LA-9510-MS

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Evaluation of Geochemical Properties Used in Area-to-Location Screening for a Nuclear Waste Repository at the Nevada Test Site

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This report was prepared by the Los Alamos National Laboratory as part of the Nevada Nuclear Waste Storage Investigations managed by the Nevada Operations Office of the US Department of Energy.

LA-9510-MS

UC-70
Issued: March 1983

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by

J. D. Purson

ABSTRACT

The area-to-location screening of a potential site for a nuclear waste repository is dependent on geologic compatibility. Specifically, the geochemical properties of candidate locations are significant in the overall site evaluation. This report describes three geochemical factors or attributes and their application to an area-to-location screening of the southwestern quadrant of the Nevada Test Site and contiguous areas. These are only 3 of 31 attributes examined in the screening process.

Geochemical and rock media considerations relevant to site screening include: (1) retardation by hydraulics--a study of ground-water movement through fractures vs a permeable matrix; (2) thermal stability of minerals--a measurement of undesirable mineral assemblages in the rock; and (3) retardation by sorption--an evaluation of the total sorptive capacity at a location, based on stratigraphy and lithology. Twelve potential host rocks situated in 20 locations are examined; 2 of these have consistently fewer favorable characteristics, and 6 others have generally fewer favorable characteristics than the 4 remaining rock units. The four units that appear most favorable by geochemical measures are the tuffaceous beds of Calico Hills, granite intrusives, the densely welded Topopah Spring tuff, and the Crater Flat Tuff at Yucca Mountain.

I. INTRODUCTION

This report describes the methods and logic employed by Los Alamos National Laboratory as part of a systematic screening of the southwestern quadrant of the Nevada Test Site (SW NTS). The screening process is designed to identify locations that are potentially suitable for a nuclear waste repository.

The Nevada Operations Office of the US Department of Energy (DOE) manages the Nevada Nuclear Waste Storage Investigations (NNWSI) project. The NNWSI project office is formally responsible for evaluating the suitability of various locations at the NTS for a mined repository that would be constructed deep underground to isolate high-level radioactive waste (US Department of Energy 1980a,b; 1981). The evaluation of technical aspects or attributes of each potential repository location is provided by personnel from Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories (SNL), the US Geological Survey (USGS), and Westinghouse Corporation.

As discussed by Sinnock et al. (1981), the method employed in screening an area for repository locations must accomplish several objectives. First, the screening method must discriminate among locations objectively. Second, only existing information and intelligent suppositions should be used in the evaluations in order to complete the screening promptly. Third, the degree of certainty and reliability of the data used in an evaluation should be considered in the final appraisal. Finally, the evaluation method used should be organized to allow anyone to easily disassemble, change, and reassemble the components of results. This will permit assessment of the net effect of assumptions, professional judgments, and newly discovered data.

In addition to these objectives, a set of guidelines for the task was given to Los Alamos by the coordinator of screening activity, S. Sinnock of SNL. An initial condition required that the repository be located only within the nine map quadrangles of the SW NTS (Christiansen and Lipman 1965; Ekren and Sargent 1965; Lipman and McKay 1965; McKay and Williams 1964; McKay et al. 1970; Orkild 1968; Orkild and O'Connor 1970; Sargent et al. 1970; Sargent and Stewart 1971). During a preliminary examination of the area (Fig. 1), 12 geologic units were identified, each of which has a thickness of at least 100 ft at a depth >500 ft but <4000 ft (Table IA). These depths represent the minimum credible thickness of overburden that might be necessary and the maximum depth that would be practical, considering thermal gradient and overburden pressure. Table IB shows stratigraphic units that are adjacent to potential host rocks but are not considered for a potential repository.

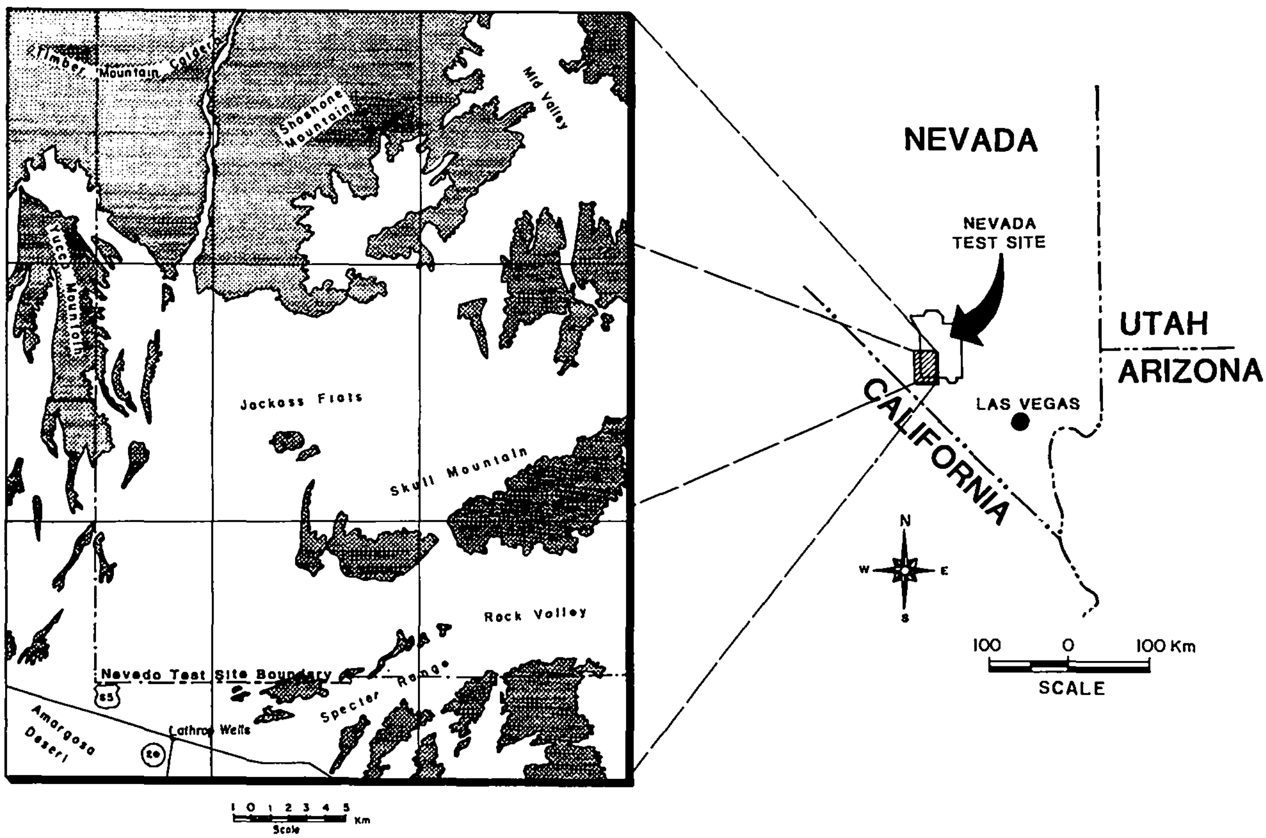

Fig. 1. NNWSI repository location screening area showing USGS quadrangle boundaries.

