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Attributes and Associated Favorability Graphs for the NNWSI Area-to-Location Screening Activity

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Abstract

Thirty-one attributes of the southwest Nevada Test Site and environs and its contained rock types were identified to guide a screening of the Nevada Research and Development Area for relatively favorable locations for the disposal of nuclear waste in a mined geologic repository. The attributes address the geologic, hydrologic, tectonic, seismic, surface, environmental, and institutional conditions of the screening area and the geomechanical, geochemical, and hydraulic conditions of contained rock types as they pertain to exploration for a repository location. The data for the attributes were compiled by scientists and engineers from federal agencies, national laboratories, state universities, and private corporations. The relative merits of alternative locations were compared by assessing how well the physical, environmental, and institutional conditions, represented by the attributes, satisfied a suite of objectives for repository development. The relative favorabilities of the attributes at alternative locations were weighted in relation to the importance of pertinent objectives and summed to produce maps showing where the more and less favorable locations occur. Descriptions of the attributes were organized to make explicit the assumptions and limitations of the data for each attribute and to explain the rationale for assigning relative favorabilities to attribute conditions.

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Attributes and Associated Favorability Graphs for the NNWSI Area-to-Location Screening Activity

Chapter 1. Introduction

A comprehensive system study was performed for the Nevada Nuclear Waste Storage Investigations (NNWSI) to screen the Nevada Research and Development Area (NRDA) of the Nevada Test Site (NTS) and nearby areas (Figure 1) to identify relatively favorable locations for the permanent disposal of radioactive waste in a mined repository. This screening was based on information available as of the summer of 1981. The screening results were intende to allow more informed decisions as to where futu repository exploration could be concentrated to opt mize the chances that the location chosen for chara terization would actually qualify as a licensed repos tory site. This screening corresponds to th "area-to-location" phase of the National Waste Term nal Storage Program's repository siting process.[1]

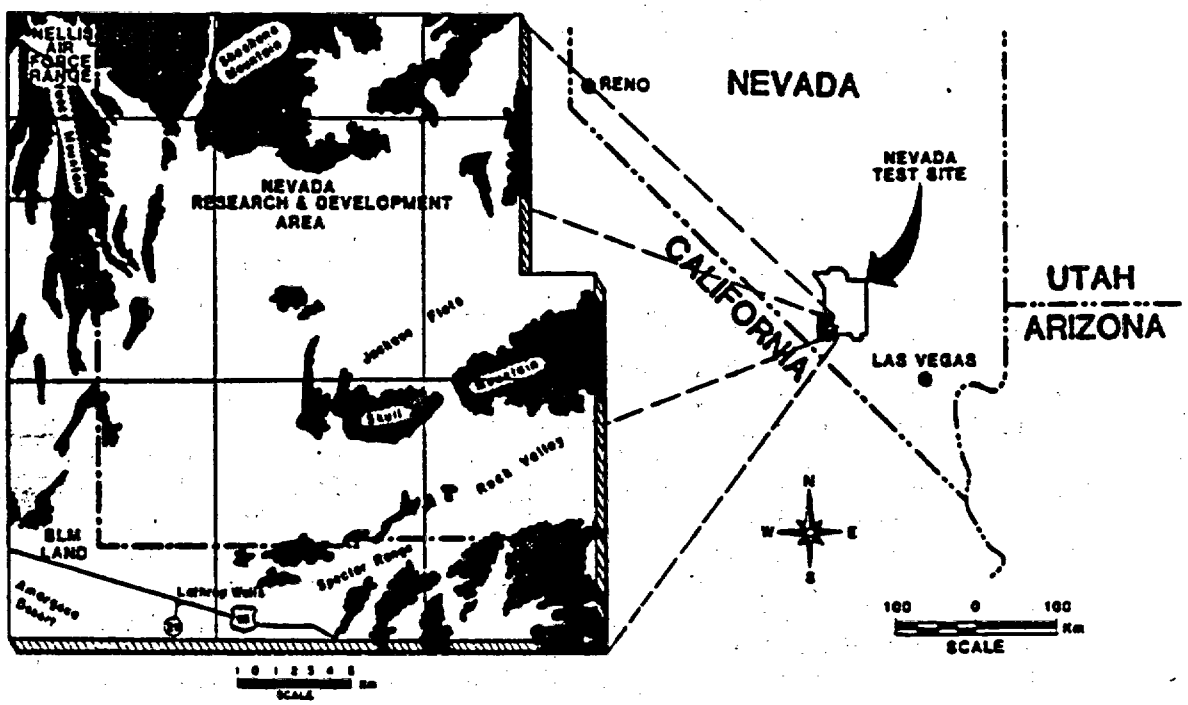

Figure 1. NNWSI Area-to-Location Screening Area

Other Screening Documents

This report is one of five documents that describe the NNWSI screening activity. The first, *A Method for Screening the Nevada Test Site and Contiguous Area for Nuclear Waste Repository Locations*,[2] provides a general description of the screening method, but contains no specific data about the screening area. Its purpose was to document the proposed screening method prior to its implementation.

The second, *Summary and Conclusions of the NNWSI Area-to-Location Screening Activity*, is the summary document that describes the screening results and provides additional information on how the screening calculations were performed, how the results were interpreted, and how the attributes discussed in this report were used to rate alternative locations and host rocks. It is the principal product of the NNWSI screening activity.

The last three documents, *Location Performance Objectives for the NNWSI Area-to-Location Screening Activity*,[4] *Attributes and Associated Favorability Graphs for the NNWSI Area-to-Location Screening Activity* (this report), and *Software for APPLICON Graphics System Support of the NNWSI Area-to-Location Screening Activity*,[5] provide detailed background information on the various elements of the screening method.

Purpose and Organization of This Report

The purpose of this report is to provide detailed descriptions of attributes and favorability graphs, two elements of the screening method used in the screening activity, and to make explicit the assumptions used in developing the attributes and favorability graphs. Chapter 1 provides background material on the screening process. Chapters 2, 3, and 4 make up the body of this report and are organized topically by the various types of attributes.

Chapter 2 describes maps and associated favorability graphs for 23 attributes that vary geographically. It is subdivided into the following topical sections: Tectonic-Seismic Attributes; Geologic-Surface Terrain Attributes; Hydrologic Attributes; Environmental Attributes; and Institutional Attributes.

Chapter 3 describes eight attributes and associated favorability graphs that vary among nine candidate host rocks occurring in the screening area. It is subdivided into geomechanical, geochemical, and hydrologic sections.

Descriptions for each of the attributes in Chapters 2 and 3 are similar. Each description includes

- Maps or lists, as appropriate, of attribute values
- Favorability graphs
- Identity of individuals who compiled the information
- List of attribute values
- Rationale for assigning values to various locations or rock types
- Confidence estimates
- Basis for favorability values
- Sources of additional readings

Chapter 4 contains maps showing locations where each candidate host rock is at least 100 ft thick between depths of 500 and 4000 ft. Following each map are a description of the mapping assumptions and confidence in the map and a list of additional readings.

Background on Screening Method

The systems study used to screen the NRDA and contiguous areas consists of four basic elements:

- Weighted hierarchical performance objectives for ideal repository locations
- Attributes based on physical conditions that discriminate among locations or rock types in the screening area (the subject of this document)
- Relative favorability graphs that rate physical conditions of the attributes with respect to objectives (also the subject of this document)
- Mathematical equations, expressed as computer algorithms, that calculate ratings for alternative locations and host rocks

To provide background information about the screening method and the roles of attributes and favorability graphs in rating alternative locations and host rocks, a brief discussion of each of these elements follows.

Hierarchial Performance Objectives

For purposes of screening, the objectives were organized into a hierarchical format called an objectives tree (Table 1). This tree relates desired site-specific, physical characteristics of repository locations to the overall national goals of long-term safety, cost effectiveness, and environmental soundness for the disposal of radioactive waste. Hierarchically organizing the objectives clarifies the logical relations between previously unstructured site-selection criteria (e.g., References 6 – 12) and overall goals.

The overall goals of long-term safety, cost effectiveness, and environmentally sound disposal of radioactive waste were divided into four major objectives that form the upper level of the tree. The goal for long-term safety is addressed by two separate upper-level objectives: containment (Objective 1.0) and isolation (Objective 2.0). Cost-effective facilities are addressed by an operational, or short-term, objective (Objective 3.0). Near-term environmental concerns are addressed by Objective 4.0. These four upper-level objectives correspond to the first four of seven NWTS repository performance objectives.[13] The other three NWTS performance objectives do not discriminate among alternative locations and, therefore, were not used in area-to-location screening.

Each upper-level objective of the tree was divided into a set of middle-level objectives. The middle-level objectives, in turn, were divided into lower-level objectives.

Weights were assigned to each objective at each level (Figure 2) to quantify them for use in the computer algorithms developed to rate alternative locations and host rocks. The weights were obtained by averaging responses of 15 individuals to a weighting poll.[3,4] Participants in the poll were asked to assign weights only to those objectives corresponding to their particular area of expertise. The weighting scheme assumes a weight of 100% for the overall goal of safe, cost-effective, environmentally sound waste disposal. Each upper-level objective accounts for some fraction of this overall weight, expressed as a percentage of the overall goal. The sum of weights for the four upper-level objectives equals 100%, i.e., the total weight of the overall goal.

To obtain weights for middle-level objectives, each upper-level objective was assumed, in turn, to equal 100%. Middle-level objectives within each branch of the tree then were assigned percentage weights equal to their fractional contribution to satisfying the appropriate upper-level objective. Thus, the sum of the weights within each of the four sets of middle-level objectives is 100%. To obtain the weight of a middle-level objective relative to the overall goal (Figure 2), its weight relative to the corresponding upper-level objective—some fraction of 100%—was multiplied by the weight of the upper-level objective relative to the overall goal—which is also some fraction of 100%. Similarly, each lower-level objective was assigned a weight relative to the appropriate middle-level objective. Weights of lower-level objectives with respect to the overall goal were similarly obtained by multiplying the appropriate weights assigned to all three objective levels (Figure 2).

This weighting scheme accommodates necessary tradeoffs in which more important objectives are met at the possible expense of others. Such tradeoffs are required, because the search for repository locations will never identify a place on the earth's surface that is ideal with respect to all, or perhaps any, of the objectives. Further discussion of the structure and rationale of the objectives tree can be found in Reference 4.

Attributes

Locations were evaluated by assessing how well each performance objective is satisfied at each location. This was done by independently evaluating how well pertinent physical conditions in alternative locations satisfy individual performance objectives. These pertinent physical conditions are called attributes and their detailed descriptions make up the body of this report.

To be useful in screening, such attributes must meet three criteria: they must

- Address the objectives
- Discriminate among alternative locations or host rocks within the screening area
- Be able to be measured or inferred on a standard basis throughout the screening area

The last restriction permits comparisons of locations and host rocks based on roughly equivalent data.* Accordingly, the attributes used in screening were sufficiently general to allow their extrapolation or interpolation into portions of the screening area where specific data were not available.

*In some cases detailed data available from restricted locations had to be sacrificed so that more general, but equivalent, detail could be expressed throughout the screening area.

Table 1. Numbers and Titles of Hierarchical Performance Objectives

NNWSI PERFORMANCE OBJECTIVES FOR REPOSITORY LOCATIONS
FOR SATISFYING THE OVERALL NATIONAL GOAL

To Provide Safe, Cost-Effective, Environmentally Sound Disposal of
Heat-Generating, Commercially Produced Radioactive Waste

1.0 Identify Locations That Permit Adequate Containment of Radionuclides in a Sealed Repository
- 1.1 Screen for Natural Systems with Potential to Resist Waste Package Disruption Processes
  - 1.1.1 Minimize Potential for Chemically Induced Release
  - 1.1.2 Minimize Potential for Mechanically Induced Release
- 1.2 Screen for Natural Systems With Minimum Potential for Waste Package Disruption Events
  - 1.2.1 Minimize Potential for Seismic Hazards to Containment in a Sealed Repository
  - 1.2.2 Minimize Potential for Erosional Disruption of Waste Packages
  - 1.2.3 Minimize Potential for Volcanic Disruption of Waste Packages
  - 1.2.4 Minimize Potential for Inadvertent Human Intrusion of a Sealed Repository
  - 1.2.5 Minimize Potential for Miscellaneous Events That Might Disrupt Containment

2.0 Identify Locations Which Permit Adequate Isolation of Radioactive Waste from the Biosphere
- 2.1 Screen for Natural Systems Which Will Retard Migration of Radionuclides
  - 2.1.1 Maximize Extent of Relatively Homogeneous Host Rock
  - 2.1.2 Maximize Groundwater Flow Time to the Accessible Environment
  - 2.1.3 Maximize Retardation of Radionuclides Along Flow Paths
  - 2.1.4 Maximize Migration Times of Volatile Radionuclides
- 2.2 Screen for Natural Systems With Low Potential for Adverse Changes to Isolation Processes
  - 2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonic Changes
  - 2.2.2 Minimize Potential for Adverse Impacts on Isolation Due to Climatic Changes
  - 2.2.3 Minimize Potential for Adverse Impacts on Isolation Due to Geomorphic Changes
  - 2.2.4 Minimize Potential for Adverse Impacts on Isolation Due to Human Activities
  - 2.2.5 Minimize Potential for Miscellaneous Events Which Might Disrupt Isolation

3.0 Identify Locations Where Safe Repository Construction and Operations Can Be Implemented Effectively With Respect to Cost
- 3.1 Screen for Locations Compatible With Safe Surface Facility Construction and Operation
  - 3.1.1 Minimize Seismic Hazards to Surface Facilities
  - 3.1.2 Minimize Surface Monitoring System Cost
  - 3.1.3 Minimize Adverse Foundation Conditions
  - 3.1.4 Minimize Wind Loading on Surface Structures
  - 3.1.5 Minimize Flooding Hazards to Surface Facilities
  - 3.1.6 Assure Availability of Natural Resources to Construct and Operate the Repository
- 3.2 Screen for Locations Suitable for Subsurface Facility Construction and Safe Operation
  - 3.2.1 Minimize Seismic Hazards to Subsurface Facilities
  - 3.2.2 Minimize Flooding Hazards to Subsurface Facilities
  - 3.2.3 Minimize Adverse Mining Conditions
  - 3.2.4 Optimize the Geometry (Thickness and Lateral Extent) of the Host Rock
  - 3.2.5 Optimize Host-Rock Homogeneity
  - 3.2.6 Maximize Compatibility of a Host Rock With Standardized Waste Package
- 3.3 Screen for Locations With Characteristics Compatible With Safe Transport of Radioactive Waste to a Repository
  - 3.3.1 Minimize Adverse Terrain Along Potential Waste Transport Routes
  - 3.3.2 Optimize Distance From Existing Transport Corridors

4.0 Identify Locations for Which Environmental Impacts Can Be Reasonably Mitigated
- 4.1 Minimize or Avoid Adverse Impacts on or from Sensitive Biotic Systems
- 4.2 Minimize Adverse Impacts on Abiotic Systems
  - 4.2.1 Minimize Impacts on Surface Geology
  - 4.2.2 Minimize Impacts on Water Quality and Availability
  - 4.2.3 Minimize Impacts on Air Quality
- 4.3 Minimize Adverse Impacts on the Existing Socioeconomic Status of Individuals in the Affected Area
  - 4.3.1 Minimize Adverse Impacts on Local Economics
  - 4.3.2 Minimize Adverse Impacts on Life Styles
  - 4.3.3 Minimize Conflict With Private Land Use
- 4.4 Conduct All Activities in a Spirit of Institutional Cooperation
  - 4.4.1 Cooperate With States
  - 4.4.2 Facilitate Compliance With Federal Regulations
- 4.5 Minimize Adverse Impacts on Significant Historic and Prehistoric Cultural Resources

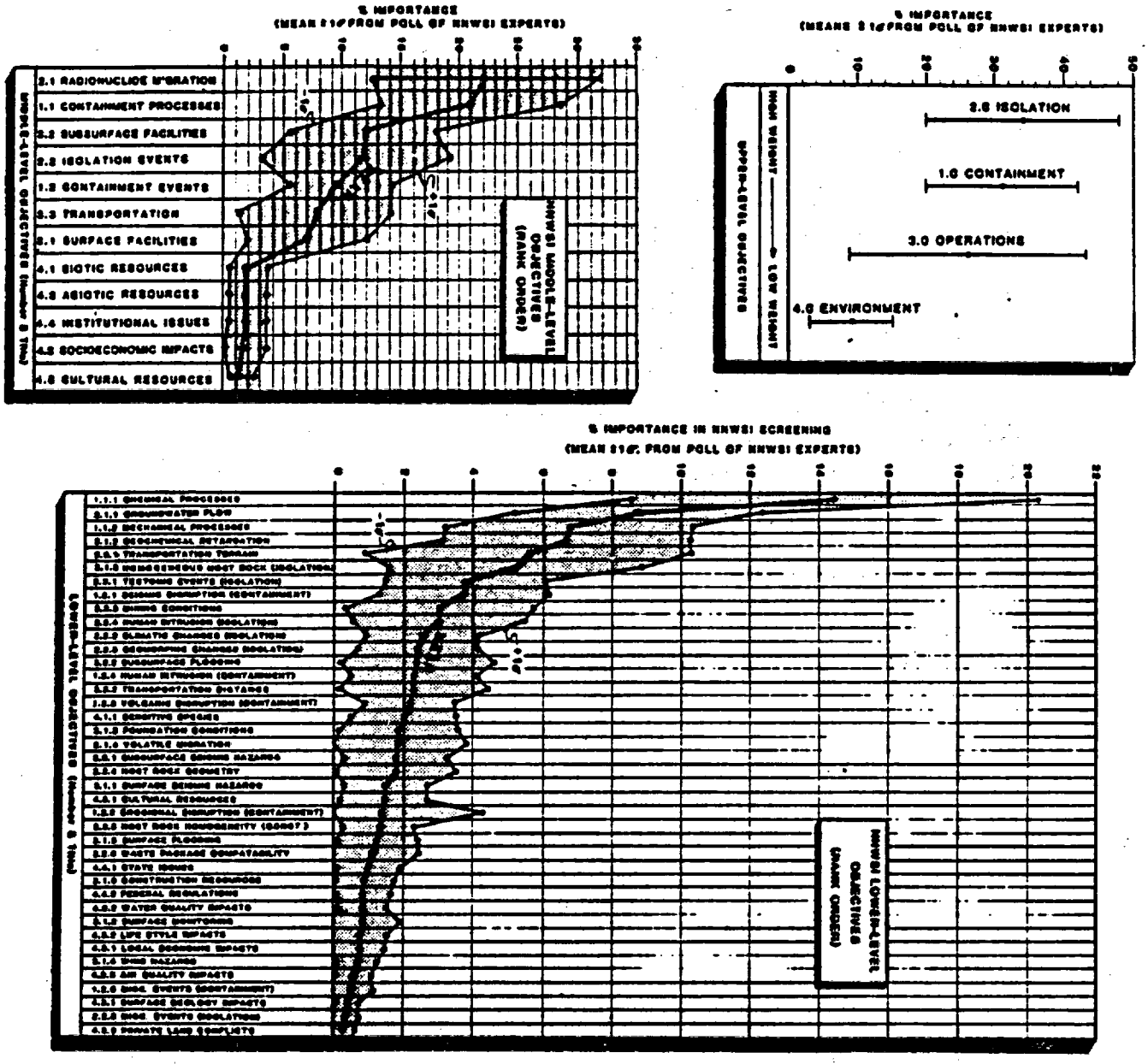

Figure 2. Upper-, Middle-, and Lower-Level Performance Objectives Ordered by Average Weight

Attributes were selected by identifying physical conditions that are potentially important for characterizing a mined geologic repository (Figure 3). Sets of pertinent attributes were listed as candidates for characterizing each component of the general model (Figure 4). This assured that due consideration was given to all potentially useful attributes for assessing near-, intermediate-, and far-field conditions and for distinguishing short-term operational and environmental concerns from long-term concerns for containment and isolation.

The list of candidate attributes in Figure 4 was screened to select those that satisfy the three criteria listed above for use in screening. This was accomplished during a series of meetings among personnel from the USGS, LANL, LLNL, SNL, DRI, EG&G, EPA, and DOE. After lengthy review and discussion, 31 usable attributes were defined (Table 2).

Confidence in extrapolations and interpolations of attribute data varies from place to place, rock type to rock type, and attribute to attribute. Attempts to quantify this confidence as proposed in Reference 2 were precluded by constraints of other work commitments by NNWSI technical experts and by schedules for completing the screening activity. However, data for the attributes represented the best judgments during the summer of 1981 of experts familiar with the corresponding subject matter. Confidence in attribute data was retained as a qualitative factor for interpreting the screening results and is discussed for each attribute in the body of this report.

Twenty-three of the 31 attributes vary geographically (Nos. 1–23, Table 2). A map was prepared for each geographical attribute to show the distribution of attribute conditions throughout the screening area. The attribute maps are included in Chapter 2.

Experts, primarily from LANL, LLNL, SNL, and USGS, worked closely with the NNWSI Technical Overview Contractor to define discriminating conditions to be used as mapping units for each of the geographical attributes (Table 2). Mapping units were selected to divide the screening area into discrete zones that discriminate among alternative locations. The specific favorability of each mapping unit for satisfying performance objectives was not a factor in selecting the mapping units. The maps were compiled solely from judgments about how physical conditions vary within the screening area. This separated relatively objective judgments about the physical data from more subjective judgments about their favorability for repositories.

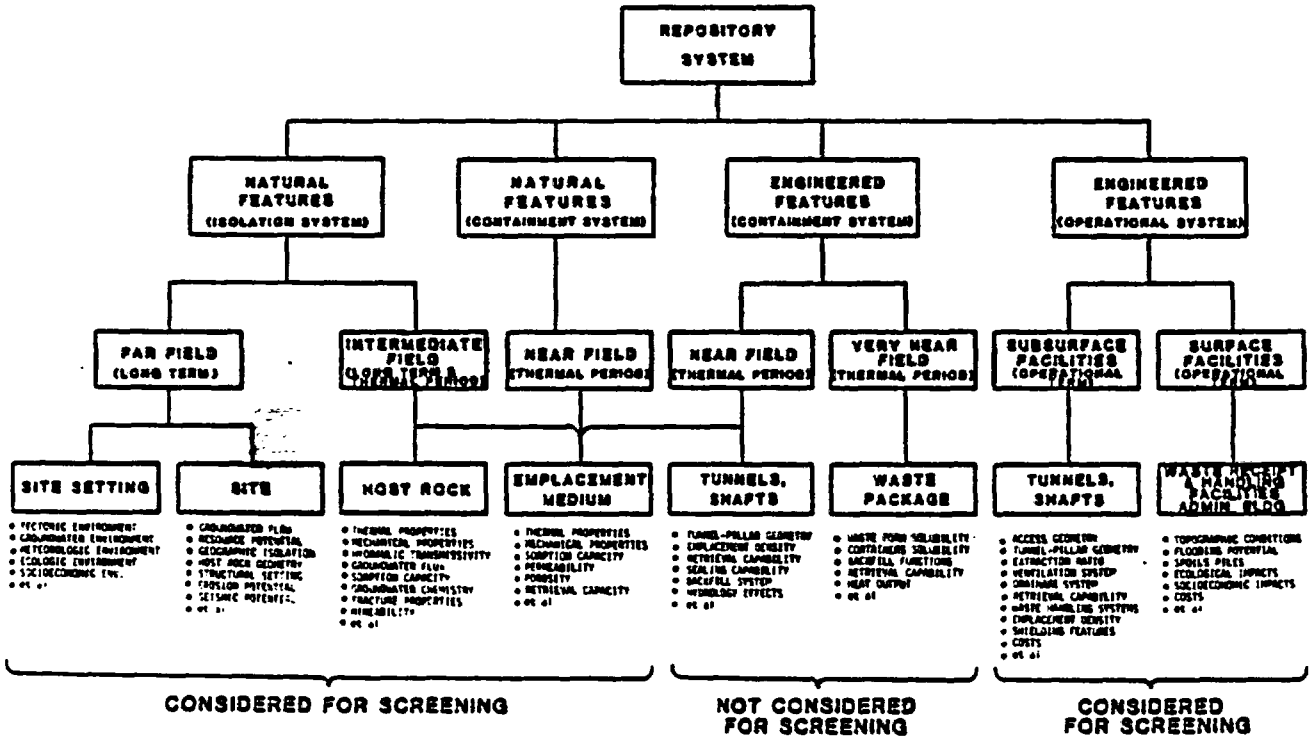

Figure 3. Candidate Attributes for Assessing Performance of Repository Components

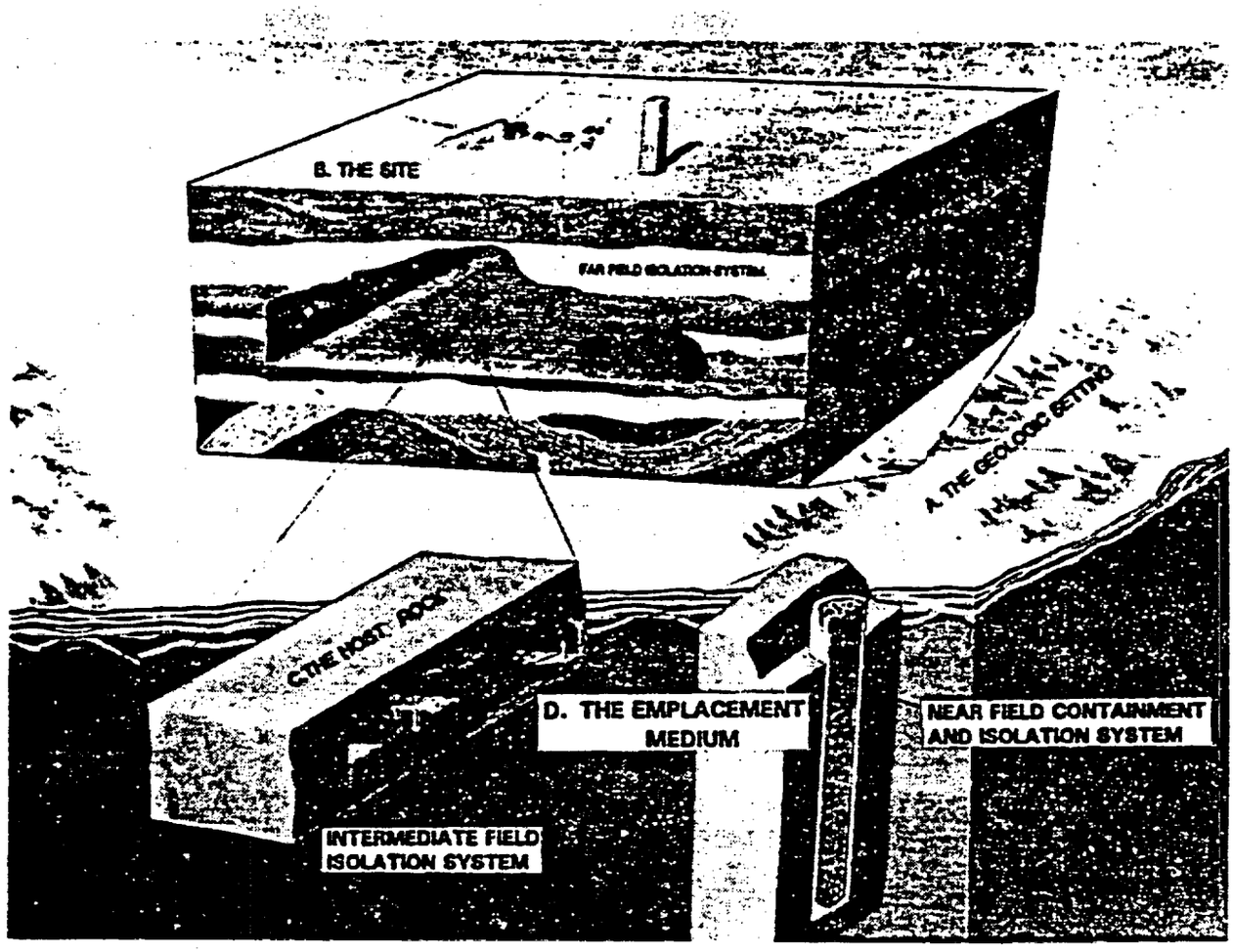

Figure 4. General Model of a Mined Geologic Repository System

Table 2. Thirty-One Attributes Selected for Discriminating Among Alternative Locations and Host Rocks

No.	Title	Discriminating Conditions	Major Contributor*
Geographical			
1	Volcanic Potential	4 Zones of Relative Potential	USGS
2	Fault Density	3 Zones of Relative Density	USGS
3	Fault Trend	3 Zones of Compass Direction	USGS
4	Age of Faulting	3 Zones of Fault Ages	USGS
5	Ground Motion (Natural)	Discrete Values of Expected Ground Acceleration (g)	USGS
6	Ground Motion (Weapon Induced)	5 Zones of Expected Ground Acceleration (g)	SNL
7	Bed Attitude	3 Zones of Amount of Rock Dip (degrees)	USGS
8	Erosion Potential	5 Zones of Erosional Intensity	SNL
9	Flood Potential	4 Zones of Flooding Hazards	SNL
10	Terrain Ruggedness	4 Zones of Slope Steepness (%)	SNL
11	Resource Potential	3 Zones of Potential for Finding Metal Ores	USGS
12	Groundwater Resources Potential	5 Zones of Potential for Groundwater Use	USGS
13	Groundwater Flux	6 Zones of Groundwater Flux (m^3/s)	USGS
14	Groundwater Flow Direction and Length	5 Zones of Upgradient Distance From Production Areas	SNL
15	Thickness of Unsaturated Zone	3 Zones of Depth to Water Table (m)	USGS
16	Sensitive Floral Species	14 Units of Potential for Finding Sensitive Species	EG&G
17	Sensitive Faunal Species	5 Zones of Species Habitats	EG&G
18	Revegetation Potential	5 Zones of Vegetation Assemblages	EG&G
19	Known Cultural Resources	3 Zones of Types of Cultural Responses	DRI
20	Potential Cultural Resources	10 Units of Potential Density of Cultural Resources	DRI
21	Air Pollution Potential	5 Zones of Air Quality	DRI
22	Permitting Difficulties	4 Zones of Land Ownership and Control	SNL
23	Private Land Use	Private and Nonprivate Land	UNLV
Host-Rock			
24	Thermal Conductivity	5 Ranges of Thermal Conductivity (W/m·K)	SEWG
25	Compressive Strength (Containment)	3 Ranges of Unconfined Compressive Strength (psi)	SEWG
26	Compressive Strength (Construction)	3 Ranges of Unconfined Compressive Strength (psi)	SNL
27	Expansion-Contraction	Expansion or Contraction Behavior Upon Heating	SEWG
28	Mineral Stability	7 Rank Orders of Mineral Stability Upon Heating	LANL
29	Stratigraphic Setting	14 Conditions of Stratigraphically Weighted Sorption	LANL
30	Hydraulic Retardation	6 Rank Orders, Radionuclide Diffusion into Rock Matrix	LANL
31	Hydraulic Transmissivity	4 Ranges of Hydraulic Transmissivity (m^2/s)	USGS

*Major Contributors

USGS = US Geological Survey
SNL = Sandia National Laboratories
EG&G = Edgarton, Germehausen, and Grier
DRI = Desert Research Institute
LANL = Los Alamos National Laboratory
SEWG = Site Evaluation Working Group

Though the purpose of screening was to identify favorable geographic locations, preliminary evaluations of candidate host rocks were performed to determine if at least one usable rock type occurs beneath locations rated most favorable. Accordingly, 8 of the 31 attributes (Nos. 24–31, Table 2) vary as a function of rock type rather than geographical position. Nine rock types known to occur in the screening area were selected for evaluation.

For each of the eight host-rock attributes, a single, discriminating value was assigned to each rock type. The values and their rationale are discussed in Chapter 3.

Maps were prepared to show where a thickness of at least 100 ft for each of these candidate rock types is inferred to occur between depths of 500 and 4000 ft. The criteria for thickness and depth were intended to rule out unrealistic alternatives while retaining a significant number of candidates for comparison. These maps are discussed in Chapter 4.

Host-rock attributes that vary with depth were not considered because each rock type occurs at different depths below different portions of the screening area, and only one value for each attribute could be conveniently assigned to each rock type due to space limitations in the computer. Therefore, pertinent

attributes for rating the relative merits of rock masses, such as in situ stress, water saturation conditions, geothermal gradient, and vertical mining haulage costs, were not addressed in the screening.

Relationship Between Attributes and Objectives

To evaluate the relative merits of alternative locations, attributes were related quantitatively to performance objectives. Relationships that make this necessary link have two basic facets. The first establishes which attributes are useful for evaluating locations with respect to each performance objective. The second defines the relative favorability of discriminating attribute conditions for satisfying the performance objectives.

A systems matrix was established wherein attributes form the rows, and objectives form the columns (Table 3). This matrix, referred to as the attribute-objective matrix, allows a graphical consideration of the usefulness of every attribute with respect to each lower-level objective. If an attribute is useful for evaluating a particular objective, a weight was assigned at the intersection of the appropriate column and row. For an objective having only one pertinent attribute, a weight of 100% was assigned to that attribute. For an objective having more than one pertinent attribute, the total weight of 100% was divided among the attributes according to the percentage contribution of each attribute in evaluating the objective. By considering every matrix intersection and making a judgment about each, weights were obtained for all the attributes with respect to all performance objectives.

These weights define the relative importance of individual attributes for evaluating specific objectives (Table 3). Weights in each column sum to 100%. Consequently, combining the contribution of all attributes for a particular objective allows comprehensive numerical analysis of locations with respect to that objective. For some objectives (i.e., 3.1.4, 3.3.2, 4.3.1, and 4.3.2), no discriminating attributes were identified or no data were available. As a result, the weights associated with these objectives did not affect the screening analyses. Discussion of the rationale for the weights assigned to each attribute with respect to particular objectives is provided in Reference 4.

The weight of each attribute-objective intersection with respect to the overall evaluations is determined by multiplying the attribute weights shown at the matrix intersections on Table 3 by the weights of the appropriate column-heading objectives from all three levels of the objectives tree. Adding all weights thus obtained for a single attribute defines a total weight for each attribute relative to the overall goal of safe, cost-effective, and environmentally sound waste disposal. Figure 5 plots these total attribute weights and orders them from the highest to the lowest weighted attributes.

Attribute weights were not determined by a poll. In lieu of a poll, the NNWSI Technical Overview Contractor from SNL assigned the attribute weights shown in Table 3 based on the consensus of its members.

The second facet of quantitative relationships between attributes and objectives establishes the relative favorability for each discriminating condition for each attribute. These relationships are expressed as favorability graphs, and they are discussed in detail for each attribute in Chapters 2 and 3. Attribute conditions that discriminate place from place or rock type from rock type are independent variables of the favorability graphs. The dependent variables are favorability numbers of a scale of 0 to 10 (Figure 6).

In effect, these graphs constituted quantitative criteria for the screening activity. They tie objectives to data as follows:

- Performance objectives establish goals
- Attributes define discriminating physical conditions in the screening area
- Favorability graphs provide a quantitative standard for assessing how well the physical conditions meet the objectives

The favorability graphs were developed by the Technical Overview Contractor. First, a general trend of favorability values for the conditions of each attribute was established. Next, high and low values were assigned, respectively, to the most and least favorable conditions. Lastly, intermediate values were interpolated between these extremes. Whole integers were used whenever possible, while preserving the general trends of the graphs.

Favorability values of zero were generally reserved for possible exclusionary conditions, such as the presence of Quaternary faults, private land, or extensive mineral deposits. However, no reasons are known that necessarily establish these conditions as exclusionary. Because the current draft NRC technical criteria for repositories[4] defines them as "undesirable conditions for features," they were assigned a favorability of zero to draw attention to such conditions. In this screening, zero favorability values were not exclusionary. For attributes whose least desirable condition was not specifically mentioned in the draft NRC criteria, a low favorability value of one, or in some cases two or more, was assigned. A value of nine or ten was generally used for the highest attainable favorability.

Table 3. Attribute-Objective Matrix Used in Screening Weights for Attributes Shown at Matrix Intersections

OBJECTIVES (WEIGHTS IN PARENTHESES)

OVERALL GOAL: PROVIDE SAFE, EFFECTIVE & ENVIRONMENTALLY SOUND RADIOACTIVE WASTE DISPOSAL

ATTRIBUTES (WEIGHTS AT MATRIX INTERSECTIONS)

LEVEL 1: 1.0 PROVIDE CONTAINMENT (31%) — LEVEL 2: 1.1 DISRUPTIVE PROCESSES; 1.2 DISRUPTIVE EVENTS

Attribute group	Attribute	1.1.1 Chemical	1.1.2 Mechanical	1.2.1 Seismic	1.2.2 Erosional	1.2.3 Volcanic	1.2.4 Human Intrusion	1.2.5 Miscellaneous
GEOGRAPHICAL – Tectonic/Seismic	1 Volcanic Potential			6		100		
	2 Fault Density	6						
	3 Fault Trend			6				
	4 Age of Faulting			20				
	5 Ground Motion (Natural)			20				
	6 Ground Motion (Weapon Induced)							100
GEOGRAPHICAL – Geologic/Surface	7 Bed Attitude (Rock Dip)							
	8 Erosion Potential				100			
	9 Flood Potential							
	10 Terrain Ruggedness							
	11 Base & Precious Metal Resource Pot						80	
GEOGRAPHICAL – Hydrological	12 Groundwater Resource Potential						60	
	13 Groundwater Flux	6						
	14 Groundwater Flow Direction & Length							
	15 Thickness of Unsaturated Zone							
GEOGRAPHICAL – Environmental	16 Sensitive Floral Species							
	17 Sensitive Faunal Species							
	18 Revegetation Potential							
	19 Known Cultural Resources							
	20 Potential Cultural Resources							
	21 Air Pollution Potential							
GEOGRAPHICAL – Institutional	22 Permitting Difficulties							
	23 Private Land Use							
HOST ROCK – Geomechanical	24 Thermal Conductivity	20	20					
	25 Compressive Strength (Containment)		40					
	26 Compressive Strength (Construction)							
	27 Expansion-Contraction		20					
HOST ROCK – Geochemical	28 Mineral Stability	10	10					
	29 Stratigraphic Setting							
	30 Hydraulic Retardation							
HOST ROCK – Hydrological	31 Hydraulic Transmissivity	60						

LEVEL 1: 2.0 PROVIDE ISOLATION (34%) — LEVEL 2: 2.1 RADIONUCLIDE MIGRATION; 2.2 DISRUPTIVE EVENTS

Attribute group	Attribute	2.1.1 Groundwater Flowpaths	2.1.2 Nuclide Retard	2.1.3 Host Rock Thick.	2.1.4 Volatile Migration	2.2.1 Tectonic	2.2.2 Climatic	2.2.3 Geomorphic	2.2.4 Human Induced	2.2.5 Disc. & Complexity
GEOGRAPHICAL – Tectonic/Seismic	1 Volcanic Potential					40				
	2 Fault Density	6			10					20
	3 Fault Trend					10				
	4 Age of Faulting					10				
	5 Ground Motion (Natural)					40				
	6 Ground Motion (Weapon Induced)								10	
GEOGRAPHICAL – Geologic/Surface	7 Bed Attitude (Rock Dip)									20
	8 Erosion Potential							60		
	9 Flood Potential							10		
	10 Terrain Ruggedness							10		20
	11 Base & Precious Metal Resource Pot								40	
GEOGRAPHICAL – Hydrological	12 Groundwater Resource Potential								40	
	13 Groundwater Flux	10	10							
	14 Groundwater Flow Direction & Length	80								
	15 Thickness of Unsaturated Zone	5					100			
GEOGRAPHICAL – Environmental	16 Sensitive Floral Species									
	17 Sensitive Faunal Species									
	18 Revegetation Potential									
	19 Known Cultural Resources									
	20 Potential Cultural Resources									
	21 Air Pollution Potential									
GEOGRAPHICAL – Institutional	22 Permitting Difficulties									
	23 Private Land Use									
HOST ROCK – Geomechanical	24 Thermal Conductivity									
	25 Compressive Strength (Containment)			30						
	26 Compressive Strength (Construction)									
	27 Expansion-Contraction									
HOST ROCK – Geochemical	28 Mineral Stability		10		5					
	29 Stratigraphic Setting		70	30	30					
	30 Hydraulic Retardation	10	10		10					
HOST ROCK – Hydrological	31 Hydraulic Transmissivity	40			40					

LEVEL 1: 3.0 PROVIDE SAFE COST EFFECTIVE CONSTRUCTION & OPERATIONS — LEVEL 2: 3.1 SURFACE FACILITIES; 3.2 SUBSURFACE FACILITIES; 3.3 TRANSPORTATION SYSTEMS

Attribute group	Attribute	3.1.1 Seismicity	3.1.2 Monitoring Equip'ts	3.1.3 Foundation Cond	3.1.4 Wind Loads	3.1.5 Flooding	3.1.6 Avail. Sat. Rel.	3.2.1 Seismicity	3.2.2 Flooding	3.2.3 Mining Cond	3.2.4 Host Rock Mech	3.2.5 Host Rock Hydrol	3.2.6 Waste Pkg Accept.	3.3.1 Terrain	3.3.2 Existing Corridor
GEOGRAPHICAL – Tectonic/Seismic	1 Volcanic Potential														
	2 Fault Density							10	10	20		60			
	3 Fault Trend														
	4 Age of Faulting														
	5 Ground Motion (Natural)	30						20							
	6 Ground Motion (Weapon Induced)	10						5							
GEOGRAPHICAL – Geologic/Surface	7 Bed Attitude (Rock Dip)										100	40			
	8 Erosion Potential			10											
	9 Flood Potential			30		100			5					30	
	10 Terrain Ruggedness		70	70										70	
	11 Base & Precious Metal Resource Pot											10			
GEOGRAPHICAL – Hydrological	12 Groundwater Resource Potential														
	13 Groundwater Flux								10						
	14 Groundwater Flow Direction & Length								10	10					
	15 Thickness of Unsaturated Zone														
GEOGRAPHICAL – Environmental	16 Sensitive Floral Species		3												
	17 Sensitive Faunal Species		7												
	18 Revegetation Potential														
	19 Known Cultural Resources		6												
	20 Potential Cultural Resources		15												
	21 Air Pollution Potential														
GEOGRAPHICAL – Institutional	22 Permitting Difficulties														
	23 Private Land Use														
HOST ROCK – Geomechanical	24 Thermal Conductivity									10			20		
	25 Compressive Strength (Containment)														
	26 Compressive Strength (Construction)									40					
	27 Expansion-Contraction												40		
HOST ROCK – Geochemical	28 Mineral Stability									10			40		
	29 Stratigraphic Setting														
	30 Hydraulic Retardation														
HOST ROCK – Hydrological	31 Hydraulic Transmissivity								60	10					

LEVEL 1: 4.0 PROVIDE ACCEPTABLE ENVIRONMENTAL IMPACTS — LEVEL 2: 4.1 BIOTIC SYSTEMS; 4.2 ABIOTIC SYSTEMS; 4.3 SOCIOECONOMIC IMPACTS; 4.4 INSTITUTIONAL IMPACTS; 4.5 CULT. RES.

Attribute group	Attribute	4.1.1 Sensitive Sys	4.2.1 Surface Geology	4.2.2 Water Quality	4.2.3 Air Quality	4.3.1 Local Economics	4.3.2 Life Styles	4.3.3 Land Use	4.4.1 State Issues	4.4.2 Federal Regs.	4.5.1 Arch. & Hist Sites
GEOGRAPHICAL – Tectonic/Seismic	1 Volcanic Potential										
	2 Fault Density										
	3 Fault Trend										
	4 Age of Faulting										
	5 Ground Motion (Natural)										
	6 Ground Motion (Weapon Induced)										
GEOGRAPHICAL – Geologic/Surface	7 Bed Attitude (Rock Dip)										
	8 Erosion Potential										
	9 Flood Potential		20								
	10 Terrain Ruggedness		80								
	11 Base & Precious Metal Resource Pot										
GEOGRAPHICAL – Hydrological	12 Groundwater Resource Potential			100							
	13 Groundwater Flux										
	14 Groundwater Flow Direction & Length										
	15 Thickness of Unsaturated Zone										
GEOGRAPHICAL – Environmental	16 Sensitive Floral Species	40									
	17 Sensitive Faunal Species	50									
	18 Revegetation Potential	10									
	19 Known Cultural Resources										30
	20 Potential Cultural Resources										70
	21 Air Pollution Potential				100						
GEOGRAPHICAL – Institutional	22 Permitting Difficulties									100	
	23 Private Land Use							100			
HOST ROCK – Geomechanical	24 Thermal Conductivity										
	25 Compressive Strength (Containment)										
	26 Compressive Strength (Construction)										
	27 Expansion-Contraction										
HOST ROCK – Geochemical	28 Mineral Stability										
	29 Stratigraphic Setting										
	30 Hydraulic Retardation										
HOST ROCK – Hydrological	31 Hydraulic Transmissivity										

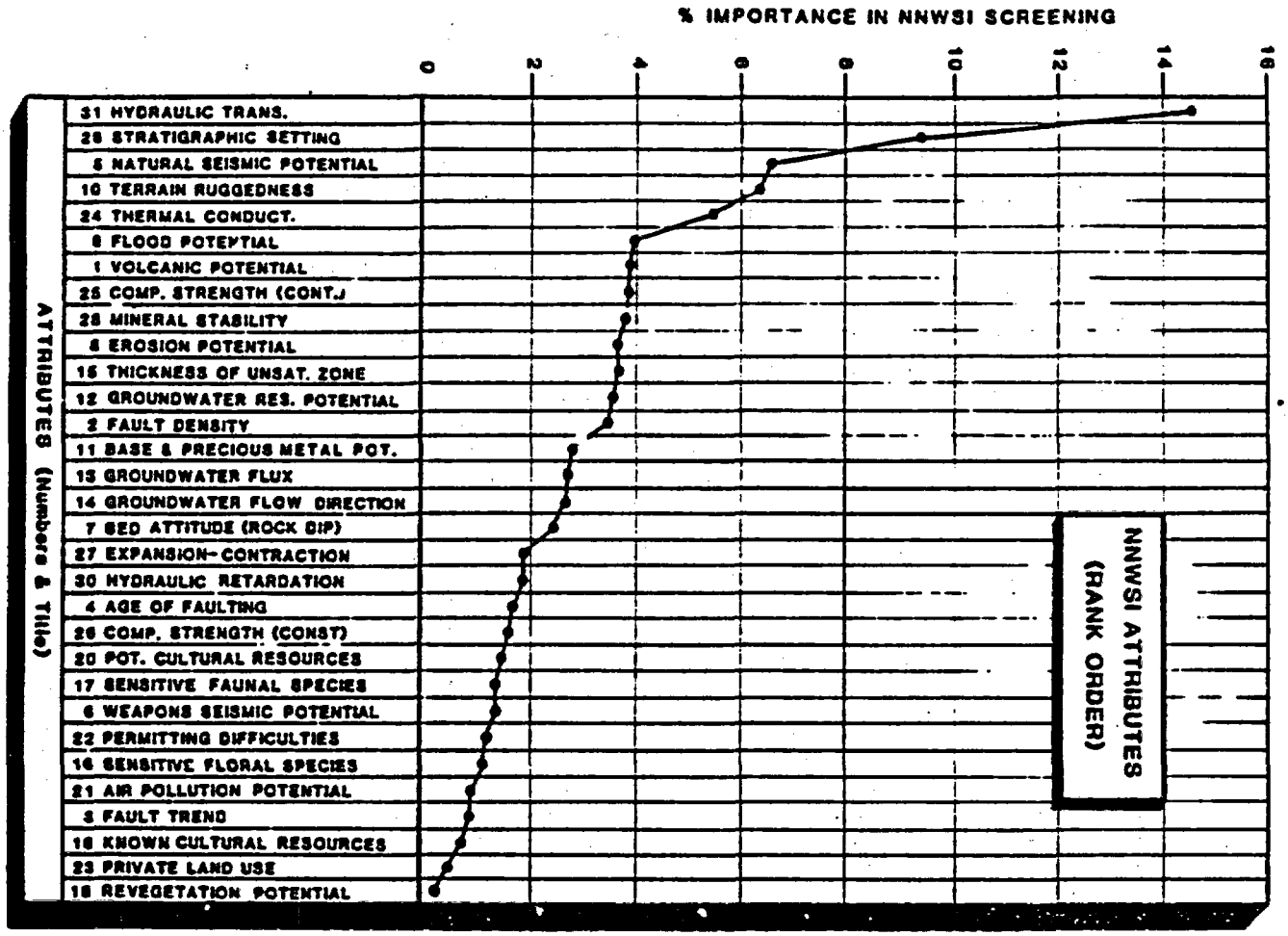

Figure 5. Attributes Ordered by Total Weight

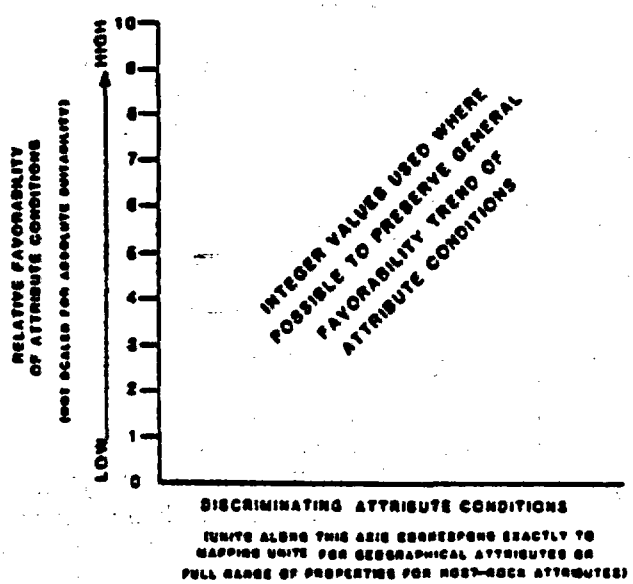

Figure 6. General Form of Favorability Graphs

With one exception, the general trend of favorabilities for attributes used to assess more than one objective is the same for each of the different objectives; therefore, only one graph was required for most attributes. The exception, compressive strength of host rocks, required two separate graphs: one for mining objectives and one for containment and isolation objectives.

