activity. Available calcite and silica geothermometry data from calcite and silica deposits along faults and in soils and cores in the vicinity of Yucca Mountain (collected for Activity 8.3.1.5.2.1.5) will be compiled and assessed as to their utility for measuring thermal and hydrothermal perturbation associated with volcanism such as that at the Lathrop Wells Volcanic center (part of which may have synchronous with a pluvial maximum). Such data will also be evaluated as a method to confirm calculations of the thermal effects. Plans for additional studies will be made depending on the findings of this activity and program needs.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.8.5.3 are given in the following table.

Method	Technical procedure Number	Title	Date
Heat flow studies	GPP-02,R0		11 Jan 82
	GPP-05,R1		7 Jan 86
Calcite and silica geothermometry	TBD[a]	Separation of oxygen and carbon from carbonate	
	TBD	Separation of oxygen from silicate	
Calcite and silica geothermometry (continued)	TBD	Separation of hydrogen from silicate	
	TBD	Liberation and collection of fluid inclusions	
	TBD	Mass-spectrometry for carbon	
	TBD	Mass-spectrometry for oxygen	
	TBD	Alpha-spectrometry	

[a]TBD = to be determined.

8.3.1.8.5.3 Study: Investigation of folds in Miocene and younger rocks of region

The objective of this study is to establish the regional pattern and rate of Neogene folding. The parameters to be determined are distribution, amplitude, and age of folds.

8.3.1.8.5.3.1 Activity: Evaluation of folds in Neogene rocks of the region

Objectives

The objective of this activity is to establish the pattern, rate, amplitude, and wavelength of post-middle-Miocene folding in the region.

Parameters

The parameters for this activity are the distribution, amplitude, and age of folds.

Description

Neogene strain within the NTS and vicinity consists of displacements due both to folding and to faulting. To explain the strain in terms of some tectonic model or theory, the contribution from folding as well as faulting must be considered. Preliminary evaluation indicates that where detachment faults are present, the wavelength of folds in upper-plate rocks is substantially less than that in lower-plate rocks. No attempt has as yet been made to rationalize fold patterns or relate them to wrench tectonics, but it is possible that the fold pattern in the area of intersection of the left-lateral fault systems (Mine Mountain and Rock Valley faults) with the right-lateral faults of the Las Vegas Valley shear zone may help show whether these faults are contemporaneous conjugate systems or independent systems of different age.

As a first step, data pertaining to folds from existing detailed geologic maps of the NTS will be abstracted and synthesized. Depending on the results of this effort, it may be necessary to supplement the data base through detailed mapping of folds in selected areas.

Evaluation of the structural attitude of Neogene rocks of the NTS and vicinity will involve synthesis of data pertaining to the structural attitude of the Horse Spring, Pavits Spring, and the younger volcanic, pyroclastic, and volcaniclastic rocks from existing detailed geologic maps.

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.8.5.3.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Evaluation of structural attitude of Neogene rocks (NTS and vicinity)	GP-01, RO	Geologic mapping	1 Mar 83

8.3.1.8.5.4 Application of results

The information derived from the studies and activities described previously will be used in the following programs and investigations:

Investigation	Subject
8.3.1.8.1	Studies to provide information required on direct releases resulting from volcanic activity.
8.3.1.8.2	Studies to provide information required on rupture of waste packages due to tectonic events.
8.3.1.8.3	Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events.
8.3.1.8.4	Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes.
8.3.1.17.1	Volcanic activity that could affect repository design or performance.