TABLE IA

STRATIGRAPHIC UNITS PRESENT IN AREA FOR HOSTING A POTENTIAL REPOSITORY

Unit	Identifier for Appendix C-1
Alluvium (unsaturated)	A
Basalts of Skull Mountain and basalt of Kiwi Mesa	B
Lavas of Dome Mountain	L
Tuff of Chocolate Mountain (welded)	CM
Nonwelded tuff--Tiva Canyon Member; Pah Canyon; Topopah Spring	NW
Densely welded Topopah Spring	TS
Nonwelded tuffaceous beds of Calico Hills	CH
Crater Flat Tuff at Yucca Mountain	YM
Ammonia Tanks Member (welded)	AT
Granite intrusives	G
Eleana Formation	EA
Carbonate rocks of Paleozoic age	PC

TABLE IB

STRATIGRAPHIC UNITS ADJACENT TO POTENTIAL REPOSITORY HORIZONS

Unit	Identifier for Appendix C-2
Nonwelded Timber Mountain Tuff	TM
Welded Timber Mountain Tuff	WTM
Wahmonie lava	WL
Fanglomerate	F
Rhyolite	RH
Bedded tuffs	BT
Tram	T
Hydrothermally altered rock	AR
Hornfels argillite	HA

These parameters were considered to be the minimum acceptable dimensions of the repository host rock; therefore, evaluations were made only for the locations where suitable host rocks were known.

Los Alamos has long been involved in scientific investigations of geotechnical aspects of the NTS. Personnel with relevant expertise in nuclear chemistry, geochemistry, mineralogy, and volcanology qualify Los Alamos to evaluate attributes that pertain to radionuclide retardation and mineralogic stability. Given the objectives and the potential host rock locations, the next step was to identify necessary geochemical considerations.

Following debate, the scientists decided that the geochemical and rock media considerations relevant to site screening could be consolidated. (1) Retardation by hydraulics considers that ground-water movement through fractures is less desirable than movement through a uniformly permeable matrix. (2) Thermal stability of minerals is a measure of undesirable mineralogic alteration phases in a potential repository host rock. (3) Retardation by sorption evaluates a potential repository location by estimating the total sorptive capacity for its lithology and stratigraphic suite. These attributes provide a reasonably accurate geochemical description of the response to nuclear waste released at a specific location. A fact essential to the discussion of these attributes is that the tuff found at the SW NTS possesses particularly useful hydraulic properties (Johnstone and Wolfsberg 1980). Figure 2 illustrates the permeability of tuff in comparison to soils and other rocks (Bear et al. 1968). The permeability of tuff matrix has been measured at Los Alamos, and the values obtained range from 1×10^{-15} k (k = permeability expressed in cm^2) to 4×10^{-13} k (Erdal et al. 1981). In comparison to other rock types, the porosity of tuff is high and highly sorptive minerals in tuffs, especially nonwelded tuff, are abundant. Sorption of contaminants transported by ground water is enhanced in tuffs because of the slow migration rate of the water. Conversely, in granites and other low-porosity

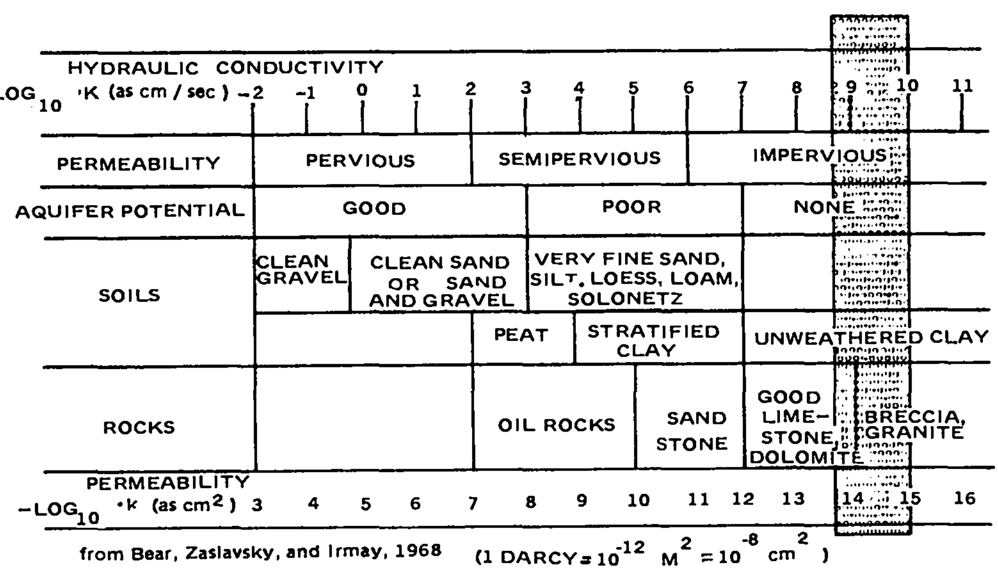

Fig. 2. Permeability of some soils and rocks, with shaded area showing tuff permeability measured at Los Alamos National Laboratory.

rocks, ground-water movement can be faster because of interconnected cracks and fractures (Brace et al. 1968). It should be noted, however, that a densely welded and fractured tuff can act as an excellent aquifer as in the case of Topopah Spring tuff in Jackass Flats. The high porosity and low permeability of nonwelded tuffs, in addition to their high sorptive capacity, increases their desirability near a repository for radionuclide isolation.

Geochemical considerations are only 3 of 31 attributes that are examined in the screening process, and final decisions cannot be made using this information alone. However, geochemical compatability, the interactions of uncontained nuclear materials with the surrounding rocks, is a significant concern, and these evaluations will have major influence in selection of a repository location. It is not possible within the scope of this report to combine these attributes into an overall evaluation. In the final screening, each attribute contributes toward specific objectives in proportion to its importance.

II. RETARDATION BY HYDRAULICS

The principal processes to evaluate in this category are ground-water flow through fractures and matrix, and diffusion into a matrix away from a fracture (Scheidegger 1960; Collins 1961; Davis and DeWiest 1966). Radioactive waste can be better contained in a rock unit if the water travels slowly through the rock unit. If chemical reactions between the ground water and rock unit are ignored, the most favorable rock unit would allow the least volume of ground water to move from one place to another in any given time. The data of Winograd and Thordarson (1975) were used to estimate ground-water flow in each stratigraphic unit considered. The evaluation is made by comparing the expected fracture density, mineralogy, permeability, and porosity of potential host rocks (Heiken and Bevier 1979; Sykes et al. 1979; Bish et al. 1981). Rocks with more fractures would tend to increase the effective porosity and permeability and therefore be less favorable than rocks with less ability to transport ground water. Some of the potential host rocks are porous but contain swelling clays that could seal fractures and pores, thus restricting ground water motion. In this evaluation, all water-transporting properties of a particular host rock are considered in comparing individual units.

The 12 potential repository units are compared in Appendix A, and the results are summarized in Table II. An arrow worth one scoring unit indicates the rock unit that should have better retardation potential. A zero, which is worth one-half scoring unit, indicates that the two units being compared have similar qualities and are considered equal. The overall score of two such units will also be equal. The score is the sum of zeros and arrows pointing toward each unit. The higher the overall score for the unit, the more desirable are the properties. It should be noted, however, that the difference in favorability between consecutively ranked units may vary widely.