The range of favorability numbers for each attribute generally encompasses the largest range from zero to ten compatible with simple graphs. This provided as much discriminating capability as possible for each attribute. For comparison, the favorability graphs could have been constructed to reflect absolute suitability in relation to all possible attribute conditions throughout the world, not just those expressed in the screening area. To effectively use the discriminating qualities of the attributes, differences among the relative merits of various locations and host rocks were enhanced, and perhaps even exaggerated, on the graphs to allow clear distinctions among the most and

least favorable. Therefore, the results of screening should not be considered assessments of absolute suitability.

The favorability graphs for geographical attributes are reproduced on the attribute maps in Chapter 2. The eight host-rock favorability graphs are presented at the beginning of Chapter 3.

Location and Host-Rock Rating Process

Ratings were calculated for each of 1514 1/2-mile-square grid cells* that comprised the screening area (Figure 7) and for each of the nine candidate host rocks. The grid cells were defined by a set of geographical X-Y coordinates and comprise a digital base map of the screening area. Each attribute map was digitized on an APPLICON Graphics System (AGS) by assigning Z values to designator numbers for mapping units at the appropriate X-Y coordinates (Figure 8). Favorability numbers from the favorability graphs were also digitized for each attribute. By replacing mapping unit numbers on the base map with corresponding favorability numbers, a favorability surface was generated for each attribute (Figure 9). Z values (or elevations) on these surfaces correspond to the favorability of an attribute at each grid cell. Digital attribute maps were preserved to keep the attribute data separate from judgments about their favorability. If the judgments change and a new favorability graph is considered appropriate, a new favorability surface can be generated easily from the original attribute map.

Weights for the attributes and objectives were also digitized (Figure 10). These weights were organized in the computer as a matrix analogous to Table 3. Weights assigned to objectives and attributes, as well as favorability values assigned to attributes, could be changed easily at an interactive cathode ray tube (CRT) terminal of the computer. Different results of favorability calculations based on different weights or favorability values were thus readily obtained.

*Alternative locations in the screening area are strictly defined as these 1/2-mile-square grid cells. Each of these grid locations was separately evaluated by data digitized and processed in an APPLICON Graphics System. Alternative repository locations were identified from screening results where about 40 or more grid cells (~10 square miles) were rated similarly.

Ratings were calculated for alternative locations using weights and favorability values for Attributes 1–23. Host-rock ratings were based only on Attributes 24–31. Attribute weights (Figure 5) were multiplied by the appropriate favorability values of the corresponding attributes. The weighted favorability values from all attribute-objective matrix intersections were summed for each grid cell of the base map. This process produced a map of 1514 individual favorability scores for the screening area. Thus, each of the 1514 grid cells was, in effect, an alternative location with its own rating.

Ranges of rating values displayed on the base map provide a graphical image of locations with greater or lesser favorability. Though each grid cell is strictly an alternative location, distinct locations for repositories required ~40 similarly rated, contiguous grid cells (~10 square miles). Due to uncertainties inherent in the many assumptions used in screening, confident discrimination among various locations was restricted to three categories: favorable, neutral, and unfavorable.

Host-rock ratings were obtained by the same process. Because the host-rock attributes do not vary geographically for a single rock type, but do vary from rock type to rock type, host-rock calculations were repeated only for each of the nine rock types rather than for each geographical grid cell. Outputs of host-rock evaluations were lists of rating numbers for each of the nine potential host rocks. These values were assigned to grid cells corresponding to the subsurface distribution of appropriate rocks yielding a geographical rating that included the contribution of host-rock attributes.

The general process for calculating ratings, R, for each 1/2-mile-square cell of the base map or each host rock can be summarized as follows:

$$R = \sum_{i=1}^{m}\left(\sum_{j=1}^{n} F_j w_{ij}\right)$$

where

- m = the total number of lower-level objectives
- n = the total number of attributes
- i = the objective number
- j = the attribute number
- F_j = the favorability value for the jth attribute at the grid cell or host rock in question
- w_{ij} = the weight of the jth attribute applied to the ith objective and is obtained by multiplying the weight of the ith lower-level objective from Figure 4 by the weight of the appropriate j^{th} attribute from Table 3

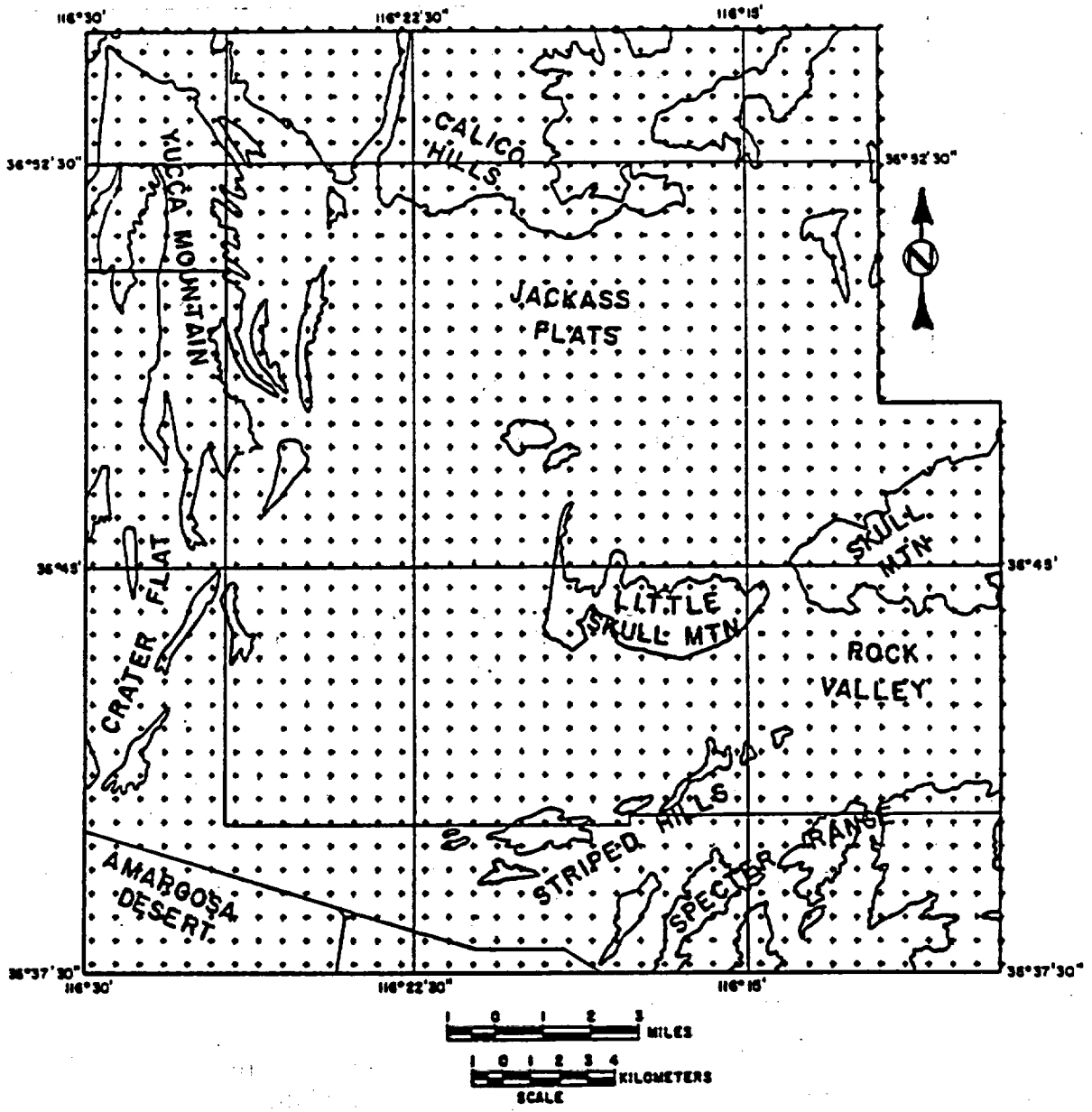

Figure 7. Digital Base Map of the Screening Area. Crosses correspond to the centers of the 1514 half-mile square grid cells that make up the screening area

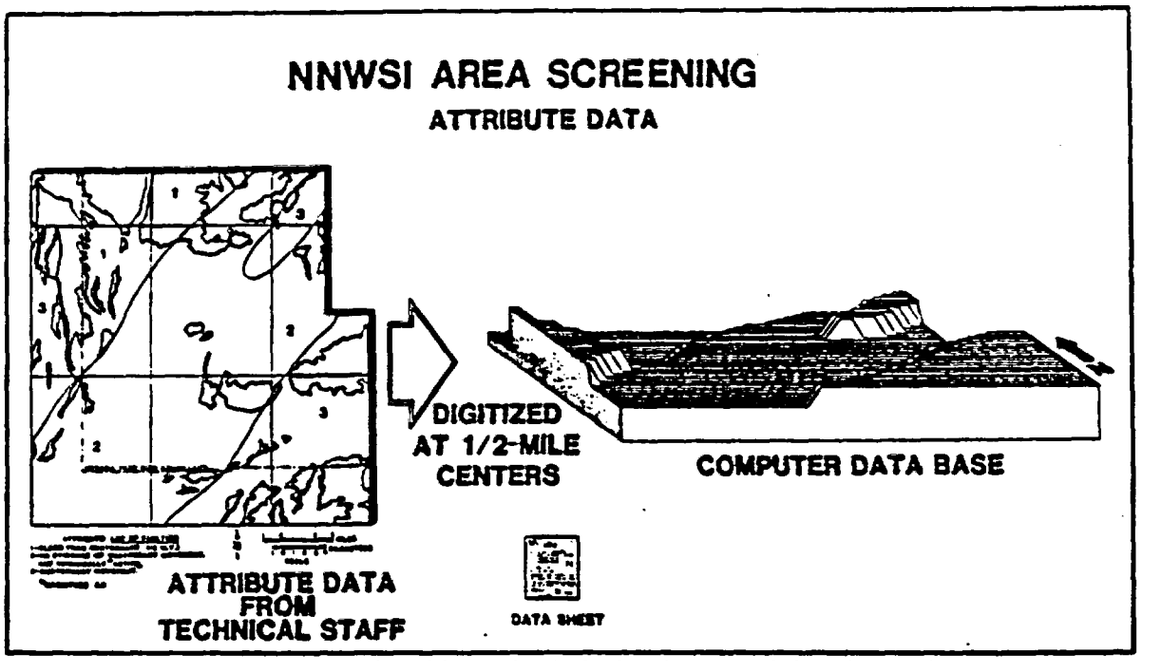

Figure 8. Example of Digitized Attribute Map. At left is the data form provided (in this case by USGS geologists); at right is digital form where map units are plotted as Z values on X-Y coordinates of base map.

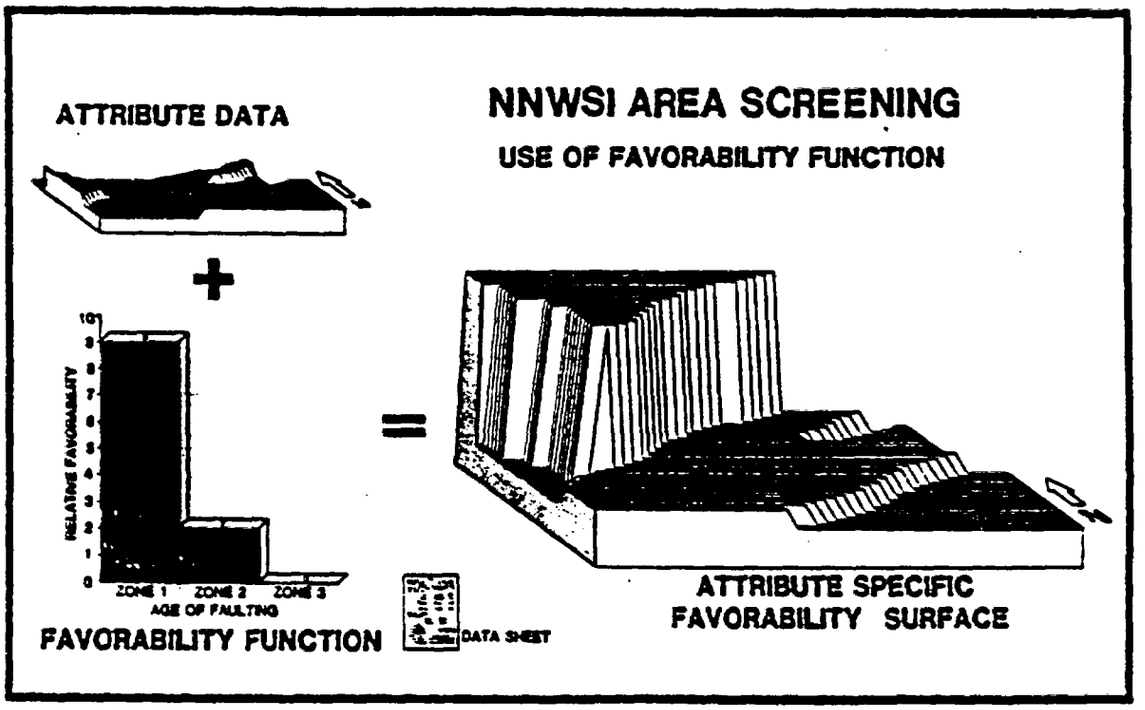

Figure 9. Example of Digitized Favorability Surface. Surfaces are obtained for each geographical attribute by assigning appropriate favorability values to mapping units and plotting favorability Z values on the base map.

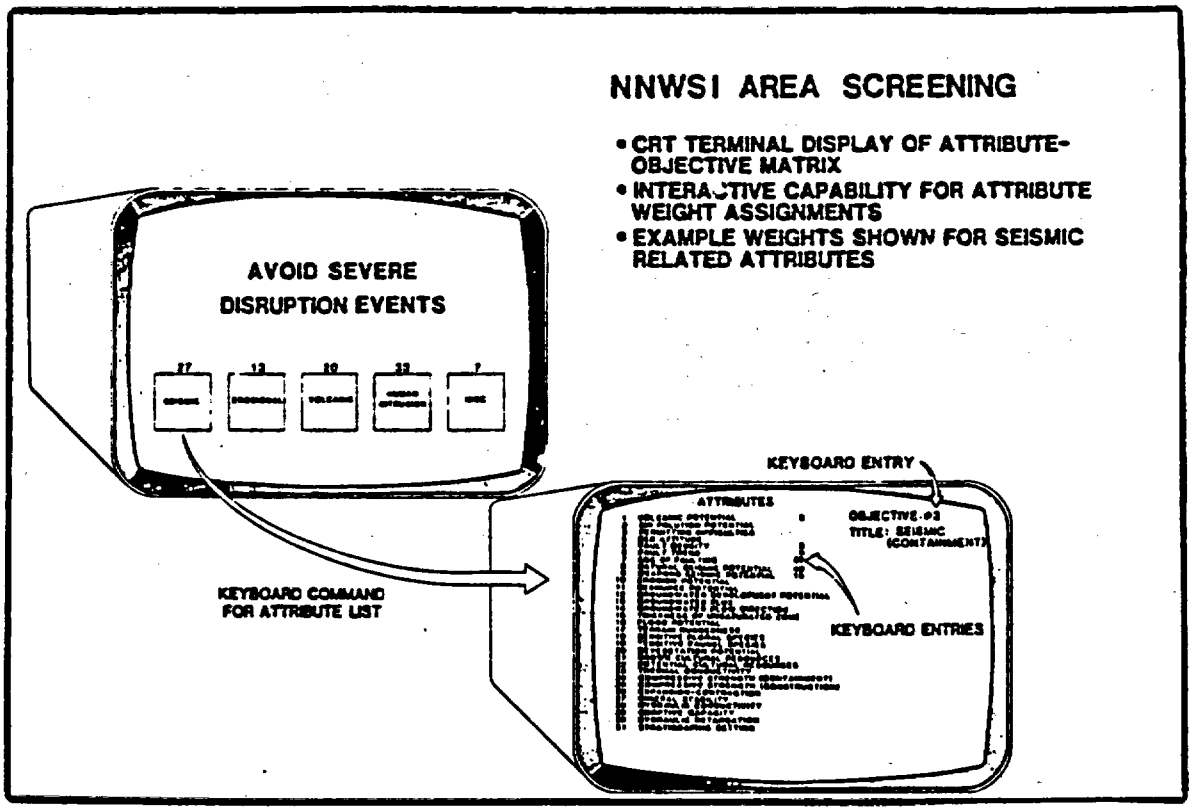

Figure 10. Schematic Example Showing How Weights for Objectives and Attributes Can Be Changed at a CRT Terminal

Interactive capabilities of the AGS terminals permitted easy investigation of the sensitivity of screening results to various assumptions about attribute weighting. The method by which various weighting assumptions were investigated was to assign all the weight to selected subsets of objectives or attributes. This allowed assessments of which combinations of objectives or attributes were responsible for high and low ratings of different locations and host rocks in the screening area. Results based on differing weighting values are discussed in a summary report on the screening activity.[3]

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[2]S. Sinnock et al (1981). *A Method for Screening the Nevada Test Site and Contiguous Area for Nuclear Waste Repository Locations*, SAND81-1438, NVO-236 (Las Vegas, NV: US Dept of Energy, Nev Oper Office, September 1981).

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[12]R. E. Johnson and R. A. Deju (1979). *Technical Requirements for Qualification of a Potential Nuclear Waste Repository Site in Basalt*, RHO-BWI-LD-19, Informal Report. (Richland, WA: Rockwell Hanford Operations, September 1979).

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Chapter 2. Geographical Attributes

This chapter presents the supporting rationale and assumptions for each of the 23 screening attributes that vary geographically. For each attribute, the following information is provided:

- A map showing how pertinent physical conditions (mapping units) are distributed throughout the screening area
- A favorability graph (inset on the map) showing the relative favorability of each mapping unit for repository locations on a scale of 0 to 10
- The persons responsible for compiling the map and the favorability graph
- A description of the mapping units
- The rationale for assigning these units to different portions of the screening area
- A discussion of the confidence that can be placed in the maps
- The basis for ascribing favorability values to the mapping units
- Objectives evaluated by the attribute
- Additional readings for supporting information

The attributes are discussed in the order of their numbers, i.e., from 1 through 23. They are grouped by topical categories as follows:

Tectonic-Seismic..... Attributes 1-6
Geologic-Surface Terrain..... Attributes 7-11
Hydrologic ..... Attributes 12-15
Environmental..... Attributes 16-21
Institutional..... Attributes 22-23

Many of the attributes in the first three topical categories are based on geological maps of the screening area. Figure 11 shows the geographical coverage of this type of mapping. Full citations for the applicable maps are provided in the "Additional Readings" section for each attribute.

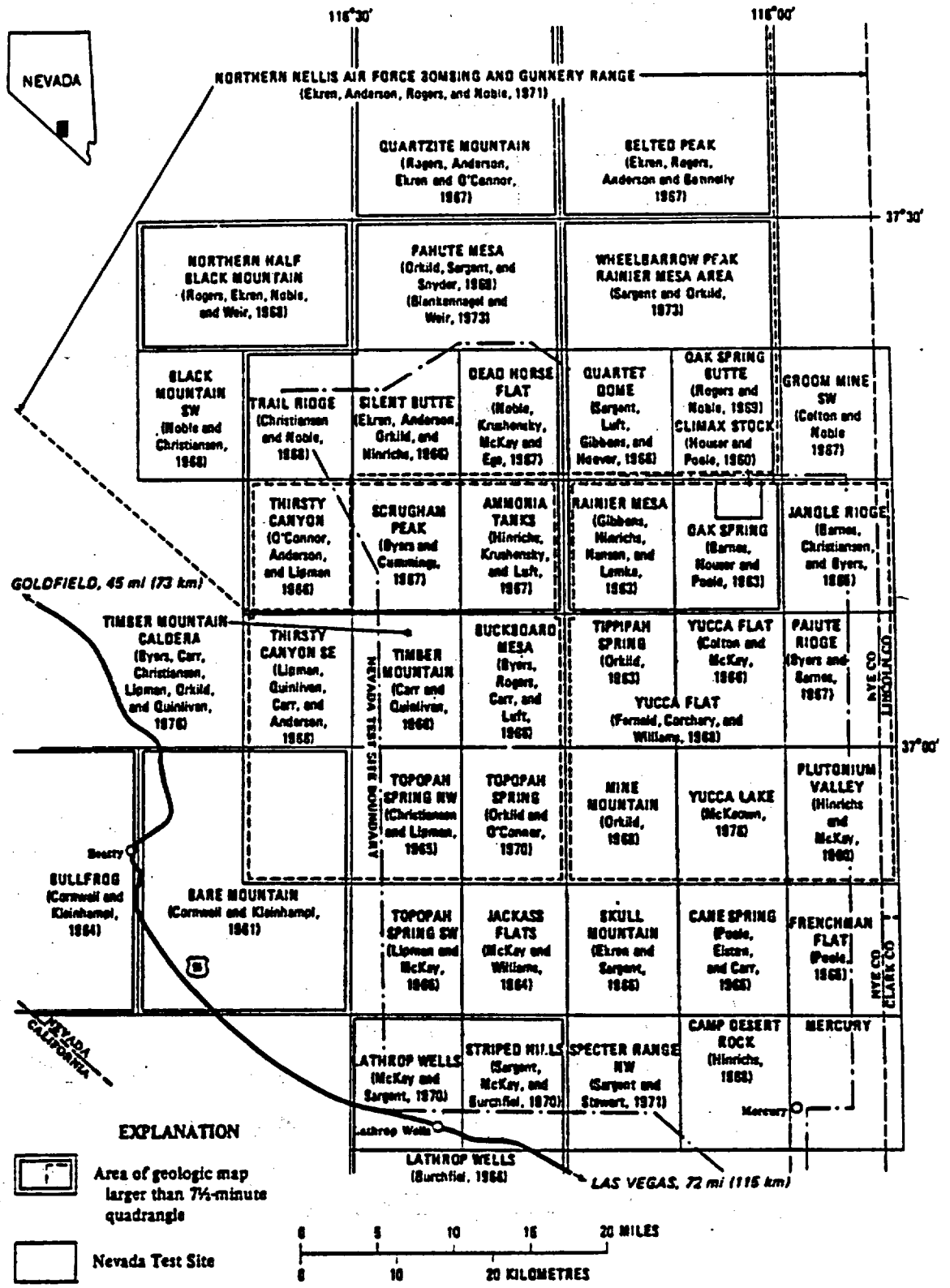

Figure 11. Index Map Showing Sources of Geologic Mapping Data for Portions of the NTS and Adjacent Regions, Including the Screening Area. G, H, and I Series maps are identified by author and date. Applicable maps are listed in the "Additional Readings" for each attribute (from Byers et al, 1976a, in "Additional Readings" for Attribute 1).

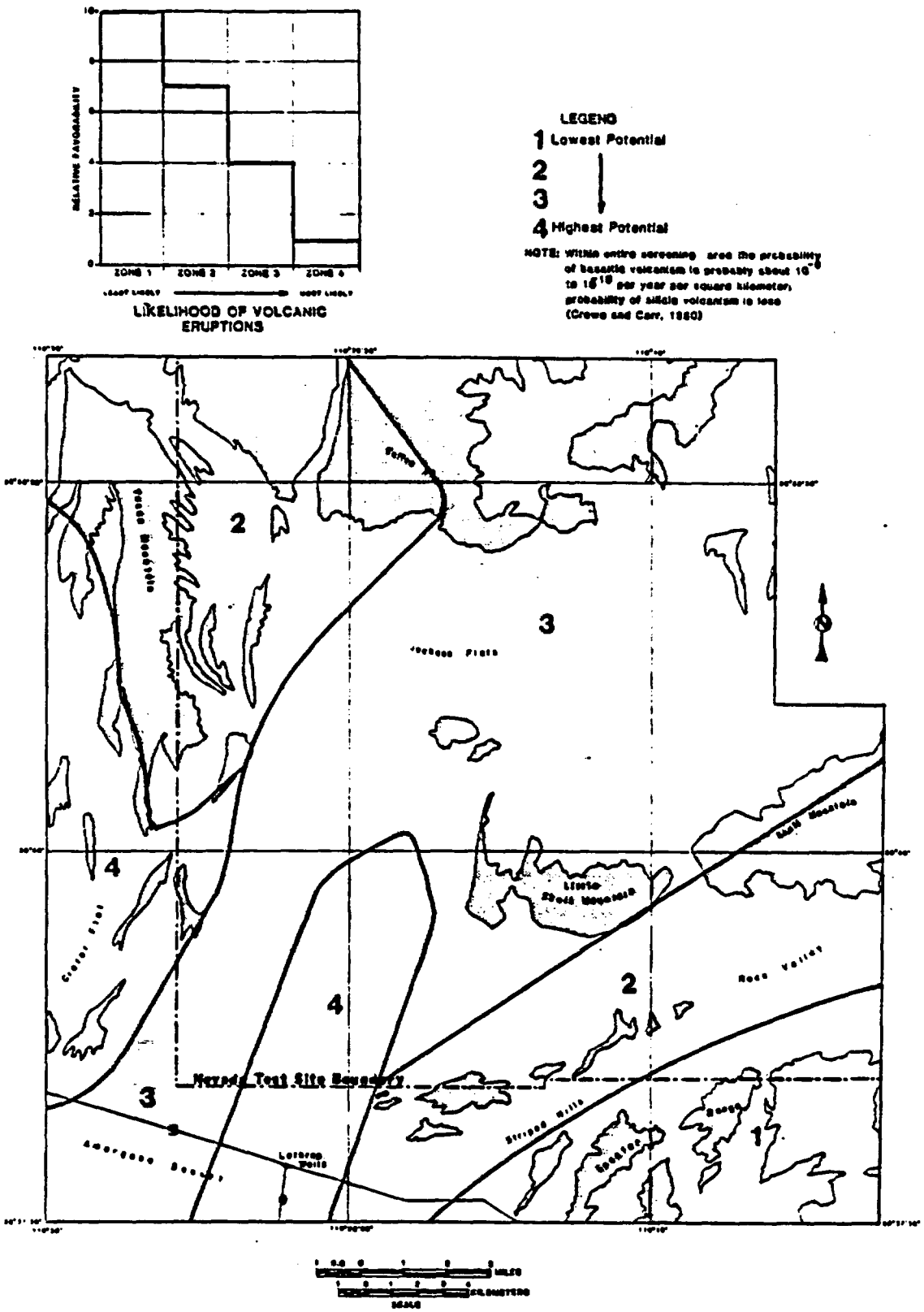

Figure 12. Map and Associated Favorability Graph for Attribute 1, Volcanic Potential

Tectonic-Seismic Attributes

Attribute 1. Volcanic Potential
(Figure 12)

Compilers

Attribute Map:
W. J. Carr (USGS), B. M. Crowe (LANL), and J. T. Neal (SNL)

Favorability Graph:
S. Sinnock (SNL), J. T. Neal (SNL), J. A. Fernandez (SNL), R. L. Hunter (SNL), and B. L. Hartway (LATA)

Mapping Units

Four Zones of Likelihood for Volcanic Eruptions

Mapping Rationale

The map shows a subjective evaluation of the relative potential for volcanism, based on the current understanding of the volcano-tectonic history of the southwest NTS.

The greatest potential (Zone 4) includes areas along the eastern edge of Crater Flat where future volcanism might be localized along inferred deep-seated faults associated with an old caldera system. The eastern portion of this area includes mapped areas of Quaternary or Pliocene basalts. Also included in Zone 4 is an area near Lathrop Wells where aeromagnetic data suggest the presence of buried Quaternary basalt and rift-like structure.

The second-highest potential (Zone 3) includes Shoshone Mountain, where rhyolitic volcanism occurred ~8–10 my ago, and parts of the seismically active, northeast-trending fault system through Jackass Flats, where basalts were extruded ~8–10 my ago.

The intermediate potential (Zone 2) includes the Rock Valley northeast-trending fault system and the Yucca Mountain/Fortymile Wash area, which has basin-range faulting and minor basalt dikes 10 my old. The lowest potential (Zone 1) is an area in which there are no volcanic rocks or seismically active faults that might serve as vents.

Confidence Estimates

The map is based on geologic mapping at a scale of 1:24,000 and a conceptual model of the volcano-tectonic history of the region. There is high confidence in the general aspects of the map, based on previous study, though specific predictions of the location as timing of future eruptions are beyond current geological understanding.

Basis for Favorability Graph

Considerations for relating volcanism potential to repository performance are

- Passage of a volcanic feeder dike through a repository could cause radioactive contaminants to be incorporated in the rising magma, thereby breaching containment; subsequent lava or ash-fall deposits at the surface could expose humans to radioactive waste.
- Heat and material introduced in the subsurface by volcanic events could alter the isolation qualities of rocks and groundwater in and near a repository.

A general objective is to avoid potentially active volcanic zones. Therefore, the lower the volcanic potential, the higher the favorability. The four zones of potential for volcanism in the screening area were transformed into a linear favorability scale with a value of 1 given to the greatest potential (Zone 4) and a value of 10 given to the least potential (Zone 1). Intermediate favorability values of 4 and 7 were assigned to Zones 3 and 2, respectively. Because none of the mapped zones in the screening area is considered unacceptable (i.e., within a few kilometers of a Quarternary volcano), a favorability of zero is not used. Preliminary calculations (Crowe and Carr, 1980) suggest that the probability of a basaltic volcanic eruption's disrupting a 10-km^2 repository in the western part of the screening

area is $\sim 10^{-8}$ to 10^{-9}/yr. This compares with probabilities of $\sim 10^{-6}$/yr/10 km^2 in the Cascade Range (Mullineaux, 1976) and the Snake River Plains (Crowe, 1978). Thus the potential for volcanism at the NTS is several orders of magnitude less than that of the Cascade Range and the Snake River Plains, two of the most recently active volcanic regions in the continental US.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.1 Minimize Potential for Seismic Hazards to Containment

1.2.3 Minimize Potential for Volcanic Disruption of Waste Packages

2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonics

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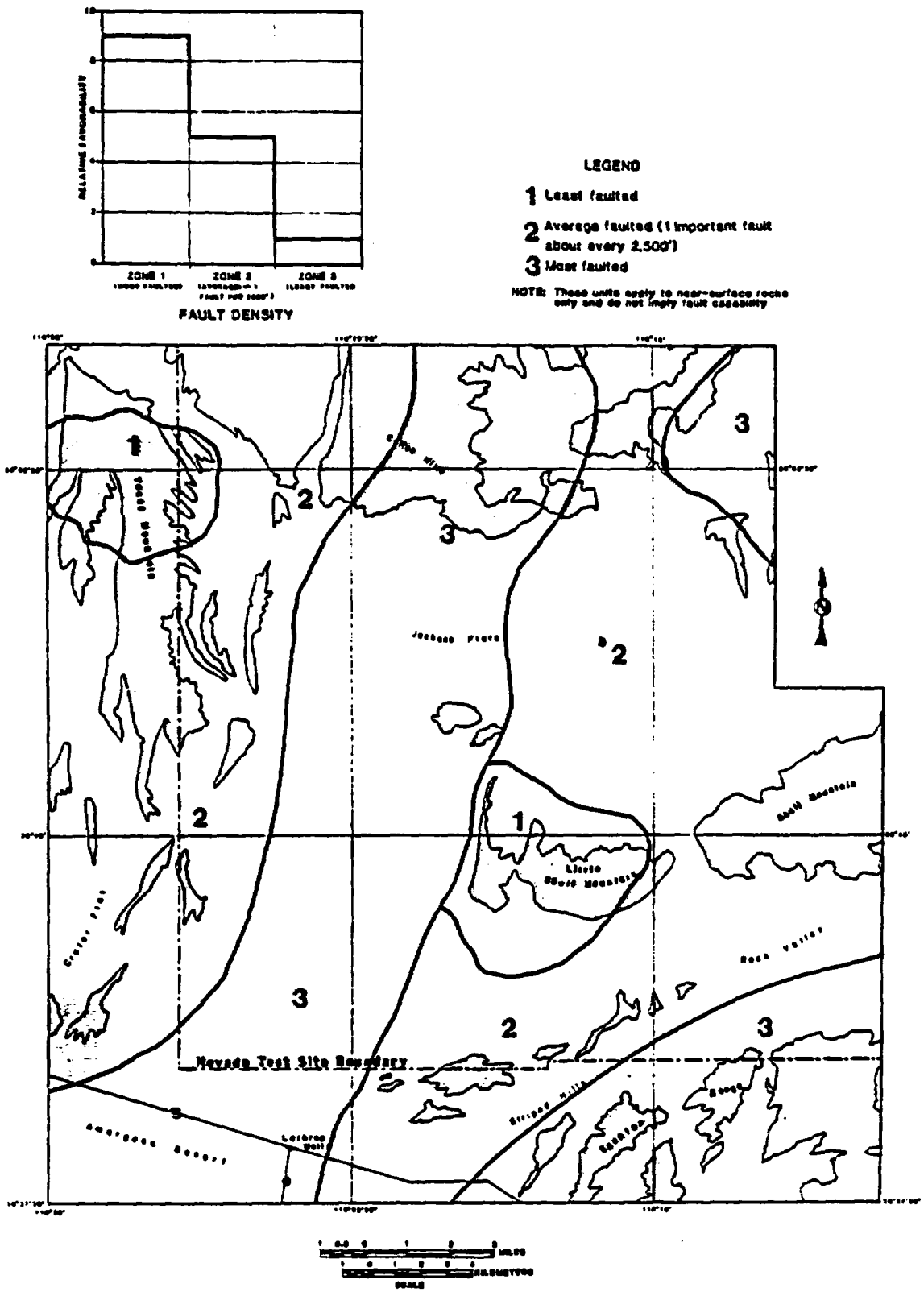

Figure 13. Map and Associated Favorability Graph for Attribute 2, Fault Density

Attribute 2. Fault Density
(Figure 13)

Compilers

Attribute Map:
W. J. Carr (USGS)
Faborability Graph:
W. J. Carr (USGS) and J. T. Neal (SNL)

Mapping Units

Three Zones of Relative Density of Faults

Mapping Rationale

The three zones depicted on the map are based on geologic mapping of faults, independent of age, exposed in the bedrock and on faults inferred from regional and local patterns of Basin and Range structures, strike-slip shear zones, and eruptive centers to be present in bedrock buried by alluvium. The most faulted areas (Zone 3) include Paleozoic rocks exposed in the southeast corner of the screening area and the Calico Hills/Jackass Flats/Lathrop Wells area, much of which is covered by alluvium where fault density is based on inference as to the bedrock structure. Average density of faulting (Zone 2) includes much of the eastern and western portions of the screening area; average faulting is defined as one major fault about every 2500 ft. Least faulted areas (Zone 1) include the northern part of Yucca Mountain and most of Little Skull Mountain. These mountains consist of large, low-dipping fault blocks, nearly undisturbed, between widely spaced faults.

Confidence Estimates

The map is based on geologic mapping of the exposed bedrock at a scale of 1:24,000 and on inferences of the bedrock structure of those areas buried by alluvium. Thus there is high confidence for the areas of exposed bedrock and low confidence for the large areas covered by alluvium. It should be noted that fault densities observed at the surface may be lower than those at a depth where older rocks may have been affected by faulting before the surface rocks were deposited.

Basis for Favorability Graph

Fault density is an indirect measure of the large-scale structural quality of near-surface rocks, and it has implications affecting hydrologic and thermomechanical properties of deeper rocks. Considerations for relating fault density to repository performance are

- The greater the fault density, the greater is the likelihood that hydrologic and thermomechanical properties of the rocks are degraded
- The greater the fault density, the greater is the difficulty of characterizing and predicting the occurrence and position of rocks with relatively homogenous properties

Though not addressed by the favorability scale, it should be noted that higher fracture densities may not be hydrologically deleterious and may even be advantageous in unsaturated rocks. A general objective is to avoid locations that are the most faulted, or conversely, to select locations that are the least faulted. Because no areas within the screening area are known to be so intensely faulted as to be unacceptable, a favorability of zero is not used. Therefore, a linear relationship is used to assign favorabilities. The least faulted areas (Zone 1) are assigned a favorability of 9, the average faulted areas (Zone 2) are assigned a favorability of 5, and the most faulted areas are assigned a favorability of 1.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.1 Minimize Potential for Chemically Induced Release
2.1.1 Maximize Extent of Relatively Homogenous Host Rock
2.1.4 Maximize Migration Time of Volatile Radionuclides
2.2.5 Minimize Site Complexity
3.2.1 Minimize Seismic Hazards to Subsurface Facilities

3.2.2 Minimize Flooding Hazards to Subsurface Facilities
3.2.3 Minimize Adverse Mining Conditions
3.2.5 Optimize Host-Rock Homogeneity

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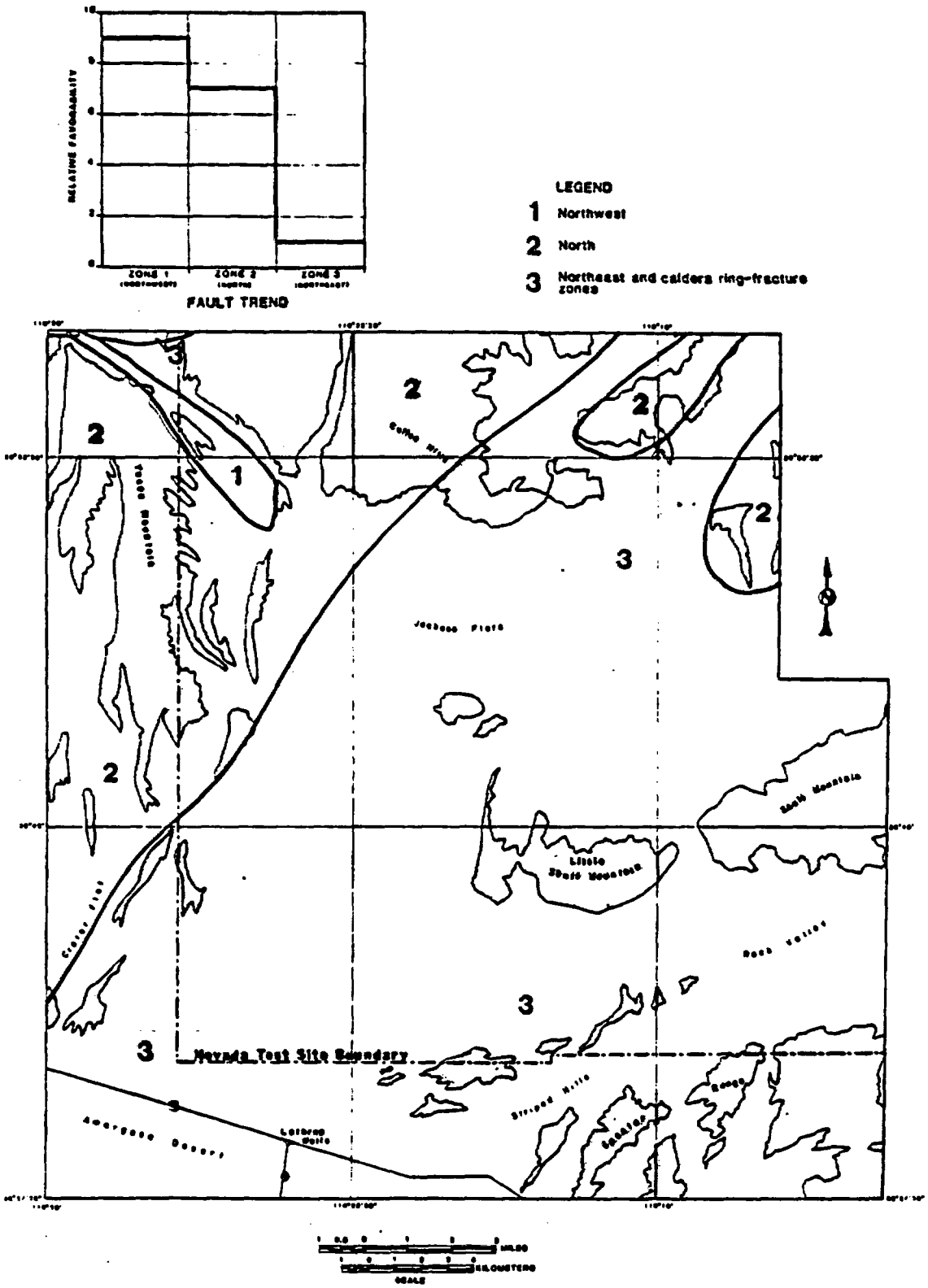

Figure 14. Map and Associated Favorability Graph for Attribute 3, Fault Trend

Attribute 3. Fault Trend
(Figure 14)

Compilers

Attribute Map:
W. J. Carr (USGS)
Favorability Graph:
W. J. Carr (USGS) and J. T. Neal (SNL)

Mapping Units

Three Zones of Faults With Differing Trends

Mapping Rationale

Studies of Quaternary fault patterns and faulting history of the screening area, as well as tectonic stress history analysis, reveal that northeast-trending strike-slip faults (Zone 3) are presently active whereas northwest-trending faults (Zone 1) are essentially inactive. Northeast-trending fault areas and caldera ring-fracture zones (Zone 3) include major active faults, such as the Cane Springs and Rock Valley faults, and an inferred area of large-scale caldera collapse features related to the Timber Mountain Caldera. North-south trending basin-range faults with minor strike-slip displacement (Zone 2) are inferred to be generally inactive. These occur in Yucca Mountain, Calico Hills, and along Fortymile Canyon. Northwest-trending faults (Zone 1) occur in a small area along Yucca Wash, the north edge of Yucca Mountain, and are considered the least likely to become active.

Confidence Estimates

The map is based on geologic mapping of the exposed bedrock at a scale of 1:24,000 and on inferences of the bedrock structure of those areas buried by alluvium. Thus there is high confidence in the general fault trends for areas of exposed bedrock and low confidence for areas covered by alluvium. The relationship between fault trend and potential fault movements is based on regional tectono-seismic interpretations, and is less well established than the actual fault trends. Thus there is only moderate confidence in the ability of the map to distinguish zones of relative activity.

Basis for Favorability Graph

Fault trends help indicate where faults are most likely to be active and where they are most likely to be inactive, thereby helping to assess stability of the repository's tectonic environment. Accordingly, this attribute compliments Attribute 4, Age of Faulting, which is based on more direct seismic and geomorphic evidence. The most active, northeast-trending strike-slip faults (Zone 3) and least active, northwest-trending faults (Zone 1) are assigned favorability values of 1 and 9, respectively, based on the rationale that nearby, active faults are not favorable for repository performance. North-trending faults (Zone 2) show only minor Quarternary activity and are judged to warrant a favorability value of 7. No fault trend zones within the screening area are known to have such intensively active faults as to be disqualified; thus a favorability value of zero is not used.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.1 Minimize Potential for Seismic Hazards to Containment

2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonics

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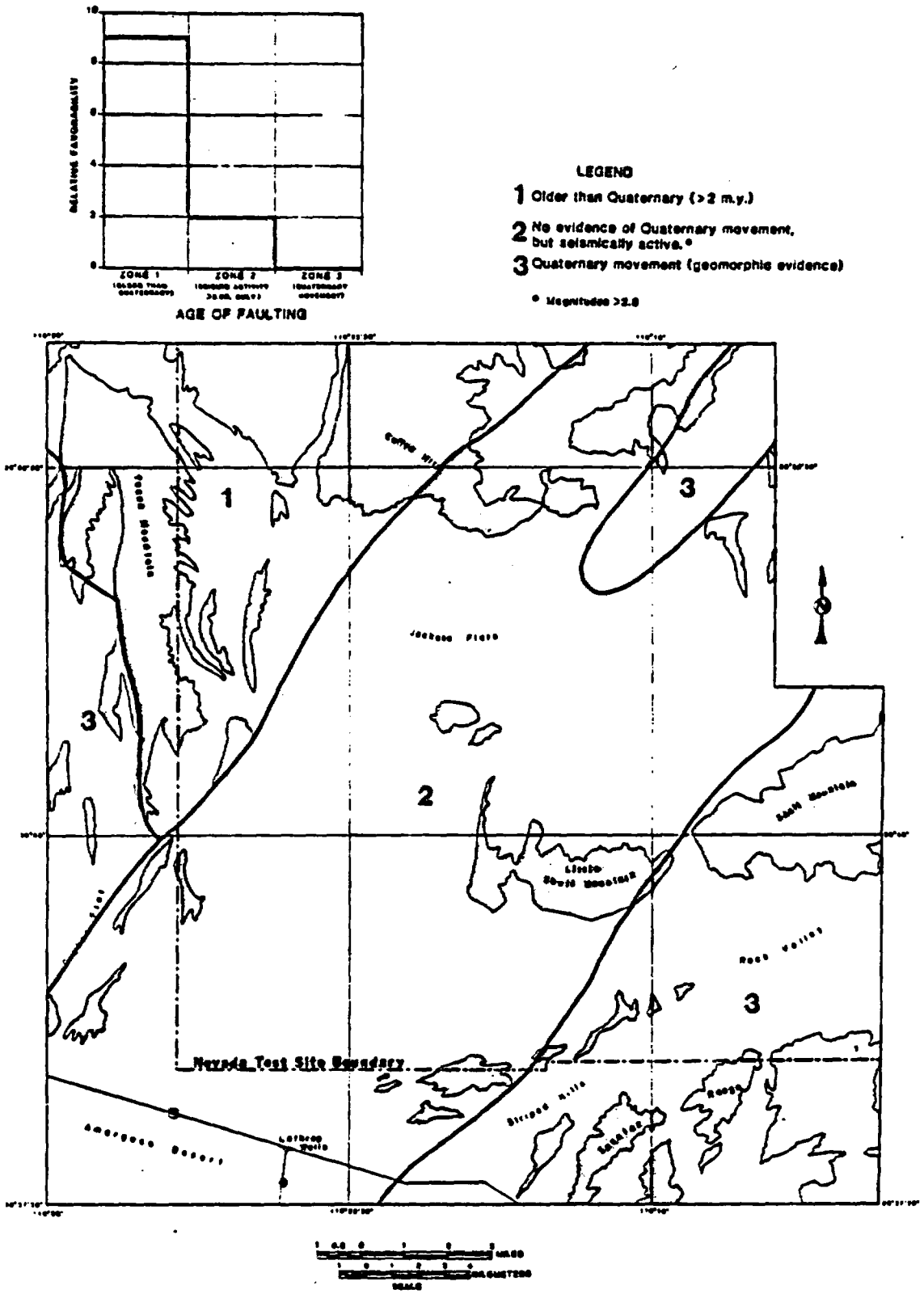

Figure 15. Map and Associated Favorability Graph for Attribute 4, Age of Faulting

Attribute 4. Age of Faulting
(Figure 15)

Compilers

Attribute Map:
W. J. Carr (USGS)
Favorability Graph:
W. J. Carr (USGS) and J. T. Neal (SNL)

Mapping Units

Three Zones of General Fault Ages

Mapping Rationale

Precise dating of fault movements generally is not possible in the screening area because of the absence of datable materials or datable events that can be related to fault displacement. Thus much interpretation and many indirect methods must be used to date fault activity, and even then only broad time periods are appropriate. Three broad time periods for fault movements are depicted on the map. Areas in which alluvium is displaced, indicating the last movement was probably in the Quaternary (Zone 3), occur in the southeast part of the screening area, particularly along the Rock Valley and Cane Spring fault zones in Crater Flat, west of Yucca Mountain, and in the northeastern part of the screening area near the Mine Mountain fault. Areas that have no evidence of Quaternary movement but that presently are seismically active with earthquakes of Richter magnitude 2 or greater (Zone 2) occur in a broad zone trending northeast through the central part of the screening area. All faults in the northwest portion of the screening area (Zone 1) are believed to have been inactive for at least the last 2 my (older than Quaternary), and seismic activity in that area is generally negligible.