8.3.1.8.5.5 Schedule and milestones

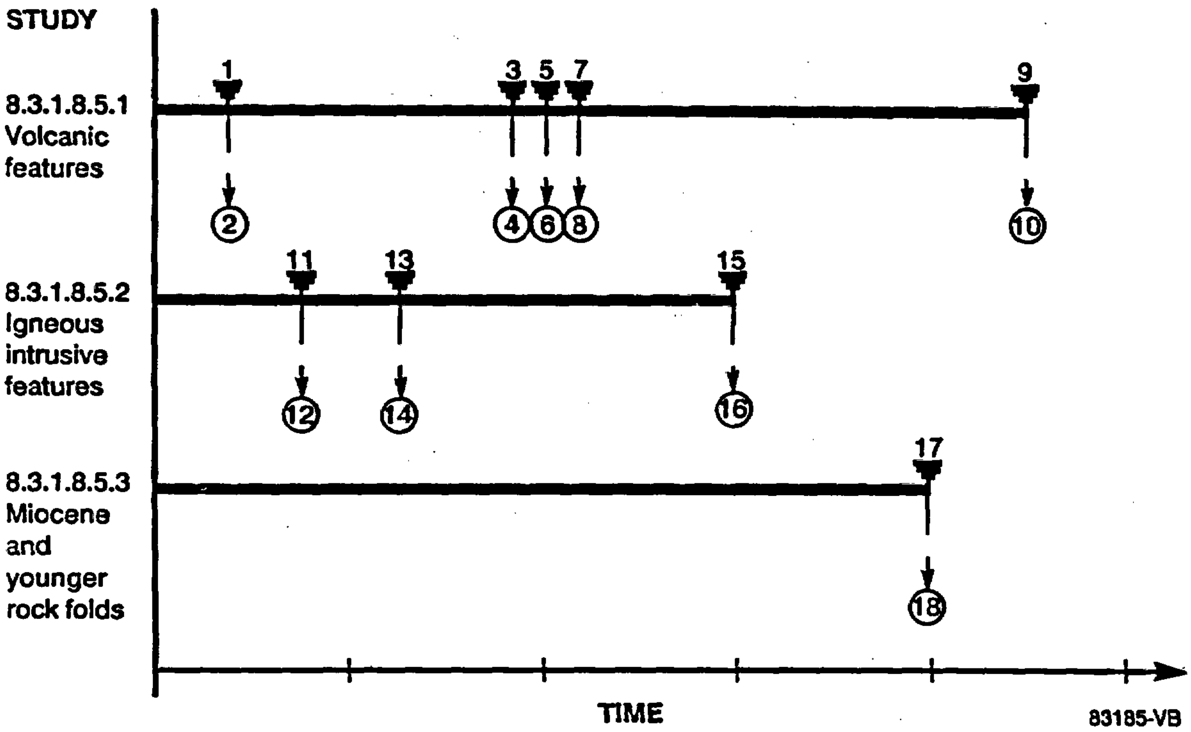
This investigation, which collects and analyzes postclosure tectonics data, contains three studies: 8.3.1.8.5.1 (characterization of volcanic features), 8.3.1.8.5.2 (characterization of igneous intrusive features), and 8.3.1.8.5.3 (investigation of folds in Miocene and younger rocks of the region). The first of these studies is ongoing while 8.3.1.8.5.2 and 8.3.1.8.5.3 are out-year studies.

In the figure that follows, the schedule information for these studies is presented in the form of timelines. The timelines extend from implementation of the approved study plans to the issuance of the final products associated with the studies. Summary schedule and milestone information for this investigation can be found in Section 8.5.1.1.

The activities of this entire investigation are planned to provide some of the data necessary to complete the analyses in Investigations 8.3.1.8.1, 8.3.1.8.2, 8.3.1.8.3, 8.3.1.8.4 and investigations in other programs.

The studies in this investigation are not seriously constrained by other program elements.

The study numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the study. Solid lines represent study durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.



The points on the timeline and the data input and output at the interfaces are described in the following table:

Point number	Description
1	Milestone Z405. Field mapping of Lathrop Wells volcanic center completed.
2	Results from mapping of Lathrop Wells volcanic center to Studies 8.3.1.8.1.1 and 8.3.1.2.1.2.
3	Milestone Z407. Report available on geochemistry of Lathrop Wells scoria sequences.
4	Results from geochemistry of Lathrop Wells scoria sequences to Study 8.3.1.8.1.1.
5	Milestone Q114. Drilling completed on volcanism drillholes.
6	Drilling information to Study 8.3.1.8.1.1.
7	Milestones Z401, Z402, Z403, and Z404. Dating of volcanic deposits generally complete.
8	Results from dating of volcanic deposit to Study 8.3.1.8.1.1.

Point number	Description
9	Milestone Z409. Report on geochemical cycles of basalt fields of the Great Basin available.
10	Results from geochemical cycles report to Study 8.3.1.8.1.1.
11	Milestone Z300. Report available on depth of Curie temperature isotherm.
12	Input from Curie temperature isotherm report to Study 8.3.1.8.1.1.
13	Milestone Z432. Report available on chemical and physical changes around dikes.
14	Results from chemical and physical changes around dikes to Studies 8.3.1.8.3.3 and 8.3.1.8.4.1.
15	Data on local heat flow anomalies available.
16	Results on local heat flow anomalies to Study 8.3.1.8.1.1.
17	Milestone Z302. Report available on evaluation of folds in Neogene rocks of the region.
18	Results from evaluation of folds in Neogene rocks of the region to Studies 8.3.1.17.4.5 (detachment faults) and 8.3.1.17.4.12 (tectonic models).