III. THERMAL STABILITY OF MINERALS

This category considers that the potential repository host rocks may contain mineral phases that are detrimental to a repository. The content of clays, opal, zeolites, or vitric phases could affect isolation of radionuclides (Boles 1972; Heiken and Bevier 1979; Sykes et al. 1979; Lappin 1980; Bish et al. 1981; Smyth and Caporuscio 1981). Smyth (1982) has demonstrated

TABLE II

RESULTS: RETARDATION BY HYDRAULICS

Repository Unit	Score
Alluvium (unsaturated)	10.0
Nonwelded tuffaceous beds of Calico Hills	10.0
Nonwelded tuff--Tiva Canyon Member; Pah Canyon; Topopah Spring	10.0
Crater Flat Tuff at Yucca Mountain	8.0
Tuff of Chocolate Mountain (welded)	8.0
Ammonia Tanks Member (welded)	6.5
Densely welded Topopah Spring	5.0
Granite intrusives	2.5
Eleana Formation	2.5
Lavas of Dome Mountain	2.5
Basalts of Skull Mountain and basalt of Kiwi Mesa	2.5
Carbonate rocks of Paleozoic age	0

that a zeolitic tuff, when heated, could alter its mineralogy, resulting in a reduction in volume. Clays, opal, and glasses could have a similar reaction to the expected temperatures near waste cannisters (Bish 1981; Longstaffe 1981). The chief concern is that the volume change may create a pathway along which contaminated fluids could escape. Therefore, more favorable host rocks should contain minimal amounts of these unstable mineral assemblages. Additionally, the volume changes might compromise the structural integrity of the repository facility.

A comparison of the unstable mineral contents among potential host rocks was made using the same procedure employed to compare hydraulic retardation (Appendix B). The results are summarized in Table III. As in Appendix A, an arrow shows the rock unit estimated to have fewer unstable minerals. Zeros indicate that the unstable mineral contents are indistinguishable between the two units. The score is the sum of zeros and arrows pointing toward a unit. As with the retardation by hydraulics category, an arrow is worth one point, and zeros are worth one-half point. Also, a unit that is considered less desirable than the other 11 units in the comparison necessarily would have a score of 0. Estimated unstable mineral contents are based on studies of the geologic units under consideration or similar units (Sheppard 1971; Byers et al. 1976; Heiken and Bevier 1979; Sykes et al. 1979; Bish et al. 1981).

IV. RETARDATION BY SORPTION

A. General Description

The sorption capacity is the best available measure of the ability of a rock to retard migration of radioactive materials in ground water from a

TABLE III

RESULTS: THERMAL STABILITY OF MINERALS

Repository Unit	Score
Carbonate rocks of Paleozoic age	10.5
Granite intrusives	10.5
Ammonia Tanks Member (welded)	8.5
Densely welded Topopah Spring	8.5
Tuff of Chocolate Mountain (welded)	7.0
Basalts of Skull Mountain and basalt of Kiwi Mesa	6.0
Crater Flat Tuff at Yucca Mountain	5.0
Lavas of Dome Mountain	4.0
Alluvium (unsaturated)	2.5
Nonwelded tuff--Tiva Canyon Member; Pah Canyon; Topopah Spring	2.5
Eleana Formation	1.0
Nonwelded tuffaceous beds of Calico Hills	0

repository to the accessible environment. Sorption capacities for some radionuclides have been measured at Los Alamos for many potential host rocks (Erdal et al. 1979a,b; Wolfsberg et al. 1979; Vine et al. 1980). Variation in the stratigraphy and lithology among locations where the potential host rock occurs may affect the relative suitability of a location. Sorption properties should be considered for a vertical distance of at least 500 ft above and 500 ft below the potential repository. Although sorption properties become less important at greater vertical distances from the repository, it is necessary to consider the sorption properties of units adjacent to the repository horizon. Lateral variability is also an important factor but data is not available and therefore not considered. The desirability of the various combinations of host rock and adjacent units are evaluated in Appendix C-1. A study of geologic cross sections for the SW NTS (McKay and Williams 1964; Christiansen and Lipman 1965; Ekren and Sargent 1965; Lipman and McKay 1965; Lipman et al. 1966; Orkild 1968; McKay et al. 1970; Orkild and O'Connor 1970; Sargent et al. 1970; Sargent and Stewart 1971; Byers et al. 1976) revealed that the 12 potential repository units are found in 20 locations; each such location is characterized by a distinct stratigraphic section. The locations of these 20 sections are shown in Appendix C-2 and have been evaluated individually. Because ground water tends to move downward under the influence of gravity, the sorption capacity for units below the potential repository site were considered more important than for units above it.

B. Method

The sorptive capacity of the various rock types of interest (Tables IA and IB) in the SW NTS is an important rock property because it indicates the potential of the rock to chemically retard the migration of radioactive contaminants to the accessible environment. The data used in this evaluation are from Daniels 1981; Erdal 1979, 1980; Erdal et al. 1979a,b; Wolfsberg et al. 1979; and Vine et al. 1980. All sorption data in Table IV have been measured at Los Alamos, with efforts to minimize variations in experimental technique. Only cesium, strontium, europium, plutonium, and americium were analyzed; no anionic species were considered. The representative sorption ratios (Table IV) are averages of values obtained by batch techniques for sorption and desorption under atmospheric conditions. The sorption ratio is defined as the activity per gram of rock divided by activity per milliliter of solution (Wolfsberg et al. 1979). Because the sorption capacities for several rocks of interest have been studied little, several assumptions have been made.

(1) The values for basalts, lava, and tuff of Chocolate Mountain are identical, based on the mineralogy of these units.

(2) The nonwelded tuff in Tiva, Pah Canyon, and Topopah Spring (identified as NW; Table IA) are identical to alluvium, and the Ammonia Tanks Member is the same as welded Topopah Spring tuff.

(3) Tuffs of Prow Pass, Bullfrog, and Tram at Yucca Mountain contain both welded and nonwelded components, which are mineralogically different; therefore, values for these units were calculated by estimating that the composition was two parts welded component similar to welded Topopah Spring tuff and one part nonwelded component similar to the tuff of Calico Hills.

(4) Europium and americium sorption ratios were considered equal if one of the ratios was not determined.

(5) In some cases (alluvium, nonwelded tuffs, and Paleozoic carbonate rocks), no plutonium values were available and the value was assumed to be 0.2 of the europium value.

The values estimated using assumptions (4) and (5) are given in parentheses in Table IV. In order to give equal credit to the vastly different sorption ratios for the 5 elements of interest, the values were normalized (Table V) to 1000 for the maximum value obtained for that element among the 12 units. The overall value to be used for the sorption attribute (Table VI) was then calculated by summing the average normalized value for americium and europium and the individual normalized values for cesium, strontium, and plutonium. The average value between europium and americium was used because these elements presumably have the same oxidation state (Wolfsberg et al. (1979).