Confidence Estimates

Because of the lack of datable materials and/or events in the Quaternary period in the screening area, low confidence is assigned to the map.

Basis for Favorability Graph

Age of faulting provides a measure of past tectonic activity and is an indication of the potential for future activity; hence it serves to evaluate long-term stability of a repository's tectonic environment. Areas with faults that have been inactive during the last 2 my (Zone 1) most probably will be tectonically stable during the isolation period of a repository; accordingly, they are assigned a favorability of 9. On the other hand, areas with faults of probable Quaternary age (Zone 3) have a strong possibility of continuing to be active and are rated 1 on the favorability scale. Areas presently seismically active but with no evidence of Quaternary movement (Zone 2) are assigned a favorability of 3. No degree of fault activity is considered unequivocally disqualifying; thus no zero favorability values are assigned.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.1 Minimize Potential for Seismic Hazards to Containment
2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonics

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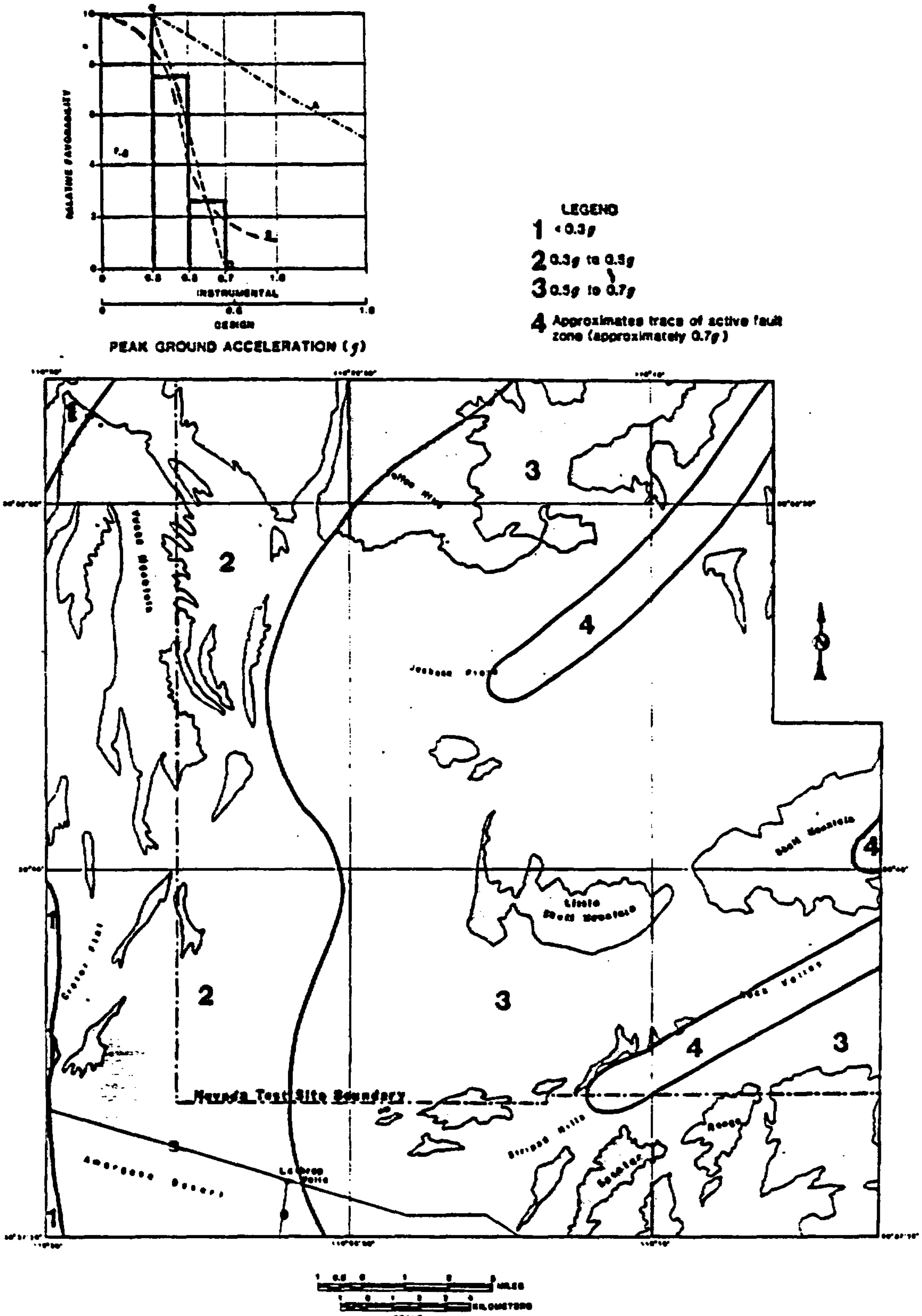

Figure 16. Map and Associated Favorability Graph for Attribute 5, Ground Motion (Natural)

Attribute 5. Ground Motion (Natural)
(Figure 16)

Compilers

Attribute Map:
J. A. Fernandez (SNL), G. N. Owen (URS/JAB), A. M. Rogers (USGS), and L. H. Wight (TERA)

Favorability Graph:
J. A. Fernandez (SNL), G. N. Owen (URS/JAB), A. M. Rogers (USGS), L. J. Vortman (SNL), and L. H. Wight (TERA)

Mapping Units

Four Zones of Expected Seismic-Induced Ground Accelerations Expressed as Percent of Acceleration due to Gravity

Mapping Rationale

Seismic motion within the screening area can be induced by natural earthquakes. Surface seismic motions will generally be stronger than those below ground. The lack of seismic data below the surface prevents quantitative assessments of ground motion at specific depths and locations. Therefore, the assumption made for screening is that surface seismic motions represent the seismic environment in general.

A deterministic analysis (Rogers et al, 1977) incorporating a map of active faults and using Schnabel and Seed's (1973) attenuation curves was used to predict the distribution of potential ground motion within the screening area. Predicted accelerations over the screening area range from 0.7 g to <0.3 g. The four zones shown on the map represent the maximum expected peak acceleration at various locations due to the independent occurrence of postulated earthquakes along fault zones represented by Zone 4. Only three of the five active faults considered in the deterministic analysis occur within the screening area—the Mine Mountain, Cane Spring, and Rock Valley faults. The arbitrary 1-mile-wide band associated with each fault (Zone 4) represents uncertainty in the exact location of the faults and associated uncertainty in maximum expected peak acceleration along the faults. Zone 3, Zone 2, and Zone 1 occur at successively farther distances from the faults occurring in Zone 4.

Confidence Estimates

The map of natural seismic accelerations is based on preliminary predictions of the maximum size of earthquakes due to fault length-magnitude relationships produced along potentially active faults. Thus, only moderate confidence is placed in the map, although the predicted accelerations are probably conservative.

Basis for Favorability Graph

Seismic motion may disturb repository operations or increase fractures and degrade hydrologic isolation. Relative favorability is taken here to be inversely proportional to the additional construction costs (surface buildings, shafts, and drifts) required to resist ground motion during the operational phase. The basis for the rationale presented here is developed in Yanev and Owen (1978). They reasoned that no additional construction costs would be incurred up to a design value of 0.3 g. Their report additionally concluded, using extremely conservative assumptions, that 30% to 35% additional costs are required to adequately resist seismic motions of 1.0 g (design) for

tunnels in tuff and granite. On an absolute scale, the following incremental cost increases for static conditions were estimated.

Static Conditions	Cost Increase
>10%	Small
>30%	Moderate
>60%	High
100%	Extremely high

The effects of seismic motion on containment and isolation after repository closure is presumed to increase with increased accelerations, and thus follows the same general trend as for effects during operational phases. Favorability values of 8, 5, 3, and 1, respectively, were assigned to the four categories of cost increases, and a straight favorability curve was drawn through those points (Line ECA) on the graph. This rationale is supported by Yanev and Owen (1978), assuming that 1.0 g (design) corresponds to 1.5 g (instrumental). A design-predicted ground acceleration (PGA) of 0.3 g would correspond to a slightly higher instrumental value. By steepening the slope at 0.3 g (instrumental) (Line ECD), conservatism is added. Line EB represents an alternative opinion about the proper shape of the favorability curve. To be consistent with the other favorability graphs, the favorability is relative and permits discrimination among discrete values of existing information corresponding to the mapping units. Since the maximum expected peak ground acceleration is mapped as 0.7 g, it was assigned a favorability of 0, using the most conservative curve (Line ECD). Following the curve to lower accelerations, mapping units of 0.7 to 0.5 g, 0.5 to 0.3 g, and <0.5 g were assigned favorabilities, respectively, of 1.5, 7.5, and 10.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.1 Minimize Potential for Seismic Hazards to Containment
2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonics
3.1.1 Minimize Seismic Hazards to Surface Facilities
3.2.1 Minimize Seismic Hazards to Subsurface Facilities

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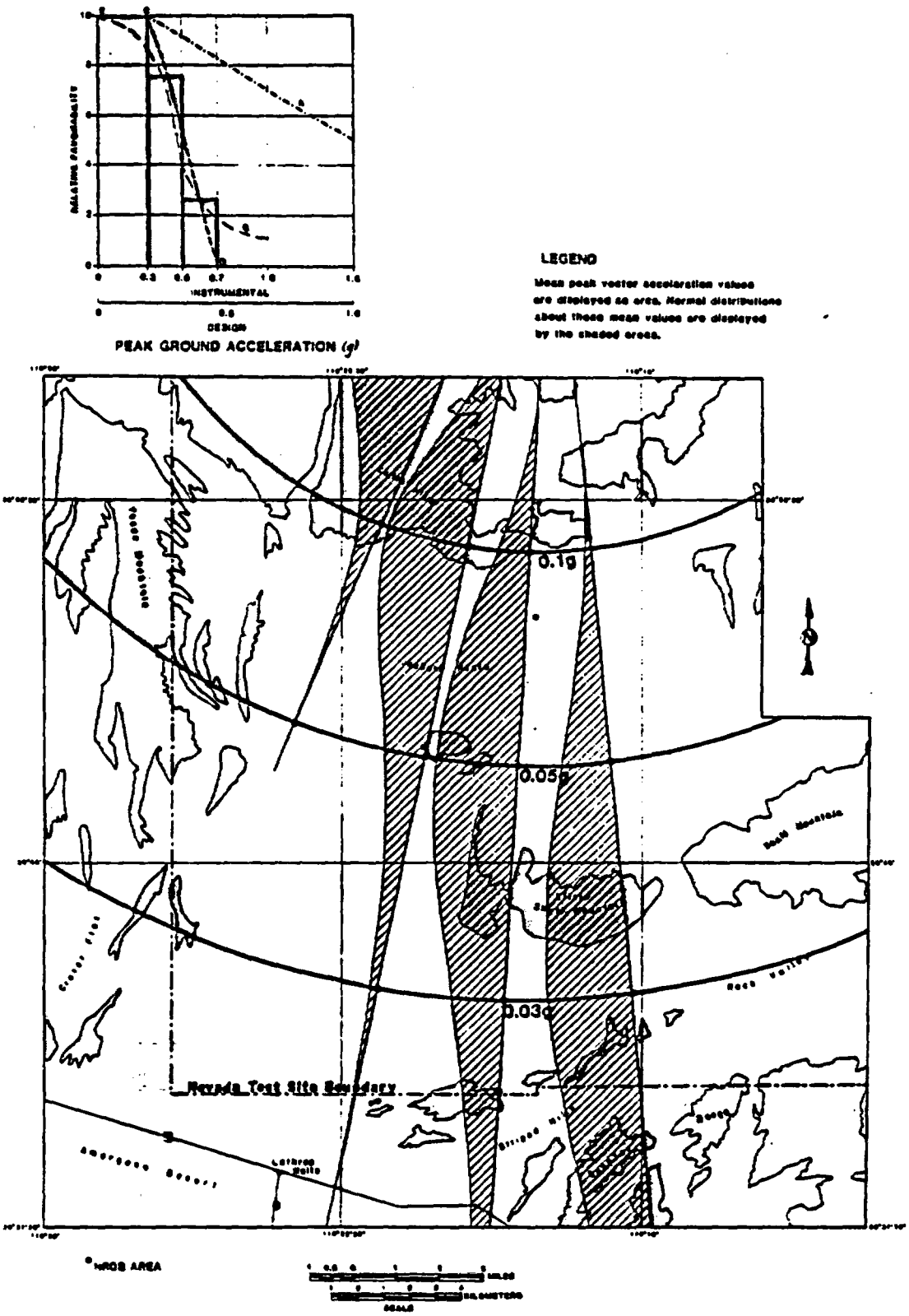

Figure 17. Map and Associated Favorability Graph for Attribute 6, Ground Motion (Weapons Induced)

Attribute 6. Ground Motion (Weapons Induced)
(Figure 17)

Compilers

Attribute Map:
L. J. Vortman (SNL)
Favorability Graph:
J. A. Fernandez (SNL), L. J. Vortman (SNL), G. N. Owen (URS/JAB), and L. H. Wight (TERA)

Mapping Units

Expected ground accelerations at each grid cell from a 0.7-megaton explosion just north of the screening area.

Mapping Rationale

Two extreme cases of nuclear explosions are assumed for screening purposes: a 1-megaton equivalent explosion in Pahute Mesa and a 0.7-megaton equivalent explosion at the southernmost usable portion of the Buckboard Mesa area. Using these hypothetical explosions and empirically derived attenuation curves from previous tests, the mean accelerations and their confidence ranges in the screening area were calculated for each grid cell. The calculated accelerations from the 0.7-megaton explosion were larger in all portions of the screening area, so this type of event was used to determine the expected accelerations. Contours for three accelerations are shown, along with probability estimates (shading) associated with each contour. Total area under the probability curves represents 1.0 probability; proportions of the shading radially inward toward the center of the contour circles represent the probability of exceeding the contoured accelerations at those distances from the explosion.

Confidence Estimates

The map of seismic accelerations from nuclear explosions is based on many measurements from many previous explosions on the NTS and is considered to have high reliability.

Basis for Favorability Graph

The graph is identical to the one for natural seismic accelerations (Attribute 5), therefore, the rationale for its construction is identical. The graph was developed independently from compilation of the two seismic maps (this attribute and Attribute 5) and was based on estimates of the favorability due to expected seismic motion, independent of its source. Therefore, weapons-induced seismic accelerations do not discriminate among alternative locations within the screening area, because all predicted accelerations are <0.3 g and thus have a favorability of 10.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.5. Minimize Potential for Miscellaneous Events Which Might Disrupt Containment
2.2.4 Minimize Potential for Adverse Impacts on Isolation Due to Human Activities
3.1.1 Minimize Seismic Hazards to Surface Facilities
3.2.1 Minimize Seismic Hazards to Subsurface Facilities

Additional Readings

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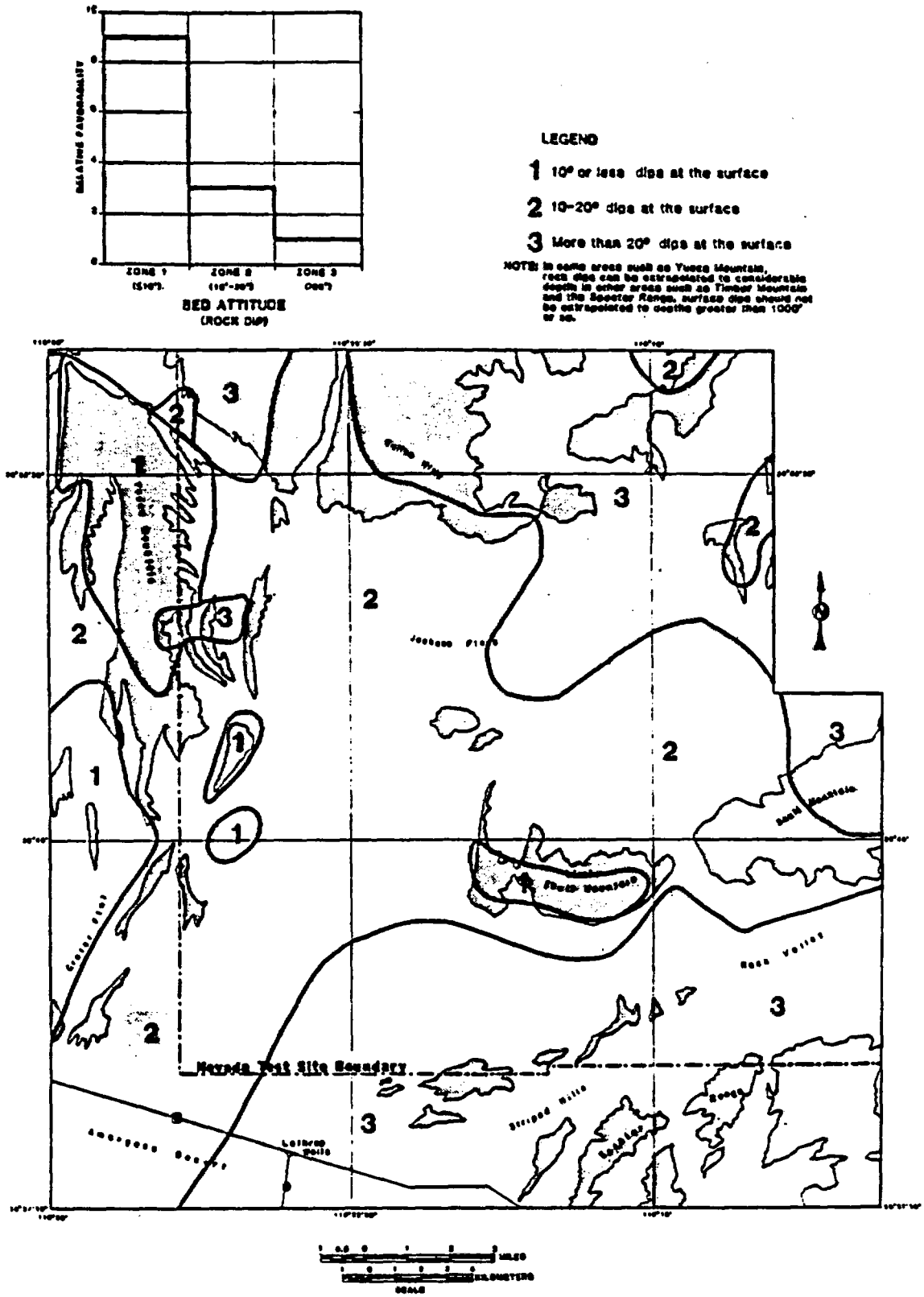

Figure 18. Map and Associated Favorability Graph for Attribute 7, Bed Attitude

Geologic-Surface Terrain Attributes

Attribute 7. Bed Attitude
(Figure 18)

Compilers

Attribute Map:
W. J. Carr (USGS)
Favorability Graph:
W. J. Carr (USGS) and J. T. Neal (SNL)

Mapping Units

Three Zones of Differing Dips of Beds at the Surface

Mapping Rationale

The three zones depicted on the map are based on the dip of rock units at the surface. Except at Yucca Mountain and Calico Hills, where there are deep drill holes, subsurface dips in the screening area can only be inferred. In the case of areas where the bedrock is covered by alluvium, the dips are inferred or extrapolated from nearby bedrock outcrops. Three zones of differing dips are shown on the map. Areas with >20° dips (Zone 3) occur in the northeastern portion, in the southern and southeastern portion, and in the northwestern portion of the screening areas, as well as in a small area on the eastern side of Yucca Mountain. Areas with 10° to 20° dips occur in alluvial-covered areas in the central and southwestern portion of the screening area. Areas with dips of 10° or less include Little Skull Mountain, Yucca Mountain, and Crater Flat.

Confidence Estimates

The bedrock outcrops have been mapped at a scale of 1:24,000, and there is high confidence in the reliability of the zones as shown. However, except for Yucca Mountain and Calico Hills, where there is deep drilling as previously noted, the confidence is poor and the bedrock dips indicate dips below depths of 500 to 1000 ft or more. For areas covered by alluvium, the confidence in the reliability of the map is poor.

Basis for Favorability Graph

The dip of rock units potentially indicates the difficulty of mining a repository. Steep dips may result in costly mining and a complex repository configuration, whereas low dips will likely result in the least cost and the simplest repository configuration. Increasing rock dips also tend to correspond to increasing geologic complexity, making confident characterization more costly. Horizontal strata obviously are optimal in terms of minability for a repository, but dips of as much as 10° probably can be used. Dips greater than 20° present substantial minability problems and probably can be used only where the repository horizon is extremely thick. Thus, dips of 10° or less (Zone 1) are assigned a favorability value of 9 and dips of >20° (Zone 3) are assigned a favorability value of 1. Dips in the range of 10° to 20° (Zone 2) are assigned a favorability value of 5. No conditions are known in the screening area that would be unequivocally disqualifying, and therefore no zero favorability value is assigned.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.2.5 Minimize Complexity of the Site
3.2.4 Optimize the Geometry of the Host Rock
3.2.5 Optimize Homogeneity of the Host Rock

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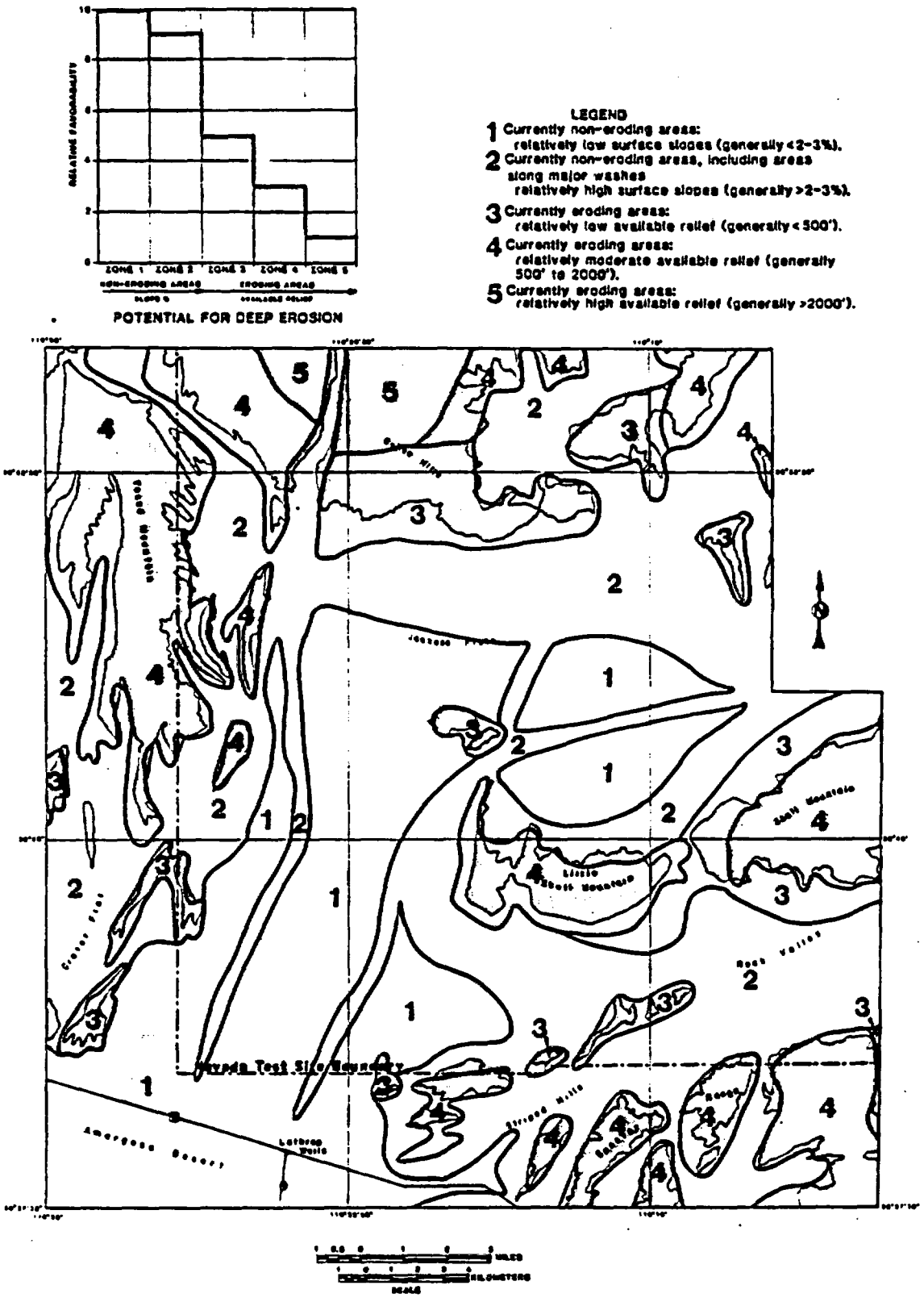

Figure 19. Map and Associated Favorability Graph for Attribute 8, Erosion Potential

Attribute 8. Erosion Potential
(Figure 19)

Compilers

Attribute Map:
S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Five Zones of Relative Erosion Potential

Mapping Rationale

The mapping units are defined as:

Zone 5 — Areas currently being eroded and high relief (>2000 ft) between ridges and nearby channels

Zone 4 — Areas currently being eroded except on some flat-topped ridges and moderate relief (500 to 2000 ft)

Zone 3 — Areas currently being eroded and low relief (<500 ft)

Zone 2 — Areas currently not being eroded but of sufficient slope (>2° to 3°) that increased runoff might cause local incision within present gullies and washes

Zone 1 — Areas currently not being eroded and not likely to be eroded even with reasonably predictable, maximum runoff

This classification is based on Glock's (1932) "available relief" concept that the gross tangent of slopes between ridgecrests and local baselevels (the heads of alluvial fans or slopes in the screening area) is a determinant of the erodability of an area. The greater the "rise" component of the tangent, the more susceptible to erosion is the volume above the "run" component of the tangent.

Confidence Estimates

The map is based on 1:24,000 scale topographic maps of the screening area from which slope maps were derived at a scale of 1:48,000. Thus there is high confidence in the reliability of the map.

Basis for Favorability Graph

The location of future erosion will be inherited from current eroding and noneroding areas. Thus the map units for erosion potential address the ability of a location to resist exhumation of repository wastes. The three currently eroding areas (Zones 5, 4, and 3) are assigned favorability values of 1, 3, and 5, respectively. The two currently noneroding areas (Zones 2 and 1) are assigned favorability values of 9 and 10, respectively, indicating that both zones are nearly equal in favorability. No conditions in the screening area are known to be unacceptable and, therefore, no zero favorability value is assigned.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.2 Minimize Potential for Erosional Disruption of Containment
2.2.3 Minimize Potential for Adverse Impacts on Isolation Due to Geomorphic Changes
3.1.3 Minimize Adverse Foundation Conditions

Additional Readings

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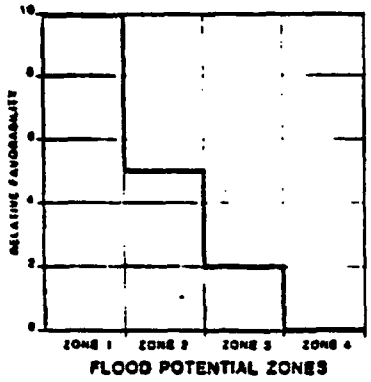

LEGEND

Actual floodways along drainage lines.

ZONE 1. Areas essentially devoid of drainage channels; Very low potential for flooding.

ZONE 2. Areas with closely spaced, small drainage channels; Flood potential limited to small proportion of the area.

ZONE 3. Areas along major washes; likely to flood less frequently or less intensely than zone 4.

ZONE 4. Areas along major washes; likely to flood more frequently or more intensely than zone 3.

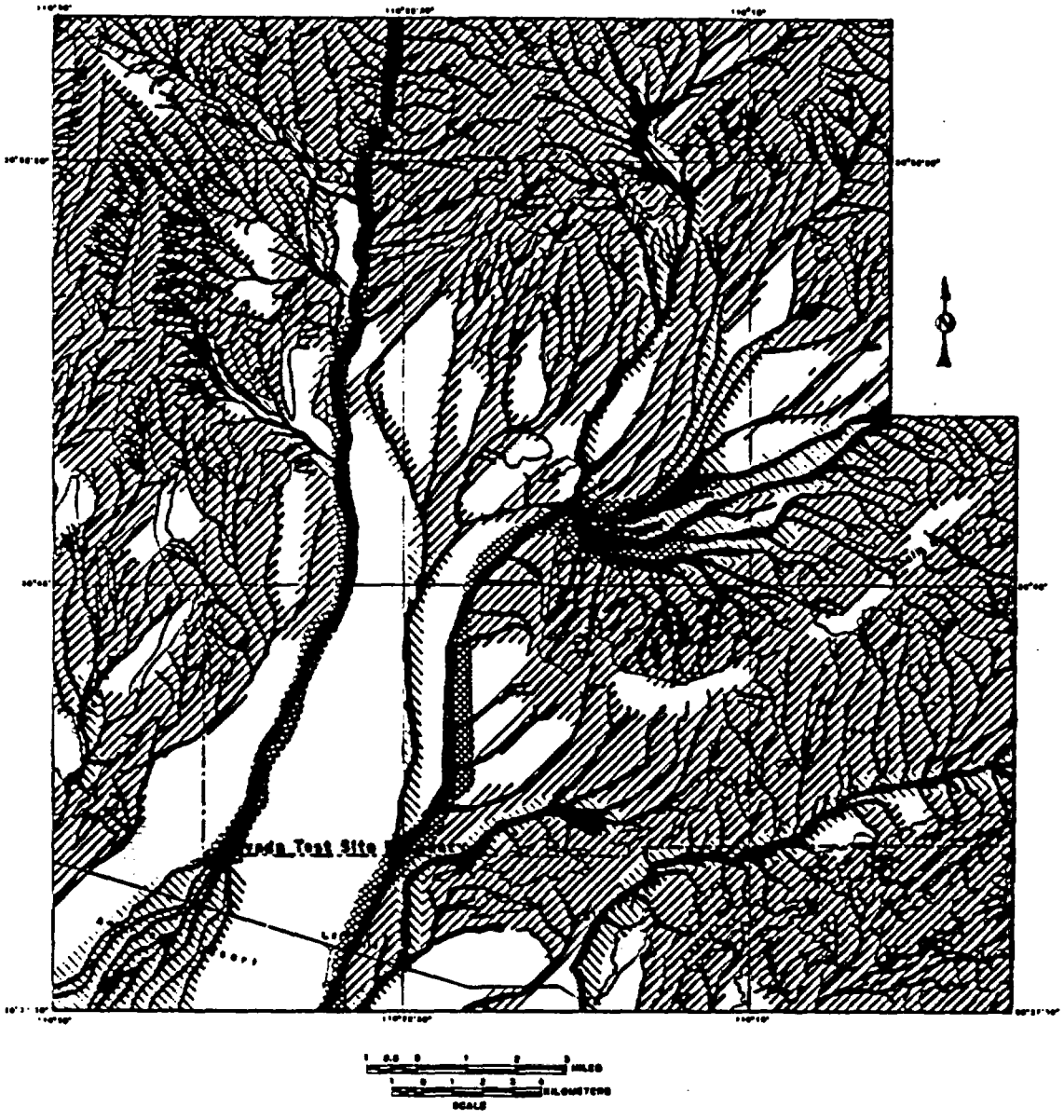

Figure 20. Map and Associated Favorability Graph for Attribute 9, Flood Potential

Attribute 9. Flood Potential
(Figure 20)

Compilers

Attribute Map:
S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Four Zones of Relative Potential for Flooding

Mapping Rationale

The mapping units are defined as:

Zone 1 — Areas essentially devoid of drainage channels and very low potential for flooding.

Zone 2 — Areas with closely spaced, small drainage channels and potential flooding limited to small portions of the area.

Zone 3 — Areas along major washes but less likely to flood with as great a magnitude or frequency as Zone 4.

Zone 4 — Areas along major washes and likely to flood more intensely and frequently than Zone 3.

The mapping units were selected on the basis of a flood potential map of Topopah Wash in Jackass Flats and concepts concerning the definition of flood areas. The four zones are based on topographic maps that show the actual ephemeral drainage channels (washes) in the screening area (black areas on the map). Due to the scale of the map, a pencil-line width often encompassed an entire wash, especially in gullies in the hills and ranges; consequently, the widths of such features were expanded to accentuate them. No perennial streams exist in the screening area.

Zone 4 corresponds to areas along the lower reaches of major washes and is likely to flood most frequently and intensely because it occurs in downstream regions where precipitation from numerous headwater areas can accumulate. The map shows the cross-hatched patterns of Zone 1 adjacent to the floodways, but this is only to designate which portions of the major floodways are included in Zone 1; i.e., Zone 1 is restricted to the floodways (solid black).

Zone 3 indicates areas within and near major washes that generally are just upstream from Zone 4 and somewhat less likely to flood as frequently or with as great a magnitude as Zone 4.

Zone 3 also includes areas where major tributaries of the main washes converge and ponding is possible.

Zone 2 comprises the largest area of the map and generally corresponds to slopes with closely spaced drainage channels in the headwater regions of the major washes. Most flooding in this zone would be confined to narrow floodways, though some overbank flow might occur in the lower portions of the zone.

Zone 1 coincides with portions of the alluvial basins where flooding of any magnitude is extremely unlikely. Areas in Zone 1 have no drainage channels of significance and have not been flooded for thousands, if not tens of thousands, of years.

Confidence Estimates

The map is based on 1:24,000 scale topographic maps of the screening area from which the four mapping units were compiled at a scale of 1:48,000. Thus there is high confidence in the reliability of the map.

Basis for Favorability Graph

Generally, flood-prone areas are to be avoided for a repository because of costs of artificially channelling water away from flood-prone areas and of mitigating the damage caused by flooding. Accordingly, Zones 1, 2, 3, and 4 are assigned relative favorabilities of 10, 5, 2, and 0, respectively. Because Zone 1 is the only one with essentially no risk from flooding, it is assigned a value of 10, whereas the other zones are all subject to some degree of flooding and are assigned values of 5 and below. A value of 0 is assigned to the zone corresponding to washes subject to frequent, large flash floods, because it is extremely imprudent to build facilities where floods are likely.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.2.3 Minimize Adverse Impacts on Isolation Due to Geomorphic Changes
3.1.3 Minimize Adverse Foundation Conditions
3.1.5 Minimize Flooding Hazards to Surface Facilities
3.2.2 Minimize Flooding Hazards to Subsurface Facilities
3.3.1 Minimize Adverse Terrain Along Potential Waste Transport Routes
4.2.1 Minimize Adverse Impacts on Natural Surface Features

Additional Readings

Christensen, R. C., and Spahr, N. E. (1980). *Flood Potential of Topopah Wash and Tributaries, Eastern Part of Jackass Flats, Nevada Test Site, Southern Nevada.* US Geol Surv Open-File Report 80-963.

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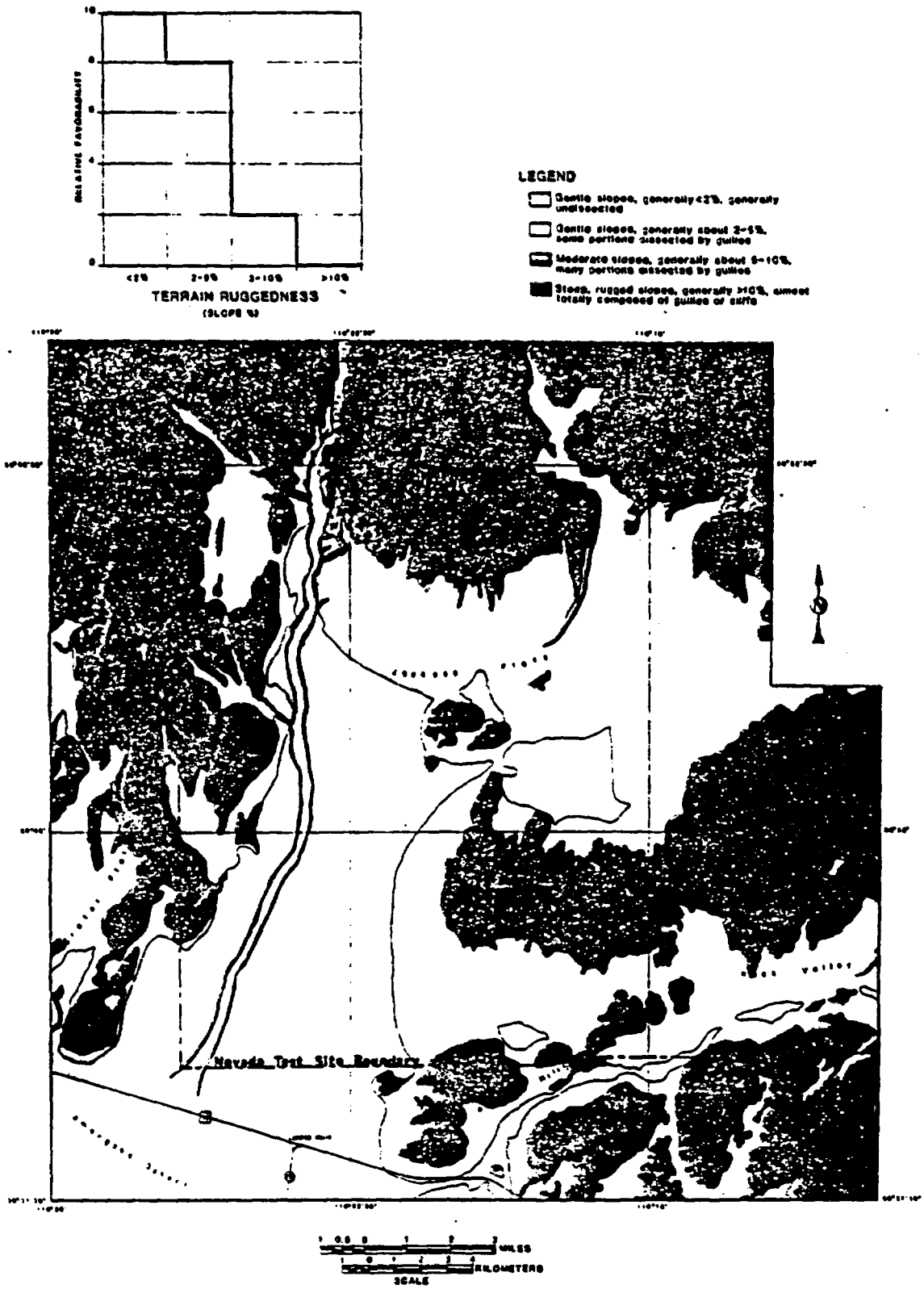

Figure 21. Map and Associated Favorability Graph for Attribute 10, Terrain Ruggedness

Attribute 10. Terrain Ruggedness
(Figure 21)

Compilers

Attribute Map:
S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Four Zones of Differing Surface Slopes

Mapping Rationale

The topographic slopes in the screening area are separated into four zones: (1) slopes less than 2%, (2) slopes in the range of 2% to 5%, (3) slopes in the range of 5% to 10%, and (4) slopes greater than 10%. These zones were mapped from the spacing of topographic contours on USGS topographic maps.

The gentle slopes in the screening area (Zones 1 and 2) occur only on alluvial areas, whereas the moderate and steep slopes (Zones 3 and 4) occur in the bedrock hills and ranges and on the upper reaches of alluvial fans flanking bedrock hills and ranges.

Confidence Estimates

The map is based on a 1:48,000 scale topographic map compiled from USGS topographic maps of the screening area at a scale of 1:24,000. Because of the small scale of the map, some areas of greater or lesser slope may be included within any given mapped slope unit. Such areas are <0.2 miles on a side. Thus there is high confidence in the reliability of the map, with the caveat noted above that because of scale considerations some small areas may be improperly included in a mapping unit.

Basis for Favorability Graph

Topographic slope affects construction costs of surface facilities for a repository and feasibility and costs of transportation of materials to a repository. Gentle slopes (Zones 1 and 2) are much more favorable than moderate (Zone 3) and steep (Zone 4) slopes. The slope ranges selected (Zones 1 to 4) are useful for evaluating construction and transportation difficulties (Hoover, Eckel, and Ohl, 1978). Slopes of >5% make rail access very difficult and greatly increase accident risks for highway transportation. Slopes of <5% generally are amenable to transportation and relatively simple construction designs for surface facilities. Therefore, a large difference in favorability is assigned to slopes of <5% or >5%:

Slope	Favorability Value
<2%	10
2% to 5%	8
5% to 10%	2
>10%	0

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.2.3 Minimize Potential for Adverse Impacts on Isolation Due to Geomorphic Changes
2.2.5 Minimize Complexity for Site Characterization
3.1.2 Minimize Surface Monitoring Costs
3.1.3 Minimize Adverse Foundation Conditions
3.3.1 Minimize Adverse Terrain Along Transportation Corridors
4.2.1 Minimize Impacts of Surface Geologic Features

Additional Readings

Hoover, D. L., Eckel, E. B., and Ohl, J. P. (1978). *Potential Sites for a Spent Unreprocessed Fuel Facility (SURFF), Southwestern Part of the Nevada Test Site.* US Geol Surv Open-File Report 78-269.

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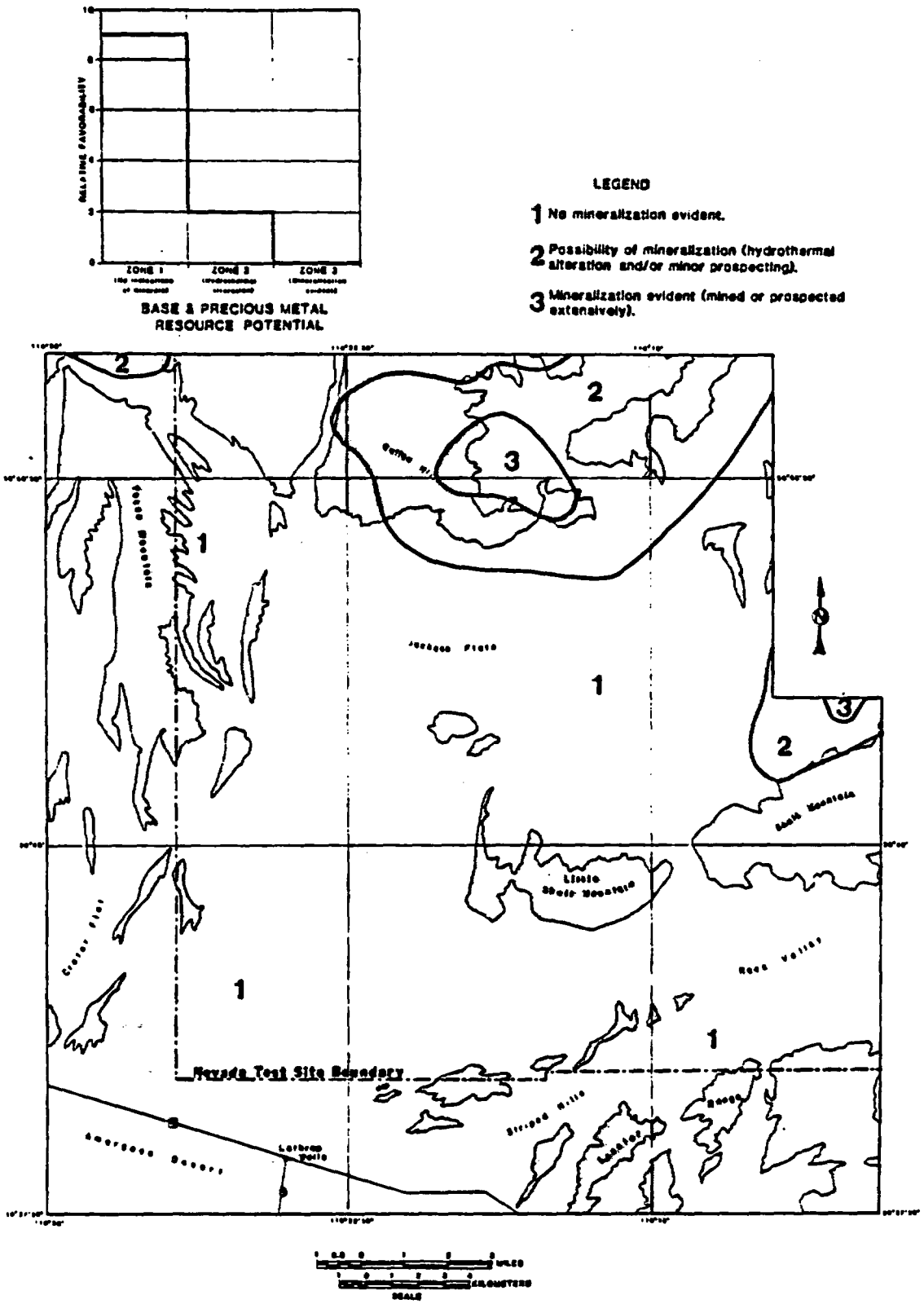

Figure 22. Map and Associated Favorability Graph for Attribute 11, Metal and Energy Resource Potential

Attribute 11. Base and Precious Metal Resource Potential
(Figure 22)

Compilers

Attribute Map:
W. J. Carr and F. Maldonado (USGS)
Favorability Graph:
W. J. Carr (USGS) and J. T. Neal (SNL)

Mapping Units

Three Zones of Potential for Developing Mines for Metallic Resources

Mapping Rationale

The three zones are based on areas where minerals exist in unusual concentrations or quantities at easily accessible depths, or where surface indications suggest a reasonable possibility of resources at depth. Surface indicators include hydrothermally altered zones and areas that have previously been prospected or mined. Accordingly, the following zones are mapped on the basis of relative potential for future extraction.

- Areas with no indication of valuable minerals.
- Areas where hydrothermal alteration and/or minor prospecting activities suggest the possibility of mineralization.
- Areas mined or prospected extensively.

Confidence Estimates

The prospect pits and hydrothermal zones are based on 1:24,000 scale geologic maps of the screening area, and there is moderate confidence in the mapped zones as indicators of mineral development potential.