Because different rock units have different sorptive capacities, it is important to consider the properties of all geologic units at a potential repository location as a single system. Heat from the waste package could drive contaminated fluid from the repository upwards. Also, natural ground water recharge would likely carry downward any contaminants driven by gravity. A study of stratigraphy where different repository units occur yields 20 locations with separate geochemical retardation settings (Table VII, Appendix C-2). Rocks within 1000 vertical feet of the hypothetical repository horizon are included in the evaluation of potential host rocks.

TABLE IV

REPRESENTATIVE SORPTION RATIOS[a]

Identifier	Cs	Sr	Eu	Pu	Am
A	8 000	200	3 500	(700)	(3 500)
B	265	81	(7 920)	840	7 920
L	265	81	(7 920)	840	7 920
CM	265	81	(7 920)	840	7 920
NW	8 000	200	3 500	(700)	(3 500)
TS	490	125	3 920	574	2 450
CH	20 900	11 125	3 625	1 125	7 500
YM	7 293	3 795	3 822	758	4 133
AT	490	125	3 920	574	2 450
G	435	18	1 025	8 000	1 025
EA	2 800	130	62 600	35 500	78 000
PC	88	2	(3 200)	(640)	3 200

[a] Parentheses indicate values estimated using assumptions (4) and (5) on page 8.

TABLE V

SORPTION RATIOS NORMALIZED TO 1000

Identifier	Cs	Sr	Eu	Pu	Am
A	380	18	56	20	45
B	13	7	130	24	100
L	13	7	130	24	100
CM	13	7	130	24	100
NW	380	18	56	20	45
TS	23	11	63	16	31
CH	1 000	1 000	58	32	96
YM	350	340	61	21	53
AT	23	11	63	16	31
G	21	2	16	225	13
EA	130	12	1 000	1 000	1 000
PC	4	1	51	18	41

TABLE VI

SORPTION SCORE

Identifier	Value	Identifier	Value
A	470	CH	2 200
B	160	YM	770
L	160	AT	100
CM	160	G	260
NW	470	EA	2 100
TS	100	PC	70

TABLE VII

LOCATIONS OF POTENTIAL REPOSITORY ROCK UNITS

Host Rock	Location
Alluvium	Western Jackass Flats Eastern Jackass Flats Lathrop Wells area, north of Highway 95 Lathrop Wells area, south of Highway 95
Basalt of Skull Mountain and Kiwi Mesa	Western Jackass Flats Eastern Jackass Flats
Lavas of Dome Mountain	All locations
Tuff of Chocolate Mountain	All locations
Nonwelded Tiva Canyon tuff	Shoshone Mountain area Jackass Flats
Densely welded Topopah Spring tuff	South of Yucca Mountain Shoshone Mountain area and northern Yucca Mountain area
Calico Hills tuff	All locations
Crater Flat Tuff	Yucca Mountain Jackass Flats
Ammonia Tanks tuff	All locations
Granite	Wahmonie/Saylier Calico Hills
Eleana Formation	All locations
Carbonate rocks of Paleozoic age	All locations

It is assumed that the heat driving contaminants upward is a temporary condition (until the canister cools), but the downward migration of ground water is a natural, continuous process. This important assumption results in weighting more heavily the rock unit intervals below the horizon of interest (Fig. 3). Rock units that are assumed to be equivalent are indicated where appropriate in Appendix C-1.

Evaluation of retardation by sorption is shown in Appendix C-I; the scores are summarized in Table VIII. The score of a potential repository location was determined by multiplying the weighting factor (WF) for an interval (Fig. 3) by the thickness (t, expressed as hundreds of feet) of each rock unit in that interval, then multiplying by the sorption score (S) from Table VI. This process is repeated for each interval and the scores are summed. The scores or ranking in the category are considered to be linear for purposes of comparison.

V. RESULTS AND DISCUSSION

Table IX summarizes the evaluation results of the three geochemically related attributes under consideration. Scores for retardation by sorption are normalized to 10 for comparative purposes. Scores for rock units that have more than one location are averaged. No attempt has been made to combine the evaluations of these three attributes because they are only a portion of the overall objective. To combine the geochemical attributes is beyond the scope of this document.

The Basalts of Skull Mountain/Kiwi Mesa and the Lavas of Dome Mountain do not have any advantageous geochemical feature that would warrant further consideration of these units. The Ammonia Tanks Member, Tuff of Chocolate Mountain, and carbonate rocks of Paleozoic age were rated the lowest for sorption. The Eleana Formation was ranked near the bottom in both thermal stability of minerals and retardation by hydraulics.

Alluvium and nonwelded tuffs such as the Tiva Canyon Member, Pah Canyon tuff, and nonwelded Topopah Spring tuff have similar high resistance to

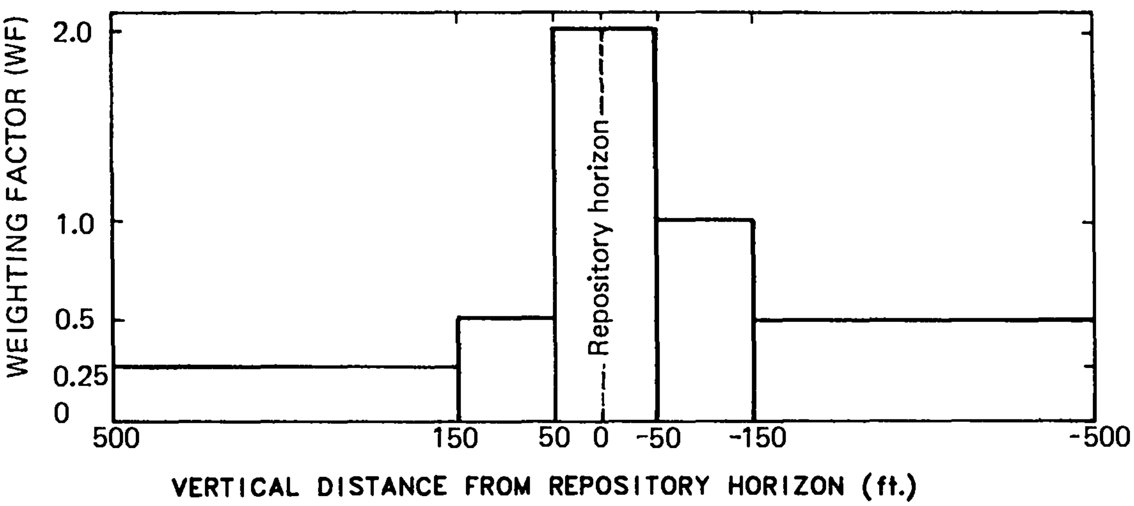

Fig. 3. Weighting factor applied to sorption score as a function of vertical distance from a potential repository site.