Basis for Favorability Graph

Avoiding areas with potential for mining will reduce the potential for human intrusion. Areas of previous mining (Zone 3) are potentially disqualifying (favorability of 0) because regulatory guidance (Draft 10 CFR 60,) indicates high undesirability of areas where future human intrusion is likely. The intermediate zone (Zone 2) is adjacent to near-potentially economic deposits and may also have hydrothermal minerals suitable for extraction. It is assigned a favorability of 3. Areas in which no known economic resources occur (Zone 1) are assigned a favorability of 8 to allow for some uncertainty.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.4 Minimize Potential for Inadvertent Human Intrusion of a Repository
2.2.4 Minimize Potential for Adverse Impacts on Isolation Due to Human Activities
3.2.5 Optimize Host-Rock Homogeneity

Additional Readings

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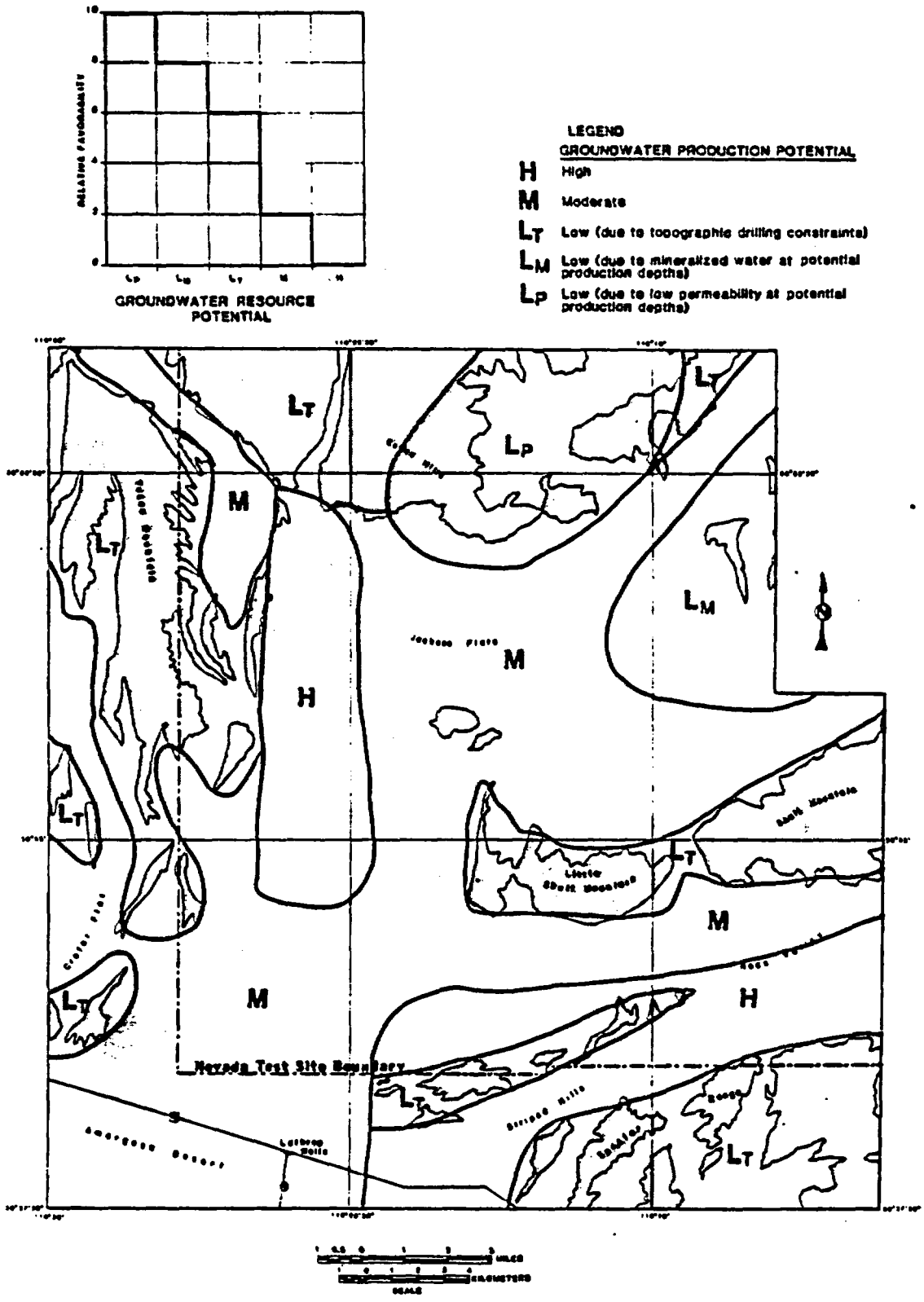

Figure 23. Map and Associated Favorability Graph for Attribute 12, Groundwater Resources

Hydrologic Attributes

Attribute 12. Groundwater Resources
(Figure 23)

Compilers

Attribute Map:
W. Wilson (USGS) and R. Waddell (USGS)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Zones of Groundwater Production Potential

Mapping Rationale

The potential for being able to develop groundwater resources in the screening area is separated into five classes based on access, probable water quality, and probable yield:

- H High, due to easy access and potential for relatively large water yields
- M Moderate, due to access and potential for relatively moderate water yields
- L_T Low, due to limited access because of rugged topography
- L_M Low, due to potentially poor water quality because of highly mineralized water (sulphate, carbonate, etc)
- L_P Low, due to potentially low water yields because of low permeability

The map delineates 13 separate zones, based on these classes.

An H zone occurs along Fortymile Wash, where wells J-12 and J-13 yield large amounts (up to 100,000 gallons per day per foot of drawdown) of water from the Topopah Spring Member of the Paintbrush Tuff. High yields in this zone may be caused in large part by fractures along a possible north-south structural lineament parallel to Fortymile Wash. The other H zone occurs in the southeast portion of the screening area where Paleozoic carbonates comprise the regional aquifer (Winograd and Thordarson, 1975). The two M zones generally occur where unsaturated alluvium obscures underlying rocks, but where welded tuff or rhyolite are thought to occur at saturated depths. These latter two rock types tend to be fractured sufficiently, even outside structurally controlled fracture zones, to provide moderate yields, as, e.g., from well J-11 in Jackass Flats (20,000 to 30,000 gpd/ft). The only difference between the H zone along Fortymile Wash and the M zones is the inferred effect of the structural lineament along Fortymile Wash. Because no compelling evidence is available to establish the location of other structurally controlled, densely fractured zones in the saturated welded tuffs or rhyolites, it is assumed that water yields throughout the M zone will be similar to those observed from well J-11. L_T zones generally occur where surface slopes are >10% and drilling would be difficult. The L_M zone occurs in the northeastern portion of the screening area where rock alteration around the Wahmonie-Salyer volcanic center is observed at the surface. It is assumed that this alteration has affected water quality by providing a source of abundant soluble minerals. A spring deposit composed of gypsum in this zone indicates poor water quality with a high sulphate content in that area. Though water yields in L_T and L_M zones may be relatively moderate or even high, terrain factors and possible poor water quality, respectively, make them unattractive for development as water supply sources. The L_P zone in the Calico Hills-Topopah Wash area is due to the presence of low permeability rocks of the Eleana Argillite. Yields from the rock would be extremely low (1 to 500 gpd/ft); thus development of water supplies from them is not feasible.

Confidence Estimates

The map is based on test-well data as of the summer of 1981 from five wells, widely distributed in Jackass Flats, Calico Hills, and Yucca Mountain; and

from regional hydrologic studies, computer models, characteristics of spring deposits, and interpretation of topographic and geologic conditions. Because of the paucity of test wells, the reliability of the map is judged to be low to moderate.

Basis for Favorability Graph

For repository concerns, future drilling for water supplies is important in two ways: (1) drilling could penetrate a repository, and (2) drilling could result in a production well that either would be considered the accessible environment or might accelerate flow rates toward the accessible environment. The greater the potential for groundwater production, the greater is the likelihood that drilling and production will occur. Accordingly, the zones of low potential for groundwater production were assigned high favorability values and the moderate and high potential areas were assigned lower values. The largest difference in relative favorability was assigned to the transition from low to moderate potential. The three low potential zones were assigned a linear relationship to favorability at the upper end of the favorability scale. The moderate and high potential areas were assigned a similar linear relationship at the low end of the favorability scale. Accordingly, relative favorabilities of 10, 8, 6, 2, and 0 were assigned to low potential due to permeability, water quality, and topography, moderate potential, and high potential, respectively.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.2.4 Minimize Potential for Inadvertent Human Intrusion of a Repository
2.2.4 Minimize Potential for Adverse Impacts on Isolation Due to Human Activities
4.2.2 Minimize Impacts on Water Quality and Availability

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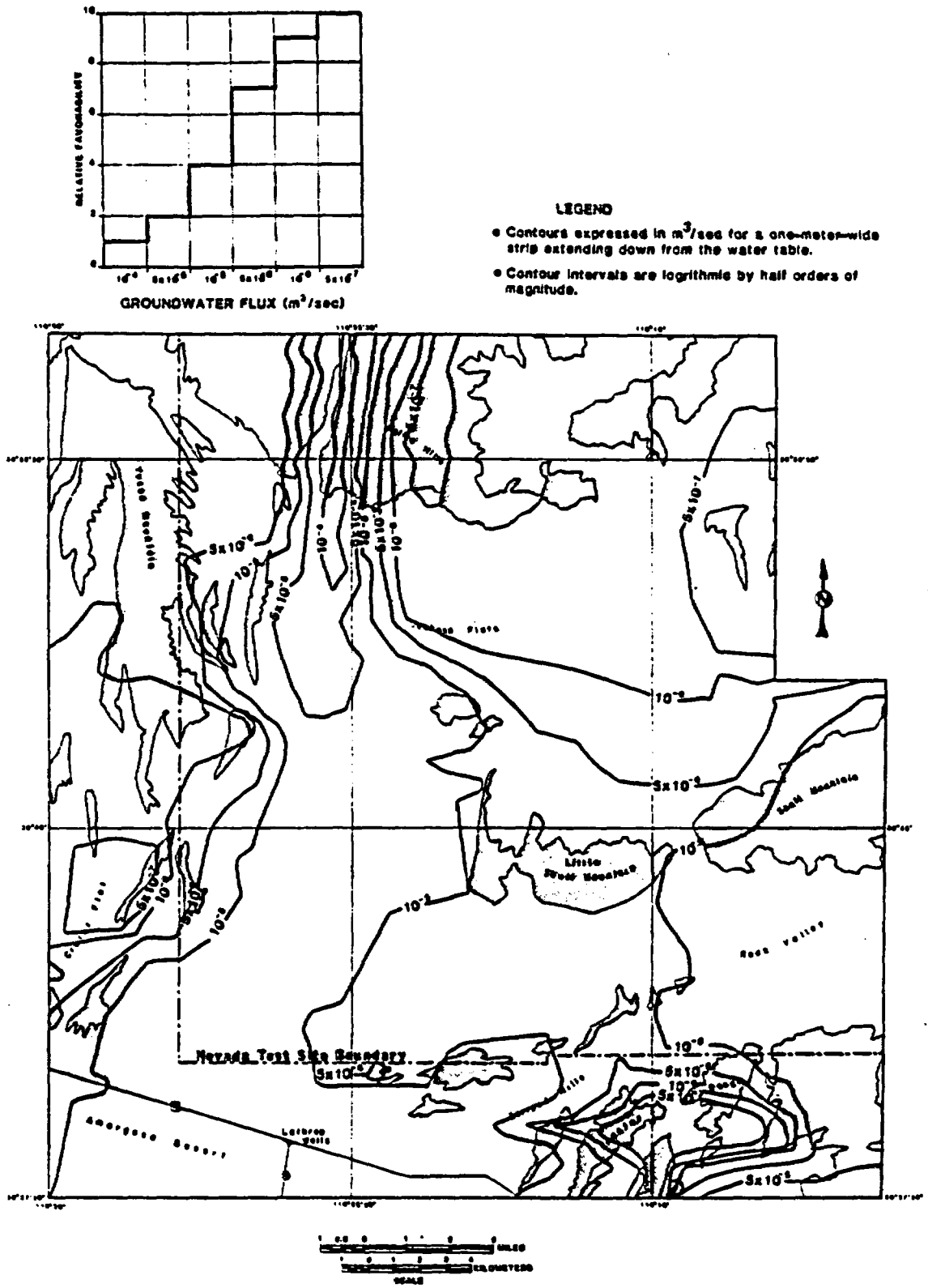

Figure 24. Map and Associated Favorability Graph for Attribute 13, Groundwater Flux

Attribute 13. Groundwater Flux
(Figure 24)

Compilers

Attribute Map:
R. Waddell (USGS)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Logarithmically Defined Zones of the Volume of Groundwater Flux Expressed in m^3/s.

Mapping Rationale

The map zones are separated by contours of flux expressed in m^3/s. The values of the contours are 5×10^{-7}, 1×10^{-6}, 5×10^{-6}, 1×10^{-5}, 5×10^{-5}, and 1×10^{-4}.

The dimension of m^3/s refers to the volume of groundwater per second moving through a 1-m-wide strip of saturated aquifer. An early version of a two-dimensional, finite element groundwater flow model developed by the USGS is the source of flux data (Waddell, 1982). Because the model is two-dimensional (x and y geographic coordinates), no information was available about the depth intervals or aquifer characteristics through which the flux occurs. Accordingly, flux represents all groundwater flowing in a 1-m-wide strip extending downward from the top of the saturated zone. USGS provided the flux data to SNL for several hundred model-grid nodes that are in and immediately surrounding the screening area. SNL contoured the data on an APPLICON Graphics System at one-half order of base 10 magnitude (logrithmic) units.

Confidence Estimates

The flux values were calculated from values of recharge, discharge, and transmissivity assigned as input parameters to the model. The calculated flux has been shown by sensitivity analysis to be particularly sensitive to the amount of recharge at Pahute Mesa north of the screening area, to the transmissivity and location of low permeability Eleana argillite, and to the transmissivity of highly permeable rocks beneath Fortymile Canyon and Fortymile Wash (Iman et al, 1980). Due to observable and partially measurable discharge at springs and seeps, which comprise the only discharge points for the groundwater basin, discharge estimates are probably as well known as for any groundwater basins. Because very little test-well data is available on transmissivities within the screening area, because recharge can only be estimated, and because the depth intervals, number, and characteristics of the aquifers are unknown, the reliability of the map is judged to be low.

Basis for Favorability Graph

The volume of groundwater flow near a repository is important for two basic reasons: (1) the amount of water available to contact emplaced wastes will influence the amount of waste that can be dissolved as a function of solubilities of waste components, and (2) flux influences groundwater velocities and flow times to the accessible environment. For both reasons, higher fluxes are less desirable. Accordingly, flux values of 5×10^{-7}, 10^{-6}, 5×10^{-6}, 10^{-5}, and 10^{-4} were assigned favorabilities of 10, 9, 7, 4, 2, and 1, respectively. At low flux magnitudes, the difference in favorability is not great because so little water is available; similarly, at high orders of magnitude, so much water is available that differences in favorability are small. But in the range from very low to high flux, the sensitivity to change is greatest.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.1 Minimize Potential for Chemically Induced Release

2.1.1 Maximize Groundwater Flow Time to the Accessible Environment
2.1.2 Maximize Retardation of Radionuclides Along Flow Paths
3.2.2 Minimize Flooding Hazards to Subsurface Facilities

Additional Readings

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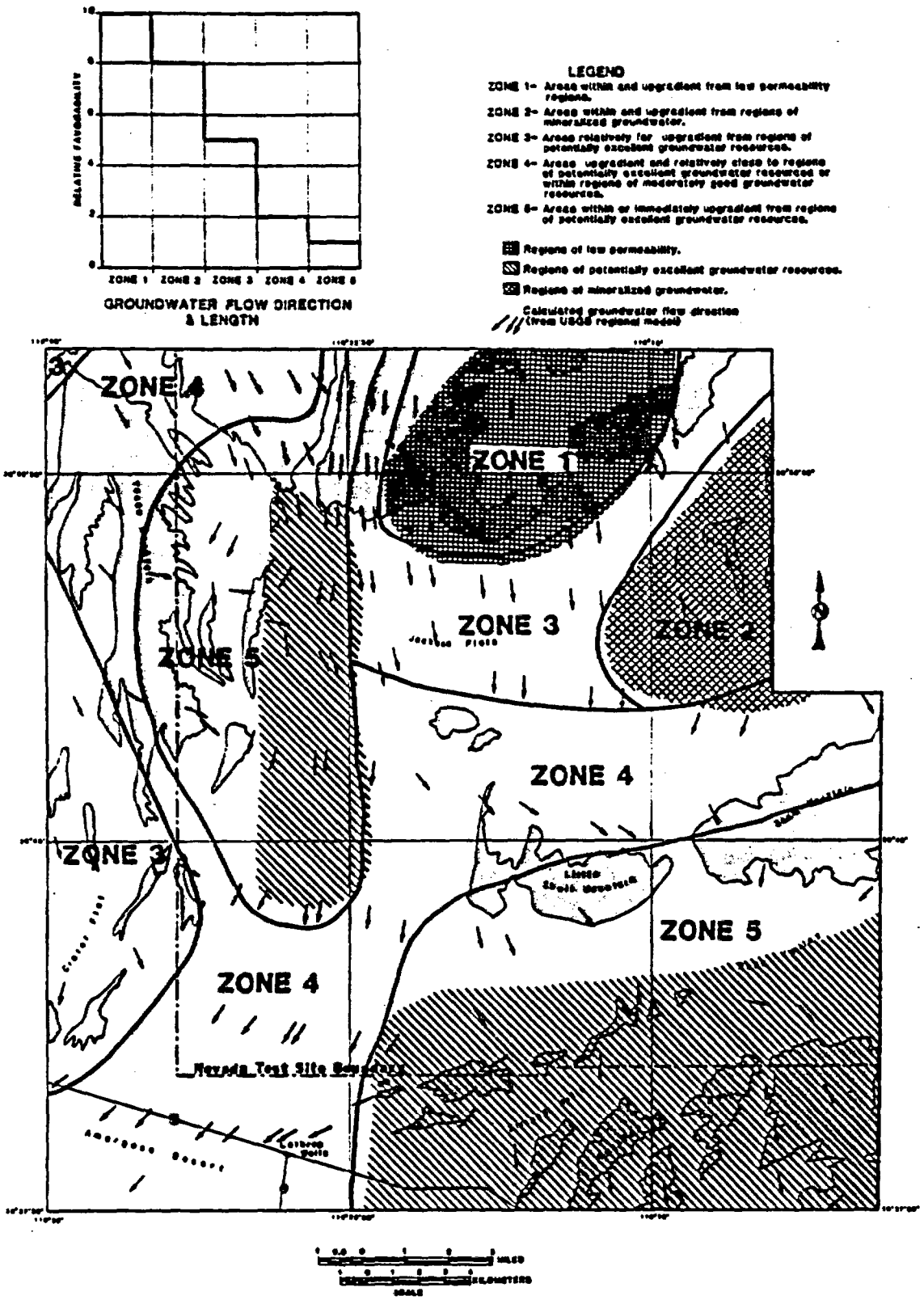

Figure 25. Map and Associated Favorability Graph for Attribute 14, Groundwater Flow Direction and Length

Attribute 14. Groundwater Flow Direction and Length
(Figure 25)

Compilers

Attribute Map:
S. Sinnock (SNL) and R. Waddell (USGS)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Zones of Flow Direction and General Length Toward Areas Potentially Considered to be the Accessible Environment

Mapping Rationale

This attribute represents an attempt to classify flow time to the accessible environment. The units mapped are

Zone 1—Areas within and a short distance upgradient from low permeability zones with little or no potential for groundwater use

Zone 2—Areas within and a short distance upgradient from places where groundwater is generally mineralized and therefore has limited potential for human use

Zone 3—Areas of moderate potential for groundwater use which occur relatively far upgradient from zones of high groundwater use potential

Zone 4—Areas upgradient and relatively close to zones of high potential for groundwater use

Zone 5—Areas within and immediately upgradient from zones of high potential for groundwater use

Flow direction (arrows on Figure 25) was calculated by an early version of a USGS regional groundwater model (Waddell, 1982). The regions of potential groundwater use (shading on Figure 25) were taken directly from Attribute 12.

Because direct estimates of flow time to the accessible environment depend on accurate knowledge of flow geometry as well as on an unambiguous definition of "accessible environment," neither of which was available at the time the map was compiled, the mapping units were selected to approximate both flow geometry and the possible locations of areas that might be considered accessible environments. The velocity of groundwater flow was assumed to be nearly constant throughout the screening area. Flow directions were calculated from EW and NS components of the hydraulic gradient, assuming isotropic media, at each node of the USGS regional flow model. Flow direction arrows were plotted for the screening area on an APPLICON Graphics System at SNL based on the gradient components provided by the USGS. The arrows were not scaled for velocity because insufficient data were available for hydraulic conductivity, effective porosity and aquifer geometry. The flow direction arrows were superposed on an Attribute 12 map showing regions of high and low groundwater use potential. The mapping zones were then delineated by interpretation of the length of flow to areas of high potential for groundwater use, i.e., to areas that might reasonably be classified as the accessible environment, and to areas of low potential for groundwater use, i.e., areas that would not reasonably be considered the accessible environment.

Confidence Estimates

The reliability of the map depends on the accuracy of the flow direction arrows, the velocity of flow at each vector, and the degree to which the groundwater resources map (Attribute 12) approximates categories of accessibility for human use. The accuracy of flow arrows depends, in turn, on the same factors discussed for the Attribute 12 map. The velocity at each model node is unknown, as is the variation of velocity with depth. Whether the Attribute 12 map expresses accessibility for human use depends on the limitations discussed for Attribute 12 as well as regulatory philosophy concerning "accessibility." Because this philosophy was still largely undefined at the time the map was compiled, it was assumed that the greater the potential for human use, the greater is "accessibility." For the above reasons, low confidence is placed in this attribute map as a measure of flow time to the accessible environment.

Basis for Favorability Graph

Because the units express a general measure of potential groundwater flow time to the accessible environment, areas farther from the accessible environment are favored over areas that are closer. Accordingly, Zones 1, 2, 3, 4, and 5 were assigned relative favorabilities of 10, 8, 5, 2, and 1, respectively. The favorabilities are based on the assumption that areas with higher potential for groundwater use are more likely to be considered the accessible environment.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.1.1 Maximize Groundwater Flow Time to the Accessible Environment

Additional Readings

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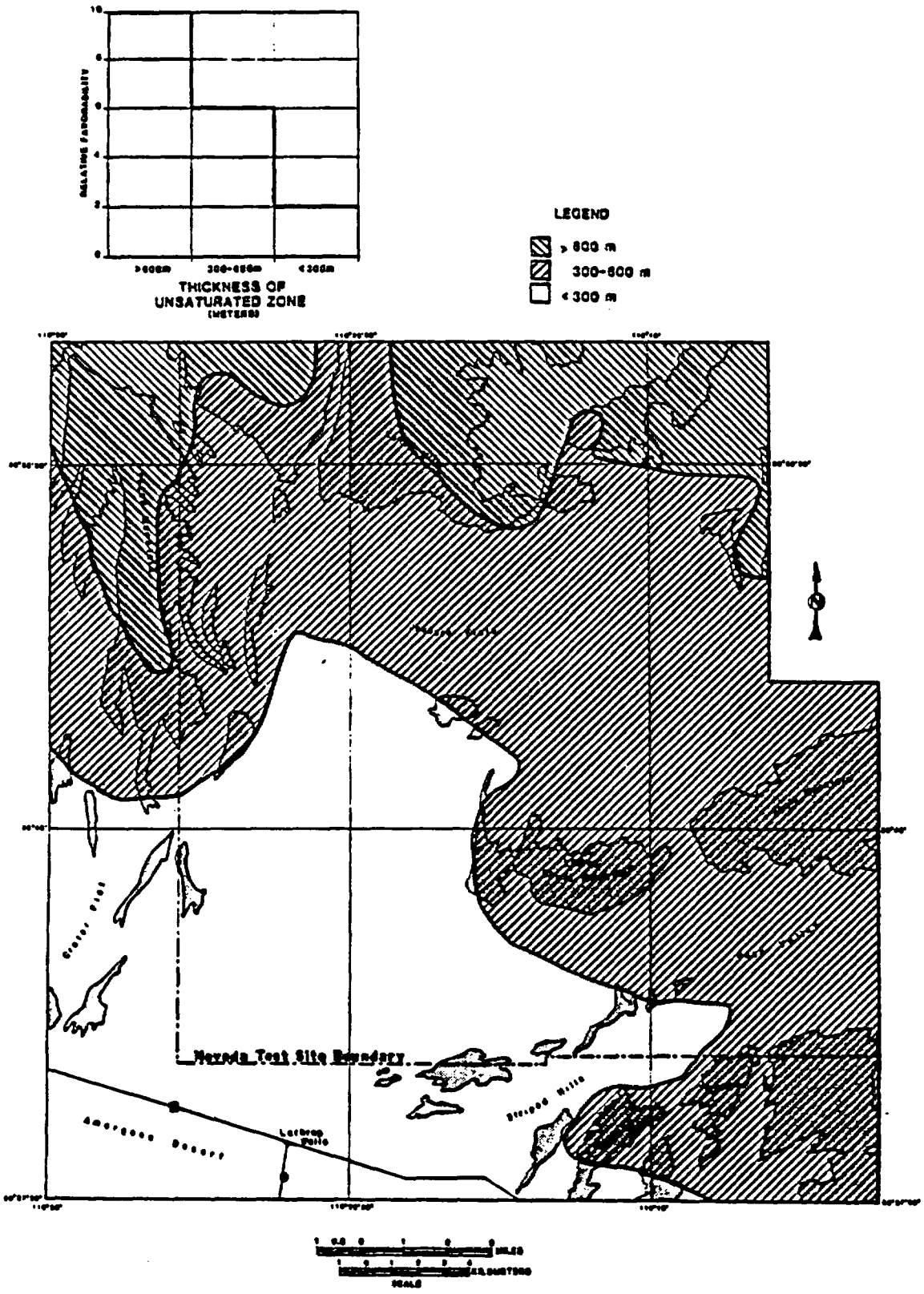

Figure 26. Map and Associated Favorability Graph for Attribute 15, Thickness of Unsaturated Zone

Attribute 15. Thickness of Unsaturated Zone
(Figure 26)

Compilers

Attribute Map:
R. Waddell (USGS) and W. Wilson (USGS)
Favorability Graph:
S. Sinnock (SNL)

Mapping Units

Zones of Differing Thickness of the Unsaturated Zone

Mapping Rationale

The units mapped are

Zone 1 = >600 m
Zone 2 = 300–600 m
Zone 3 = <300 m

The geographical boundaries of the mapping units were based on estimated water table and surface elevations. Water table elevations were manually contoured based on known elevations from existing wells and interpretation, extrapolation, and interpolation. Surface elevations were obtained from published topographic maps. The elevations along the water table contours were subtracted from the elevations of topographic contours where they intersected. The resulting data points of elevation differences were manually contoured to produce a contour map of the depth to the water table. The resulting irregular contours, due primarily to topographic conditions, were manually smoothed to produce the attribute map.

Confidence Estimates

The reliability of the map depends on the accuracy of the original contours of water table and surface elevations. Surface elevations were accurately known from published topographic maps. In the screening area, the water table elevations were based on measured water composite levels in USW-G1, USW-H1, Ue25a#1, Ue25a#3, J11, J12, J13, and HTW-6. Consequently, near these wells the reliability of the map is high; for most of the screening area, however, the reliability is low.

Basis for Favorability Graph

The depth to the water table provides a means for estimating (1) the thickness of rock available for siting in the unsaturated zone and (2) the thickness of a hydraulic buffer between the surface and a repository across which water cannot flow upward (discounting convective flow due to heat from a repository in unsaturated rocks). Generally, the thicker the unsaturated zone, the more favorable is a location. Accordingly, the three mapping units of >600 m, 300–600 m, and <300 m were scaled in a linear fashion to relative favorabilities of, respectively, 10, 6, and 2. A low favorability value of 2 was selected, rather than some lesser value, because even a location with a very thin unsaturated zone may be quite acceptable for a repository.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.1.1 Maximize Groundwater Flow Time to the Accessible Environment
2.2.2 Minimize Potential for Adverse Impacts Due to Climatic Changes
3.2.2 Minimize Flooding Hazards to Subsurface Facilities
3.2.3 Minimize Adverse Mining Conditions

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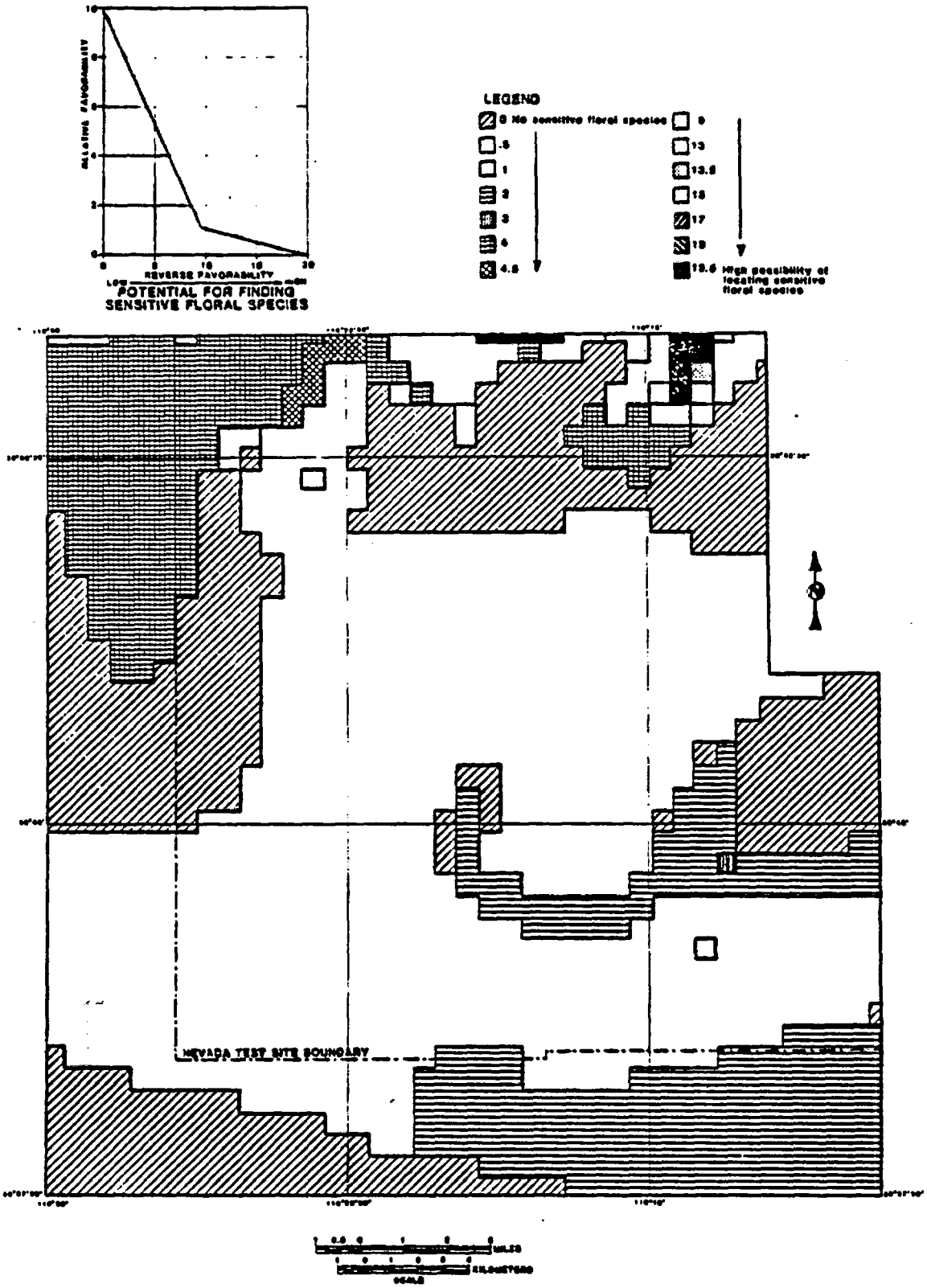


Figure 27. Map and Associated Favorability Graph for Attribute 16, Sensitive Floral Species

Environmental Attributes

Attribute 16. Sensitive Floral Species
(Figure 27)

Compilers

Attribute Map:
W. A. Rhoads and Elizabeth Collins (EG&G)
Favorability Graph:
J. A. Fernandez (SNL)

Mapping Units

Twenty Units of Relative Potential for Finding Sensitive Species

Mapping Rationale

The area boundaries of known and suspected sensitive floral species are based primarily on topographic contours. The boundaries often encompass an appropriate range of elevation for each floral species. The maps of individual species show the possible distribution and known occurrences of species populations (Figures 28–30). The known occurrences are based on knowledge available as of the summer of 1981. Subsequent surveys have shown some of these maps to be too restrictive. Sensitive species are defined to be taxa which have one of the following characteristics:

- Potentially threatened or potentially endangered; rare (likely to exist in small or dwindling numbers in one or a few populations); or infrequently encountered (thinly dispersed over the local area) so that governmental protection is under consideration, eminent, or in place
- Valuable for commercial or recreational purposes and therefore under governmental management
- Of scientific or aesthetic value

The rationale for the mapping of each floral species is provided below:

- *Lathyrus hitchcockianus* (Mojave Sweetpea) (Figure 28)—The lower elevation range of possible distribution roughly corresponds to *Coleogyne* and *Artemisia* vegetation at 5,000 ft. The preferred habitat is in gravelly washes where water collects between 5,000 and 6,000 ft. A recent survey in the vicinity of Yucca Mountain concluded that (a) the known population of *L. hitchcockianus* was located at an elevation of 5,600 ft; (b) its possible distribution was smaller than originally reported; and (c) *L. hitchcockianus* "requires a substantial, high elevation, recharge area to ensure adequate moisture in its wash habitat" (Collins et al, 1981).
- *Astragalus funereus* (Funeral Milk-Vetch) (Figure 28)—The possible distribution roughly corresponds to *Coleogyne* and *Artemisia*, and *Artemisia*-Pinyon-Juniper vegetation from 3,500 to 7,500 ft. The zone of highest confidence is 4,500 to 5,000 ft on steep slopes with loose gravelly volcanic substrate.
- *Sclerocactus polyancistrus* (Mojave Fishhook) (Figure 28)—The possible distribution corresponds roughly to *Artemisia*-Pinyon-Juniper vegetation between 5,500 and 7,500 ft. It grows in open areas on gravelly slopes and near flat rocks of igneous origin.
- *Arctomecon merriamii* (Bear Poppy) (Figure 28)—The preferred habitat is dolomitic or limestone outcrops on steep ranges from 2,500 to 4,000 ft in fairly level patches of shallow, gavelly soil among flat rock masses. The zone of highest confidence is from 3,000 to 4,000 ft in *Larrea-Atriplex* vegetation.
- *Phacelia beatleyae* (Beatley's Scorpion Weed) (Figure 29)—The possible distribution encompasses Skull and Little Skull Mountains between 4,000 and 5,000 ft. Plants are scattered in small localized populations on steep south- and west-facing slopes and washes in loose light-colored volcanic tuff.
- *Penstemon pahutensis* (Pahute Beardtongue) (Figure 29)—The possible distribution corresponds roughly to *Artemisia*-Pinyon-Juniper vegetation from 5,000 to 7,500 ft. The species is

not restricted to any soil type or exposure, though in undisturbed areas the species is found primarily in open areas on loose soil, or in rocky areas among boulders or in crevices.

- *Trifolium andersonii* ssp. *beatleyae* (Beatley's Five Leaf Clover) (Figure 29)—The possible distribution corresponds roughly to *Artemisia*-Pinyon-Juniper vegetation from 5,500 to 7,500 ft. Stream beds and bright-colored tuffaceous gravel on low hills are the preferred habitats.
- *Phacelia parishii* (Parish's Scorpion Weed) (Figure 29)—This species occurs at low elevation in flat areas of light-colored calcareous sandstone or siltstone knolls derived from Rocks of Pavits Spring and the Horse Spring Formation. The lower limit of the possible distribution line corresponds to the 4,000 ft contour and encompasses *Larrea-Ambrosia* vegetation.
- *Gilia nyensis* (Nye County Gilia) (Figure 30)—This species is found over a wide elevation range—from 2,500 to 8,000—but is restricted to deep, loose volcanic sands in flat areas and on moderate slopes. It is usually found in open spaces among shrubs. The possible distribution was restricted to the region around Fortymile Wash, which more accurately defines the optimal habitat.
- *Perityle megalocephala* var. *intricata* (no common name) (Figure 30)—This species is generally restricted to limestone and dolomitic ranges. The zone of highest confidence is on slopes from 3,500 to 4,500 ft. Populations are most dense on steep slopes, cliff faces above washes, and along the tops of ridges.

Confidence Estimates

The screening area was reconnoitered by field surveys; there is a moderate level of confidence in the maps of individual species (Figures 28–30) and, therefore, in the composite map (Figure 27).

Basis for Favorability Graph

The ten floral species were ranked for importance based primarily on rarity. A ranking based on the "Rarity-Endangerment-Vigor-Distribution-Tolerance to Distribution" rating system was attempted but not used for screening because it provided little discrimination between the species. Of primary interest in the summer of 1981 was *Lathyrus hitchcockianus*, which was then considered a "potential candidate endangered species." The remainder of the species are divided into three categories of importance (Table 4). Because of the potential geographic overlap of the ten sensitive floral species maps, a reverse favorability scheme is used. Favorability and reverse favorability values are tabulated below. The sum of these values for each species is always equal to 10.

Table 4. Favorability and Reverse Favorability for Ten Species in the Screening Area

	Favorability	Reverse Favorability
Lathyrus hitchcockianus		
Possible distribution	1	9
Astragalus funereus and *Sclerocactus polyancistrus*		
Known population	5	5
Possible distribution	6	4
Arctomecon merriamii, *Phacelin beatleyae*, and *Penstemon pahutensis*		
Known population	7	3
Possible distribution	8	2
Trifolium andersonii ssp. *beatleyae*, *Phacelia parishii*, *Gilia nyensis*, *Perityle megalocephala* var. *intricata*		
Known population	9	1
Possible distribution	9.5	0.5

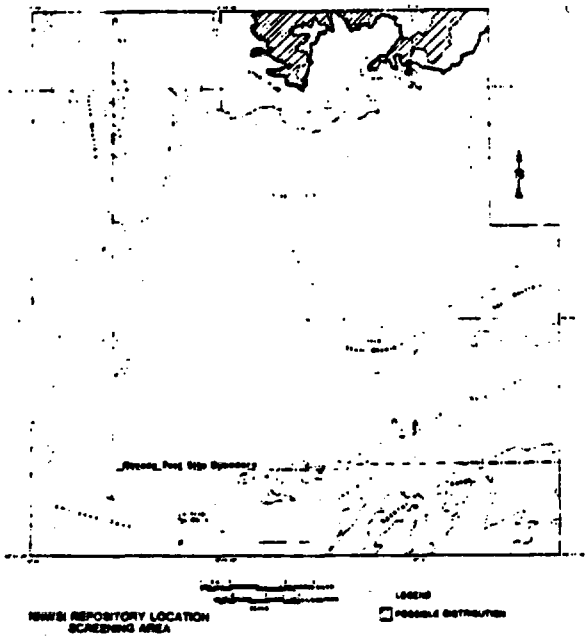
The greater the reverse favorability, the lower will be the desirability of the site for locating a nuclear waste repository. Reverse favorability values of 9 to 19.5 are scaled to favorability values of 10 to 0. A one-to-one correlation exists between the reverse favorability and favorability values, i.e., a reverse favorability of 0 corresponds to a favorability of 10, 1 to 9, 2 to 8, 3 to 7, 4 to 6, 5 to 5, 6 to 4, 7 to 3, 8 to 2, and 9 to 1.

Objectives Evaluated by This Attribute

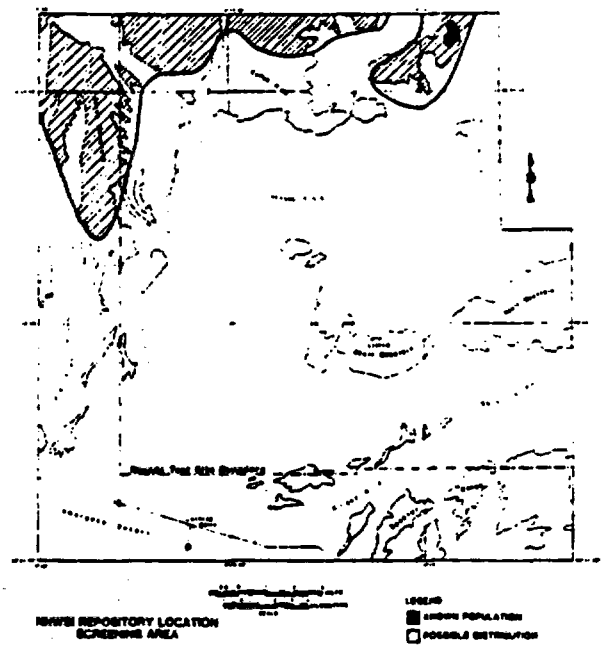
(See Sinnock and Fernandez, 1984, for discussion)

3.1.2 Minimize Surface Monitoring Cost

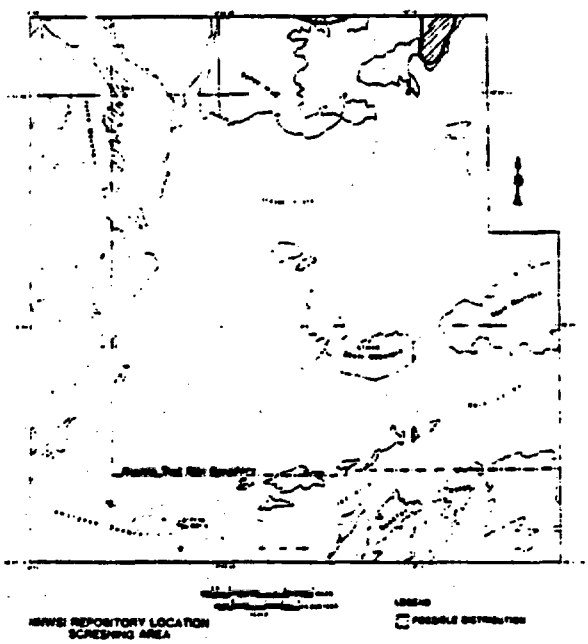
4.1.1 Minimize Adverse Impacts on Sensitive Biotic Systems



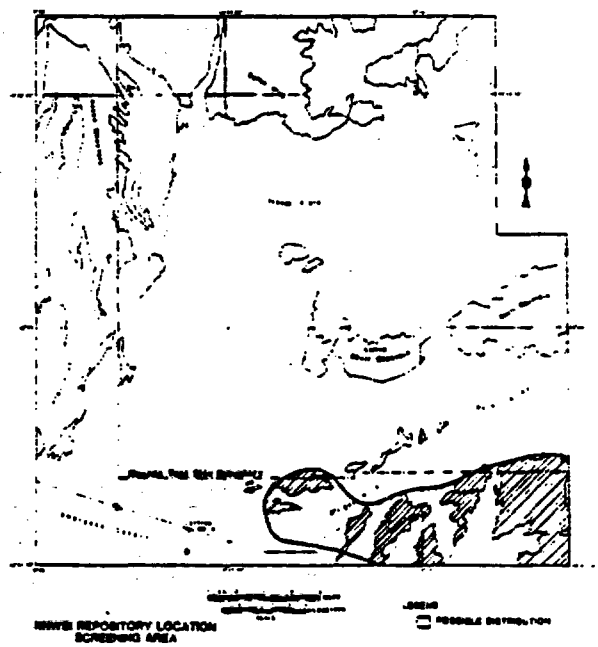
Attribute: *Lathyrus hitchcockianus* (Mojave Sweetpea)



Attribute: *Astragalus funereus* (Funeral Milk-Vetch)

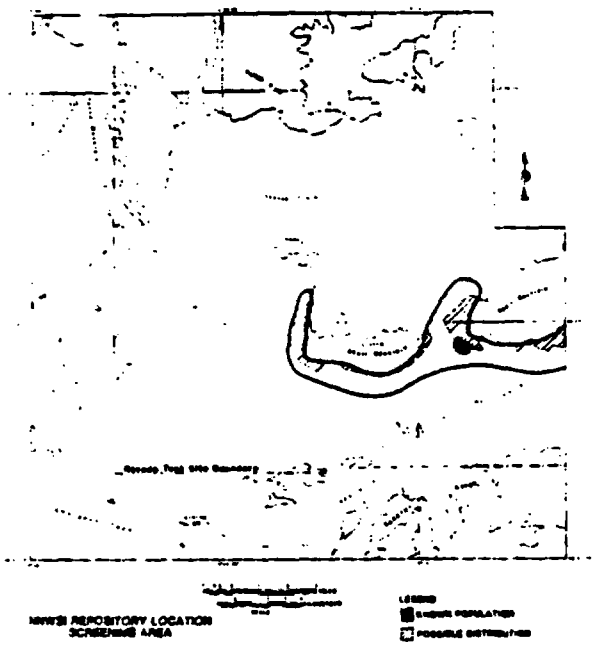


Attribute: *Sclerocactus polyancistrus* (Mojave Fishhook)

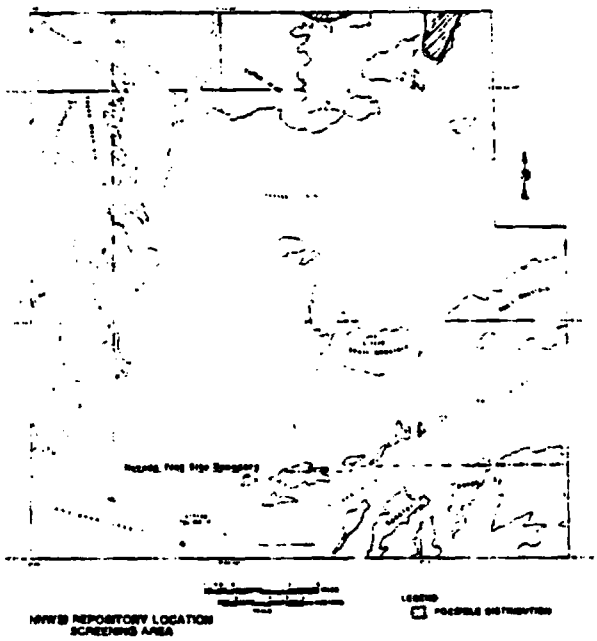


Attribute: *Arctomecon merriamii* (Bear Poppy)

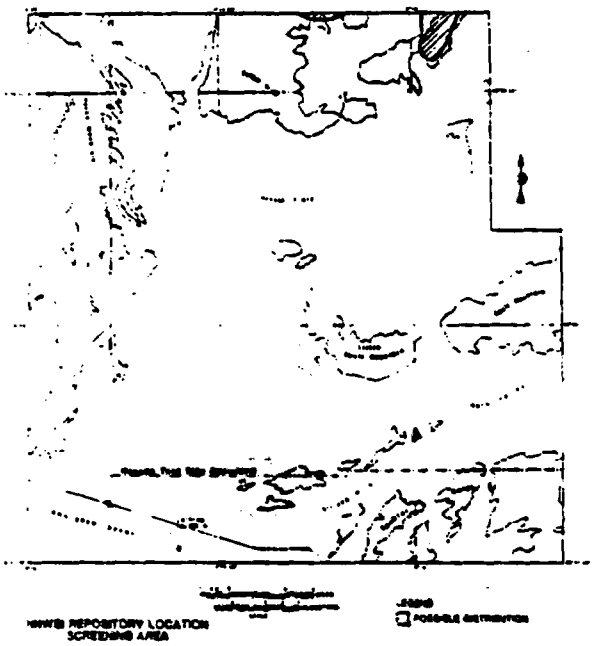
Figure 28. Possible Distribution of *Lathyrus hitchcockianus*, *Astragalus funereus*, *Sclerocactus polyancistrus*, and *Arctomecon merriamii*



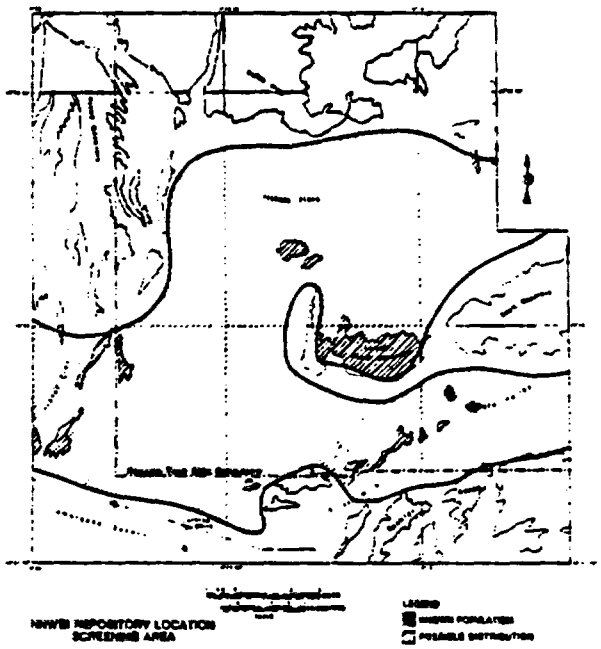
Attribute: *Phacelia beatleyae* (Beatley's Scorpion Weed)



Attribute: *Penstemon pahutensis* (Pahute Beardtongue)

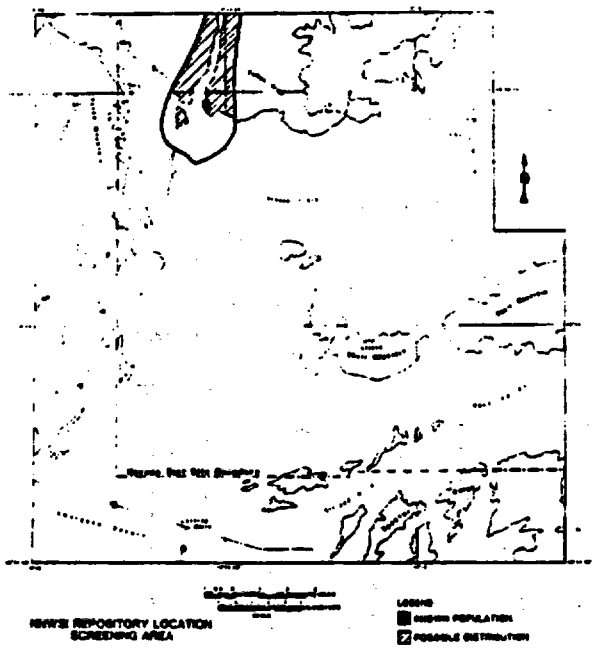


Attribute: *Trifolium andersonii* ssp. *beatleyea* (Beatley's Five Leaf Clover)

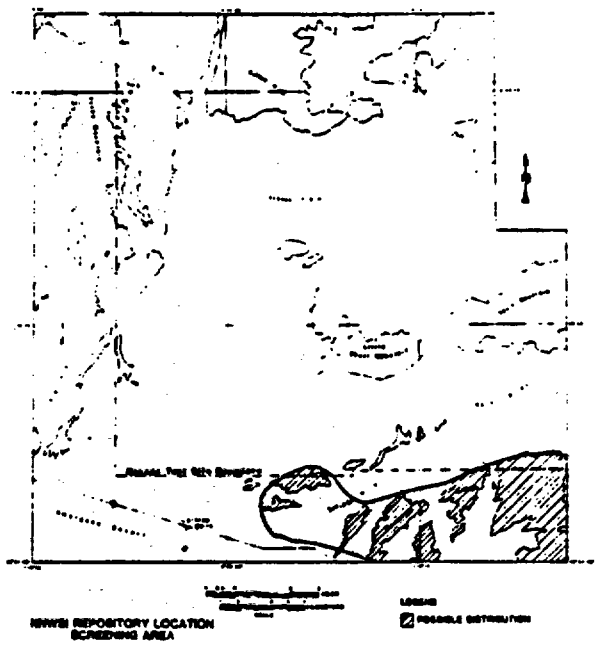


Attribute: *Phacelia parishii* (Parish's Scorpion Weed)

Figure 29. Possible Distribution of *Phacelia beatleyae, Penstemon pahutensis, Trifolium andersonii* ssp. *beatleyea*, and *Phacelia parishii*



Attribute: *Gilia nyensis* (Nye County Gilia)



Attribute: *Parityle megalocephala* var. *intricata* (No common name)

Figure 30. Possible Distribution of *Gilia nyensis* and *Parityle megalocephala* var. *intricata*

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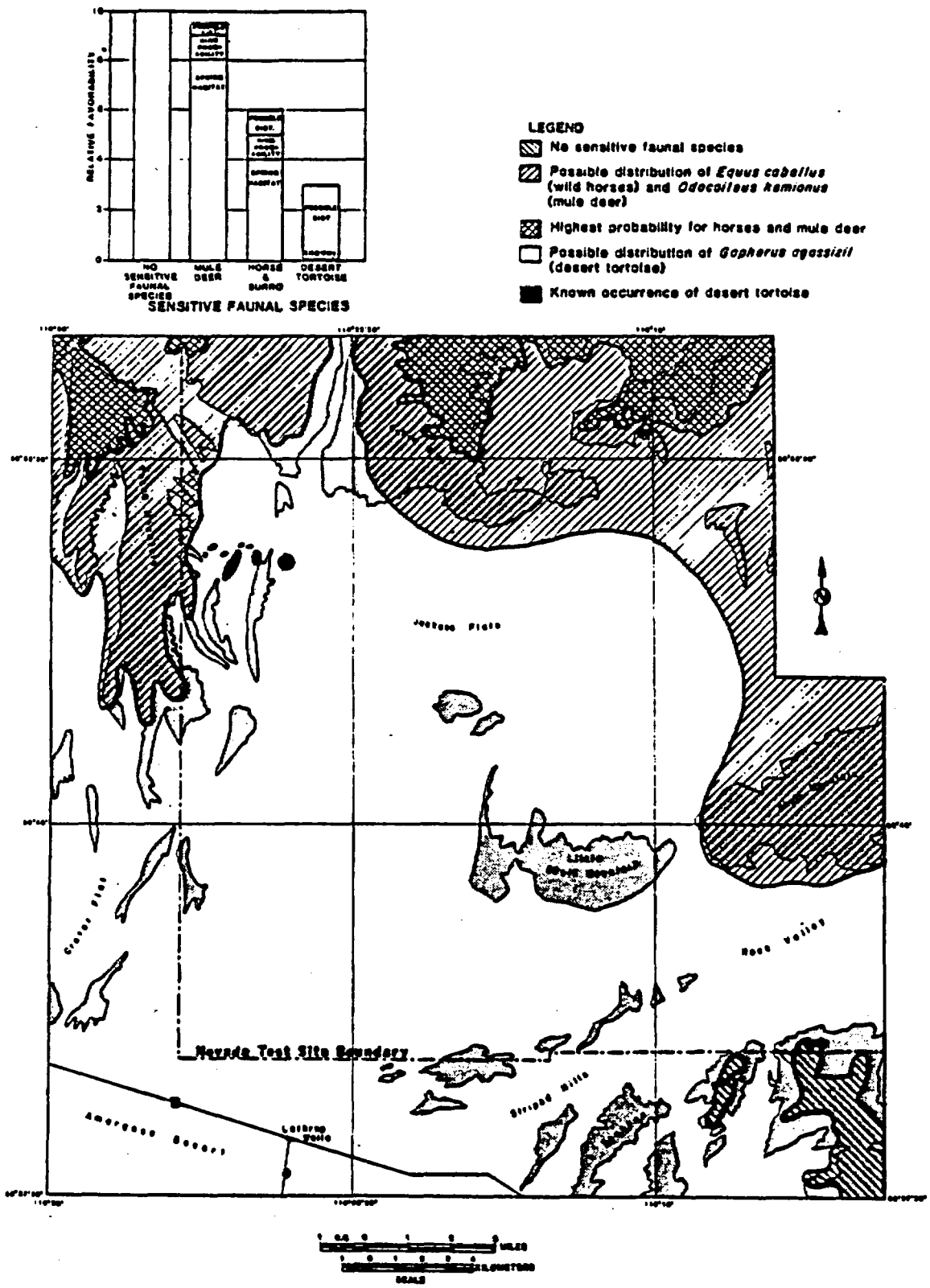

Figure 31. Map and Associated Favorability Graph for Attribute 17, Sensitive Faunal Species

Attribute 17. Sensitive Faunal Species
(Figure 31)

Compilers

Attribute Map:
W. A. Rhoads, T. P. O'Farrell, and E. Collins (EG&G)
Favorability Graph:
J. A. Fernandez (SNL)

Mapping Units

Nine Zones of Known and Possible Habitats for Four Different Faunal Species

Mapping Rationale

The sensitive fauna considered for area screening were *Equus caballus* (wild horses), *E. asinus* (burros), *Odocoileus hemionus* (mule deer), and *Gopherus agassize* (desert tortoise). Sensitive species are defined to be taxa with one of the following characteristics

- Potentially threatened or potentially endangered; rare (likely to exist in small or dwindling numbers in one or a few populations), or infrequently encountered (thinly dispersed over the local area) so that governmental protection is under consideration, eminent, or in place
- Valuable for commercial or recreational purposes and therefore under governmental management
- Of scientific or aesthetic value

Wild horses and mule deer are associated with *Artemisia* and *Artemisia*-Pinyon-Juniper vegetation and generally graze above 5,000 ft, although they seasonally appear below 5,000 ft in *Coleogyne* vegetation. Burros are not common in the NTS area but are occasionally sighted near springs. Locations of wild horses, mule deer, and burros are determined by habitats containing water and food supply. Documented sightings of these species have occurred at Cane Spring and Topopah Spring. Desert tortoises are found throughout the *Larrea* communities. The highest density occurs in Rock Valley because the vegetation is more diverse and dense and the soil is firmer than that of Jackass Flats. A reconnaissance survey resulted in positive evidence of the presence of desert tortoises in certain locations. These locations define the known occurrences.

Confidence Estimates

The area of highest confidence for wild horses and mule deer is above 5,000 ft. Most of the area of possible distribution of desert tortoises has not been adequately surveyed; therefore, lower confidence is placed in the distribution of this species.

Basis for Favorability Graph

Favorability ratings are based on the protection status offered to each sensitive faunal species. The burro and wild horses are protected from "capture, branding, harassment, or death," under the Federal Wild Horse and Burro Act (Public Law 92-195). Mule deer are game animals protected by the State of Nevada. The Bureau of Land Management and the Nevada Division of Wildlife consider the desert tortoise as a sensitive species and protect it on lands under their jurisdiction. The US Fish and Wildlife Service is currently reviewing the desert tortoise for candidacy as a threatened species. In view of the similar status of horses, burros, and the desert tortoise, they all received equal importance in assigning favorabilities. However, horses and burros are much more mobile and less susceptible to human interference than desert tortoises. For example, desert tortoises could be directly affected by increased vehicular traffic and capture by people. For this reason, areas where desert tortoises are found received lower favorability.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

3.1.2 Minimize Surface Monitoring Costs
4.1.1 Minimize Adverse Impacts on Sensitive Biotic Systems

Additional Readings

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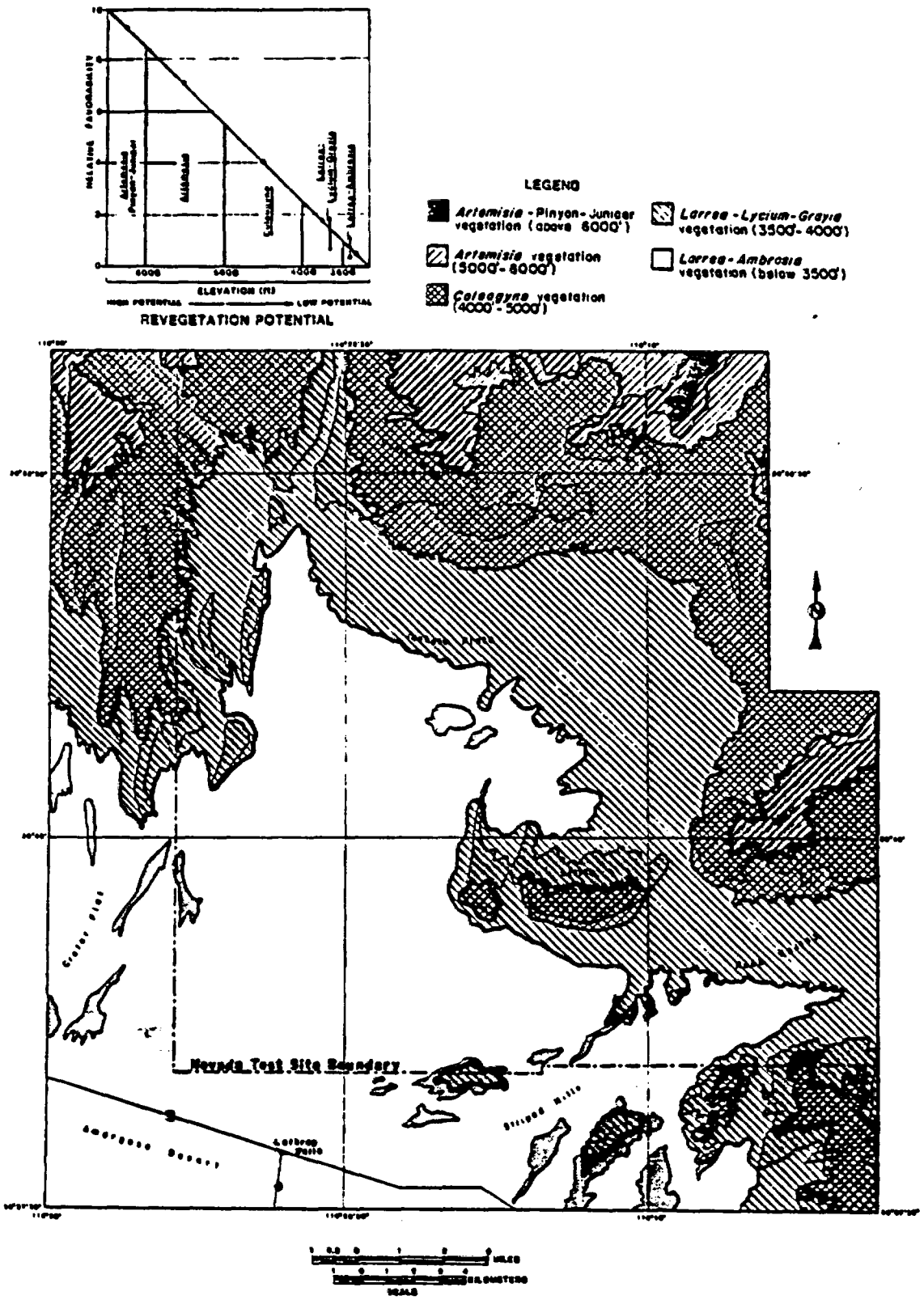

Figure 32. Map and Associated Favorability Graph for Attribute 18, Revegetation Potential

Attribute 18. Revegetation Potential
(Figure 32)

Compilers

Attribute Map:
W. A. Rhoads and E. Collins (EG&G)
Favorability Graph:
J. A. Fernandez (SNL)

Mapping Units

Five Zones of Vegetation Assemblages

Mapping Rationale

Revegetation potential is mapped for the screening area in terms of five major plant associations: *Larrea-Ambrosia*, *Larrea-Lycium-Grayia*, *Coleogyne*, *Artemisia*, and *Artemisia*-Pinyon-Juniper. The boundaries of each plant association are only general, and different plant associations may occur within each general plant association.

Revegetation potential depends on many factors, e.g., slope exposure, precipitation, elevation, drainage, soil substrate, and the extent and type of surface disturbance. An analysis incorporating these and other factors does not exist for the screening area, but revegetation potential of these arid lands is inferred to correlate with mean annual precipitation. Lower-elevation plant communities, such as *Larrea-Ambrosia*, may take centuries to recover from a disturbance, whereas a higher-elevation plant community, such as *Artemisia*-Pinyon-Juniper, may take decades or less to recover.

Confidence Estimates

Plant associations depend, in part, on elevation. Though neighboring associations overlap, the mapped ranges are typical for each association. High confidence is associated with the elevations selected because the NTS area as a whole is one of the most extensively surveyed areas in the US.

Basis for Favorability Graph

An unavoidable direct impact from repository operations is the disturbance of surface vegetation and subsequent wind and water erosion. The ability of the site to revegetate is one measure of the severity of damage a site can sustain. There is a general correlation between the elevation and revegetation potential; vegetation at higher elevations receives more precipitation, and therefore recovers faster. Revegetation potential is inferred to be proportional to the mean annual precipitation and hence elevation. In lieu of more detailed information, the relationship between favorability and elevation is inferred to be linear. The favorability value for each plant association is the value that would correspond to the elevation at the midpoint of the plant association. Thus, the following favorabilities are assigned:

	Midpoint Elevation	Favorability
Artemisia-Pinyon-Juniper	6250	9.6
Artemisia	5500	7
Coleogyne	4500	4
Larrea-Lycium-Grayia	3750	1.7
Larrea-Ambrosia	3250	0.4

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

4.1.1 Minimize Adverse Impacts on Sensitive Biotic Systems

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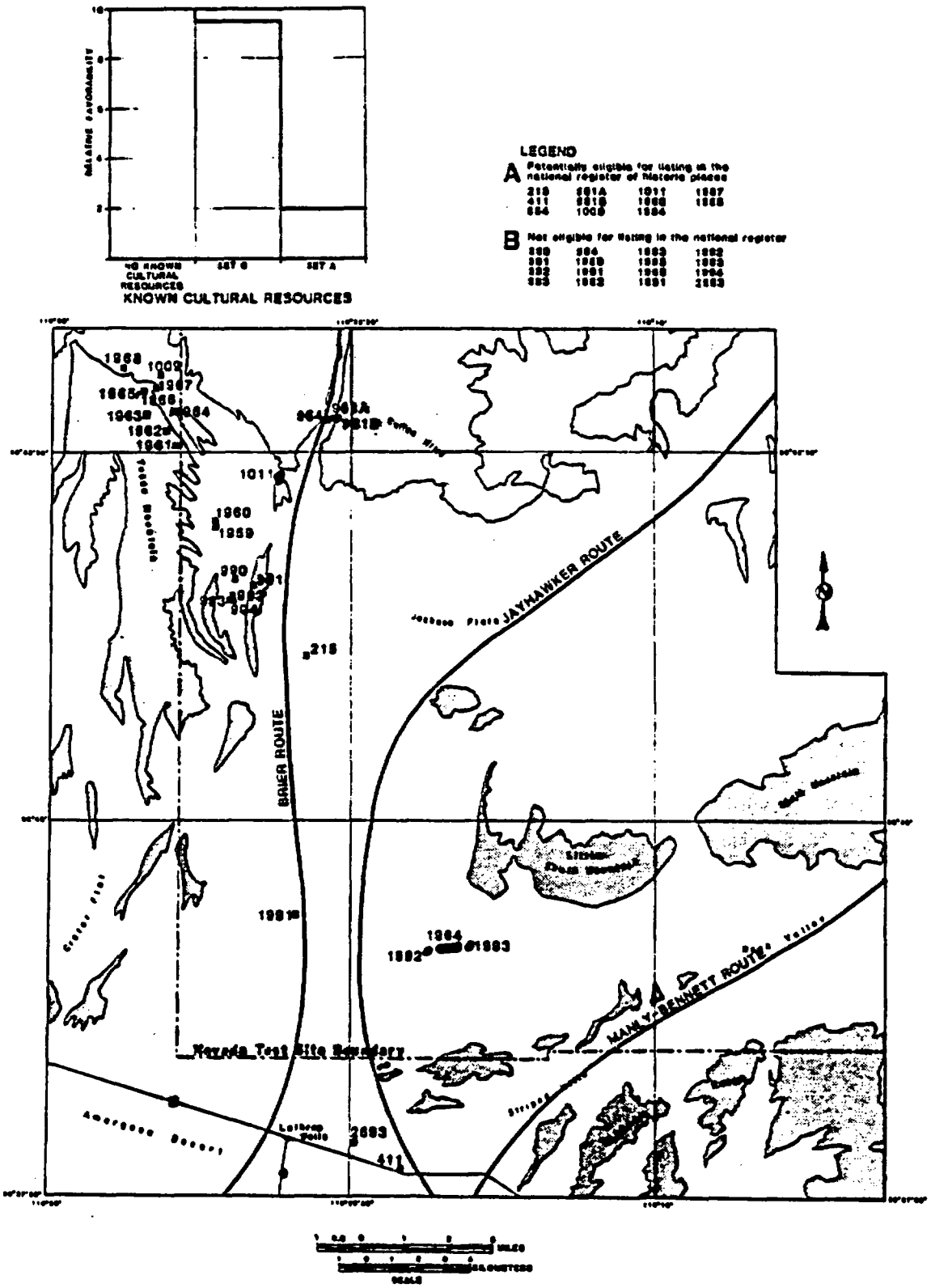

Figure 33. Map and Associated Favorability Graph for Attribute 19, Known Cultural Resources

Attribute 19. Known Cultural Resources
(Figure 33)

Compilers

Attribute Map:
L. C. Pippin and D. L. Zerga (DRI)
Favorability Graph:
J. A. Fernandez (SNL) and L. C. Pippin (DRI)

Mapping Units

Three Zones of Types of Cultural Resources

Mapping Rationale

Historic and prehistoric cultural resources were considered for screening. The earliest record of Euro-American presence on the NTS is a stone block with the inscription, "R. J. Bryor, 1847." After 1847, a group of California-bound immigrants passed through the NTS via three routes: Brier Route, Jayhawker Route, and the Manly-Bennett Route. Mining, a major part of Nevada's history, has also been done at the NTS. Three mining districts lie just outside the screening area: the Bare Mountain or Flourine District, the Mine Mountain District, and the Wahmonie District. Prospects for cultural resources are known to occur in the Calico Hills and Lathrop Wells areas; however, their significance as historic sites is unclear, and they were not considered.

Prehistoric cultural resources were divided into seven site types:

Residential bases
Field camps
Workshops
Knapping stations
Quarries
Isolates
Tinajitas

Locations of prehistoric cultural resources are determined predominantly by the living habits of the prehistoric native American cultures. For example, the locations of water resources and food supplies influenced the habitats or camps of the prehistoric people.

The significance of a historic or prehistoric site, i.e., the potential to yield valuable information concerning past lifestyles, determines the basic mapping units. Cultural resource sites were classified as potentially eligible or not eligible for listing in the National Register of Historic Places. Accordingly, the three mapping units are

- Sites that have sufficient value to be potentially eligible
- Sites that exist but have insufficient value to be eligible
- Areas where no cultural resources exist

Confidence Estimates

The number of known cultural resources is based on an archaeological reconnaissance of less than 0.01% of the total screening area and does not reflect all cultural resources that may exist. Archaeological reconnaissance of the southern NTS has been limited to small-scale archaeological clearance of proposed projects and, therefore, is not an accurate measure of the number of cultural resources for the screening area. It is important to note that all localities may contain cultural resources. Therefore, confidence is low in the map as a comprehensive delineation of cultural sites. To supplement current understanding of known, existing cultural resources, another attribute, potential cultural resources (Attribute 20), was developed.

Basis for Favorability Graph

Each cultural site covers an extremely small area relative to the size of individual screening area grid cells. Thus, more than one site can occur within any of the screening cells. To account for this, reverse favorability values were defined for each category (similar to the floral species favorability curve). Reverse favorability values for categories A, B, and no known cultural resources are 8, 0.5, and 0, respectively. The relative favorability of a screening unit is low if the density of cultural resources is high.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

3.1.2 Minimize Surface Monitoring Costs

4.5.1 Minimize Adverse Impacts on Cultural Resources

Additional Readings

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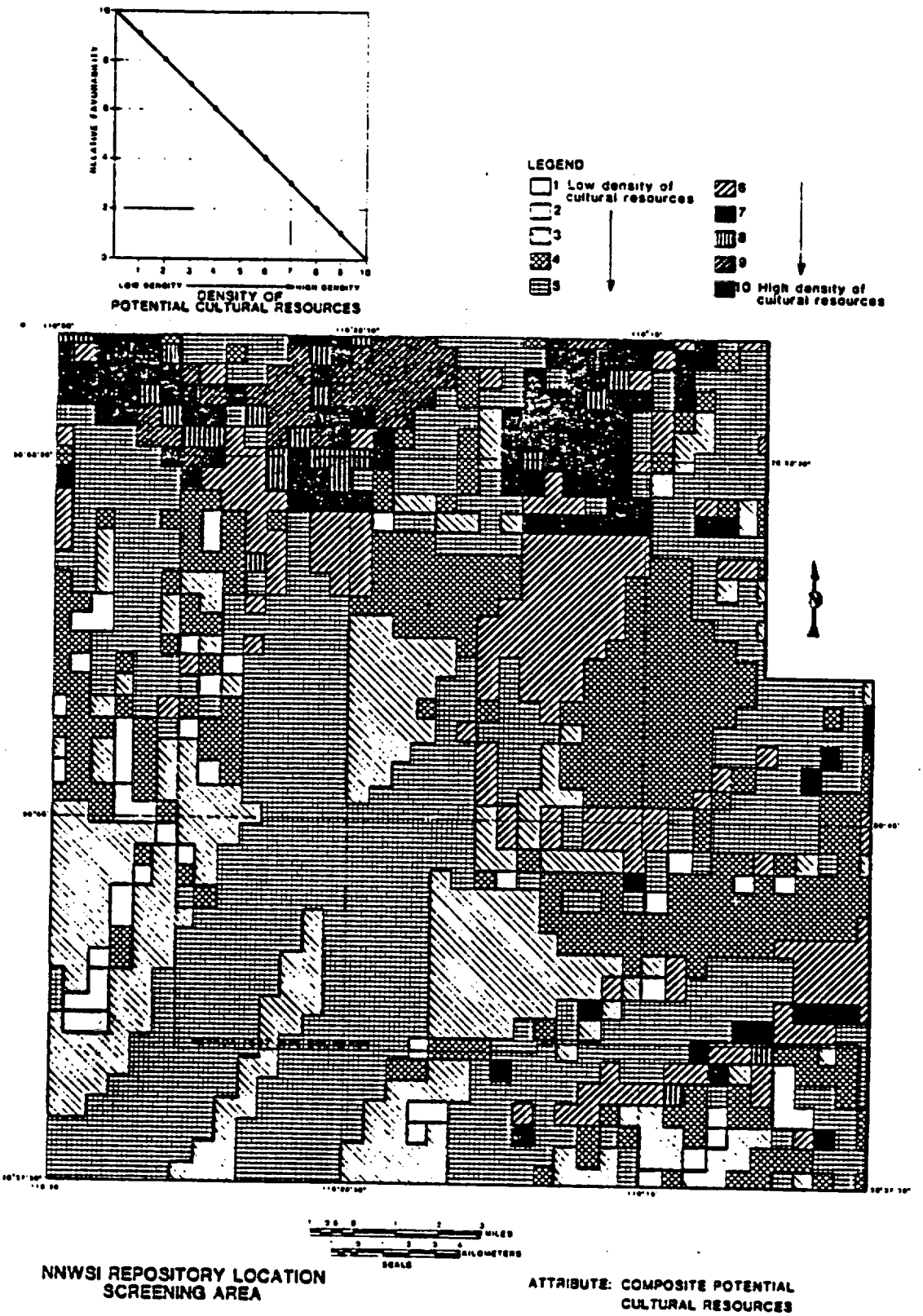

Figure 34. Map and Associated Favorability Graph for Attribute 20, Potential Cultural Resources

Attribute 20. Potential Cultural Resources
(Figure 34)

Compilers

Attribute Map:
L. Pippin (DRI) and J. A. Fernandez (SNL)
Favorability Graph:
J. A. Fernandez (SNL)

Mapping Units

Ten Zones of Density of Potential Cultural Resources

Mapping Rationale

Because information about cultural resources is sparse within the screening area, it was necessary to estimate where cultural resources might be most abundant. Four parameters were selected to estimate the potential for cultural resources:

- Locations of water resources
- Potential locations of toolstone materials and/or mineral resources
- The physiographic setting
- The location of potential biotic resources

It was assumed that localities with water, toolstone, mineral, physiographic, floral, and fauna resources have a high potential to contain densely distributed cultural resources. A map was prepared for each of these four elements (Figure 35).

For the first parameter, proximity to water resources, three zones were considered: minor springs, major ephemeral drainage channels, and all other localities (Figure 35, upper left). They were assigned weighting values of 4, 2, and 0, respectively. Ephemeral drainage systems considered were Fortymile Wash, Topopah Wash, Rock Valley Wash, and Yucca Wash. A distance of 2 km was arbitrarily chosen as the distance from a water resource that would influence the cultural resource density.

For the second parameter, it was inferred that the availability of sources of toolstone materials (rock outcrops) would influence the density of prehistoric archaeological sites. During historic times, miners were attracted by the prospect of finding minerals in various rock outcrops in southern Nevada. While specific outcrops of workable toolstone and mineral resources cannot be identified due to incomplete data. bedrock exposures probably provide the best opportunity for these resources and may correlate with the occurrence of prehistoric or historic cultural resources. Thus, it was considered sufficient to distinguish between mountainous areas where bedrock is exposed and nonmountainous areas generally covered with alluvium (Figure 35, upper right). Weighting values assigned to these areas were 1 and 0, respectively.

The lower-left map in Figure 35 is based on the physiographic setting. Great Basin historians have long recognized that certain kinds of sites are more commonly found on certain topographic features. Four identifiable physiographic settings were mapped:

Setting (Figure 35 lower-left)	Weighting Value
0–10% slope, mountainous terrain	3
0–10% slopes, open areas	2
>40% slopes	1
All other physiographic environments	0

Preferred habitation areas generally occur on slopes of low inclination that provide shelter from adverse meteorological conditions. A minimum horizontal distance of 500 ft was used to determine if a slope was greater than 40%. A smaller horizontal distance was not possible to map due to the scale of the map. If an area was encountered that had a slope of >40% anywhere within the screening unit, the screening unit was assigned to the >40%-slope category.

The last parameter is based on the fact that higher elevation zones are richer in food, shelter, and firewood resources (Figure 35, lower right). Plant associations that correlate directly with elevation were used to define different zones within the screening area. Weighting values of 1, 2, 3, and 4 were assigned to successively higher elevation zones corresponding to *Larrea-Ambrosia* through *Artemisia*-Pinyon-Juniper mapping units.

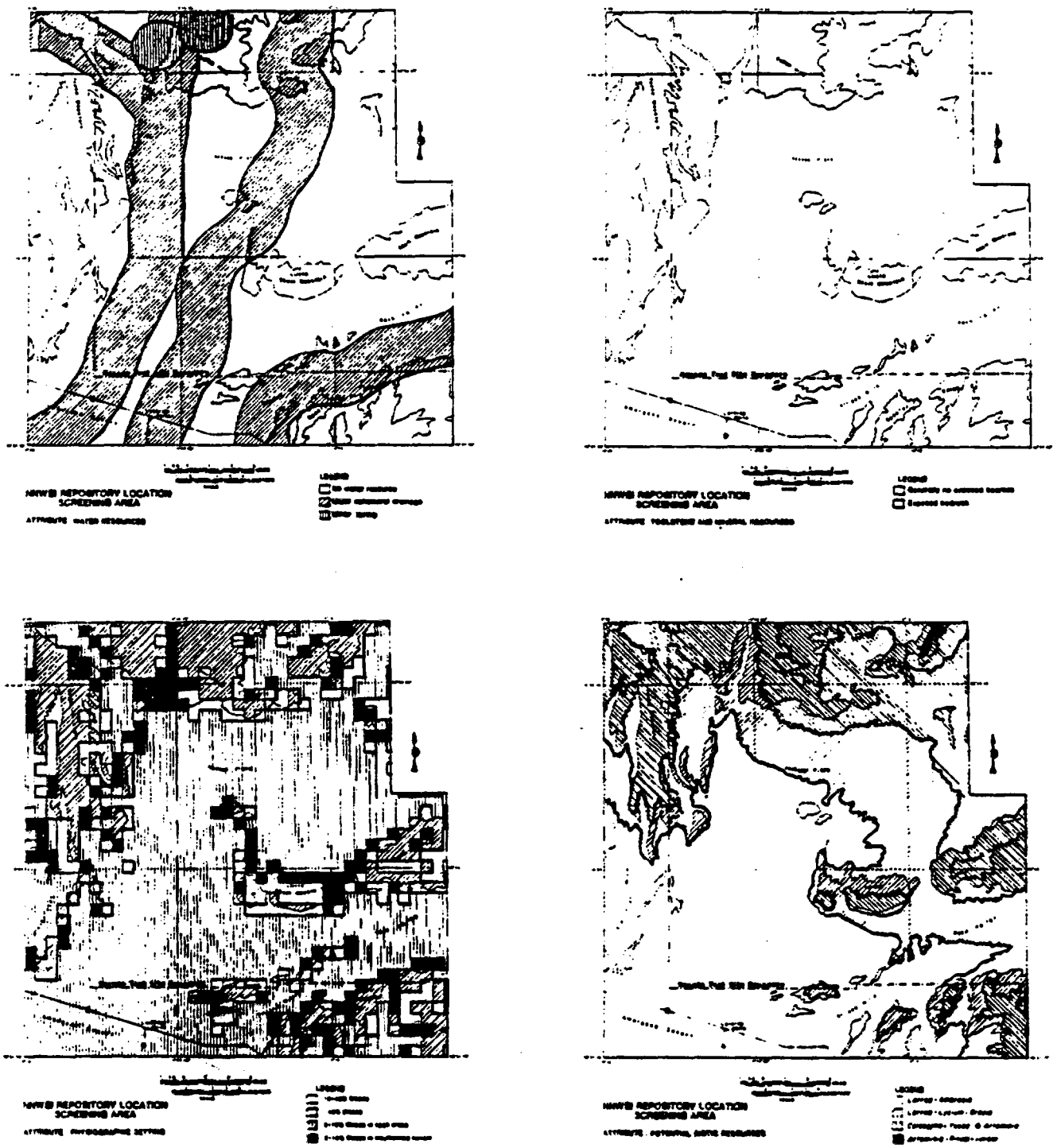

Figure 35. General Distribution of Water Resources, Bedrock Exposures, Topographic Slopes, and Biotic Resources That May Correlate With the Occurrence of Cultural Resources

Each of the four parameter maps was digitized and the composite potential cultural resources attribute map was obtained by summing the weighting value associated with each of the four component maps at each grid cell. The higher the summed weight, the higher is the probability of encountering prehistoric and historic archaeological resources. These data were current as of the summer of 1981. Subsequent work has shown they may be restrictive in some cases.

Confidence Estimates

Previous archaeological reconnaissance indicated that higher densities of cultural resources occur around springs, in areas having greater vegetation, and in areas with rock outcrops of valuable mineral resources. The four parameters—water resources, toolstone materials and/or mineral resources, slope, and potential biotic resources—were judged to be the most significant parameters that could be mapped and that support previous archaeological investigations. This combination of maps is based on archaeological experience. It is a logical approach in understanding where a high density of cultural resources may be located, and because of this, the overall composite map is rated with medium confidence. High confidence cannot be assigned because surveys have not been conducted to verify portions of the composite map.

Basis for Favorability Graph

Areas with greater potential of finding cultural resources are less favorable because the potential for disrupting resources of historic value is greater in these areas. Accordingly, the summed weights shown on the composite map were linearly scaled from 10 (favorability 0) to 0 (favorability 10).

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

3.1.2 Minimize Surface Monitoring Costs

4.5.1 Minimize Adverse Impacts on Cultural Resources

Additional Readings

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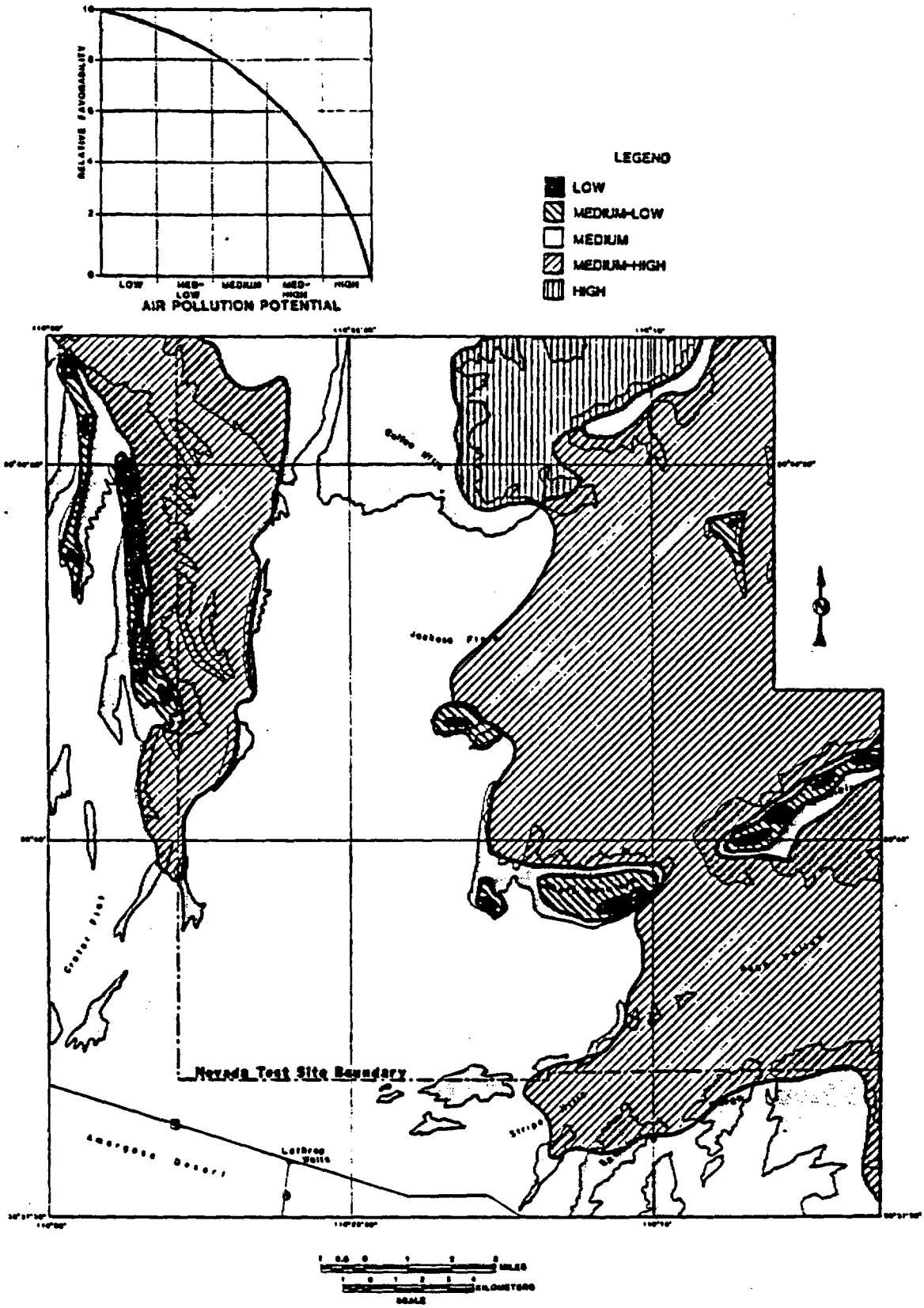

Figure 36. Map and Associated Favorability Graph for Attribute 21, Air Pollution Potential

Attribute 21. Air Pollution Potential
(Figure 36)

Compilers

Attribute Map:
John Bowen (DRI)
Favorability Graph:
John Bowen (DRI)

Mapping Units

Five Zones of Potential for Deterioration of Air Quality

Mapping Rationale

Air pollution can occur as a result of numerous activities. Exhausts from trucks and automobiles, dust from disturbed land (onsite or along utility corridors), and actual construction are all sources of airborne pollutants. Because uniform air quality information is lacking in the screening area and uncertainty exists about source emissions, only the most general estimates of the potential for air pollution were developed for screening. Only stationary sources of air pollution were considered. A location that will enhance the likelihood of air pollution is one where minimal dispersion of pollutants will occur. This situation can occur at locations where meteorological stagnation accompanied by strong temperature inversions is likely. Under these conditions, air motions near the surface depend on surface heating and terrain. The map primarily considers the effect of terrain on air movement under stagnating conditions. Terrain can trap air pollutants in closed basins or permit it to flow down slopes. The conditions defining each category on the map are listed in Table 5.

Confidence Estimates

The pollution potential zones were obtained from published topographic maps. These zones define terrain features that influence the volume of circulating air. There is high confidence that the areas delineated represent the potential for air pollution at a scale appropriate for screening.

Table 5. Relationship Between Air Pollution Potential and Terrain

Pollution Potential	Terrain Features
Low	Ridges and high peaks
Medium-Low	Mesas surrounding high peaks
Medium	Steep cliffs, steep valley terrain, and slopes with no wind restrictions
Medium-High	Open basins
High	Closed or nearly closed basins

Basis for Favorability Graph

Air pollution potential can be related to the volume of atmosphere in which pollutants may be trapped. This volume is not necessarily a physical volume enclosed by terrain features, but may be the volume of air moving into and out of an area. The smaller the volume, the higher will be the pollution potential. Because the concentration of air pollutants is inversely proportional to the air volume, increasing the volume of a small area will cause a larger decrease in air pollutant concentration than a similar volumetric increase of a larger volume. The small volume would correspond to the high air pollution potential, whereas the large volume would correspond to the low air pollution potential. Therefore, the curve at the origin rises more quickly in favorability than the portion of the curve at the upper range.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

4.2.3 Minimize Impacts on Air Quality

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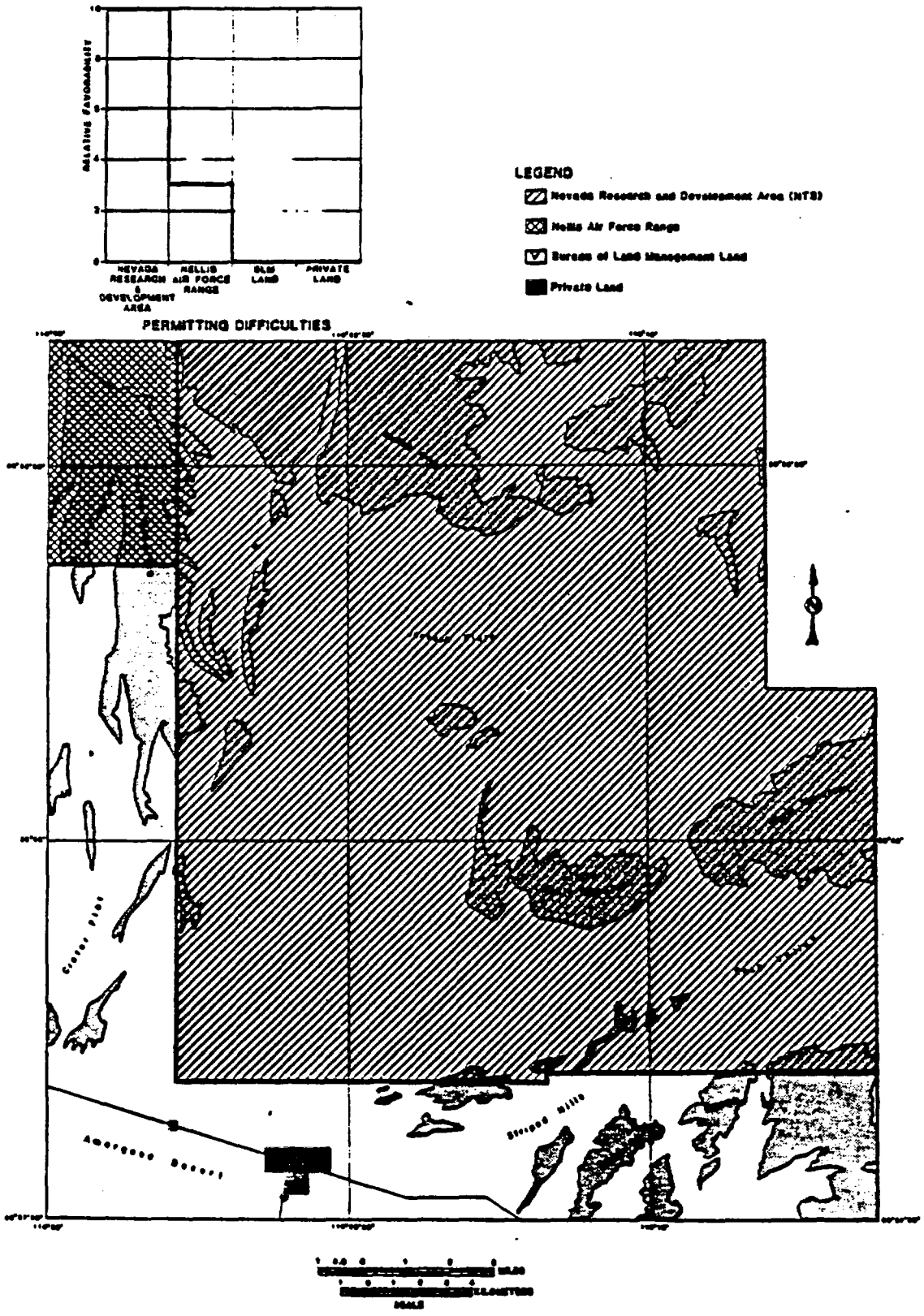

Figure 37. Map and Associated Favorability Graph for Attribute 22, Permitting Difficulties

Institutional Attributes

Attribute 22. Permitting Difficulties
(Figure 37)

Compilers

Attribute Map:
S. G. Bertram and J. A. Fernandez (SNL); B. Yantis (UNLV)
Favorability Graph:
S. G. Bertram and J. A. Fernandez (SNL)

Mapping Units

Four Zones of Land Ownership and Control

Mapping Rationale

Existing legal boundaries separating land control or ownership by BLM, DOE, Air Force, and private parties are shown. The private land shows four quarter-sections near Lathrop Wells. Not all land in these quarter-sections is privately owned but the source data (Land Status Map of Nevada) does not permit better resolution.

Confidence Estimates

The boundaries of land ownership and control are precisely known, so confidence in this map is high.

Basis for Favorability Graph

Permanent land control will be required for a repository and surrounding controlled area. Prior to construction of a repository, a great variety of exploration and testing will be done to determine whether the site is acceptable. Such exploration and testing will include trenching, geophysical surveys, drilling and testing, and an exploratory shaft with underground workings. These activities require permits and/or temporary withdrawals of the land explicitly for exploration and testing. In the case of land on the NTS, which presently is controlled by the DOE, permitting is easily accomplished and no withdrawal is necessary; for NTS land a favorability value of 10 was assigned. For Air Force land, an interagency agreement between the DOE and the Air Force is required, and a favorability value of 3 was assigned. For BLM land, a temporary land withdrawal under the Federal Lands Policy Management Act may be required prior to construction of a shaft (or adit); a favorability of 0 was assigned to BLM land. Private land is also assigned a favorability value of 0.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

4.4.2 Assure Compliance With Federal Regulations

Additional Readings

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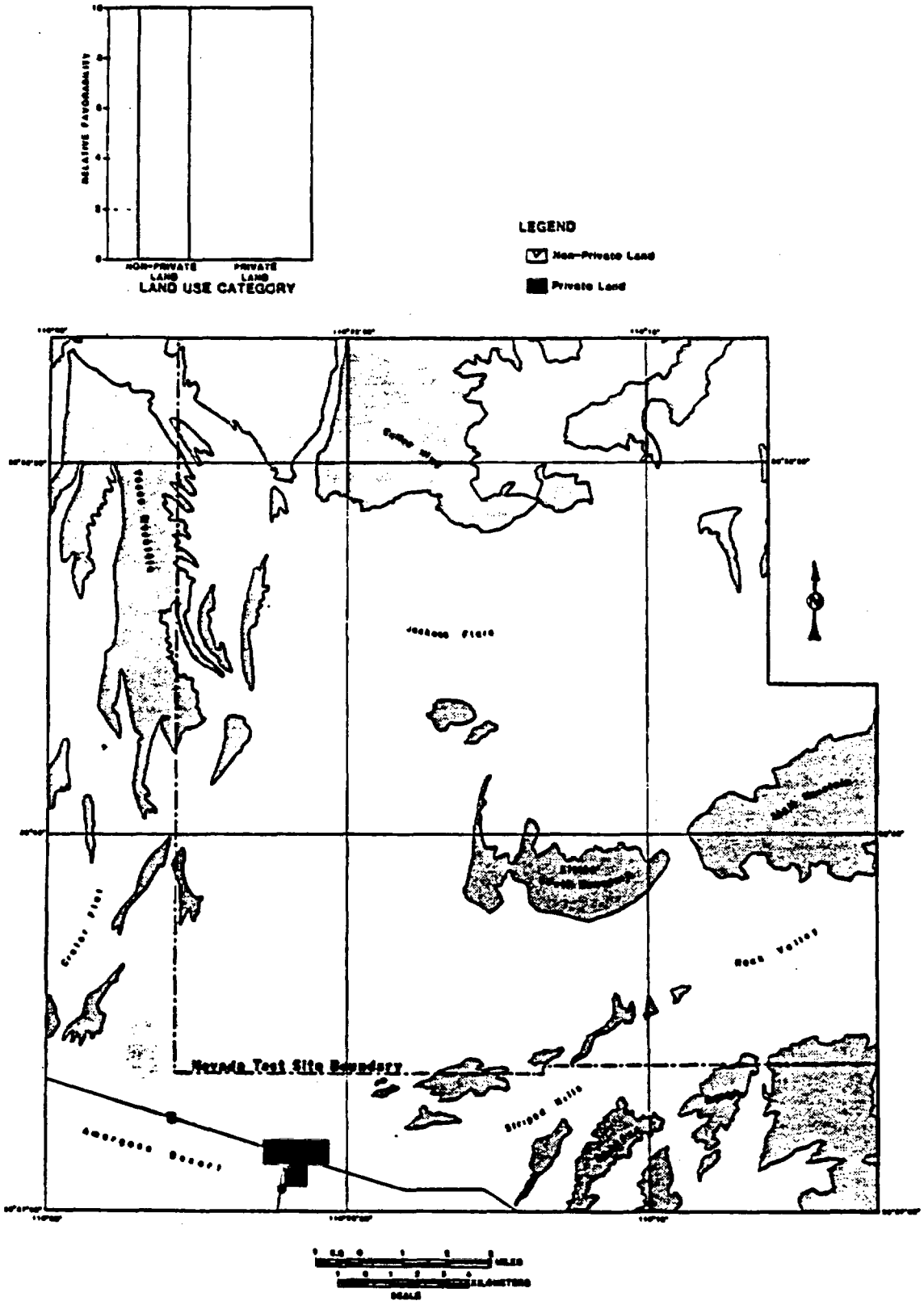

Figure 38. Map and Associated Favorability Graph for Attribute 23, Private Land Use

Attribute 23. Private Land Use
(Figure 38)

Compilers

Attribute Map:
S. G. Bertram and J. A. Fernandez (SNL); B. Yantis (UNLV)
Favorability Graph:
S. G. Bertram and J. A. Fernandez (SNL)

Mapping Units

Two Zones of Land Use: Private and Nonprivate

Mapping Rationale

The private land delineated on the map represents an area larger than the actual private landholdings, because each grid cell in the screening area is displayed entirely as private land if any private land falls within the cell.