TABLE VIII

RESULTS: RETARDATION BY SORPTION

Repository Unit and Geographic Location	Score
Eleana Formation (all locations)	12 862
Calico Hills tuff (all locations)	10 374
Granite at Wahmonie/Saylier	5 962
Granite at Calico Hills	5 962
Crater Flat Tuff in Jackass Flats	4 516
Crater Flat Tuff in Yucca Mountain	3 801
Nonwelded Tiva Canyon tuff in Shoshone Mountain area	3 528
Basalt of Skull Mountain and Kiwi Mesa in western Jackass Flats	3 486
Densely welded Topopah Spring tuff in Shoshone Mountain area and northern Yucca Mountain area	3 469
Alluvium in Lathrop Wells area, north of Highway 95	3 028
Nonwelded Tiva Canyon tuff in Jackass Flats	2 911
Alluvium in Lathrop Wells area, south of Highway 95	2 678
Alluvium in eastern Jackass Flats	2 520
Densely welded Topopah Spring tuff, south of Yucca Mountain	2 396
Alluvium in western Jackass Flats	2 338
Basalt of Skull Mountain and Kiwi Mesa in eastern Jackass Flats	1 956
Lavas of Dome Mountain (all locations)	1 492
Tuff of Chocolate Mountain (all locations)	980
Ammonia Tanks tuff (all locations)	612
Carbonate rocks of Paleozoic age (all locations)	428

ground-water movement. Unfortunately, they all have abundant, unstable mineral phases and provide moderately low sorption potential.

Granite is a possible host rock for a repository because it contains almost no unstable minerals to cause problems. Although granite has a low sorptive capacity, any repository in granite would be overlain by the Eleana Formation, which has been shown to have a high sorptive capacity. This situation would be favorable if it were not for the fractures and microcracks in granite that allow more ground-water influx than would most other potential repository units.

The tuffaceous beds of Calico Hills scored highest in retardation by hydraulics because of the high porosity and low permeability that is

TABLE IX

SUMMARY OF GEOCHEMICAL EVALUATION

Repository Unit	Identifier Used in Appendix C-1	Score: Retardation by Hydraulics	Score: Thermal Stability of Minerals	Score: Retardation by Sorption
Nonwelded tuffaceous beds of Calico Hills	CH	10.0	0	8.1
Granite intrusives	G	2.5	10.5	4.6
Crater Flat tuff near Yucca Mountain	YM	8.0	5.0	3.2
Densely welded Topopah Spring	TS	5.0	8.5	2.7
Ammonia Tanks Member (welded)	AT	6.5	8.5	0.5
Nonwelded tuff--Tiva Canyon Member; Pah Canyon; Topopah Spring	NW	10.0	2.5	2.7
Alluvium (unsaturated)	A	10.0	2.5	2.4
Tuff of Chocolate Mountain	CM	6.5	7.0	0.8
Eleana Formation	EA	2.5	1.0	10.0
Carbonate rocks of Paleozoic age	PC	0	10.5	0.3
Basalts of Skull Mountain and basalt of Kiwi Mesa	B	2.5	6.0	2.7
Lavas of Dome Mountain	L	2.5	4.0	1.2

characteristic of nonwelded tuffs. There are few open fractures, forcing ground water to move through the tuff matrix. The large area of rock that the water contacts, together with the high sorptive capacity of the rock, make the tuff of Calico Hills a favorable host for a repository. However, the high sorptive capacity is caused by the same minerals that are unstable when subjected to the heat expected from waste cannisters in a repository. Because of the very low score in thermal stability of minerals for the tuff of Calico Hills, that unit's suitability as a repository horizon depends entirely on the relative importance of this attribute. It is possible that the engineering of a repository could reduce or eliminate the problems caused by mineral instability.

Only two of the potential host rocks never occurred in the lowest 40% of the scorings in all three categories. They are the densely welded Topopah Spring tuff and the Crater Flat Tuff at Yucca Mountain. Neither rock unit was found to be unfavorable by comparison with other units. The Topopah Spring tuff is relatively free of unstable minerals, has some ability to inhibit ground-water movement, and is located where retardation of radionuclides by sorption would be better than average. The Crater Flat Tuff at Yucca Mountain (1) scores fourth in ability to retard migration of radionuclides by hydraulics, (2) has an average content of unstable minerals, and (3) has an acceptable sorption rate as a result of highly sorptive adjacent units.

VI. CONCLUSIONS

In the screening method there are 31 attributes, each of which, in proportion to its importance, contributes towards the recommendation of a particular location and target horizon for the waste repository. The geochemical attributes evaluated by Los Alamos will have a significant impact on the final product of the screening process. Two of the proposed host rocks were found to have consistently low favorability (Table IX): Basalts of Skull Mountain/Kiwi Mesa and Lavas of Dome Mountain. Six rock units have a mixture of good and bad qualities that could exclude them from further consideration based on geochemistry alone. The remaining four formations, Calico Hills tuff, Granite intrusives, Crater Flat Tuff, and Topopah Spring tuff, are potentially acceptable as an emplacement medium, provided that their geochemical deficiencies are mitigated by the favorability of other attributes.

ACKNOWLEDGMENTS

Contributors from Los Alamos to the evaluations discussed in this report include B. M. Crowe, B. R. Erdal, R. Rundberg, K. Wolfsberg, and R. G. Warren. Only through their diligent efforts were these thorough evaluations possible. Special thanks are due S. Sinnock of SNL, who supplied maps and figures.

Word processing and preparation of the paper for final printing were done by S. E. Daly and P. R. O'Rourke; illustrations and drafting were done by J. Repa. Critical review and suggestions for the manuscript were provided by D. T. Vaniman, R. G. Warren, and B. R. Erdal.