Confidence Estimates

Boundaries of private land ownership are precisely known and high confidence is placed in the map, though the mapped areas include some nonprivate land.

Basis for Favorability Graph

Permanent control will be required for a repository and surrounding controlled area, and long-term withdrawal will be required for the surface above the repository. Private land is considered less desirable for repository development because it would require condemnation action and is therefore assigned a zero favorability. Nonprivate land, all of which is federal land, would not require condemnation and is assigned a favorability value of 10.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

4.3.3 Assure Cooperation With State and Private Parties

Additional Readings

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Chapter 3. Host-Rock Attributes

This chapter presents the supporting rationale and assumptions for each of the eight attributes, which vary among the nine candidate host rocks. The geographical occurrence of the nine rock types shown in Figure 39 is discussed in Chapter 4. The values assigned to each of the rock types for each attribute and the corresponding favorability graphs are shown in Figure 40. Note that Attributes 25 and 26 are both characterized by identical values for unconfined compressive strength. The difference between them occurs only in the favorability graphs, whereby a separate graph is used for containment and isolation objectives (Attribute 25) and construction objectives (Attribute 26).

For each attribute (Attributes 25 and 26 considered as a single attribute), the following information is provided:

- The persons responsible for assigning attribute values and favorability numbers to the rock types
- The attribute values, which vary among rock types
- The rationale for assigning particular values to each rock type
- A discussion of confidence in the assignments
- The basis for ascribing favorability values to attribute values
- Additional readings for supporting information

The discussion is organized to explain the appropriate items on Figure 40; referral to this figure is required throughout the remainder of this chapter. The attributes are discussed in the order of their numbers, i.e., from 24 through 31. They are grouped by topical categories as follows:

Geomechanical ..... Attributes 24-27
Geochemical..... Attributes 28-29
Hydrological ..... Attributes 30-31

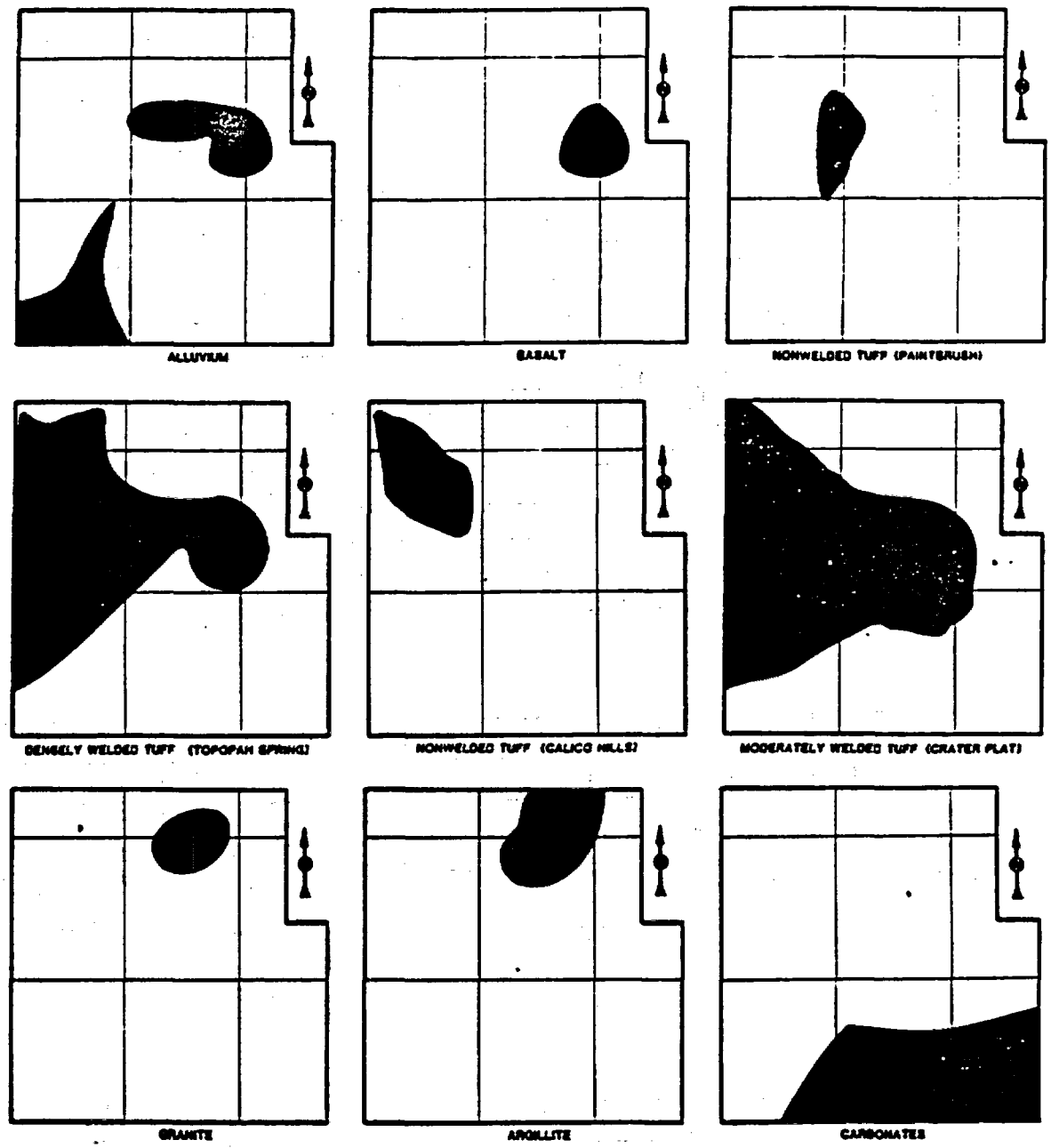

Figure 39. Maps of Underground Extent of Nine Candidate Host Rocks. Showing the inferred geographic extent where a thickness of at least 100 ft occurs between depths of 500 ft and 4000 ft.

ROCK TYPES	24 THERMAL CONDUCTIVITY (W/m-K)	25/26 UNCONFINED COMPRESSIVE STRENGTH (psi)	27 EXPANSION-CONTRACTION BEHAVIOR	28 MINERAL STABILITY (RANK ORDER)	29 STRATIGRAPHIC SETTING (WEIGHTED) *	30 HYDRAULIC RETARDATION (RANK ORDER) *	31 HYDRAULIC TRANSMISSIVITY (cm^2/s)
ALLUVIUM	0.5-1.5	< 7000	CONTR	7	2000-4000	1	10^{-3}
BASALT	1.5-2.5	>20000	EXPAN	4	2000-4000	6	10^{-3}
NONWELDED TUFF (PAINTBRUSH)	0.5-1.5	< 7000	CONTR	7	2000-4000	2	10^{-4}
DENSELY WELDED TUFF (TOPOPAH SPRING)	1.5-2.5	7000-20000	EXPAN	2	2000-4000	5	10^{-2}
NONWELDED TUFF (CALICO HILLS)	0.5-1.5	< 7000	CONTR	9	10000-12000	1	10^{-5}
MOD. WELDED TUFF (CRATER FLAT et al)	1.5-2.5	7000-20000	EXPAN	5	4000-6000	3	10^{-4}
GRANITE	2.5-3.5	>20000	EXPAN	1	4000-6000	5	10^{-5}
ARGILLITE	1.5-2.5	< 7000	CONTR	8	>12000	6	10^{-5}
CARBONATES	3.5-4.5	7000-20000	EXPAN	1	<2000	7	10^{-2}

* RANK ORDERS BASED ON LIST OF ROCK TYPES ORIGINALLY CONSIDERED. THOSE OCCURRING OUTSIDE OF SCREENING AREA BEFORE SCREENING AREA WAS DIMINISHED TO CURRENT BOUNDARIES

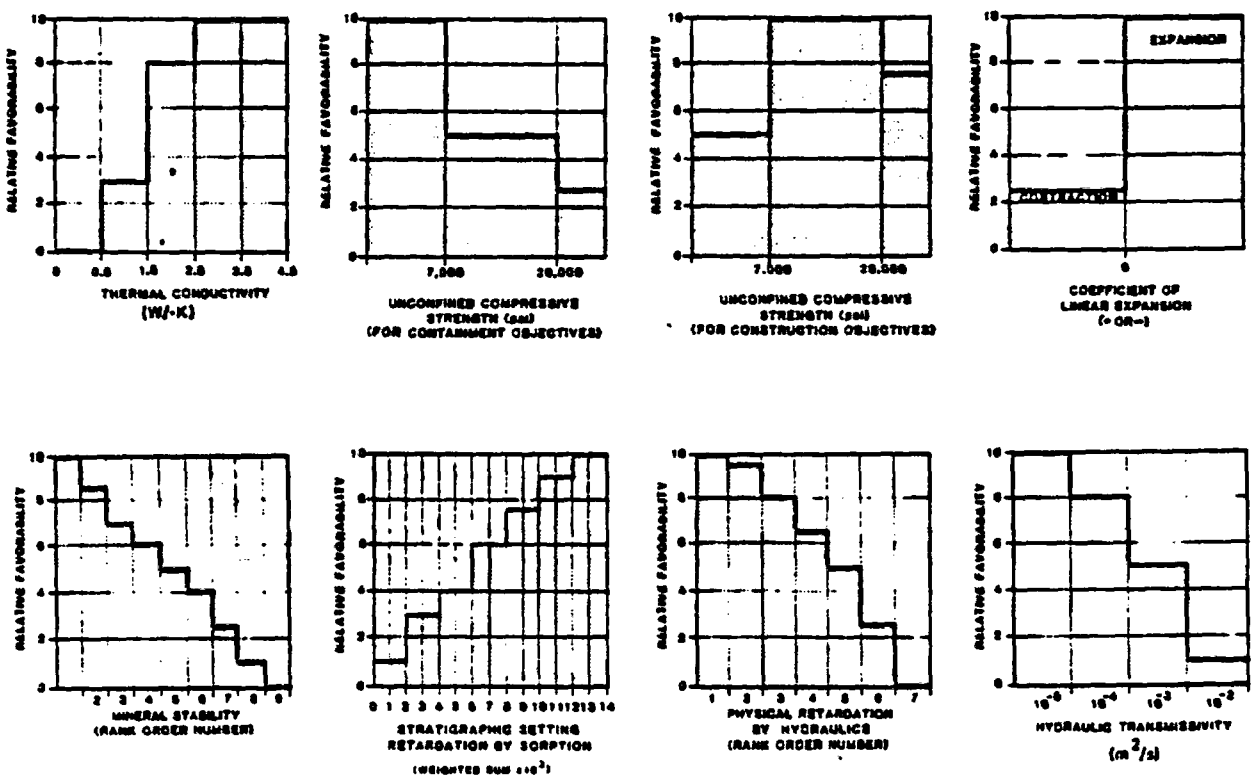

Figure 40. Favorability Graphs for the Eight Host-Rock Attributes (bottom) and Values of Each Attribute Assigned to Each of the Nine Candidate Host Rocks (top)

Geomechanical Attributes

Attribute 24. Thermal Conductivity
(Figure 40)

Compilers

Host-Rock Values:
A. R. Lappin and S. Sinnock (SNL), R. C. Carlson (LLNL), F. Maldonado (USGS), and J. D. Purson (LANL)

Favorability Graph:
A. R. Lappin and S. Sinnock (SNL), R. C. Carlson (LLNL), F. Maldonado (USGS), and J. D. Purson (LANL)

Host-Rock Units

Thermal conductivity ranges for each of the nine potential host rocks in the screening area in units of 0.5 to 1.5, 1.5 to 2.5, 2.5 to 3.5, and >3.5 W/m·K.

Rationale for Host-Rock Values

The attribute units were selected with two objectives in mind:

- To be broad enough (each unit includes a range of 1 W/m·K) to encompass variations that might be expected in the thermal conductivity of specific host rocks
- To distinguish the various host rocks on the basis of their thermal conductivity

A value of 0.5 W/m·K was set as the lower limit on the basis that all potential host rocks, except for uncommon instances of poorly consolidated alluvium with a very low water content, possess thermal conductivities greater than that value. A value of >3.5 W/m·K was chosen as the upper limit on the basis that all potential host rocks, except for uncommon instances of very dense carbonate rocks, would not exceed 3.5 W/m·K by >1 W/m·K.

Alluvium: A value of 0.5–1.5 W/m·K was assigned to all areas of unsaturated alluvium. The actual value may vary between 0.2 and 1.2 W/m·K, depending on porosity, degree of saturation, mineralogy, and degree of induration. Because only special, rare conditions result in values below 0.5 W/m·K, it was judged that including alluvium in the 0.5–1.5 W/m·K mapping unit was appropriate.

Basalt: A value of 1.5 to 2.5 W/m·K was assigned to all areas of basalt. Thermal conductivity for basalts range from 0.1 to 6.0 W/m·K, depending on vesicularity, fractures, and mineralogy; it commonly clusters about values of 1.0 to 3.0 W/m·K.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Members): A value of 0.5–1.5 W/m·K was assigned to these nonwelded tuffs. The thermal conductivity for tuffs in general ranges from ~0.7 to 3.0 W/m·K, depending on porosity, mineralogy, fractures, and degree of saturation. For the screening activity, nonwelded tuff is defined as tuff with >25% porosity. For these porous tuffs, thermal conductivity values generally range from ~0.7 to 1.4 W/m·K.

Densely Welded Tuff (Topopah Spring Member): A value of 1.5–2.5 W/m·K was assigned to densely welded tuff. Welded tuffs are defined for the screening activity as those with porosity of <25%. These welded tuffs generally have thermal conductivities in the range assigned.

Nonwelded Calico Hills Tuff: (Same as above for Pah Canyon, Yucca Mountain, and Upper Topopah Spring Member.)

Moderately Welded Tuff (Crater Flat Tuff and Underlying Unnamed Tuff Units): A value of 1.5–2.5 W/m·K was assigned to moderately welded tuff of the Crater Flat and underlying tuff units. Moderately welded tuff is defined as having a porosity of ~20%. Thermal conductivities for moderately welded tuff are in the range of 1.5–2.2 W/m·K, depending on porosity, mineralogy, fracture, and degree of saturation.

Argillite (Eleana Formation): A value of 1.5–2.5 W/m·K was assigned to the Eleana argillite. Thermal

conductivity for argillites and shales ranges from ~1.0 to 3.0 W/m·K, depending on quartz content, porosity, degree of compaction, and clay mineralogy. The Eleana argillite varies from ~1.8 to 2.7 W/m·K, depending primarily on quartz content. Throughout the mapped area, the range of 1.5–2.5 W/m·K was judged to encompass almost all the argillite in the mapping unit.

Carbonate (Lower Paleozoic Limestones and Dolomites): A value of ~3.5 W/m·K was assigned to Paleozoic carbonates. Carbonate thermal conductivity values range from ~2.0 to 5.0 W/m·K depending on mineralogy, porosity, fractures, and degree of solutioning. Generally, dolomites have higher thermal conductivities than limestone.

Granite (Tertiary Intrusives): A value of 2.5–3.5 W/m·K was assigned to granitic intrusives. Thermal conductivity for granites ranges from ~2.5 to 3.5 W/m·K, depending on mineralogy, fractures, and degree of alteration.

Confidence Estimates

Alluvium: High confidence was assigned to the value of 0.5–1.5 W/m·K based on laboratory thermal conductivity measurement for alluvium from the screening area.

Basalt: Low confidence is assigned to the value of 1.5–2.5 W/m·K. There are no measurements of the thermal conductivity of basalts from the screening area. The assignment of the thermal conductivity unit is only inferred from visual inspection of the basalt in Jackass Flats and comparison with known thermal conductivities of basalts from regions other than the NTS.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Members): High confidence is assigned to the 0.5–1.5 W/m·K thermal conductivity range for this unit. This confidence is based on numerous thermal conductivity measurements of core samples from drill holes Ue25a#1 and USW-G 1 at Yucca Mountain and from G-tunnel at the NTS.

Densely Welded Tuff (Topopah Spring Member): High confidence is assigned to thermal conductivity values of 1.5–2.5 W/m·K for densely welded tuff. This value range is based on numerous measurements of thermal conductivity of the Topopah Spring Member on core samples from drill holes J-13, Ue25a#1, and USW-G 1 at Yucca Mountain and for the densely welded Grouse Canyon Member in G-tunnel at the northern NTS. These values are matrix values and do not take into account lithophysal zones that occur in the central portions of the unit. Lithophysal zones may reasonably be presumed to lower the effective thermal conductivity, perhaps below 1.5 W/m·K.

Nonwelded Calico Hills Tuff: (Same as above for Nonwelded Paintbrush tuff.)

Moderately Welded Tuff (Crater Flat Tuff and Underlying Unnamed Tuff Units): High confidence was assigned to the range of 1.5–2.5 W/m·K for this unit, based on thermal conductivity measurements on core samples from drill holes USW-G 1 and J-13.

Argillite (Eleana Formation): High confidence was assigned the range of 1.5–2.5 W/m·K for argillite, based on laboratory measurements of thermal conductivity on core samples from drill holes Ue25a#3 at Calico Hills and the Ue16 series at Syncline Ridge. Also, a near-surface heater test conducted at Syncline Ridge produced temperature profiles consistent with laboratory determinations of thermal conductivity.

Carbonate (Lower Paleozoic Limestones and Dolomites): High confidence was assigned to the >3.5 W/m·K value for carbonates, though some beds, especially limestones, may be less, and some interbedded quartzite layers may approach 6.0–8.0 W/m·K. No measurements have been made of the thermal conductivity of carbonates in the screening area.

Granite (Tertiary Intrusives): High confidence was assigned to the 2.5–3.5 W/m·K value for granite. It is possible that the granites in the mapping area might be highly altered and have thermal conductivities below the lower limit of the assigned range. No thermal conductivity measurements have been made of the Tertiary granites in the screening area. Values of ~3.0 W/m·K have been measured for the Mesozoic Climax Stock in the northern NTS and the stripa granite in Sweden.

Basis for Favorability Graph

Thermal conductivity data will be used to predict temperature changes caused by a repository. These changes will affect the local stress field and may contribute to inducing new fractures or modifying existing ones, thereby enhancing permeability along pathways for possible radionuclide migration. Stresses created by temperature changes also may crack the waste form and thus affect containment. Some rocks undergo mineralogical and chemical changes upon heating, which in turn may affect permeability or geochemical transport and retardation systems both in the host rock and the backfill. The greater the thermal conductivity of the host rock, the lower the ultimate temperature will be. Therefore, higher thermal conductivities are given higher favorability ratings.

The effects of thermal conductivity depend, in part, on the amount of thermal energy (canister power level) contained in the emplaced waste. With low power levels, induced temperature changes will be low; with high power levels, the temperature changes will be large. Thus, the effect of thermal conductivity on peak temperature will be greater as canister power level increases. This rationale is shown in Table 6, where favorability values for each of the thermal conductivity units are assigned for each of three different canister power levels.

Table 6. Favorability Rating for Thermal Conductivity as a Function of Canister Power Level (in kW)

Conductivity (W/m·K)	Favorability 0.1 kW	0.55 kW	3.5 kW
0.5	8	3	1
1.5	10	8	3
2.5	10	10	6
3.5	10	10	8
3.5	10	10	10

The middle thermal output (0.55 kW) was used to define the favorability graph for screening purposes. The gross thermal loading (expressed in kW/acre) also will affect peak temperatures. Thus, undesirable repository temperatures can be reduced by aging waste or spacing individual canisters less densely. Almost any thermal conductivity can be accommodated by a repository, and its favorability is basically related to the costs for the necessary design accommodations.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.1 Minimize Potential for Chemically Induced Release
1.1.2 Minimize Potential for Mechanically Induced Release
3.2.3 Minimize Adverse Mining Conditions
3.2.6 Maximize Compatibility With Waste Package

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Attributes 25 and 26. Unconfined Compressive Strength
(Figure 40)

Compilers

Host-Rock Values:
S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Unconfined, uniaxial compressive strength for each of the nine potential host rocks in the screening area in units of: <7,000, 7,000 to 20,000, and >2,000 psi.

Rationale for Host-Rock Values

Unconfined, uniaxial compressive strength is a simple, relatively available measure of one of the mechanical properties of potential host rocks. Other mechanical properties, such as bulk modulus and Poisson's ratio, are much more difficult to measure, and consequently fewer such measures are available. Unconfined compressive strength is only a very general representation of rock strength. Actual in situ strengths can be quite different from the laboratory measurement, depending on temperature, lithostatic pressure, excavation geometry, hydrostatic pressure, nature of interstitial fluids, strain rate, shear stresses, and others.

The units of compressive strength were selected with two objectives in mind:

- To be broad enough to encompass variations that might be expected in the strength of specific host rocks
- To distinguish the various host rocks on the basis of their strength

The units were chosen to distinguish in a general way relatively low-strength rocks (<7,000 psi) from relatively high-strength rocks (>20,000 psi). A transitional unit (7,000 to 20,000 psi) was included to bridge the gap between soft and hard rocks.

Alluvium: An unconfined compressive strength of <7,000 psi was assigned to unsaturated alluvium. Compressive strength of alluvium is generally quite low because it has little cohesion or binding cements. Some indurated caliche horizons may approach the strength of soft limestones, but most alluvium in the screening area is unconsolidated or poorly consolidated and compressive strengths are in the range of hundreds of psi.

Basalt: An unconfined compressive strength of >20,000 psi was assigned to basalts in Jackass Flats. Basalt compressive strength is generally quite high, ranging from ~25,000 to 50,000 psi.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Members): An unconfined compressive strength of <7,000 psi was assigned to these nonwelded tuffs. Compressive strength of tuff is inversely proportional to porosity. Thus, nonwelded tuffs (>25% porosity) are weaker than welded tuffs (<25% porosity). Strengths of nonwelded tuffs generally range from ~5,000 to 8,000 psi (porosity from ~40% to 20%).

Densely Welded Tuff (Topopah Spring Member): An unconfined compressive strength of 7,000–20,000 psi was assigned to densely welded tuff. Strengths of densely welded tuffs can range upwards from ~7,000 or 8,000 psi at ~20% porosity to perhaps 60,000 psi at <10% porosity. However, the range of 7,000 to 20,000 psi best characterizes this unit based on an inference that porosity is generally between ~12–13% and 20%.

Nonwelded Calico Hills Tuff: (Same as above for Pah Canyon, Yucca Mountain, and upper Topopah Spring Member.)

Moderately Welded Tuff (Crater Flat and Underlying Unnamed Tuff Units): An unconfined compressive strength of 7,000–20,000 psi was assigned to moderately welded Crater Flat and underlying tuffs. Porosity of these moderately welded tuffs generally ranges from ~20% to 25%; thus their strength matches that of densely welded tuff as defined for this screening exercise.

Argillite (Eleana Formation): An unconfined compressive strength of <7,000 psi was assigned to Eleana argillite. Compressive strengths of shales generally range from ~4,000 psi to ~10,000 psi. Slates range from ~10,000 psi to ~40,000 psi. Argillite is shale that has been slightly metamorphosed (but not to slate metamorphic grades) and therefore can reasonably be inferred to be between the strengths of

shale and slate. The strength of the Eleana argillite is proportional to the quartz content of the rock. The strength of some high-quartz varieties or more highly metamorphosed varieties may exceed 7,000 psi, but <7,000 psi probably best characterizes the bulk of the argillite in the screening area.

Carbonate (Lower Paleozoic Limestones and Dolomites): An unconfined compressive strength of 7,000 to 20,000 psi was assigned to carbonate rocks. Limestones generally range from ~10,000 psi to ~40,000 psi, with most values falling below 20,000 psi. Dolomite ranges from ~12,000 psi to ~30,000 psi and is generally somewhat stronger than limestone. The range of 7,000–20,000 psi probably encompasses most of the carbonate rocks in the screening area.

Granite (Tertiary Intrusives): An unconfined compressive strength of more than 20,000 psi was assigned to granite. The unconfined compressive strength of granites generally ranges from ~20,000 psi to ~40,000 psi.

Confidence Estimates

Alluvium: High confidence is assigned to a value of <7,000 psi for alluvium. There are no measurements of the unconfined compressive strength of alluvium from the NTS, but measurements on alluvium from other areas all fall below 7000 psi.

Basalt: High confidence is assigned to a value of >20,000 psi for basalt. There are no laboratory measurements of the strength of basalts in Jackass Flats, but measurements on basalt from other areas all fall above 20,000 psi.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Members): High confidence is assigned to a value of <7,000 psi for nonwelded tuffs, though some of the less porous rocks in the unit may have slightly higher strengths. The confidence is based on numerous laboratory tests of unconfined strength of nonwelded tuffs on core from drill holes in the screening area and on samples from G-tunnel in the northern NTS.

Densely Welded Tuff (Topopah Spring Member): High confidence is assigned to a value of 7,000 to 20,000 psi for densely welded tuff based on measurements of core from drill holes in the screening area.

Nonwelded Calico Hills Tuff: (Same as above for Pah Canyon, Yucca Mountain, and Upper Topopah Spring Member.)

Moderately Welded Tuff (Crater Flat and Underlying Unnamed Tuff Units): High confidence is assigned to a value of 7,000–20,000 psi for moderately welded tuff based on measurements of cores from drill holes in the screening area.

Argillite (Eleana Formation): Moderate confidence is assigned to a value of <7,000 psi for argillite, with the recognition that high-quartz strata may fall in the 7,000–20,000 psi range. The confidence is based on laboratory measurements of core samples from Calico Hills in the screening area and from Syncline Ridge just northeast of the screening area. Some quartzite strata with unconfined compressive strengths approaching 30,000 psi may be interbedded with the argillite.

Carbonate (Lower Paleozoic Limestones and Dolomites): Moderate confidence is assigned to a value of 7,000 to 20,000 psi for the carbonates. Some rock layers, especially dolomites or interbedded quartzites, may exceed 20,000 psi. There are no laboratory measurements of rock strength of carbonate rocks from the screening area.

Granite (Tertiary Intrusives): High confidence is assigned to a value of >20,000 psi for granite. It should be noted that the granite may be highly altered, in which case compressive strengths may drop below 20,000 psi. There are no laboratory tests of the compressive strength of the Tertiary granites in the screening area; tests of the Mesozoic Climax Stock on the NTS yield a compressive strength of ~30,000 psi.

Basis for Favorability Graph

Host-rock strength provides a crude measure for (1) assessing the costs of mining and (2) predicting the thermal effects of heat-generating waste upon increases or decreases in permeability of the host rock. In general, the stronger the rock, the higher the mining costs and the less likely the rock will fail mechanically. Weaker rock, on the the other hand, is easier to mine but more likely to fail mechanically, though decreased permeability may occur with ductile failure. Strong rocks under thermal loads may tend to fail by fracturing, whereas weaker rocks will be more likely to fail by slow creep, thus tending to seal fractures along which waste might migrate.

Two favorability graphs have been selected: one for construction safety and cost, the other for isolation and containment. Rock strength relates to favorability with respect to these two objectives in different manners, requiring separate favorability graphs. Each graph constitutes a separate attribute for screening, though the strength data are identical for both attributes.

Attribute 25—Compressive Strength for Construction Safety and Cost: Considerations for relating rock strength to construction are

- Cost of underground excavation
- Cost of providing structural support for underground openings to protect workers
- Limits on extraction ratios

Strong rocks are generally more expensive to mine, whereas weak rocks generally require more expensive support systems. Weak rocks require lower extraction ratios than strong rocks. Therefore, both very strong and very weak rocks are considered less favorable than intermediate-strength rocks. Intermediate-strength rocks (7,000 to 20,000 psi) are assigned a favorability value of 10. Because this intermediate range was assumed to require expensive drill and blasting techniques (as opposed to lower-cost mechanical mining techniques), the additional costs for stronger rocks (greater bit wear, slower drilling penetration, etc) is assumed to be less than the additional cost for hardening of workings in weaker rocks. Rocks with strengths of >20,000 psi are assigned a favorability value of 7.5 and those of <7,000 psi are assigned a value of 5 to reflect the above assumption. The favorability value of 5 for the weakest rocks reflects the fact that all of the potential host rocks in the screening are judged to be safely mineable and able to be kept open with appropriate mine designs and mining practices.

Attribute 26—Compressive Strength for Isolation and Containment: Considerations for relating rock strength to isolation and containment are

- Stronger rocks tend to be more brittle, and therefore tend to fracture rather than creep, thereby decreasing confidence that permeability will not increase
- Stronger rocks tend to support open, permeable fractures more readily than weaker rocks, which tend to squeeze fractures closed under in situ stresses
- Weaker rocks (particularly tuffs) tend to be more porous and thus allow fluids to flow and diffuse from fractures into the rock matrix, thus providing greater potential for radionuclide retardation.

For these reasons, weaker rocks are assigned a relative favorability value of 10. Because the intermediate-strength (7,000 to 20,000 psi) rocks have sufficient strength to support open fractures and respond in a brittle manner within the temperatures and pressures expected in a repository, they are assigned a favorability value of 5, indicating a considerable drop in favorability when fracturing becomes likely. The strongest rocks (>20,000 psi) are assigned a relative favorability value of 2.5, indicating a less significant decrease in favorability with increased brittleness beyond that needed to sustain fracturing. A lower limit-of-favorability value of 2.5 indicates that all potential host rocks in the screening area are acceptable on the basis of rock strength alone.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.2 Minimize Potential for Mechanically Induced Release (Attribute 25)
2.1.3 Maximize Extent of Relatively Homogeneous Host Rock (Attribute 25)
3.2.3 Minimize Adverse Mining Conditions (Attribute 26)

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Attribute 27. Expansion-Contraction Behavior
(Figure 40)

Compilers

Host-Rock Values:
A. R. Lappin and S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Information is given on whether each of the nine potential host rocks expands or contracts upon heating.

Rationale for Host-Rock Values

For most solid materials, expansion occurs upon heating as a result of the faster movement of molecules. This property is generally measured by a thermal expansion coefficient (either linear or volumetric). However, upon heating some rocks undergo mineralogical changes that result in reduced volumes of the new minerals as opposed to the old, thus causing the rock mass to contract. This is particularly true for rocks containing expandable clays and some types of zeolites. In these cases, heating releases the water that is either adhering to mineral surfaces or lightly bound within the lattice structures. If the water is driven off, the rock generally contracts, concommitantly releasing water. Thus, although the expansion or contraction of a rock upon heating is primarily a function of its mineralogy, it also depends on the degree of saturation, lithostatic stress, and, the temperature increase to which the rock is subjected. No attempt was made to quantify the amount of expansion or contraction that will occur upon heating, but it was possible to place each of the nine candidate host rocks into either an expanding or contracting behavior category.

Alluvium: Contraction upon heating is assigned to unsaturated alluvium. This is based on an inference that zeolites derived from the tuffs and expandable clays from argillite and tuffs probably occur in sufficient amounts in the alluvium of the screening area to cause contraction.

Basalt: Expansion upon heating is assigned to basalts in Jackass Flats. A linear expansion coefficient of $5.4 \pm 1 \times 10^{-6}$°C^{-1} is found for basalts outside the NTS, and it assumed the basalts in Jackass Flats behave similarly.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Member): Contraction upon heating is assigned to the nonwelded tuffs of this unit. Linear contraction coefficients of these tuffs generally range from 0 to -10×10^{-6}°C^{-1}. Contraction is thought to be caused by dehydration of hydrated glass, expandable clays, and zeolites that begin to dehydrate at ~85°C–150°C. These values are based on measurements of the volumetric behavior upon heating of core samples obtained from drillholes in the screening area.

Densely Welded Tuff (Topopah Spring Member): Expansion upon heating is assigned to this unit. Linear coefficients of expansion of ~5 to 10×10^{-6}°C^{-1} have been measured in the laboratory for core samples obtained from drillholes in the screening area.

Nonwelded Calico Hills Tuff: (Same as for Nonwelded Paintbrush Tuff)

Moderately Welded Tuff (Crater Flat and Underlying Unnamed Tuff Units): Expansion upon heating is assigned to this unit. Measurement of the Bullfrog Member of the Crater Flat Tuff indicates a thermal expansion coefficient of ~6 to 10×10^{-6}°C^{-1} for samples obtained from drillholes in the screening area.

Argillite (Eleana Formation): Contraction upon heating is assigned to the Eleana argillite. This contraction is caused by abundant expandable clays that dehydrate and shrink upon heating above ~85°C. Data from a heater test in Eleana argillite at Syncline Ridge just northeast of the screening area shows much contraction upon heating.

Carbonate (Lower Paleozoic Limestones and Dolomites): Expansion upon heating is assigned to carbonate rocks. Linear coefficients of expansion of $\sim 7 \pm 2 \times 10^{-6}$°C^{-1} are reasonable for limestones, and it is inferred that dolomite behaves similarly.

Granite (Tertiary Intrusives): Expansion upon heating is assigned to granite. Coefficient of linear expansion of $8 \pm 3 \times 10^{-6}$°C^{-1} are reasonable for most granites, and it is inferred the granites in the screening area behave similarly.

Map Confidence Estimates

Alluvium: Because of uncertainty regarding the mineralogy of the alluvium, intermediate confidence is placed on the assignment of contraction behavior to alluvium.

Basalt: Though there are no measurements on the volumetric behavior of basalts in Jackass Flats upon heating, high confidence is assigned to the expansion behavior.

Nonwelded Paintbrush Tuff (Pah Canyon, Yucca Mountain, and Upper Topopah Spring Member): High confidence is assigned to contraction behavior upon heating of this unit.

Densely Welded Tuff (Topopah Spring Member): High confidence is assigned to expansion behavior upon heating of the western portion of this unit where it is above the water table. However, only intermediate confidence is assigned to expansion behavior upon heating of the eastern portion of this unit where it is below the water table. The densely welded tuff above the water table is devitrified and consists largely of quartz and feldspar, whereas below the water table it may not be completely devitrified and may have considerable zeolites and clay minerals.

Nonwelded Calico Hills Tuff: High confidence is assigned to contraction behavior upon heating of this unit.

Moderately Welded Tuff (Crater Flat and Underlying Unnamed Tuff Units): High confidence is assigned to expansion behavior upon heating of this unit. Some interlayered zeolitic zones in the Crater Flat Tuff may contract upon heating.

Argillite (Eleana Formation): High confidence is assigned to contraction behavior upon heating of the argillite in the area around Mine Mountain, but only for the upper portion of the unit at Calico Hills in the screening area. For deeper horizons and those farther from drill hole Ue25a#3 at Calico Hills, low confidence in behavior upon heating is assigned.

Carbonate (Lower Paleozoic Limestones and Dolomites): High confidence is assigned to expansion behavior of the carbonate unit.

Granite (Tertiary Intrusives): High confidence is assigned to expansion behavior upon heating of granite.

Basis for Favorability Graph

The expansion or contraction behavior of a rock upon heating is important for assessing repository construction and maintenance cost during operations and for assessing containment and isolation of the wastes after sealing of a repository. If a rock expands, it will create compressive stresses in the area of expansion that may seal existing pores and fractures, thus decreasing fluid and radionuclide migration pathways (isolation), or it may even create new fractures, enhancing potential migration pathways. Expansion may also cause rocks to squeeze in upon the emplaced wastes, making retrieval more difficult should it be necessary. Rock contraction, might open new fissures, which would threaten isolation capacity by providing new migration pathways for liberated radionuclides. This might also reduce containment capacity by providing pathways for fluids to contact and dissolve the emplaced wastes. Though either expansion or contraction may have beneficial or detrimental effects on repository construction and performance, it is judged in the absence of definitive analysis that expansion behavior, if not too much, is preferred over contraction behavior.

Accordingly, expansion is assigned a relative favorability value of 10. Contraction, not an unacceptable condition for repositories, is assigned a relative favorability value of 2.5.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.2 Minimize Potential for Mechanically Induced Release

3.2.6 Maximize Compatibility With Waste Package

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Geochemical Attributes

Attribute 28. Thermal Stability of Minerals
(Figure 40)

Compilers

Host-Rock Values:
B. M. Crowe, R. G. Warren, and J. D. Purson (LANL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Rank ordering from 1 to 9, most to least stable, respectively, is given for the relative stability of host rocks under conditions of increasing temperature induced by the emplacement of heat-generating nuclear wastes.

Rationale for Host-Rock Values

The stabilities of host rocks in the screening area were ranked relative to each other based on their content of stable and unstable minerals under increased temperature. The ranking scale is from 0 to 9, with the most stable rocks (granite and carbonates) ranked 1 and the least stable (Calico Hills Tuff) ranked 9. The six remaining host rocks are assigned ranks of 2, 4, 5, 7, 7, and 8. These numbers were obtained by qualitative ranking of 12 rock types occurring in the vicinity of the screening area, including the 9 candidate host rocks. Thus some ranking values are not exhibited by the nine candidates; i.e., rankings of 3 and 6.

Alluvium: Alluvium is composed of predominantly unconsolidated particles. Each basin contains alluvium composed of rock particles from surrounding ranges. In the screening area, these ranges are composed primarily of tuffs, as well as some argillite, carbonate, rhyolite, and basalt. During erosion, transportation, deposition, and diagenesis, the particles may change, including some argillization, zeolitization, devitrification of individual particles, and calcification. The net result in the screening area is a complex mineraological assemblage in alluvium with high likelihood of zeolites and clays occurring in significant amounts. Therefore, the potential for volumetrically significant mineralogical changes upon heating is relatively high. For this reason, alluvium is assigned a rank of 7 for mineral stability.

Basalt: Basalt is generally composed of relatively stable primary minerals with some glass. Secondary minerals can include clays and zeolites that usually fill vesicles or line fractures. The small amounts of glass and relatively small volume of vesicles and fractures make basalt generally stable under heating, with limited volume changes primarily restricted to fracture and vesicle-filling minerals. Basalt is assigned a rank of 4 for mineral stability.

Nonwelded Tuff (Tiva Canyon, Pah Canyon, Yucca Mountain and Upper Topopah Spring Members): This unit is generally composed of minor feldspars and quartz, some glass, and secondary clays; in some places, clays comprise >90% of the rock. The relatively large amount of clay and vitric phases make this unit highly susceptible to volume and mineral changes upon heating. It is assigned a rank of 7 for mineral stability.

Densely Welded Tuff (Topopah Spring Member): This unit is predominantly devitrified with quartz and feldspar comprising the bulk of the rock. Some minor glass phases, clays, and zeolites (especially near the bottom of the unit) occur, so minor mineral changes upon heating could occur. This unit is assigned a rank of 2 for mineral stability.

Nonwelded Tuff (Calico Hills): This unit is predominantly composed of zeolites (clinoptilolite and mordenite) and significant clays. Because nearly the entire rock is composed of minerals that alter under heating, it is assigned a rank of 9 for mineral stability.

Moderately Welded Tuff (Crater Flat and Unnamed Underlying Units): This unit has complex mineralogical variations with depth. Some stratigraphic zones are welded, devitrified, and silicified, whereas others are moderately welded and predominantly altered to zeolites (clinoptilolite, mordenite,

analcine). Because the mineral stability depends on the zone of interest within the unit, some zones are composed of stable minerals, other of unstable zeolites and/or clays. This unit is assigned a rank of 5 for mineral stability.

Granite: Granite is composed almost entirely of feldspars and quartz, which are very stable. Accordingly, it is assigned a rank of 1.

Argillite: Argillite is composed almost entirely of clay, mostly illite and montmorillonite. Because these minerals are unstable upon heating (especially montmorillonite), this unit is assigned a rank of 8 for mineral stability.

Carbonate: Carbonates are almost entirely composed of calcite and/or dolomite, both stable minerals under heating. Accordingly, this unit is assigned a rank of 1 for mineral stability.

Basis for Favorability Graph

For containment and isolation of radionuclides, it is important to minimize the mineral phases that change when heat is introduced to host rock by emplacement of radioactive wastes. Clays, opals, zeolites, and vitric phases may dehydrate and/or change volume when subjected to the anticipated heat generated near a waste canister. This change could create new pathways, due to induced fractures, along which contaminated fluids might migrate. Stability of minerals also is desirable because changes might adversely affect the rock's capability to support mined openings. Accordingly, the higher the rank order of the rock (more stable), the greater is its favorability. Ranks of 1 through 9 were assigned favorabilities of 10, 8.5, 7, 6, 5, 4, 2.5, 1, and 0, respectively.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.1 Minimize Potential for Chemically Induced Release
1.1.2 Minimize Potential for Mechanically Induced Release
2.1.2 Maximize Retardation of Radionuclides Along Flow Paths
2.1.4 Maximize Migration of Volatile Waste Components
3.2.3 Minimize Adverse Mining Conditions
3.2.6 Maximize Compatibility With Waste Package

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Attribute 29. Geochemically Controlled Stratigraphic Setting
(Figure 40)

Compilers

Host-Rock Values:
B. R. Erdal, K. Wolfsberg, B. M. Crowe, R. G. Warren, and J. D. Purson (LANL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Weighted sum of sorption values in units of 2,000 of rocks of interest, overlying rocks, and underlying rocks.

Rationale for Host-Rock Values

This attribute considers sorption capacity for a vertical distance of 500 ft above and below the center of each candidate host rock.

The sorptive capacity indicates the potential of a rock to chemically retard the migration of radioactive contaminants in moving groundwater. Estimates of sorption capacity for each of the nine candidate host rocks are shown in Table 7. All sorption data in Table 7 were measured at LANL, thereby minimizing differences due to experimental technique. Only cesium, strontium, europium, plutonium, and americium were considered; no anionic species were considered. The representative sorption ratios in Table 7 are the average of the values obtained by batch techniques for sorption and desorption under atmospheric conditions. Because several rocks of interest have not been extensively studied or have not been studied at all, several assumptions have been made:

1. The nonwelded tuff of Tiva Canyon, Pah Canyon, and Yucca Mountain Members is identical to alluvium.
2. Tuffs of the Prow Pass, Bullfrog, and Tram Members of the Crater Flat Tuff at Yucca Mountain are composed of both welded and nonwelded components that are mineralogically different; therefore, values for the Crater Flat unit were calculated by assuming the composition was two parts welded (similar to Topopah Spring Member) and one part nonwelded (similar to Calico Hills).
3. If the sorption ratio for europium was available for a given rock type and the value for americium was not, the americium value was assumed to be the same as the europium value.
4. A similar but inverse assumption was made if only the americium value was known.
5. In some cases (alluvium, nonwelded tuff, Tiva Canyon, and carbonates), no plutonium values were available, and the value was assumed to be 0.2 of the europium value.

Values estimated using assumptions 3–5 are given in parentheses in Table 7. To give equal credit to the vastly different sorption ratios for the five elements of interest, the values among the rock types for each radionuclide were normalized (Table 8) to a maximum value of 1000. The overall value used for sorption capacity of each rock type (Table 9) was calculated by adding the average of the normalized values for americium and europium to the normalized values for cesium, strontium, and plutonium from Table 8. The average value between europium and americium was used because these elements presumably have the same oxidation state.

Table 7. Representative Sorption Ratios for Specific Radionuclides and Rock Types. Parentheses indicate assumed values based on chemical similarities among radionuclides (see Rationale for Host-Rock Values, assumptions 3 and 4).

	Sorption Capacity (ml/mg)				
Rock Type	Cs	Sr	Eu	Pu	Am
Alluvium	3,000	200	3,500	(700)	(3,500)
Basalt	265	81	(7,920)	840	7,920
Nonwelded Tuff (Tiva Canyon, Pah Canyon, Yucca Mtn)	8,000	200	3,500	(700)	(3,500)
Densely Welded Tuff (Topopah Spring)	490	125	3,920	574	2,450
Nonwelded Tuff (Calico Hills)	20,900	11,125	3,625	1,125	7,500
Moderately Welded Tuff (Crater Flat)	7,293	3,795	3,822	758	4,133
Granite	435	18	1,025	8,000	1,025
Argillite	2,800	130	62,600	35,500	78,000
Carbonates	88	2	(3,200)	(640)	3,200

Table 8. Normalized Sorption Ratios for Selected Radionuclides and Rock Types

	Sorption Capacity (ml/mg)				
Rock Type	Cs	Sr	Eu	Pu	Am
Alluvium	380	18	56	20	45
Basalt	13	7	130	24	100
Nonwelded Tuff (Tiva Canyon, Pah Canyon, Yucca Mtn)	380	18	56	20	45
Densely Welded Tuff (Topopah Spring)	23	11	63	16	31
Nonwelded Tuff (Calico Hills)	1,000	1,000	58	32	96
Moderately Welded Tuff (Crater Flat)	350	340	61	21	53
Granite	21	2	16	225	13
Argillite	130	12	1,000	1,000	1,000
Carbonates	4	1	51	18	41

Table 9. Sorption Values Used for Screening

Rock Type	Value
Alluvium	470
Basalt	160
Nonwelded Tuff (Tiva Canyon, Pah Canyon, Yucca Mtn)	470
Densely Welded Tuff (Topopah Spring)	100
Nonwelded Tuff (Calico Hills)	2,200
Moderately Welded Tuff (Crater Flat, et al)	770
Granite	260
Argillite	2,100
Carbonate	70

Sorption properties were considered at distances in the near field (or within a single host rock) and as a function of the stratigraphic setting out to 500 vertical feet from the host rock. This attribute approaches the multiple barrier concept by considering a more encompassing setting than that which is defined by a single host rock's properties. It is assumed that sorption properties become less important at greater vertical distances from the repository. Accordingly, distances away from the center of the host rock were weighted as shown in Figure 41. In nearly all cases, the 500-ft limit for calculation requires consideration of the sorption properties of rock units adjacent to the candidate host rock. Groundwater tends to move downward under the influence of gravity; therefore, sorption capacity for units below the host rock were weighted more heavily than for units above. A related assumption is that heat, which may drive contaminants upward, is temporary (until the canister cools), while downward migration of groundwater is a natural, continuous process. The stratigraphy of the nine candidate host rocks yields 15 distinct locations in the screening area, each with its own geochemical retardation setting (Figure 42). Each of these locations was rated according to its unique stratigraphic-geochemical conditions (Table 10). Ratings were determined by multiplying the weighting factor (WF) for an interval (Figure 41) by a thickness factor (TF) (feet × 0.01) of each rock unit that occurs in that interval, then multiplying the weighted thickness of the interval by the sorption score (S) corresponding to the rock type within the interval (Table 9). This process was repeated for each weighted interval and the resulting scores were summed to obtain a total score for each of the 15 locations (Table 11). Generalized units in ranges 2000 were assigned to each of the host rock units for the parametric value of this attribute (Table 10).

The overall score or value for the sorption capacity of each of the nine rock types is not meant to imply a quantitative parameter for calculations of radionuclide retardation, but is an estimate of the relative capability of the rocks to retard migration. Because the exact mineralogical and textural controls on sorption measurements are poorly understood, no implication is made about the physical properties that contribute to each rock's sorption capacity. However, it should be noted that zeolites and clays tend to facilitate sorption, perhaps accounting for the very high relative values for the Calico Hills nonwelded tuff, which is highly zeolitized and the argillite, which is predominantly clay.

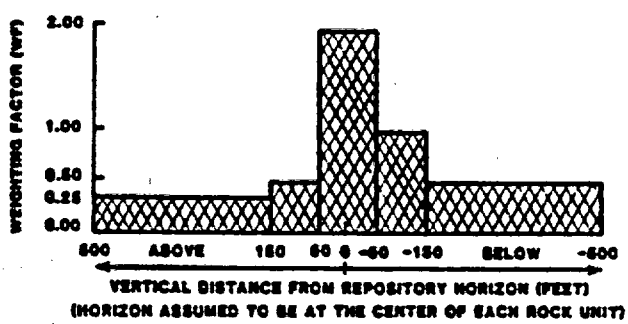

Figure 41. Weighting of Vertical Intervals Above and Below Center of Rock Units for Evaluation of System Potential of the Stratigraphic Setting

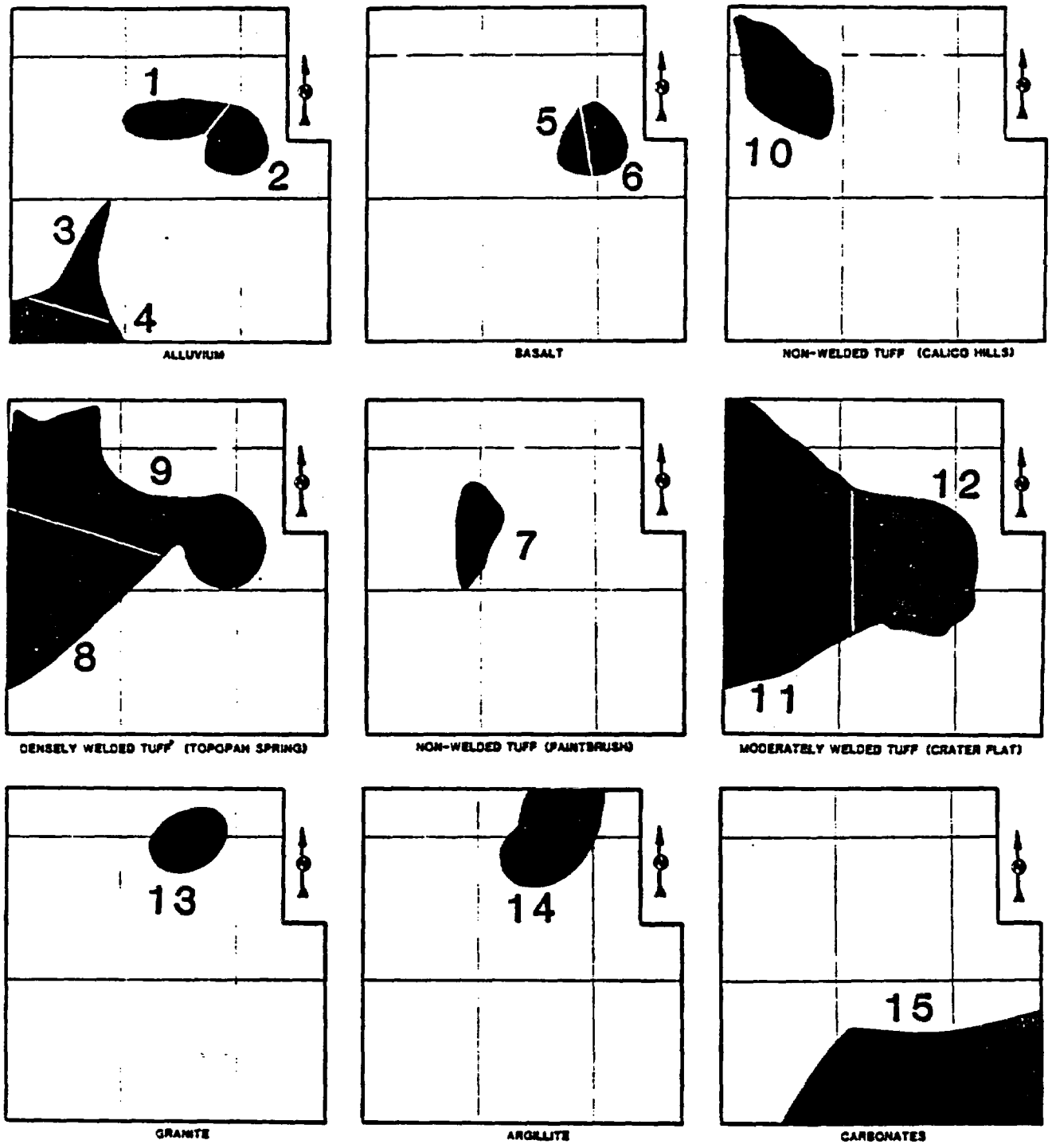

Figure 42. Locations of 15 Distinct Stratigraphic Settings (Dark) of Nine Candidate Host Rocks for Geochemical Retardation Potential

Table 10. Summary of Geochemically Controlled Sorption Score for 15 Stratigraphic Settings

Host Rock	Geographic Location*	Score**	Assigned Attribute Value
Alluvium	1-Western Jackass Flats	2338	
	2-Eastern Jackass Flats	2520	
	3-Lathrop Wells area, north of Highway 95	3028	2,000–4,000
	4-Lathrop Wells area, south of Highway 95	2678	
Basalt	5-Western Jackass Flats	3486	2,000–4,000
	6-Eastern Jackass Flats	1956	
Nonwelded Tuff (Tiva Canyon, et al)	7-Entire area	2911	2,000–4,000
Densely Welded Tuff (Topopah Spring)	8-Southern Yucca Mountain	2396	
	9-Northern Yucca Mountain	3469	2,000–4,000
Nonwelded Tuff (Calico Hills)	10-Entire area	10374	10,000–12,000
Moderately Welded Tuff (Crater Flat, et al)	11-Yucca Mountain	3801	
	12-Jackass Flats	4516	4,000–6,000
Granite	13-Calico Hills	5962	4,000–6,000
Argillite	14-Entire area	12862	12,000
Carbonate	15-Entire area	428	2,000

*See Figure 8.
**See Table 11.

Table 11. Summary of Calculations for Geochemically Controlled Sorption Scores for 15 Stratigraphic Settings

Candidate Rock[1]	Geographic Location[2]	Rating for Units ABOVE Repository Horizon: Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Units in Interval[3]	Thickness Factor (t = 0.01) (TF)	Sorption Score[4] (S)	Subtotal Value (WF) x (TF) x (S)	Rating for Units BELOW Repository Horizon: Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Units in Interval[3]	Thickness Factor (t = 0.01) (TF)	Sorption Score[4] (S)	Subtotal Value (WF) x (TF) x (S)	Total Value
Alluvium	(1)	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
		50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
		0-50	2.0	A	0.5	470	470			A	0.5	470	117	
								150-500	0.5	B	0.5	160	40	
										TB	3.5	100	175	
						ABOVE TOTAL:	1116					BELOW TOTAL:	1222	2338
	(2)	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
		50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
		0-50	2.0	A	0.5	470	470			A	0.5	470	117	
										B	1.0	160	40	
								150-500	0.5	TB[5]	0.5	770	192	
										TB	1.5	100	75	
						ABOVE TOTAL:	1116					BELOW TOTAL:	1484	2520
	(3)	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
		50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
		0-50	2.0	A	0.5	470	470			A	2.5	470	587	
								150-500	0.5	TB	1.0	770	385	
						ABOVE TOTAL:	1116					BELOW TOTAL:	1912	3028
	(4)	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470		470
		50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470		470
		0-50	2.0	A	0.5	470	470	150-500	0.5	A	2.5	470		587
										PC	1.0	70		35
						ABOVE TOTAL:	1116					BELOW TOTAL:	1562	2678
Basalts	(5)	150-500	0.25	A	3.5	470	411	0-50	2.0	B	0.5	160		160
		50-150	0.5	A	1.0	470	235	50-150	1.0	TB[1]	1.0	770		770
										TB	2.0	100		100
		0-50	2.0	B	0.5	160	160	150-500	0.5	CB	1.5	2200		1650
						ABOVE TOTAL:	806					BELOW TOTAL:	2680	3486
	(6)	150-500	0.25	A	3.5	470	411	0-50	2.0	B	0.5	160	160	
		50-150	0.5	A	1.0	470	235	50-150	1.0	TB[5]	1.0	100	770	
										TB	2.0	100	100	
		0-50	2.0	B	0.5	160	160	150-500	0.5	WL[6]	1.5	160	120	
						ABOVE TOTAL:	806					BELOW TOTAL:	1150	1796
Welded Tuff (Paleozoic)	(7)	150-500	0.25	A	3.5	470	411	0-50	2.0	WB	0.5	470	470	
		50-150	0.5	A	1.0	470	235			WP[7]	0.5	2200	1100	
		0-50	2.0	WB	0.5	470	470	50-150	1.0	TB	0.5	100	50	
								150-500	0.5	TB	3.5	100	175	
						ABOVE TOTAL:	1116					BELOW TOTAL:	1795	2911
Densely Welded Tuff (Topopah Spring)	(8)	150-500	0.25	WB	3.5	470	294	0-50	2.0	TB	0.5	100	100	
				TB	1.0	100	25	50-150	1.0	TB	1.0	100	100	
		50-150	0.5	TB	1.0	100	50			TB	1.0	100	50	
		0-50	2.0	TB	0.5	100	100	150-500	0.5	CB	1.0	2200	1100	
										TB	1.5	770	577	
						ABOVE TOTAL:	469					BELOW TOTAL:	1927	2396
	(9)	150-500	0.25	WB	3.5	470	294	0-50	2.0	TB	0.5	100	100	
				TB	1.0	100	25	50-150	1.0	TB	1.0	100	100	
		50-150	0.5	TB	1.0	100	50	150-500	0.5	TB	1.0	100	50	
		0-50	2.0	TB	0.5	100	100			CB	3.5	2200	2750	
						ABOVE TOTAL:	469					BELOW TOTAL:	3000	3469
Nonwelded Tuff (Calico Hills)	(10)	150-500	0.25	TB	3.5	100	42	0-50	2.0	CB	0.5	2200	2200	
				CB	1.0	2200	550	50-150	1.0	CB	1.0	2200	2200	
		50-150	0.5	CB	1.0	2200	1100	150-500	0.5	CB	1.0	2200	1100	
		0-50	2.0	CB	0.5	2200	2200			TB	2.0	770	962	
						ABOVE TOTAL:	3892					BELOW TOTAL:	6462	10374
Moderately Welded Tuff (Crater Flat, et al.)	(11)	150-500	0.25	TB	3.5	770	674	0-50	2.0	TB	0.5	770	770	
		50-150	0.5	TB	1.0	770	385	50-150	1.0	TB	1.0	770	770	
		0-50	2.0	TB	0.5	770	770	150-500	0.5	TB	0.5	770	192	
										TB(CB)[8]	3.0	160	240	
						ABOVE TOTAL:	1829					BELOW TOTAL:	1972	3801

Table 11. (continued)

Candidate Rock[1]	Geographic Location[2]	Rating for Units ABOVE Repository Horizon: Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Units In Interval[3]	Thickness Factor (t x 0.01) (TF)	Sorption Score[4] (S)	Subtotal Value (WF) x (TF) x (S)	Rating for Units BELOW Repository Horizon: Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Units In Interval[3]	Thickness Factor (t x 0.01) (TF)	Sorption Score[4] (S)	Subtotal Value (WF) x (TF) x (S)	Total Value
	(12)	150-500	0.25	CH	3.0	2300	1100	0-50	2.0	BM	0.5	770	770	
				TM	1.5	700	300	50-150	1.0	TM	1.0	770	770	
		50-150	0.5	TM	1.0	770	385	150-500	0.5	BM	0.5	770	192	
		0-50	2.0	TM	0.5	770	770			T[6]	3.0	150	300	
						ABOVE TOTAL:	2544					BELOW TOTAL:	1972	4516
Granite	(13)	150-50	0.25	GA[5]	3.5	2100	1837	0-50	2.0	G	0.5	300	300	
		50-150	0.5	GA(GA)[5]	1.0	2100	1050	50-150	1.0	G	1.0	300	300	
		0-50	2.0	GA(GA)[5]	0.5	2100	2100	150-500	0.5	G	3.5	300	455	
						ABOVE TOTAL:	4987					BELOW TOTAL:	975	5962
Argillite	(14)	150-50	0.25	GA	3.5	2100	1837	0-50	2.0	GA	0.5	2100	2100	
		50-150	0.5	GA	1.0	2100	1050	50-150	1.0	GA	1.0	2100	2100	
		0-50	2.0	GA	0.5	2100	2100	150-500	0.5	GA	3.5	2100	3675	
						ABOVE TOTAL:	4987					BELOW TOTAL:	7875	12862
Carbonate	(15)	150-500	0.25	PC	3.5	70	61	0-50	2.0	PC	0.5	70	70	
		50-150	0.5	PC	1.0	70	35	50-150	1.0	PC	1.0	70	70	
		0-50	2.0	PC	0.5	70	70	150-500	0.5	PC	3.5	70	122	
						ABOVE TOTAL:	1029					BELOW TOTAL:	262	428

[1]Occurrence in screening area shown on Figure 5.
[2]Geographic location is shown on maps in Figure 42.
[3]Rock units and their thicknesses were determined using USGS maps for the area, symbols as follow:

A = Alluvium	BM = Crater Flat, et al.	BT = Bedded Tuff
B = Basalt	CH = Calico Hills	G = Granite
TS = Topopah Spring	UL = Yucca Mountain, et al.	T = Tuff
TM = Timber Mountain	BA = Argillite	
PC = Carbonate	AR = Hornfels(?)	

[4]Sorption scores is from Table 9.
[5]Unaveled Timber Mountain judged similar to unaveled Yucca Mountain.
[6]Yucca Mountain judged similar to Basalt.
[7]Bedded Tuff judged similar to Calico Hills.
[8]Tuff given score of 150.
[9]Hornfels judged similar to argillite.

Discussion of Confidence

None given. See individual technical reports (Additional Readings) for discussion of many factors affecting geochemical retardation.

Basis for Favorability Graph

The sorption properties of rock units surrounding a repository will be important in delaying migration of radionuclides to the surface or some nearby aquifer. The better the sorption characteristics of all rocks along potential flow paths from a repository, the better the geologic setting is for retarding radionuclide migration to the accessible environment. Higher values for this attribute indicate better retarding properties of the setting in which a potential host rock occurs. Discrete favorability values of 1, 2.5, 4, 6, 7.5, 9, and 10 were assigned, respectively, to the low-to-high increments of 2000 for the full range of values found in the screening area (Table 10). The favorability values were chosen to approximate a linear relationship between weighted sorption values and favorability and to maximize distinctions within the range of values for the rocks in the area. A value of 1, rather than something less, was chosen for the lowest favorability to indicate that all settings have some capability for retardation of nuclide migration by sorption.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.1.2 Maximize Retardation of Radionuclides Along Flow Paths

2.1.3 Maximize Extent of Relatively Homogeneous Host Rock

2.1.4 Minimize Migration of Volatile Waste Components

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Hydrologic Attributes

Attribute 30. Hydraulic Retardation
(Figure 40)

Compilers

Host-Rock Values:
B. R. Erdal, K. Wolfsberg, and C. J. Duffy (LANL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Ranking numbers for the potential for hydraulically retarding radionuclide migration through particular rock types.

Rationale for Host-Rock Values

From the point of view of containment of radioactive waste in a given rock unit, it is important to maximize the time necessary for the constituents of a given volume of water to be transported a given distance, independent of any chemical reactions that may occur. The principal processes evaluated for this attribute are the estimated relations among fracture flow, matrix flow, and diffusion into the matrix from fractures. Thus, the effective porosities of the matrix and fractures of the rock are important factors in determining hydraulic retardation. Concentration gradients for radionuclides in solution in groundwater provide a mechanism to cause migration of waste elements from areas of high concentration, such as along fractures connected to waste emplacement areas, to areas of lower concentration, such as pores in a rock surrounding the fractures. Twelve rock types, including the nine candidate host rocks, were scored with respect to their relative capacity for diffusion (Figure 43). Based on these scores, the rock types were ranked. Several of the rocks scored the same, so the ranks range only from 1 to 7. Higher ranks correspond to greater capacity for matrix diffusion. The rank of 4 corresponds to one of the rock types not considered in screening, so this rank is not assigned to any of the nine candidates. Comments about the rock properties that affect hydraulic retardation for each candidate host rock follow.

Alluvium: Alluvium is generally characterized by interconnected pores that occur as interstices among individual particles of coarse sediment. This characteristic facilitates the diffusion of radionuclides into a large volume of alluvial material. In addition, diffusion into the matrix of individual rock particles is facilitated because each particle will be initially surrounded by solutions with higher concentrations of radionuclides than solutions in the particles. Alluvium is assigned a relative rank of 1 for hydraulic retardation.

Basalt: Basalt is generally characterized by a highly impermeable, very low porosity matrix, and few-to-numerous interconnected fractures. Because of the nature of the matrix, little diffusion of radionuclides from fractures into the matrix can occur. For this reason, basalt is assigned a rank of 6 for hydraulic retardation.

Nonwelded Tuff (Tiva Canyon, Pah Canyon, and Yucca Mountain Members): Nonwelded tuff is generally characterized by a highly porous, but low-permeability, matrix and few, widely spaced, interconnected fractures. Though nonwelded tuff is generally impermeable, the paucity of interconnected fractures and the high intrinsic porosity facilitates movement of radionuclides into the rock matrix from existing fractures. This rock unit is assigned a relative rank of 2 for hydraulic retardation.

Densely Welded Tuff (Topopah Spring Member): Densely welded tuff is generally characterized by moderate matrix porosity. Matrix permeability is generally low. Fractures tend to be numerous, but due to local differences in fracture conditions and interconnectedness, fracture permeability is highly variable. Though the matrix is quite impermeable, its moderate porosity will allow some diffusion of radionuclides into the matrix. This rock unit is assigned a rank of 5 for hydraulic retardation.

ROCK UNITS	BINARY COMPARISON (ARROWS POINT TO BETTER ROCK, CIRCLES EQUAL ROUGH EQUALITY)											SCORE **	RANK
ALLUVIUM	←	←	←	○	←	○	←	←	←	←	←	10.0	1
BASALTS OF SKULL MTN. & KIWI MESA	○	↓	↓	↓	↓	↓	↓	○	○	←		2.5	6
LAVAS OF DOME MTN.*		↓	↓	↓	↓	↓	↓	○	○	←		2.5	6
TUFF OF CHOCOLATE MTN. (WELDED)*			↓	←	↓	↓	○	←	←	←		6.5	4
NONWELDED PAINTBRUSH TUFF				←	○	←	←	←	←	←		9.5	2
DENSELY WELDED TOPOPAH SPRING TUFF					↓	↓	↓	←	←	←		5.0	5
NONWELDED CALICO HILLS TUFF						←	←	←	←	←		10.0	1
MODERATELY WELDED CRATER FLAT TUFF							←	←	←	←		8.0	3
INTRACALDERA AMMONIA TANKS (WELDED)*								←	←	←		6.5	4
GRANITE									○	←		2.5	6
ARGILLITE										←		2.5	6
CARBONATES												0.0	7

* DOES NOT OCCUR IN SCREENING AREA WITH 100 FT THICKNESS BETWEEN DEPTHS OF 500 AND 400 FT.

** OBTAINED BY SUMMING ARROWS POINTING TOWARD EACH ROCK UNIT, ZEROS COUNT FOR 0.5

Figure 43. Comparison Matrix for Ranking Hydraulic Retardation Potential of Twelve Rock Types Occurring In and Near the Screening Area

Nonwelded Tuff (Calico Hills): This unit is similar to the nonwelded tuffs of the Tiva Canyon, Pah Canyon, and Yucca Mountain members, but is highly zeolitized. The open lattice structure of zeolites facilitates diffusion of radionuclides into the rock matrix, thus improving its hydraulic retardation somewhat with respect to nonzeolitized tuffs. This unit is assigned a rank of 1 for hydraulic retardation.

Moderately Welded Tuff (Crater Flat): Moderately welded tuff is generally characterized by fracture-porosity features intermediate between nonwelded and densely welded tuffs. Thus porosity is higher and fracture density lower than densely welded tuff and vice versa for nonwelded tuff. Its hydraulic retardation capability is likewise intermediate between the capabilities of densely welded and nonwelded tuff. This unit is assigned a rank of 3 for hydraulic retardation.

Granite: Granite is generally characterized by extremely low matrix porosity and permeability and variable fracture permeability depending on the nature and interconnectedness of fractures. However, slow flow through fractures will permit some diffusion of radionuclides into the rock matrix and along fractures perpendicular to flow. Granite is assigned a rank of 6 for hydraulic retardation.

Argillite: Argillite is generally characterized by high matrix porosity but very low permeability and low fracture permeability due to the ductile behavior of the rock, which tends to seal any fractures that may form. The interlayering of clays comprising the rock generally will constrain diffusion to bedding plans and retard diffusion across bedding. For this reason, the hydraulic retardation is limited in argillites and a rank of 6 is assigned to this rock unit.

Carbonate: Carbonate rocks are generally characterized by very low matrix porosity and permeability and highly variable fracture permeability. Water flow tends to dissolve the rock, creating a system of interconnected, highly permeable flow conduits through the rock mass. The opportunity for diffusion of radionuclides into the rock matrix is severely limited by both the nature of concentrated flow and the low porosity of the rock matrix. This unit is assigned a rank of 7 for hydraulic retardation.

Discussion of Confidence

None given. See individual technical reports (Additional Readings) for discussion of factors affecting diffusion.

Basis for Favorability Graph

If a large amount of diffusion occurs, the rock will act as a sponge to radionuclides, thereby reducing contaminant migration rates. The better the capability of a rock to retard radionuclide migration by hydraulic diffusion processes, therefore, the greater is its favorability. The favorability values assigned to individual ranks are based on the assumption that the higher rank numbers (lower retardation capacities) drop rapidly in favorability, whereas the lower rank numbers (higher retardation capacity) are more similar with respect to favorability. The favorability graph thus approximates the general form of a curve with an equation of $y = x^m$, where m is >1. The favorability values assigned to ranks 1 through 7 are, respectively, 10, 9.5, 8, 6.5, 5, 2.5, and 0. Only seven ranks are used because, of the nine rocks originally rated, some ranked equal.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

2.1.1 Maximize Groundwater Flow Time
2.1.2 Maximize Retardation of Radionuclides Along Flow Paths
2.1.4 Minimize Migration of Volatile Waste Components

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Attribute 31. Hydraulic Transmissivity
(Figure 40)

Compilers

Host-Rock Values:
W. Wilson and R. Waddell (USGS) and S. Sinnock (SNL)
Favorability Graph:
S. Sinnock (SNL)

Host-Rock Units

Hydraulic transmissivity in m^2/s at logarithmic intervals of 10^{-5}, 10^{-4}, 10^{-3}, and 10^{-2}.

Rationale for Host-Rock Values

A transmissivity has been assigned to each of the nine potential host rocks in the screening area. Transmissivity is a measure of an aquifer's ability to transmit water. Units of hydraulic transmissivity are length squared per second; units for screening are expressed as m^2/s. Most values used for screening were obtained by multiplying transmissibility values reported in USGS Prof. Paper 712-C (Winograd and Thordarson, 1975) by 1.45×10^{-7}. The source values in transmissibility and the derived transmissivity values are shown in Table 12 for rock types similar to those in the screening area. The transmissibility values were obtained from pump tests or professional estimates.

Each rock type is defined by a range of measured transmissivities (Figure 44), and a general value within that range was assigned to each rock type for screening. The values assigned are based on a logarithmic scale, and each rock is assigned to an order of magnitude between 10^{-5} and 10^{-2} m^2/s, generally corresponding to the middle to upper range of transmissivity for that rock type. Comments about the particular water transmitting properties of each candidate rock type follow.

Alluvium: Transmissivity of alluvium is generally high due to interconnected porosity of the unconsolidated material. Porosity ranges from ~15% to 45% and averages ~30% based on samples obtained primarily from Frenchman and Yucca Flats. The degree of interconnected porosity depends on the sorting characteristics, calicification, and argillization of the alluvium. Caliche or clays, if abundant, can fill the voids between particles, thereby lowering porosity and perhaps transmissivity. Much of the alluvium in the screening area is above the zone of saturation. Based on the range of measured transmissibilities, a value of transmissivity of 10^{-3} m^2/s was assigned to alluvium. All tests were conducted on Yucca and Frenchman Flats.

Basalt: Transmissivity of basalt must be inferred from pump test results in well J-11 in Jackass Flats, where the tested interval spanned ~111 ft of basalt and 179 ft of welded tuff. About one-third of the observed transmissivity is assumed to come from the basalt in accordance with the proportion of the total test interval developed in the basalt. This yields a transmissivity of $\sim 1.5 \times 10^{-3}$ m^2/s for the basalt. All, or nearly all, transmissivity is assumed to be due to interconnected cooling fractures and tectonic joints.

Nonwelded Tuff (Tiva Canyon, Yucca Mountain, Pah Canyon, and Upper Topopah Spring Members): Transmissivity of nonwelded tuff is generally low due to the lack of effective porosity. These rocks are formed by volcanic ash settling over the land. Small glass shards that form the ash are generally fused where they touch one another, yielding little interconnected pore space. However, porosity of these rocks is generally very high, up to ~40%. Alteration of the glass shards commonly occurs, producing clays, zeolites, or quartz and feldspars. Permeability and associated transmissivity generally decreases with the degree of argillization or zeolitization. Transmissivity is primarily through fractures because matrix permeability is so low, though many fractures are probably discontinuous or sealed with secondary minerals. When fractures are intersected in tunnels or wells, initial high yields of water rapidly decrease, suggesting that sets of discontinuous, water-bearing fractures quickly drain, whereupon yields are reduced. This unit is devitrified but not highly argillized or zeolitized; therefore, its permeability is generally higher than the nonwelded zeolitized Calico Hills bedded tuff. This unit was assigned a transmissivity of 10^{-4} m^2/s based on the range of measured values for similar rocks beneath Pahute Mesa. In many parts of the screening area, this unit is generally above the zone of saturation.

Table 12. Ranges of Hydraulic Transmissivity for Selected Rock Types in the NTS Area

Rock Type	Measure of Transmissibility Reported in Winograd & Thordarson, 1975 (gpd/ft)	Test Well	Corresponding Transmissivity (m^2/s)
Alluvium	2,400 33,500	74–706 91–74	3.5×10^{-4} 4.9×10^{-3} [a] 1×10^{-2}
Basalt	<10,000[b]	74–61 (J-11)[b]	1.5×10^{-3}
Nonwelded Tuff (not zeolitized)	200 1,000	90–74 81–67	2.9×10^{-5} 1.5×10^{-4}
Nonwelded Tuff (zeolitized)	100–200	(see p C-46, Winograd & Thordarson)	$1.5–2.9 \times 10^{-5}$
Densely Welded Tuff	18,000[b] 100,000	74–61 (J-11) 73–58 (J-13)	2.6×10^{-3} 1.5×10^{-2}
Moderately Welded Tuff	—	USW-H-1[a]	1×10^{-5} to 1×10^{-4}
Granite	—	—[c]	9.5×10^{-7} to 7×10^{-5}
Argillite	<500 0.83	(see p C-43, Winograd & Thordarson) 84–67	7.5×10^{-5} 1.2×10^{-7}
Carbonate	3,500 86,000[d] 900,000[e]	87–62 67–68 76–69a	5.1×10^{-4} 1.2×10^{-2} $\times 10^{-1}$

[a]Value provided by W. Wilson.

[b]Well J-11 was tested from an interval that spanned basalt and underlying Topopah Spring tuff. Thus some fraction of the measured total transmissibility of 28,000 is due to water from basalt and some from the Topopah Spring. It is assumed that 10,000 gpd per ft is due to yield from basalt and 18,000 gpd per ft is due to Topopah Spring.

[c]Data on Granite from Murray (1980) where transmissivity of the Climax Stock granite is reported directly based on permeability measurement in the Climax Mine.

[d]Based on recovery rather than drawdown curve.

[e]Estimated from specific capacity.

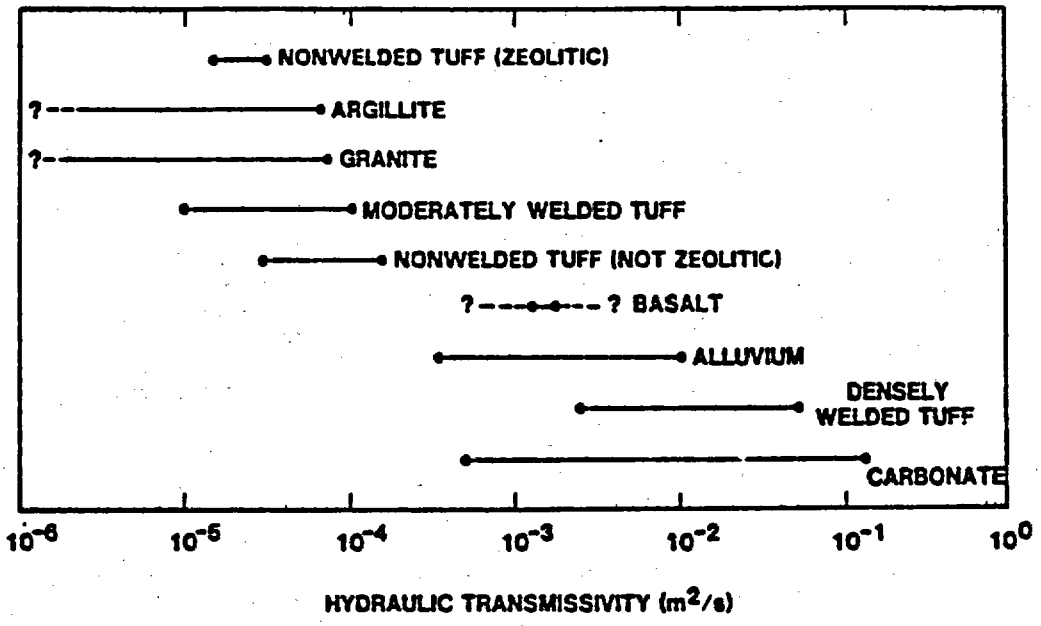

Figure 44. Range of Hydraulic Transmissivity for Selected Rock Types in the NTS Area

Densely Welded Tuff (Topopah Spring Member): Transmissivity of densely welded tuff is generally high, and where it is saturated this unit serves as an aquifer. Effective porosity is primarily along well-developed fracture systems composed of both cooling fractures and tectonic joints. The brittle nature of this type of tuff distinguishes its hydraulic properties from the more ductile nonwelded tuff; welded tuff tends to support more fractures. Lithophysae in the central parts of ash-flow cooling units may contribute to its transmissivity if these openings are connected by open fractures. Porosity of the matrix of welded tuff is generally <20%, ranging to as low as 2%–3%. Because the permeability is fracture-dominated, alteration of the rock to secondary minerals, such as zeolites and clays, only affects transmissivity if the alteration products fill or restrict fractures. The densely welded Topopah Spring Member was assigned a transmissivity of 10^{-2} m^2/s based on well tests in J-11, J-12, J-13, and wells in similar welded tuffs at Pahute Mesa and Timber Mountain. Throughout much of the screening area the Topopah Spring occurs above the zone of saturation.

Nonwelded Tuff (Calico Hills): The same general properties discussed for the nonwelded Tiva Canyon, Pah Canyon, Yucca Mountain, and Upper Topopah Spring apply to the Calico Hills nonwelded unit, except that the Calico Hills is highly zeolitized and its permeability and transmissivity is therefore probably less. A transmissivity of 10^{-5} m^2/s was assigned to the Calico Hills based on well tests on J-12 and of similar zeolitized, nonwelded tuffs below Yucca Flat. Within the screening area, most of the Calico Hills occurs above the zone of saturation.

Granite: Transmissivity of granite is generally very low. Because the intrinsic interconnected porosity of solid granite is essentially 0, and nearly all the transmissivity occurs in fractures. Fractures in granite are generally quite tight and often sealed with secondary minerals. Based on hydraulic tests in the Climax Stock at the north end of Yucca Flat, a transmissivity of 10^{-5} m^2/s is assigned to granite. The granite in the screening area (inferred to occur beneath Calico Hills) is a Tertiary stock as opposed to the Mesozoic Stock at Climax. Mineralized zones around Calico Hills are thought to be due to hydrothermal alteration associated with emplacement of the Tertiary stock. If this alteration extends into the stock, the granite here may be more transmissive than the older stock at Climax.

Argillite: Transmissivity of argillite is generally very low. Total porosity is generally high, approaching 30%–40% in some argillites, but the overlap of oriented clays that comprise the rock make interconnected porosity and associated permeability very low. Fractures tend to be tightly sealed due to the highly ductile nature of the rock. A transmissivity of 10^{-5} m^2/s was assigned to argillite based on test wells in Yucca Flat. Some of the argillite at Calico Hills and Upper Topopah Wash is probably above the zone of saturation.

Carbonate: Transmissivity of carbonates is highly variable, but generally carbonates have high transmissivity and are prolific aquifers. Interconnected matrix porosity of carbonates is generally very low due to the nature of interlocking calcite or dolomite crystals, but bulk interconnected porosity along fractures can be very well developed, resulting in high permeability. Because carbonates are relatively soluble in water, fractures tend to be loci of solution openings in the rock. Under extreme conditions, solution along fractures can be great enough to create solution channels. The location of solution channels in carbonates is difficult to predict. In the massive carbonate section of the southeast corner of the screening area, it is likely that some depths and locations are highly transmissive, whereas others are very tight. Because some zones within any relatively small volume of rock are likely to contain transmissive solution-opened fractures, a high transmissivity of 10^{-2} m^2/s was assigned to the carbonate rocks. This value is based on well tests in Yucca Flat.

Discussion of Confidence

Because of the unknown influence of local structural conditions, low confidence is assigned to all values for transmissivity.

Basis for Favorability Graph

Low hydraulic transmissivity is desirable for rocks surrounding a repository. Favorability values were assigned to order of magnitude intervals of hydraulic transmissivity based on an assumption that the relative favorability for rocks $<10^{-4}$ m^2/s is generally high, whereas rocks $>10^{-2}$ are generally unfavorable. Thus a large step occurs in the graph between values of 10^{-4} and 10^{-3}. As the hydraulic transmissivity increases, the favorability drops at an increasing rate; thus the graph approximates a curve of the general form expressed by $y = x^m$ where m is >1. Favorability values of 10, 8, 5, and 1 were assigned, respectively, to transmissivities of 10^{-5}, 10^{-4}, 10^{-3}, and 10^{-2} m^2/s.

Objectives Evaluated by This Attribute

(See Sinnock and Fernandez, 1984, for discussion)

1.1.1 Minimize Potential for Chemically Induced Release
2.1.1 Maximize Groundwater Flow Time
2.1.4 Minimize Migration of Volatile Waste Components
3.2.2 Minimize Subsurface Flooding Hazards
3.2.3 Minimize Adverse Mining Conditions

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Chapter 4. Host-Rock Maps

This chapter presents the supporting rationale and assumptions for selecting and mapping the nine rock types considered in screening. The rock types selected for comparison were chosen from all rock types known or thought to exist within boundaries of nine 7 1/2-minute topographic quadrangles that encompass the screening area (Table 13). After these rock types were identified, each was compared to four criteria:

- Is the rock unit at least 100 ft thick?
- Does this thickness occur between depths of 500 and 4000 ft?
- Is the rock unit generally of the same physical character throughout its volume of occurrence?
- Is the area of occurrence of generally constant character at least 2000 acres?

These criteria were designed to eliminate rock types judged to be too shallow, too deep, too complex, or too restricted in area for serious consideration. The 100-ft thickness was based on the assumption that about 30 vertical feet would be mechanically disturbed by repository construction, and that a zone above and below the mechanically disturbed zone approximately equal in thickness to it would provide a conservative "buffer" whereby rock thermal and mechanical parameters outside the "buffer" would not significantly affect the local conditions to which emplaced waste would be subjected. One hundred feet was the nearest round number that satisfied this discretionary set of inferred conditions. The upper depth criterion of 500 ft was set to ensure that the candidate rocks were sufficiently deep to be beyond the reach of natural erosion during the next 10 to 100,000 years. The lower depth of 4,000 ft was based on the inferred effects of in situ temperatures and stresses that, below that depth, were considered too costly and troublesome to attempt to ameliorate. The requirement for relative homogeneity of physical character was based on a presumption that heterogeneous materials would be unduly difficult to characterize and model sufficiently for demonstrations of compliance with regulatory standards. The 2,000-acre requirement allows consideration only of rock masses that can accept ~100,000 metric tons of waste 10 years old or less at densities no greater than about 50 to 100 thermal kW per acre.

Twelve rock units in the nine 7 1/2-minute quadrangles met all four criteria (Table 13). Values for the eight host-rock attributes were assigned to these twelve rock types. Subsequently, the formal screening area was redefined to a smaller area (Figure 1), and three of the twelve rock types that occur outside the redefined area were dropped from consideration. Accordingly, nine rock types comprise the candidates considered in screening.

The rock types, their attribute values, and the associated favorability graphs are presented in Figure 40 (Chapter 3). Some of the attributes are expressed as ranks based on the 12 originally considered rock units. Because the ranks were scaled to twelve rocks and rescaling to nine rocks was considered unnecessary, ranks associated with the three rock types dropped from consideration do not appear in the current list.

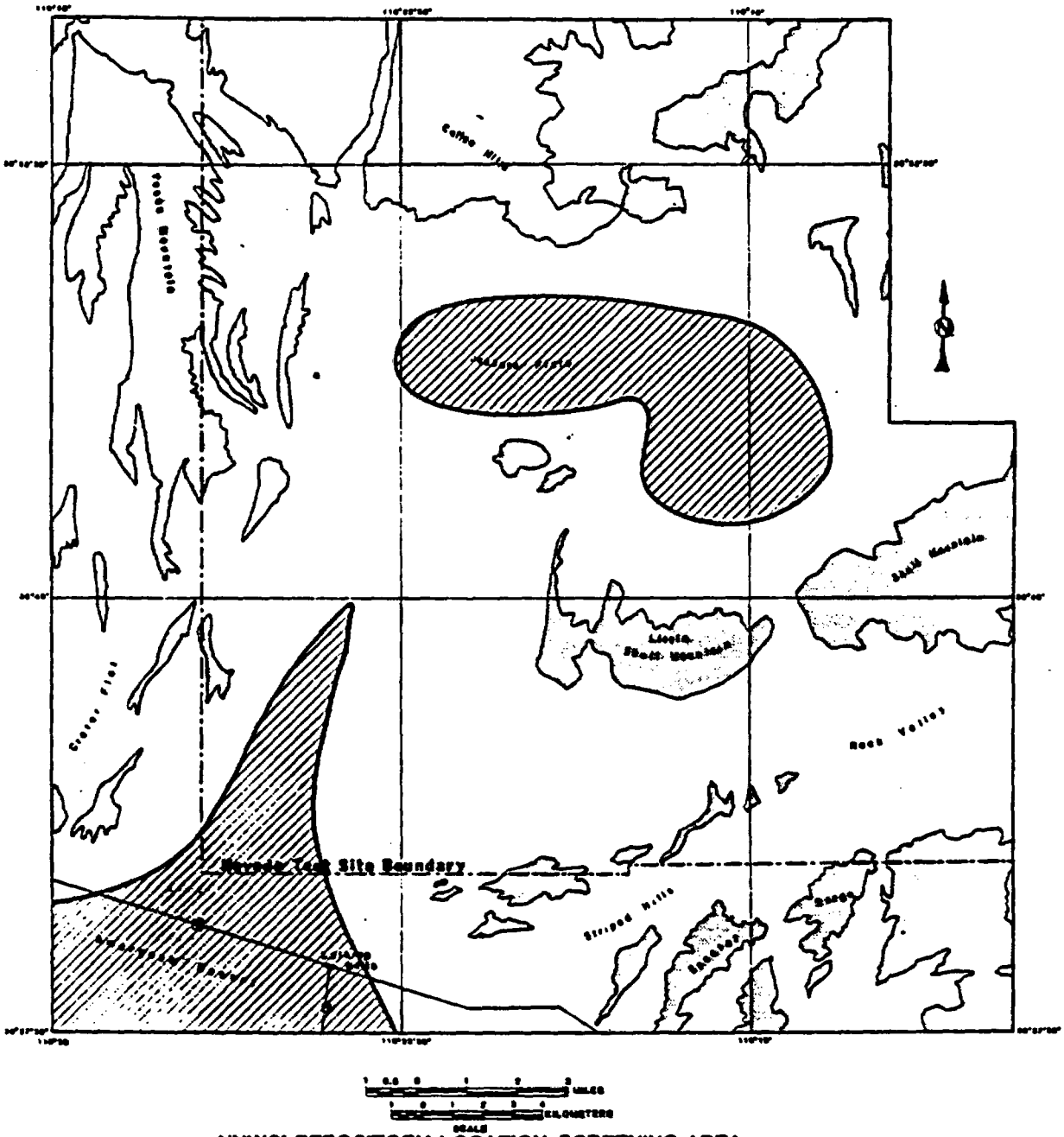
This chapter discusses the assumptions and data sources on which the maps showing the distribution of the nine candidate host rocks were based. For each candidate rock unit, the following information is provided:

- A map of where 100 ft of the rock unit occurs between depths 500 and 4,000 ft
- A list of attribute values assigned to the rock unit (upper right corner of the map)
- The compilers of the map
- The rationale for the rock unit boundaries on the map
- Confidence estimates for the map
- Additional readings for supporting information on the distribution of the rock type in the vicinity of the screening area

Table 13. Relation of Rock Types Occurring in Nine Topographic Quadrangles Encompassing the Screening Area to Criteria for Consideration in Screening

Lithologic Unit	Thick Enough?	Deep Enough?	Shallow Enough?	Comments
Young Basalt	No	No	Yes	Unacceptable
Alluvium	Yes	Yes	Yes	Acceptable; unsaturated zone only
Thirsty Canyon Tuff	No	No	Yes	Unacceptable
Ammonia Tanks Member of Timber Mountain Tuff	?	No	Yes	Unacceptable
Rainier Mesa Member of Timber Mountain Tuff	?	No	Yes	Unacceptable
Shoshone Rhyolites	Yes	No	Yes	Unacceptable
Rhyolites of Forty-Mile Canyon	Yes	Yes	Yes	Unacceptable; too variable
Nafic Lavas of Dome Mountain	Yes	Yes	Yes	Unacceptable; too variable
Basalt Lavas of Skull Mountain	No	Yes	Yes	Unacceptable
Basalt Lavas of Kiwi Mesa	Yes	Yes	Yes	Acceptable
Tiva Canyon Member of the Paintbrush Tuff	Yes	Yes	Yes	Acceptable; nonwelded
Yucca Mountain Member of the Paintbrush Tuff	Yes	Yes	Yes	Acceptable; nonwelded
Pah Canyon Member of the Paintbrush Tuff	Yes	Yes	Yes	Acceptable; nonwelded
Tuff of Chocolate Mountain	Yes	Yes	Yes	Acceptable; single welded unit inside the caldera
Topopah Spring Member of the Paintbrush Tuff	Yes	Yes	Yes	Acceptable; welded
Rhyolite Lavas and Tuffs of Calico Hills	Yes	Yes	Yes	Acceptable; this nonwelded unit may be too complex to the east to be mapped.
Wahmonie/Salyer Formation	Yes	Yes	Yes	Unacceptable; too variable
Prow Pass Member of the Crater Flat Tuff	Yes	Yes	Yes	Acceptable; moderately welded
Bullfrog Member of the Crater Flat Tuff	Yes	Yes	Yes	Acceptable; moderately welded
Tram Member of the Crater Flat Tuff	Yes	Yes	Yes	Acceptable; above rhyodacite at base, moderately welded, lithic-rich, no vitriphere
Rocks of Pavita Springs/ Horse Spring Formation	?	Yes	Yes	Unacceptable; too variable
Older Tuffs	Yes	No	No	Unacceptable
Eleana Argillite	Yes	Yes	Yes	Acceptable
Paleozoic Carbonates	Yes	Yes	Yes	Acceptable
Pre-Cambrian/Paleozoic Clastics	Yes	Yes	Yes	Acceptable
Granitic Intrusives	Yes	Yes	Yes	Acceptable

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	0.8–1.6
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	<7,000
27	EXPANSION OR CONTRACTION UPON HEATING	CONTRACTION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	7
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	3,000–4,000
30	HYDRAULIC RETARDATION-DIFFUSION (RANK ORDER)	1
31	HYDRAULIC TRANSMISSIVITY (cm²/sec)	10^{-6}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : ALLUVIUM

Figure 45. Subsurface Distribution (Cross Hatches) and Attribute Values of Alluvium

Alluvium
(Figure 45)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where alluvium at least 100 ft thick occurs between depths of 500 and 4000 ft. Both Tertiary and Quarternary alluvium are included in the mapping unit, though all the Tertiary alluvium occurs below the surface. The unit includes a variety of conditions with respect to degree of induration, degree of particle sorting, type of alluvial clasts, and degree of saturation, but it is judged sufficiently homogeneous in gross properties to be mapped as a single unit. The boundaries of the unit are based on observed thicknesses in drill holes J-11, J-12, and J-13, an observed gravity low trending along the southern portion of Fortymile Wash, and an assumption that the alluvial deposits of the basins generally become thinner toward the bedrock outcrops in the ranges. The boundaries are only approximate, but probably represent the general region where the alluvium occurs with requisite thickness and depth. The absence of the mapped unit in Rock Valley is because insufficient thickness of alluvium occurs in there.

Confidence Estimates

High confidence in the occurrence of the mapped unit is assigned only to the central part of the Jackass Flats basin in the region surrounding well J-11, where about 1000 ft of alluvium is known to occur. Intermediate confidence is assigned to two separate mapped areas of alluvium based on uncertainties about whether the requisite thickness occurs below 500-ft depths. The thickness of alluvium in the area between Calico Hills and bedrock outcrops just south of the EMAD facility probably is 600 ft or greater (yielding 100 ft of thickness at more than 500-ft depth), but lack of certainty is judged sufficient to merit only an intermediate confidence assignment. About 500 ft of alluvium occurs at well J-12, and it is assumed that the thickness increases to the requisite 600 ft south along the trend of a gravity low. Because of this assumption, intermediate confidence is assigned to the mapping unit along this trend. Confidence in the geometry of the suballuvial surface decreases on either side of the southerly trend of Fortymile Wash where it enters the Amargosa Valley, and, as a result, low confidence is assigned to the regions where alluvium is mapped outside the gravity low trough and south of the NTS boundary.