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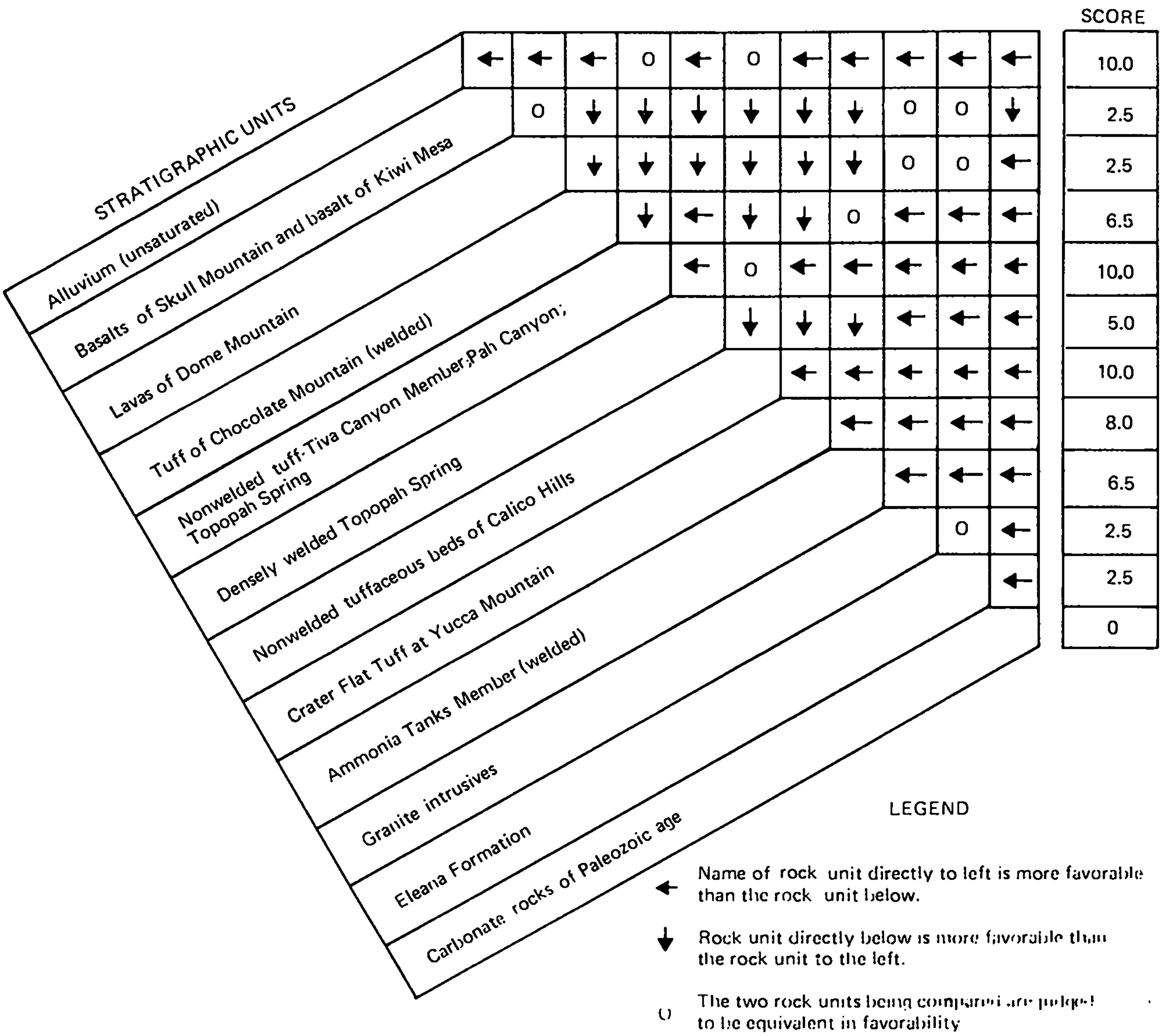
APPENDIX A

RETARDATION BY HYDRAULICS



APPENDIX B

THERMAL STABILITY OF MINERALS

STRATIGRAPHIC UNITS												SCORE
Alluvium (unsaturated)	↓	↓	↓	O	↓	←	↓	↓	↓	←	↓	2.5
Basalts of Skull Mountain and basalt of Kiwi Mesa		←	↓	←	↓	←	←	↓	↓	←	↓	6.0
Lavas of Dome Mountain			↓	←	↓	←	↓	↓	↓	←	↓	4.0
Tuff of Chocolate Mountain (welded)				←	↓	←	←	↓	↓	←	↓	7.0
Nonwelded tuff-Tiva Canyon Member; Pah Canyon; Topopah Spring					↓	←	↓	↓	↓	←	↓	2.5
Densely welded Topopah Spring						←	←	O	↓	←	↓	8.5
Nonwelded tuffaceous beds of Calico Hills							↓	↓	↓	↓	↓	0
Crater Flat Tuff at Yucca Mountain								↓	↓	←	↓	5.0
Ammonia Tanks Member (welded)									↓	←	↓	8.5
Granite intrusives										←	O	10.5
Eleana Formation											↓	1.0
Carbonate rocks of Paleozoic age												10.5

LEGEND

← Name of rock unit directly to left is more favorable than the rock unit below.

↓ Rock unit directly below is more favorable than the rock unit to the left.

O The two rock units being compared are judged to be equivalent in favorability.

APPENDIX C

RETARDATION BY SORPTION

Appendix C-1

Evaluation: Desirability of Geologic Units
Above and Below a Potential Repository Horizon

Appendix C-2

Maps: Potential Repository Unit Locations

APPENDIX C-1

EVALUATION: DESIRABILITY OF GEOLOGIC UNITS ABOVE AND BELOW A POTENTIAL REPOSITORY HORIZON

		Rating for Units ABOVE Repository Horizon						Rating for Units BELOW Repository Horizon						
Repository Unit	Geographic Location	Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Total Value
Alluvium	Western	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
	Jackass	50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
	Flats	0-50	2.0	A	0.5	470	470			A	0.5	470	117	
								150-500	0.5	B	0.5	160	40	
						ABOVE total:	1116			TS	2.5	100	125	
												BELOW Total:	1222	2338
	Eastern	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
	Jackass	50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
	Flats	0-50	2.0	A	0.5	470	470			A	0.5	470	117	
										B	1.0	160	80	
						ABOVE total:	1116	150-500	0.5	TM(YM)*	0.5	770	192	
										TS	1.5	100	75	
												BELOW Total:	1404	2520
	Lathrop Wells	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
	Area, North	50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
	of Hwy. 95	0-50	2.0	A	0.5	470	470	150-500	0.5	A	2.5	470	587	
										YM	1.0	770	385	
						ABOVE total:	1116					BELOW total:	1912	3028
	Lathrop Wells	150-500	0.25	A	3.5	470	411	0-50	2.0	A	0.5	470	470	
	Area, South	50-150	0.5	A	1.0	470	235	50-150	1.0	A	1.0	470	470	
	of Hwy. 95	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

* Nonwelded TM judged similar to nonwelded YM.

APPENDIX C-1 (cont)

Repository Unit	Geographic Location	Rating for Units ABOVE Repository Horizon: Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Rating for Units BELOW Repository Horizon: Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Total Value
Basalts of Skull Mtn. and Kiwi Mesa	Western part of Jackass Flats	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	TM(YM)	1.0	770	770	
		0-50	2.0	B	0.5	160	160	150-500	0.5	TS	2.0	100	100	
										CH	1.5	2200	1650	
						ABOVE total:	806					BELOW total:	2680	3486
	Eastern part of Jackass Flats	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	TM(YM)	1.0	770	770	
		0-50	2.0	B	0.5	160	160	150-500	0.5	TS	2.0	100	100	
										WL(B)*	1.5	160	120	
						ABOVE total:	806					BELOW total:	1150	1956
								* WL judged similar to B.						
Lavas of Dome Mountain	Dome Mountain	150-500	0.25	L	3.5	160	140	0-50	2.0	L	0.5	160	160	
		50-150	0.5	L	1.0	160	80	50-150	1.0	L	0.5	160	80	
		0-50	2.0	L	0.5	160	160	150-500	0.5	F(A)*	0.5	470	235	
										F(A)	2.5	470	587	
										Rh(TS)**	1.0	100	50	
						ABOVE total:	380					BELOW total:	1112	1492
								* F judged similar to A. ** Rh judged similar to TS.						
Tuff of Chocolate Mountain	Chocolate Mountain	150-500	0.25	CM	3.5	160	140	0-50	2.0	CM	0.5	160	160	
		50-150	0.5	CM	1.0	160	80	50-150	1.0	CM	1.0	160	160	
		0-50	2.0	CM	0.5	160	160	150-500	0.5	CM	3.5	160	280	
						ABOVE total:	380					BELOW total:	600	980
Nonwelded Tiva Canyon Tuff	Shoshone Mountain Area	150-500	0.25	WTM(A)*	3.5	470	411	0-50	2.0	NW	0.5	470	470	
		50-150	0.5	BT(CH)**	0.5	2200	550	50-150	1.0	NW	0.5	470	235	
				NW	0.5	470	117			BT(CH)**	0.5	2200	1100	
		0-50	2.0	NW	0.5	470	470	150-500	0.5	TS	3.5	100	175	
						ABOVE total:	1548					BELOW total:	1980	3528
	Jackass Flats	150-500	0.25	A	3.5	470	411	0-50	2.0	NW	0.5	470	470	
		50-150	0.5	A	1.0	470	235	50-150	1.0	BT(CH)**	0.5	2200	1100	
		0-50	2.0	NW	0.5	470	470			TS	0.5	100	50	
								150-500	0.5	TS	3.5	100	175	
						ABOVE total:	1116					BELOW total:	1795	2911

* Partially to moderately welded WTM judged similar to A.
** BT judged similar to CH.

APPENDIX C-1 (cont)

Repository Unit	Geographic Location	Rating for Units ABOVE Repository Horizon: Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Rating for Units BELOW Repository Horizon: Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Total Value
Densely welded Topopah Springs	Southern Yucca Mountain Area	150-500	0.25	MW	2.5	470	294	0-50	2.0	TS	0.5	100	100	
				TS	1.0	100	25	50-150	1.0	TS	1.0	100	100	
		50-150	0.5	TS	1.0	100	50	150-500	0.5	TS	1.0	100	50	
		0-50	2.0	TS	0.5	100	100			CH	1.0	2200	1100	
										YM	1.5	770	577	
						ABOVE total:	469					BELOW total:	1927	2396
	Shoshone Mountain Area and northern Yucca Mtn. Area	150-500	0.25	MW	2.5	470	294	0-50	2.0	TS	0.5	100	100	
				TS	1.0	100	25	50-150	1.0	TS	1.0	100	100	
		50-150	0.5	TS	1.0	100	50	150-500	0.5	TS	1.0	100	50	
		0-50	2.0	TS	0.5	100	100			CH	2.5	2200	2750	
						ABOVE total:	469					BELOW total:	3000	3469
Calico Hills Tuff	Calico Hills	150-500	0.25	TS	2.5	100	62	0-50	2.0	CH	0.5	2200	2200	
				CH	1.0	2200	550	50-150	1.0	CH	1.0	2200	2200	
		50-150	0.5	CH	1.0	2200	1100	150-500	0.5	CH	1.0	2200	1100	
		0-50	2.0	CH	0.5	2200	2200			YM	2.5	770	962	
						ABOVE total:	3912					BELOW total:	6462	10 374
Crater Flat Tuff	Yucca Mountain Area	150-500	0.25	YM	3.5	770	674	0-50	2.0	YM	0.5	770	770	
		50-150	0.5	YM	1.0	770	385	50-150	1.0	YM	1.0	770	770	
		0-50	2.0	YM	0.5	770	770	150-500	0.5	YM	0.5	770	192	
										T(CM)*	3.0	160	240	
						ABOVE total:	1829					BELOW total:	1972	3801
	Jackass Flats Area	150-500	0.25	CH	2.0	2200	1100	0-50	2.0	YM	0.5	770	770	
				YM	1.5	700	289	50-150	1.0	YM	1.0	770	770	
		50-150	0.5	YM	1.0	770	385	150-500	0.5	YM	0.5	770	192	
		0-50	2.0	YM	0.5	770	770			T(CM)*	3.0	160	240	
						ABOVE total:	2544					BELOW total:	1972	4516
Ammonia Tanks	Timber Mountain Area	150-500	0.25	AT	3.5	100	87	0-50	2.0	AT	0.5	100	100	
		50-150	0.5	AT	1.0	100	50	50-150	1.0	AT	1.0	100	100	
		0-50	2.0	AT	0.5	100	100	150-500	0.5	AT	3.5	100	175	
						ABOVE total:	237					BELOW total:	375	612

* T judged similar to CM.

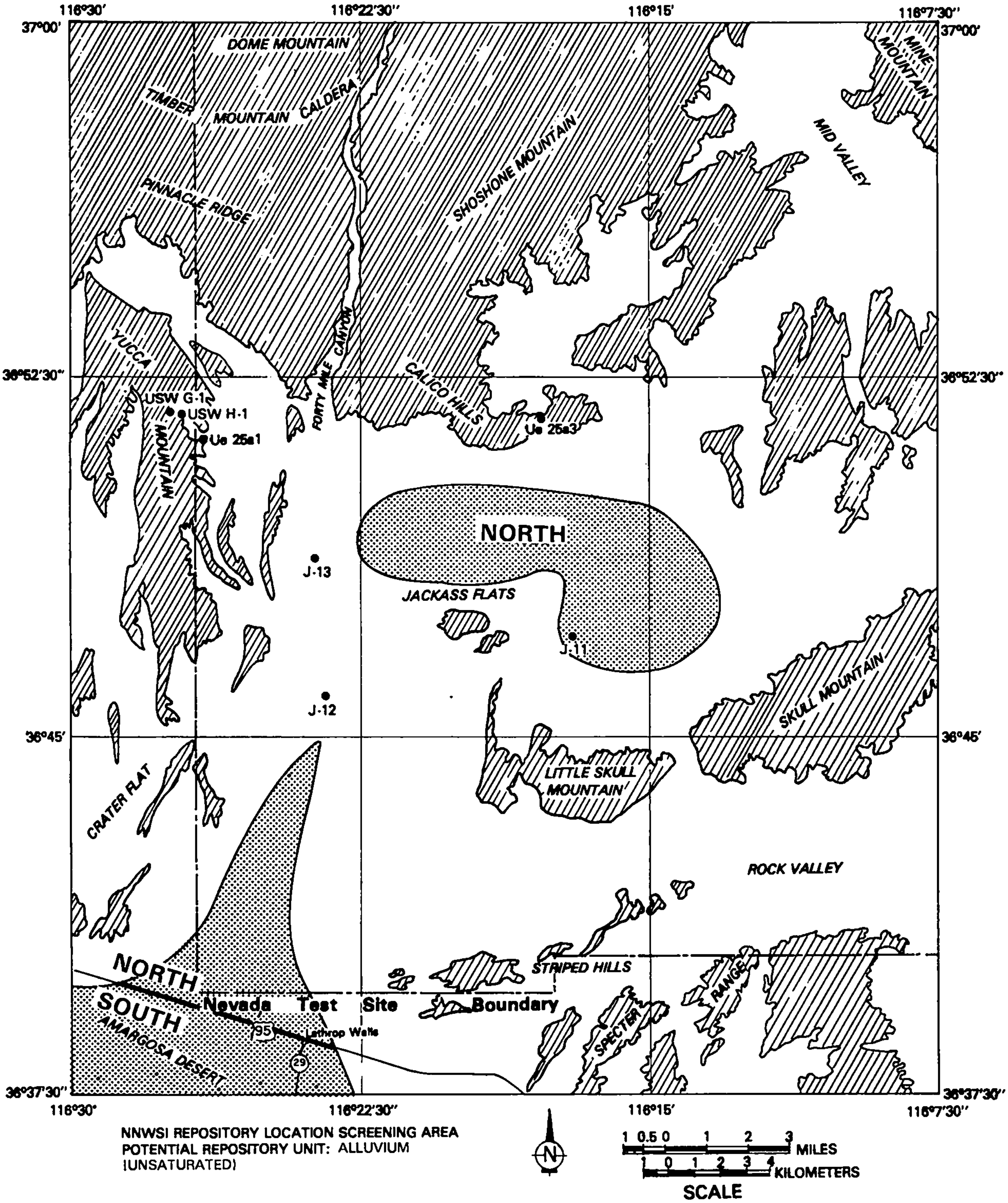
APPENDIX C-1 (cont)