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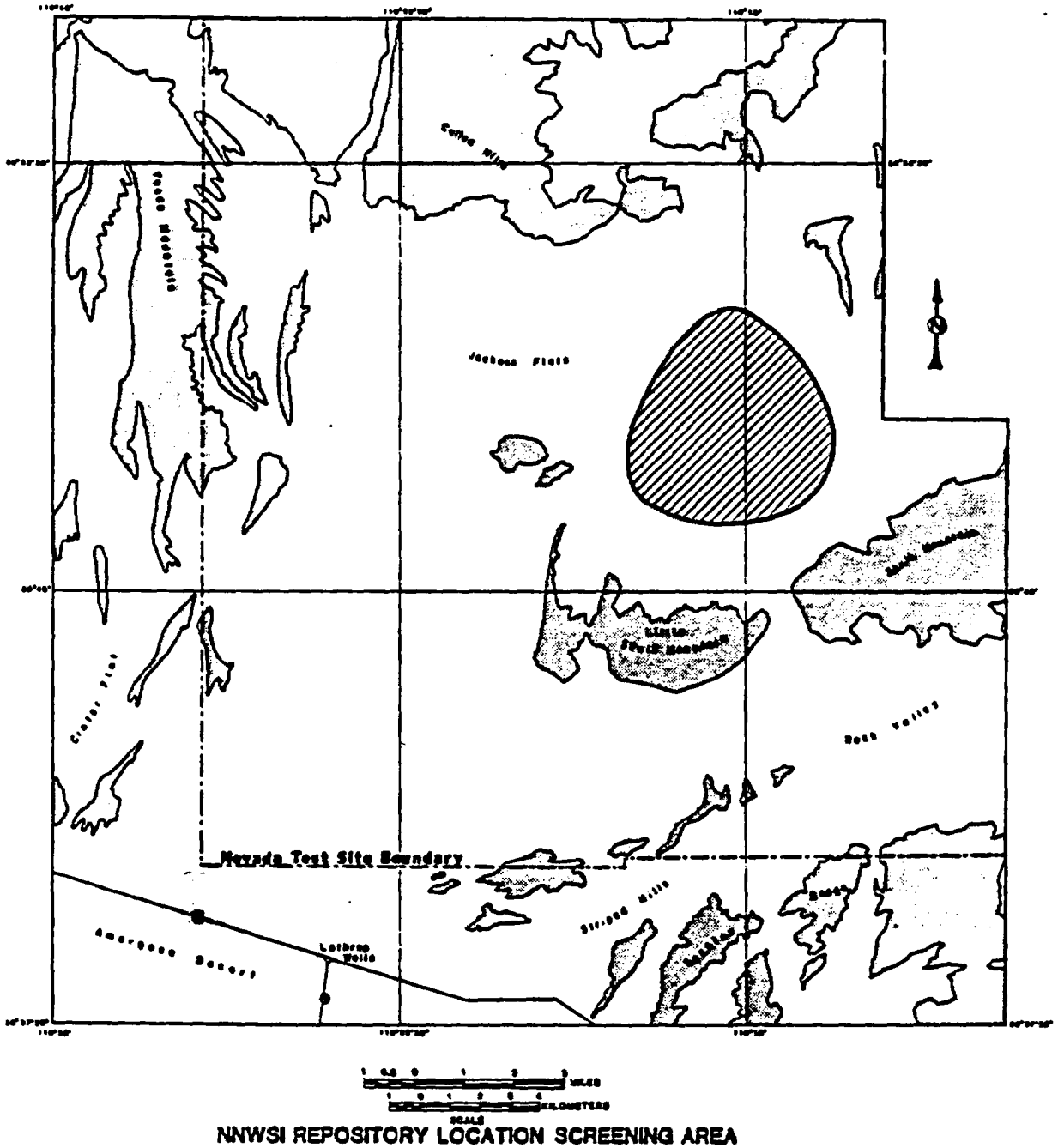
Sargent, K. A., and Stewart, J. H. (1971). *Geologic Map of the Specter Range NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-884.

Young, R. A. (1972). *Water-Supply for Nuclear Rocket Development Station at the Atomic Energy Commission's Nevada Test Site.* US Geol Surv Water-Supply Pap 1938, 19 p.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°C)	1.6-2.6
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	>20,000
27	EXPANSION OR CONTRACTION UPON HEATING	EXPANSION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	4
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	2,000-4,000
30	HYDRAULIC RETARDATION-DIFFUSION (RANK ORDER)	6
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-5}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : BASALT (Kiwi Mesa, Skull Mountain units)

Figure 46. Subsurface Distribution (Cross Hatches) and Attribute Values of Basalt

Basalt
(Figure 46)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where basalt at least 100 ft thick occurs between depths of 500 and 4000 ft. Basalt of the requisite thickness and depth was penetrated in well J-11 in east-central Jackass Flats. The area shown on the map is based on the presumption that the basalt in well J-11 is correlative with basalt cropping out on Skull Mountain, Little Skull Mountain, Kiwi Mesa, and small hills protruding above alluvium in central Jackass Flats, and on the inference that the basalt becomes progressively closer to the surface along radial transects from well J-11 toward outcrop areas. The basalt mapped occurs below alluvium and above silicic Tertiary volcanic rocks; it is presumed, therefore, to be of Tertiary age.

Confidence Estimates

High confidence is assigned to the occurrence of the unit with requisite thickness and depth throughout the mapped area, though confidence—especially for depth and somewhat for thickness—decreases outward from drill hole J-11.

Additional Readings

Christiansen, R. L., and Lipman, P. W. (1965). *Geologic Map of the Topopah Spring NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-444.

Ekren, E. B., and Sargent, K. A. (1965). *Geologic Map of the Skull Mountain Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-387.

Lipman, P. W., and McKay, E. J. (1965). *Geologic Map of the Topopah Spring SW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-439.

McKay, E. J., and Sargent, K. A. (1970). *Geologic Map of the Lathrop Wells Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-883.

McKay, E. J., and Williams, W. P. (1964). *Geology of the Jackass Flats Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-368.

Orkild, P. P. (1968). *Geologic Map of the Mine Mountain Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-746.

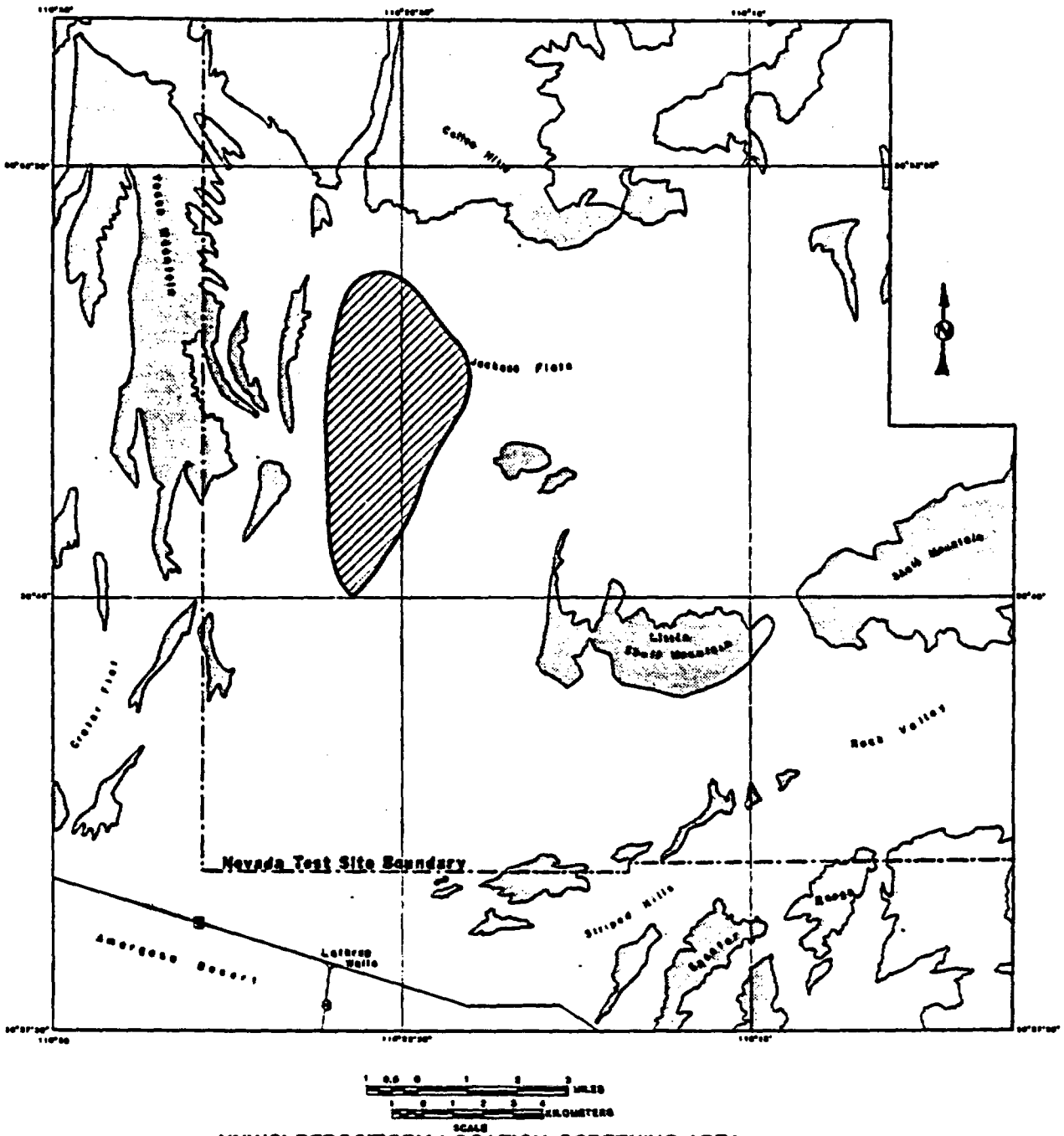
Orkild, P. P., and O'Connor, J. T. (1970). *Geologic Map of the Topopah Spring Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-849.

Sargent, K. A., McKay, E. J., and Burchfiel, B. C. (1970). *Geologic Map of the Striped Hills Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-882.

Sargent, K. A., and Stewart, J. H. (1971). *Geologic Map of the Specter Range NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-884.

Young, R. A. (1972). *Water-Supply for Nuclear Rocket Development Station at the Atomic Energy Commission's Nevada Test Site.* US Geol Surv Water-Supply Pap 1938, 19 p.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	0.5–1.5
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	<7,000
27	EXPANSION OR CONTRACTION UPON HEATING	CONTRACTION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	7
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	3,000–4,000
30	HYDRAULIC RETARDATION–DIFFUSION (RANK ORDER)	2
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-4}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : NON-WELDED TUFF (Portions of Paintbrush Formation)

Figure 47. Subsurface Distribution of Nonwelded Paintbrush Tuff and Attribute Values

Nonwelded Paintbrush Tuff
(Lower Tiva Canyon, Pah Canyon, Yucca Mountain, and Upper Topopah Spring Members)
(Figure 47)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where nonwelded tuff of the Tiva Canyon, Pah Canyon, Yucca Mountain, and Topopah Spring Members of Paintbrush Tuff at least 100 ft thick occurs between depths of 500 and 4000 ft. Though the map unit includes multiple stratigraphic units, it is considered to be a single, vertically continuous zone of similar rocks with respect to physical properties. Only the lower portions of the Tiva Canyon and the upper part of the Topopah Spring Members, which are nonwelded, are included in the mapping unit. The entire Pah Canyon and Yucca Mountain Members are assumed to be nonwelded. The unit is characterized by various degrees of welding, mineral assemblages, degrees of matrix porosity, fracture conditions, degrees of saturation, thicknesses of individual members, and interflow bedding conditions, but is judged sufficiently homogeneous to qualify as a single mapping unit. The boundaries of the mapping unit are based on observed thicknesses in drill holes J-12, J-13, and in outcrops on Shoshone Mountain and observed depths in drill holes USW-G-1, USW-H-1, Ue25a#1, 4, 5, 6, and 7. The boundaries are only approximate, but are judged to represent the general area where nonwelded Paintbrush Tuffs occur with requisite thickness and depth.

Confidence Estimates

A high confidence in both depth and thickness is obtained between wells J-12 and J-13. Other mapped areas are assigned intermediate confidence based on some uncertainty regarding whether the required thickness of nonwelded tuff occurs. This uncertainty is based on both thickness and degree of welding uncertainties.

Additional Readings

Byers, F. M., Jr., Carr, W. J., Orkild, P. P., Quinlivan, W. D., and Sargent, K. A. (1976). *Volcanic Suites and Related Cauldrons of Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada.* USGS Prof Pap 919, 70 p.

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McKay, E. J., and Williams, W. P. (1964). *Geology of the Jackass Flats Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-368.

Orkild, P. P. (1968). *Geologic Map of the Mine Mountain Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-746.

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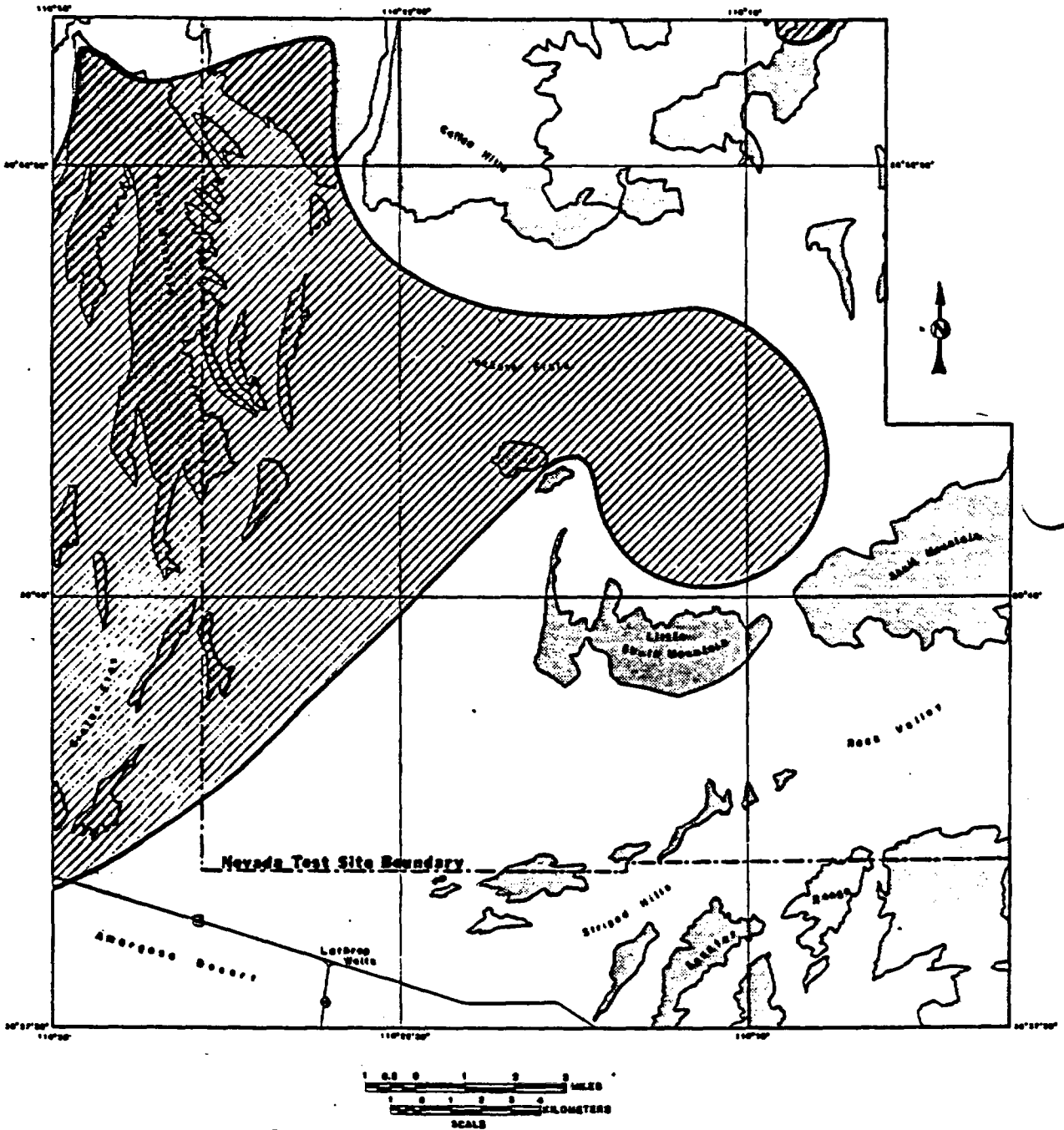
Sargent, K. A., and Stewart, J. H. (1971). *Geologic Map of the Specter Range NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-884.

Spengler, R. W., and Rosenbaum, J. G. (1980). *Preliminary Interpretations of Geologic Results Obtained From Boreholes UE25a-4, -5, -6, and -7, Yucca Mountain, Nevada Test Site.* US Geol Surv Open-File Report 80-929.

Spengler, R. W., Byers, F. M., Jr., and Warner, J. B. (1981). *Stratigraphy and Structure of Volcanic Rocks In Drill Hole USW-G1, Yucca Mountain, Nye County, Nevada.* US Geol Surv Open-File Report 81-1349.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	1.6–2.8
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	7,000–20,000
27	EXPANSION OR CONTRACTION UPON HEATING	EXPANSION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	2
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	2,000–4,000
30	HYDRAULIC RETARDATION–DIFFUSION (RANK ORDER)	6
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-6}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : DENSELY WELDED TUFF (Topopah Spring Member)

Figure 48. Subsurface Distribution of Densely Welded Topopah Spring Tuff and Attribute Values

Densely Welded Tuff
(Central Portion of Topopah Spring Member of the Paintbrush Tuff)
(Figure 48)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where densely welded tuff of the Topopah Spring Member of the Paintbrush Tuff occurs at least 100 ft thick occurs between depths of 500 and 4000 ft. Only that portion of the Topopah Spring Member that is densely welded is included in the mapping unit. The unit is characterized by various degrees of welding, mineral assemblages, degrees of matrix porosity, fracture conditions, occurrences of lithophysal zones, and degrees of saturation, but is judged sufficiently homogeneous to qualify as a single mapping unit. The boundaries of the unit are based on observed thicknesses in drill holes J-11, J-12, J-13, Ue25a#1, USW-G-1, USW-H-1, and in outcrops in the Yucca Mountain, southern Crater Flat, and Shoshone Mountain areas. The boundaries are only approximate, but represent the general regions where the welded tuff of the Topopah Spring Member occurs with requisite depth and thickness.

Confidence Estimates

A high confidence is placed on the occurrence of the mapping unit consistent with thickness and depth criteria throughout the approximate region within the mapping boundaries.

Additional Readings

Byers, F. M., Jr., Carr, W. J., Orkild, P. P., Quinlivan, W. D., and Sargent, K. A. (1976). *Volcanic Suites and Related Cauldrons of Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada.* USGS Prof Pap 919, 70 p.

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Lipman, P. W., and McKay, E. J. (1965). *Geologic Map of the Topopah Spring SW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-439.

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McKay, E. J., and Williams, W. P. (1964). *Geology of the Jackass Flats Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-368.

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Sargent, K. A., McKay, E. J., and Burchfiel, B. C. (1970). *Geologic Map of the Striped Hills Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-882.

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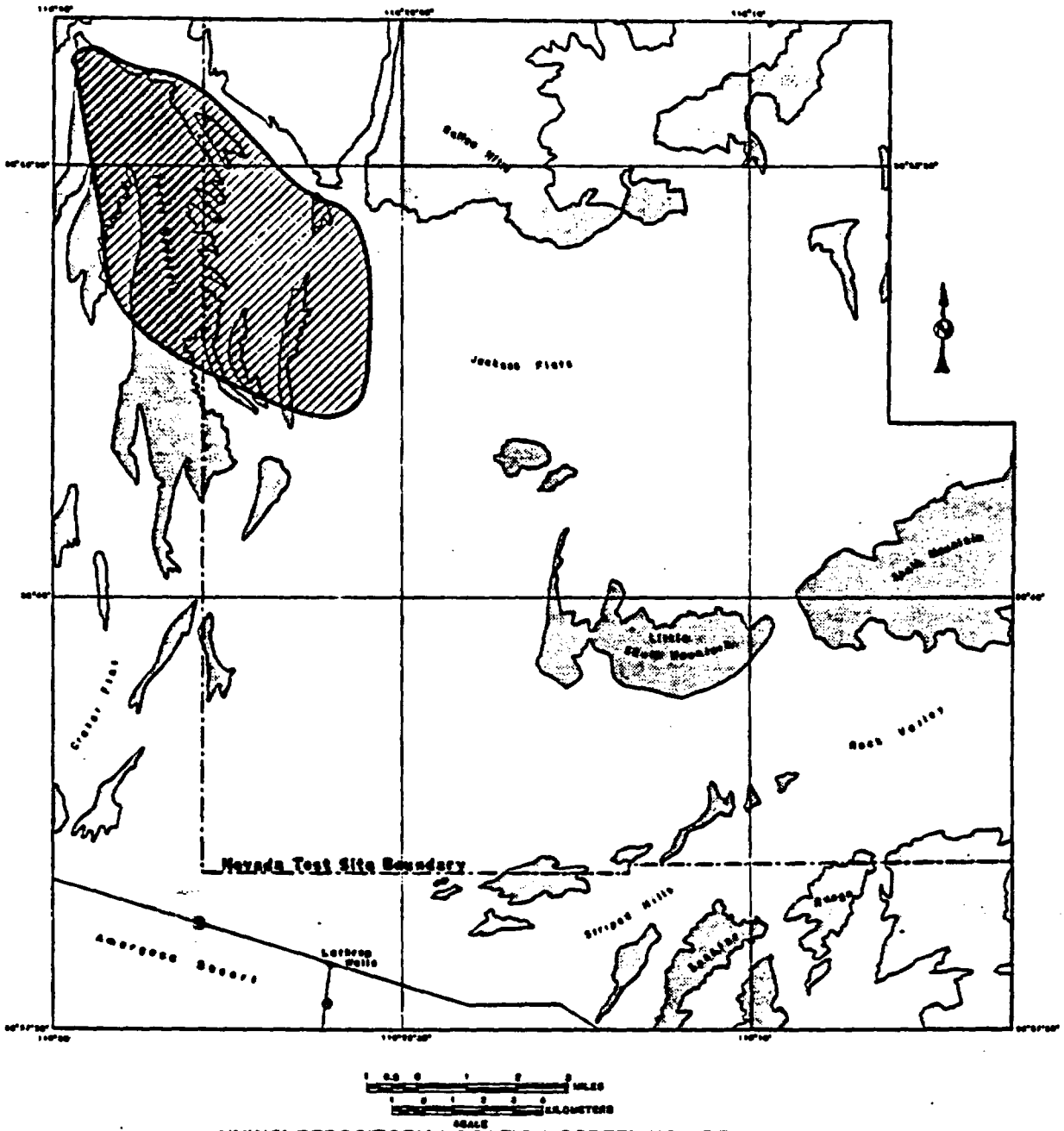
Spengler, R. W., Byers, F. M., Jr., and Warner, J. B. (1981). *Stratigraphy and Structure of Volcanic Rocks in Drill Hole USW-G1, Yucca Mountain, Nye County, Nevada.* US Geol Surv Open-File Report 81-1349.

Young, R. A. (1972). *Water-Supply for Nuclear Rocket Development Station at the Atomic Energy Commission's Nevada Test Site.* US Geol Surv Water-Supply Pap 1938, 19 p.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	0.6–1.6
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	<7,000
27	EXPANSION OR CONTRACTION UPON HEATING	CONTRACTION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	0
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	10,000–12,000
30	HYDRAULIC RETARDATION-DIFFUSION (RANK ORDER)	1
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-6}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : NON-WELDED TUFF (Calico Hills Formation)

Figure 49. Subsurface Distribution of Nonwelded Calico Hills Tuff and Attribute Values

Nonwelded Tuff
(Lower Topopah Spring and Calico Hills)
(Figure 49)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where nonwelded tuff of the lower Topopah Spring Member of the Paintbrush Tuff and the Calico Hills Tuff at least 100 ft thick occurs between depths of 500 and 4000 ft. The mapping unit includes vertically contiguous nonwelded portions of the tuffs included in the Topopah Spring and Calico Hills stratigraphic units. The unit is characterized by various degrees of welding, porosity, mineral assemblages, fracture conditions, and degrees of saturation, but was judged sufficiently homogeneous to qualify as a single mapping unit. The boundaries of the unit are based on observed thicknesses in drill holes Ue25a#1, USW-G-1, and USW-H-1 and on outcrop patterns in the northern Yucca Mountain area and the Calico Hills/Fortymile Wash area. The boundaries are only approximate, but represent the general area where the nonwelded tuffs of the Topopah Spring and Calico Hills occur with requisite thicknesses and depth. The eastern boundary is based on a judgment that, although the Calico Hills occurs to the east of the boundary in sufficient depth and thickness, the rocks change from predominantly nonwelded tuffs to predominantly rhyolites, which are too complex to delineate with any confidence.

Confidence Estimates

A high confidence is assigned to the occurrence of the mapping unit consistent with depth and thickness criteria in the northern part of the mapped area. This confidence is based on outcrop observations at Prow Pass and drill hole information from USW-G-1, USW-H-1, and Ue25a#1. Low confidence is assigned to the southwest portion of the mapped area based on the presumption that the unit thins to the west and south and on uncertainty as to where its thickness becomes less than 100 ft.

Additional Readings

Byers, F. M., Jr., Carr, W. J., Orkild, P. P., Quinlivan, W. D., and Sargent, K. A. (1976). *Volcanic Suites and Related Cauldrons of Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada.* USGS Prof Pap 919, 70 p.

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Christiansen, R. L., Lipman, P. W., Carr, W. J., Byers, F. M., Jr., Orkild, P. P., and Sargent, K. A. (1977). "Timber Mountain-Oasis Valley Caldera Complex of Southern Nevada." *Geol Soc Bull*, 88:943-959.

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McKay, E. J., and Sargent, K. A. (1970). *Geologic Map of the Lathrop Wells Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-883.

McKay, E. J., and Williams, W. P. (1964). *Geology of the Jackass Flats Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-368.

Orkild, P. P. (1968). *Geologic Map of the Mine Mountain Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-746.

Orkild, P. P., and O'Connor, J. T. (1970). *Geologic Map of the Topopah Spring Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-849.

Sargent, K. A., McKay, E. J., and Burchfiel, B. C. (1970). *Geologic Map of the Striped Hills Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-882.

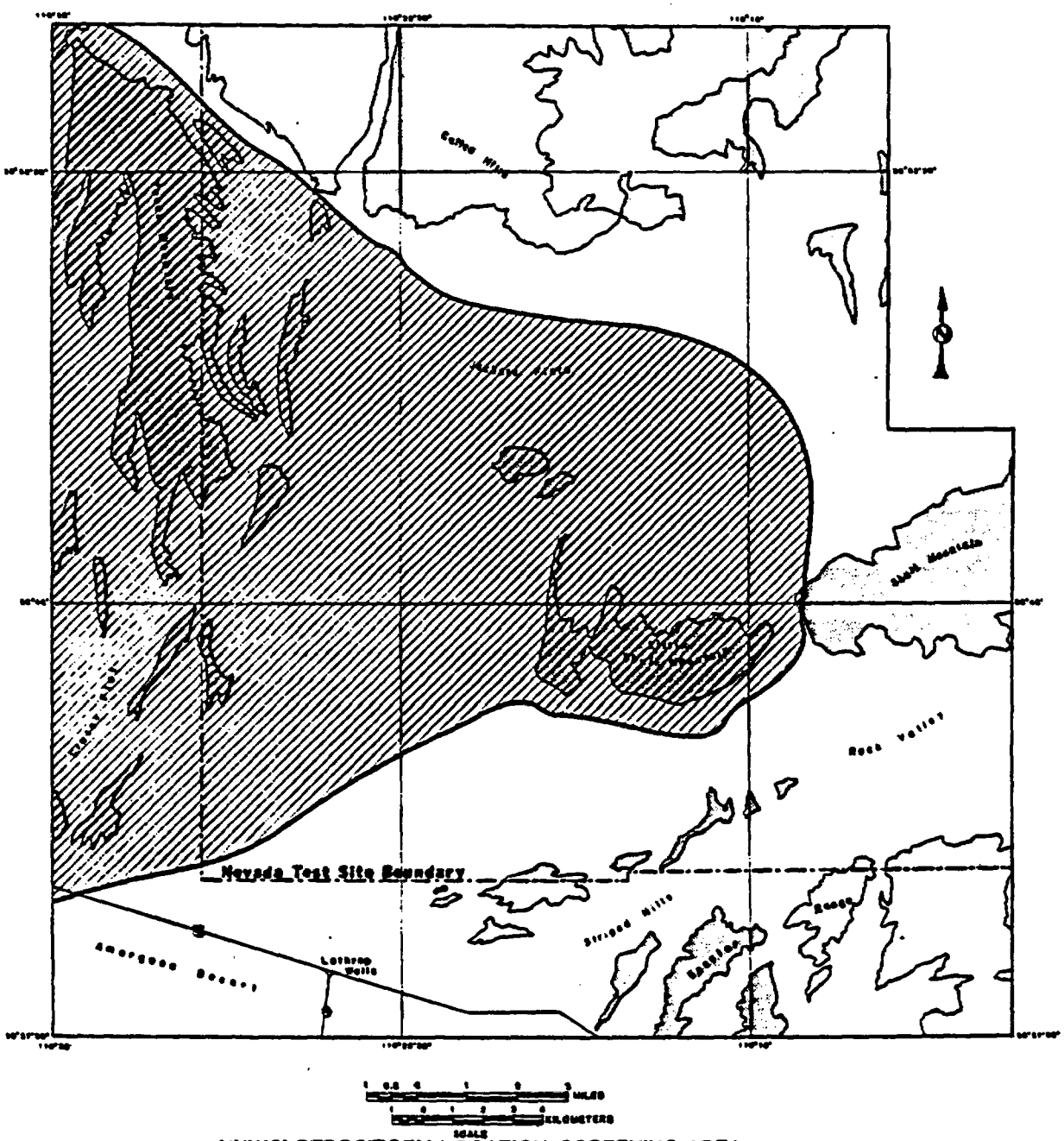
Sargent, K. A., and Stewart, J. H. (1971). *Geologic Map of the Specter Range NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-884.

Spengler, R. W., and Rosenbaum, J. G. (1980). *Preliminary Interpretations of Geologic Results Obtained From Boreholes UE25a-4, -5, -6, and -7, Yucca Mountain, Nevada Test Site.* US Geol Surv Open-File Report 80-929.

Spengler, R. W., Byers, F. M., Jr., and Warner, J. B. (1981). *Stratigraphy and Structure of Volcanic Rocks In Drill Hole USW-G1, Yucca Mountain, Nye County, Nevada.* US Geol Surv Open-File Report 81-1349.

Young, R. A. (1972). *Water-Supply for Nuclear Rocket Development Station at the Atomic Energy Commission's Nevada Test Site.* US Geol Surv Water-Supply Pap 1938, 19 p.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	1.6–2.5
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	7,000–20,000
27	EXPANSION OR CONTRACTION UPON HEATING	EXPANSION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	6
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	4,000–6,000
30	HYDRAULIC RETARDATION–DIFFUSION (RANK ORDER)	3
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-6}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : MODERATELY WELDED TUFF (Crater Flat Formation et al.)

Figure 50. Subsurface Distribution of Moderately Welded Crater Flat Tuff and Attribute Values

Moderately Welded Tuff
(Crater Flat Tuff and Underlying Units)
(Figure 50)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where moderately welded tuff of the Crater Flat Tuff and underlying units occurs at least 100 ft thick and between depths of 500 and 4000 ft. The main stratigraphic units included in the mapping unit are the Prow Pass, Bullfrog, and Tram Members of the Crater Flat Tuff and some underlying unnamed tuff deposits that are partially to moderately welded. The Crater Flat and underlying tuffs are characterized by various degrees of welding, mineral assemblages, degrees of porosity, and modes of origin, but are judged sufficiently homogeneous in gross properties to qualify as a single mapping unit. The boundaries of mapping units are based on observed occurrences of Crater Flat tuff in wells J-12, J-13, USW-G-1, USW-H-1, and in outcrops south of Little Skull Mountain, on the west edge of Skull Mountain, north of US Highway 95 west of the screening area, and at Prow Pass. The boundary is approximate, but represents the general region where the map unit occurs with requisite thickness and depth. The Tram Member and underlying units are probably confined to the Yucca Mountain area.

Confidence Estimates

A high confidence is placed on the occurrence of the mapped unit consistent with thickness and depth criteria throughout the approximate region within the mapping boundaries.

Additional Readings

Christiansen, R. L., and Lipman, P. W. (1965). *Geologic Map of the Topopah Spring NW Quadrangle, Nye County, Nevada.* US Geol Surv Geol Quad Map GQ-444.

Christiansen, R. L., Lipman, P. W., Carr, W. J., Byers, F. M., Jr., Orkild, P. P., and Sargent, K. A. (1977). "Timber Mountain-Oasis Valley Caldera Complex of Southern Nevada." *Geol Soc Bull*, 88:943-959.

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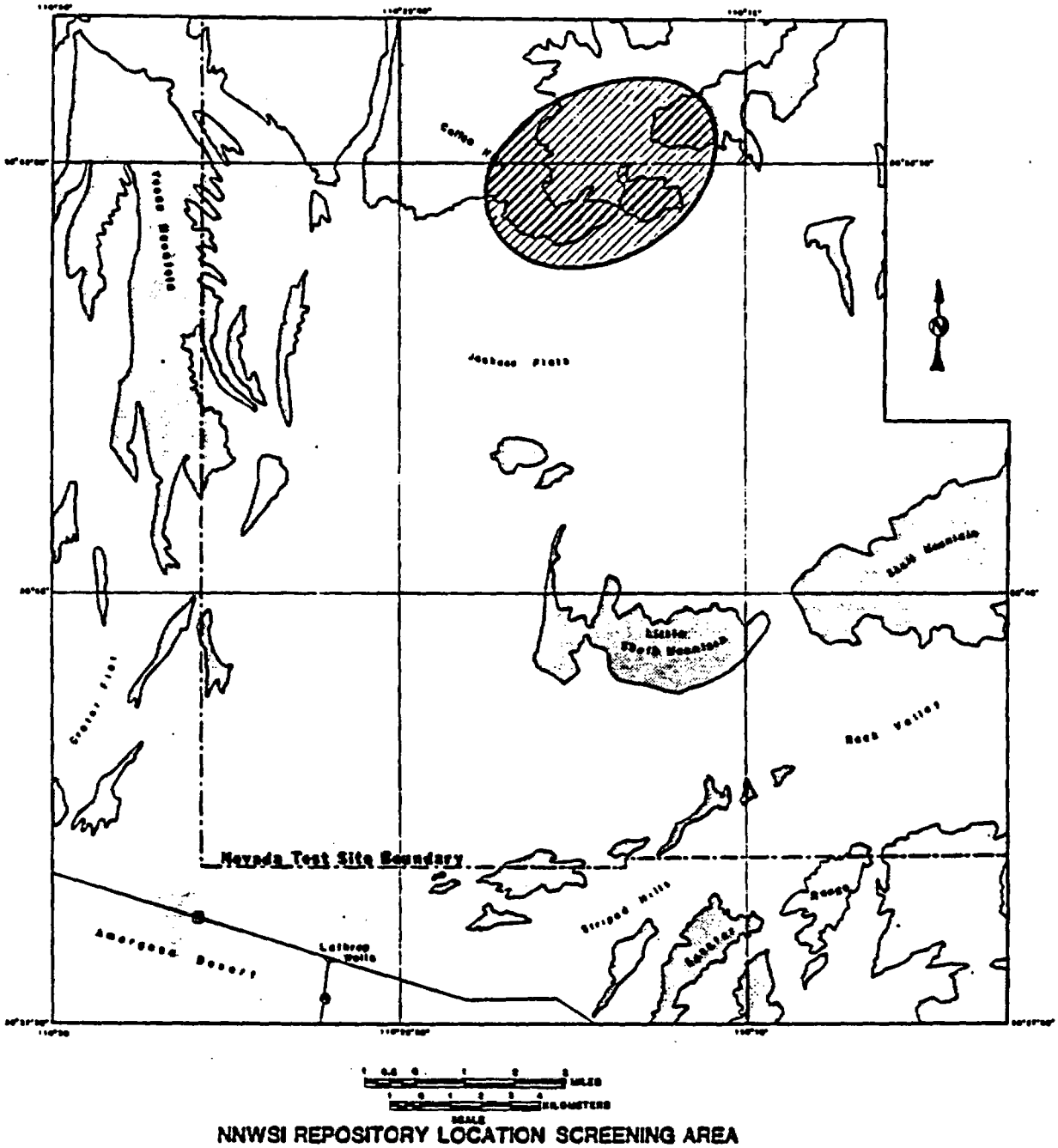
	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	2.5–3.5
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	>20,000
27	EXPANSION OR CONTRACTION UPON HEATING	EXPANSION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	1
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	4,000–6,000
30	HYDRAULIC RETARDATION–DIFFUSION (RANK ORDER)	6
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-9}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : GRANITE (Inferred intrusive beneath Calico Hills)

Figure 51. Subsurface Distribution of Granite and Attribute Values

Granite
(Figure 51)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where granite at least 500 ft thick is inferred to occur between depths of 500 and 4000 ft. The mapping unit is comprised of Tertiary intrusive granite inferred to exist in the screening area. The unit is probably characterized by various degrees of alteration, permeability, fracture conditions, and mineral assemblages, but is judged sufficiently homogeneous to qualify as a single mapping unit. The boundaries of the unit are based on distribution of alteration zones around Calico Hills and in drill hole Ue25a#3, on the location of gravity and magnetic highs over the Calico Hills and the Wahmonie area, and on structural doming at the Calico Hills. The boundaries are only approximate, but represent the general areas where granite occurs with requisite depth and thickness is inferred to occur.

Confidence Estimates

Low confidence is assigned to the occurrence of a granite body within 4000 ft of the surface at Calico Hills. Though gravity, magnetic, structural, and alteration observations suggest a granite body is present, drill hole Ue25a#3 did not penetrate granite to its total depth of about 2500 ft. The granite may be within 4000 ft of the surface, but this is uncertain.

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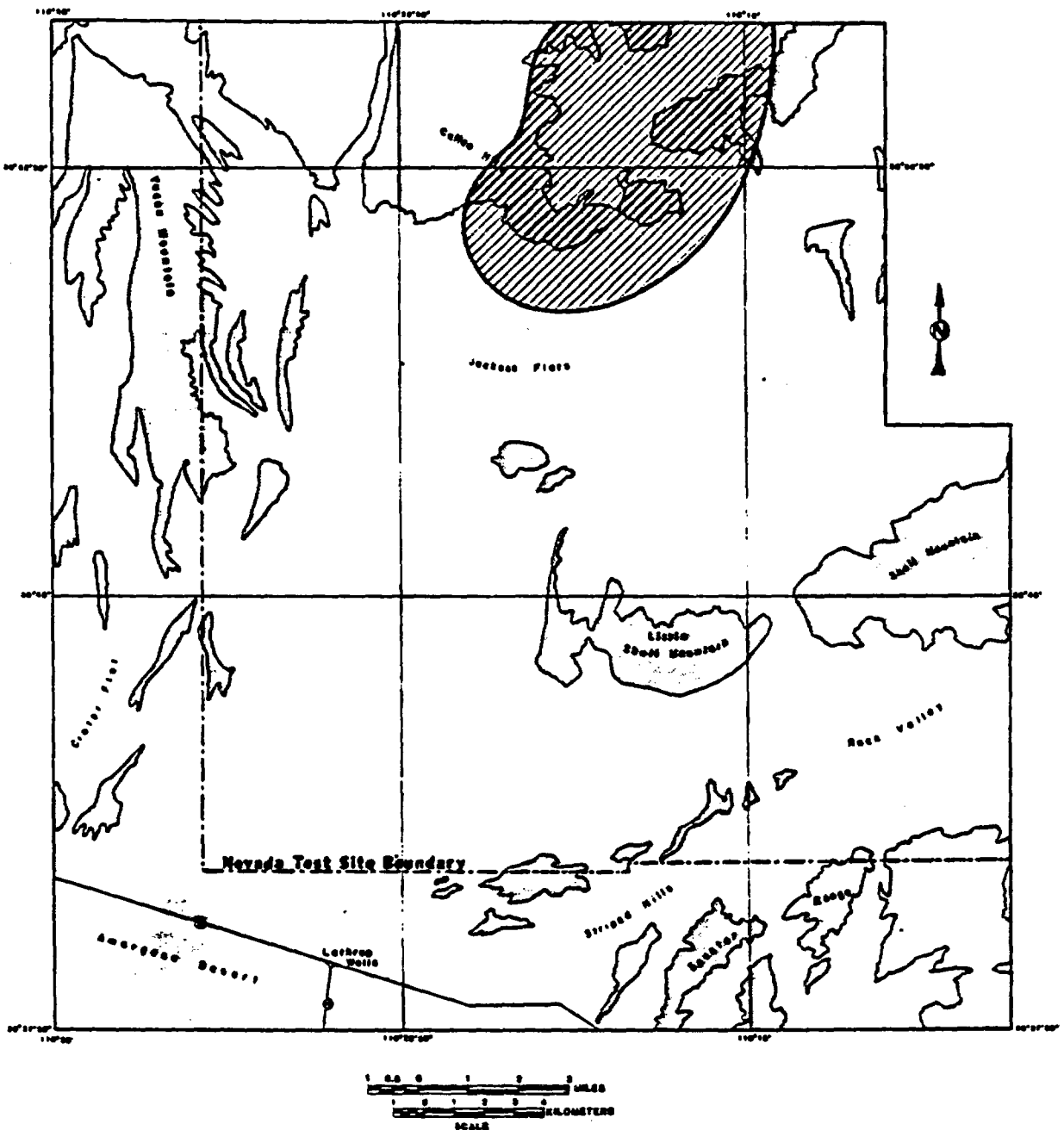
Snyder, D. B., and Oliver, H. W. (1981). *Preliminary Results of Gravity Investigations of the Calico Hills, Nevada Test Site, Nye County, Nevada.* US Geol Surv Open-File Report 81-101.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	1.0–2.0
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	<7,000
27	EXPANSION OR CONTRACTION UPON HEATING	CONTRACTION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	0
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	>12,000
30	HYDRAULIC RETARDATION–DIFFUSION (RANK ORDER)	0
31	HYDRAULIC TRANSMISSIVITY (cm^2/sec)	10^{-4}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : ARGILLITE (Eleana Formation)

Figure 52. Subsurface Distribution of Argillite and Attribute Values

Argillite
(Eleana Formation)
(Figure 52)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where argillaceous facies of the Eleana Formation at least 100 ft thick occurs between depths of 500 and 1000 ft. Only those portions of the Eleana Formation dominated by argillaceous material are included in the mapping unit. The unit is characterized by variations in the relative proportions of quartz and argillaceous material. Quartzite and carbonate facies of the Eleana Formation are interbedded within portions of the mapped area. However, the mapping unit is judged to contain at least one sufficiently homogeneous horizon of requisite depth and thickness to qualify for mapping as a potential repository unit. The boundaries of the unit are based on observed thicknesses in drill hole Ue25a#3, on outcrops north of Calico Hills and at Mine Mountain, and on geomorphic pediment forms suggestive of underlying shales along Upper Topopah Wash. The boundaries are approximate, but represent the general area where Eleana argillites occur with requisite depth and thickness.

Confidence Estimates

High confidence is placed on the occurrence of the mapping unit consistent with depth and thickness criteria throughout the approximate area within the mapping boundaries.

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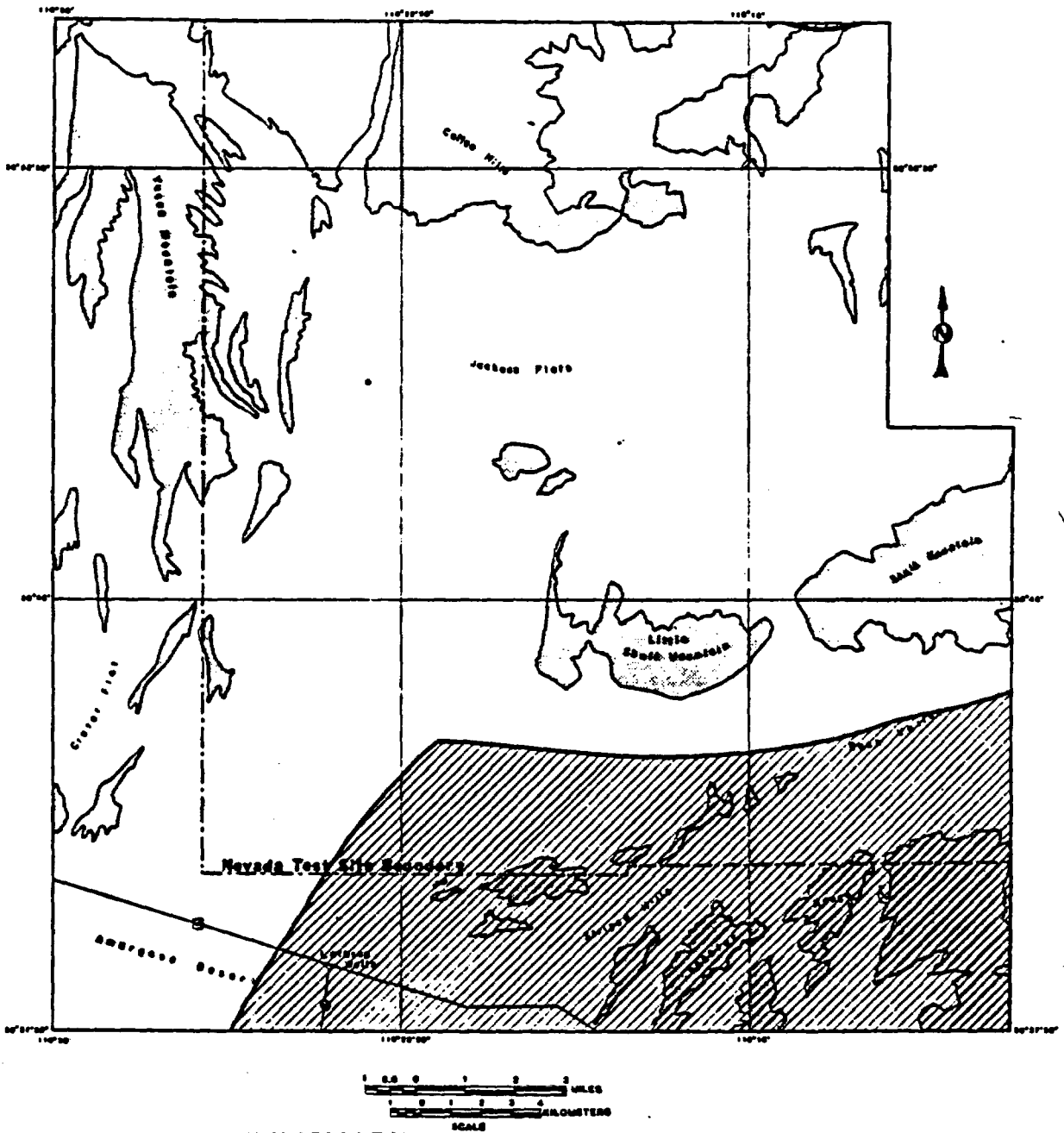
Snyder, D. B., and Oliver, H. W. (1981). *Preliminary Results of Gravity Investigations of the Calico Hills, Nevada Test Site, Nye County, Nevada.* US Geol Surv Open-File Report 81-101.

	ATTRIBUTE	VALUE
24	THERMAL CONDUCTIVITY (W/m°K)	3.5-4.5
25 & 26	UNCONFINED COMPRESSIVE STRENGTH (psi)	7,000-20,000
27	EXPANSION OR CONTRACTION UPON HEATING	EXPANSION
28	MINERAL STABILITY UPON HEATING (RANK ORDER)	1
29	STRATIGRAPHIC SETTING (WEIGHTED SORPTION SUM)	<2.000
30	HYDRAULIC RETARDATION-DIFFUSION (RANK ORDER)	7
31	HYDRAULIC TRANSMISSIVITY (cm²/sec)	10^{-6}



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY HOST ROCK : CARBONATES (Cambrian-Silurian formations)

Figure 53. Subsurface Distribution of Paleozoic Carbonates and Attribute Values

Carbonate
(Paleozoic Limestones and Dolomites of Cambrian Through Devonian Age) (Figure 53)

Compilers

F. Maldonado (USGS) and S. Sinnock (SNL)

Mapping Rationale

The map shows where Paleozoic carbonates at least 100 ft thick occur between depths of 500 and 4000 ft. The unit is characterized by limestones and dolomites with minor interbeds of clastic rocks, such as argillites, quartzites, and siltstones. In the screening area, the clastic rocks are considered to be too minor in occurrence to be included as a separate mapping unit. The carbonates and minor interbedded clastics vary with respect to degree of fracturing, bulk permeability, mineral assemblages, and degree of dissolution, but are considered sufficiently homogeneous to qualify as a single mapping unit. The boundaries of the unit are based on abundant outcrop evidence in the Striped Hills-Specter Range area and along the southwest edge of Mid-Valley. The boundaries are approximate but represent the general area where carbonate rocks occur with the requisite depth and thickness.

Confidence Estimates

High confidence is assigned to the occurrence of the mapping unit consistent with depth and thickness criteria throughout the mapped area.

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