		Rating for Units ABOVE Repository Horizon						Rating for Units BELOW Repository Horizon						
Repository Unit	Geographic Location	Interval ABOVE Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Interval BELOW Repository (ft)	Weighting Factor (WF)	Rock Unit and Thickness (t) (x 100 ft)		Sorption Score (S)	Subtotal Value (WF) x (t) x (S)	Total Value
Granite	Wahmonie/ Saylier	150-500	0.25	AR(EA)*	3.5	2100	1837	0-50	2.0	G	0.5	260	260	
		50-150	0.5	AR(EA)*	1.0	2100	1050	50-150	1.0	G	1.0	260	260	
		0-50	2.0	AR(EA)*	0.5	2100	2100	150-500	0.5	G	3.5	260	455	
						ABOVE total:	4987					BELOW total:	975	5962
	* AR judged similar to EA.													
	Calico Hills Area	150-500	0.25	HA(EA)*	3.5	2100	1837	0-50	2.0	G	0.5	260	260	
		50-150	0.5	HA(EA)*	1.0	2100	1050	50-150	1.0	G	1.0	260	260	
		0-50	2.0	HA(EA)*	0.5	2100	2100	150-500	0.5	G	3.5	260	455	
						ABOVE total:	4987					BELOW total:	975	5962
	* HA judged similar to EA.													
Eleana Formation		150-500	0.25	EA	3.5	2100	1837	0-50	2.0	EA	0.5	2100	2100	
		50-150	0.5	EA	1.0	2100	1050	50-150	1.0	EA	1.0	2100	2100	
		0-50	2.0	EA	0.5	2100	2100	150-500	0.5	EA	3.5	2100	3675	
						ABOVE total:	4987					BELOW total:	7875	12 862
Paleozoic Carbonates		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:	166					BELOW total:	262	428

APPENDIX C-2

MAPS: POTENTIAL REPOSITORY UNIT LOCATIONS

(Geographic divisions correspond with those used in Appendix C-1)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TIMBER MOUNTAIN CALDERA
MINE MOUNTAIN
MID VALLEY
SHOSHONE MOUNTAIN
PINNACLE RIDGE
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
USW G-1
USW H-1
Ue 25a1
Ue 25a3
NORTH
J-13
JACKASS FLATS
J-11
J-12
SKULL MOUNTAIN
CRATER FLAT
LITTLE SKULL MOUNTAIN
ROCK VALLEY
STRIPED HILLS
NORTH
SOUTH
AMARGOSA DESERT
Nevada Test Site Boundary
95
Lathrop Wells
29
SPECTER RANGE
NNWSI REPOSITORY LOCATION SCREENING AREA
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(UNSATURATED)
N
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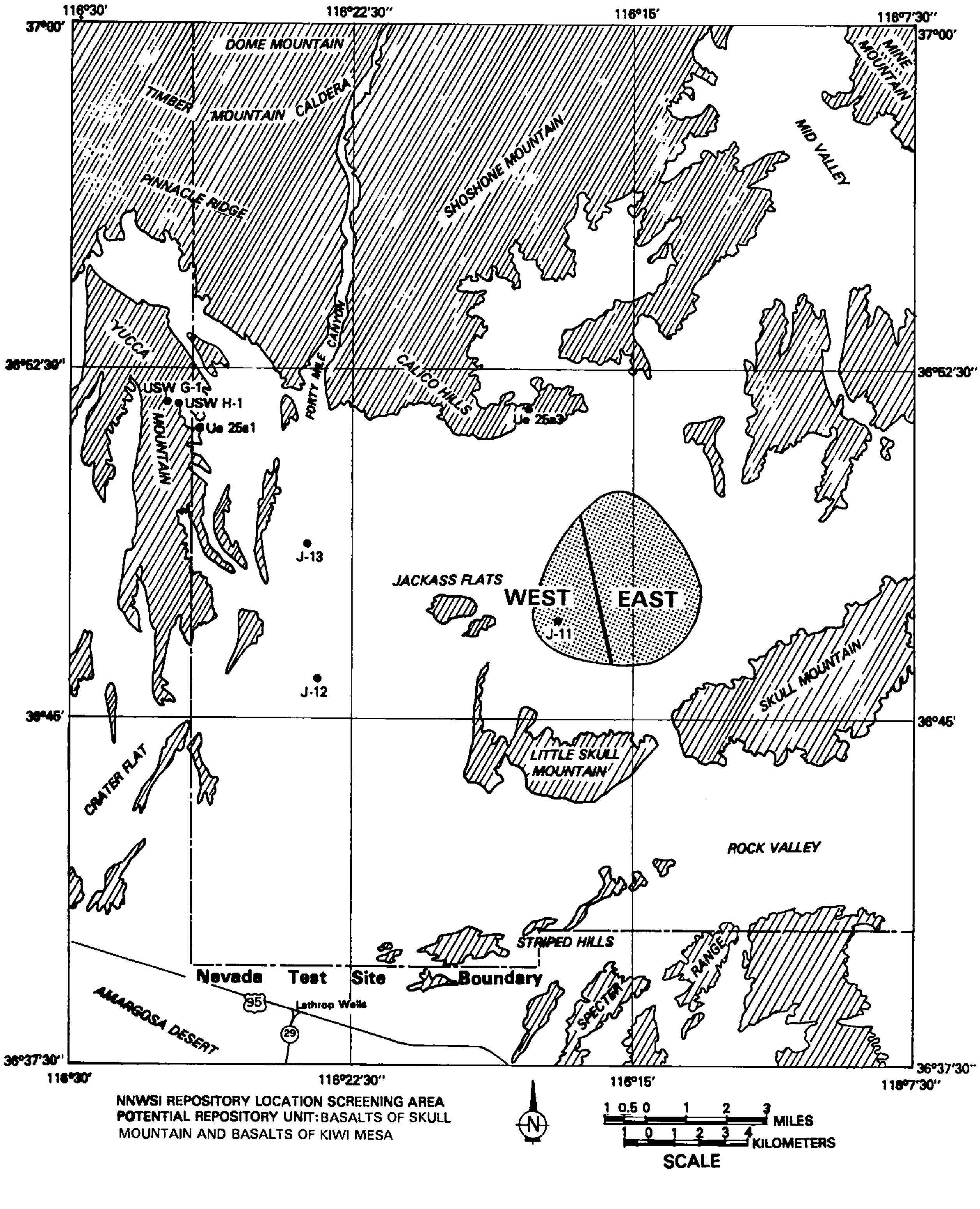
1 0 1 2 3 4 KILOMETERS
SCALE



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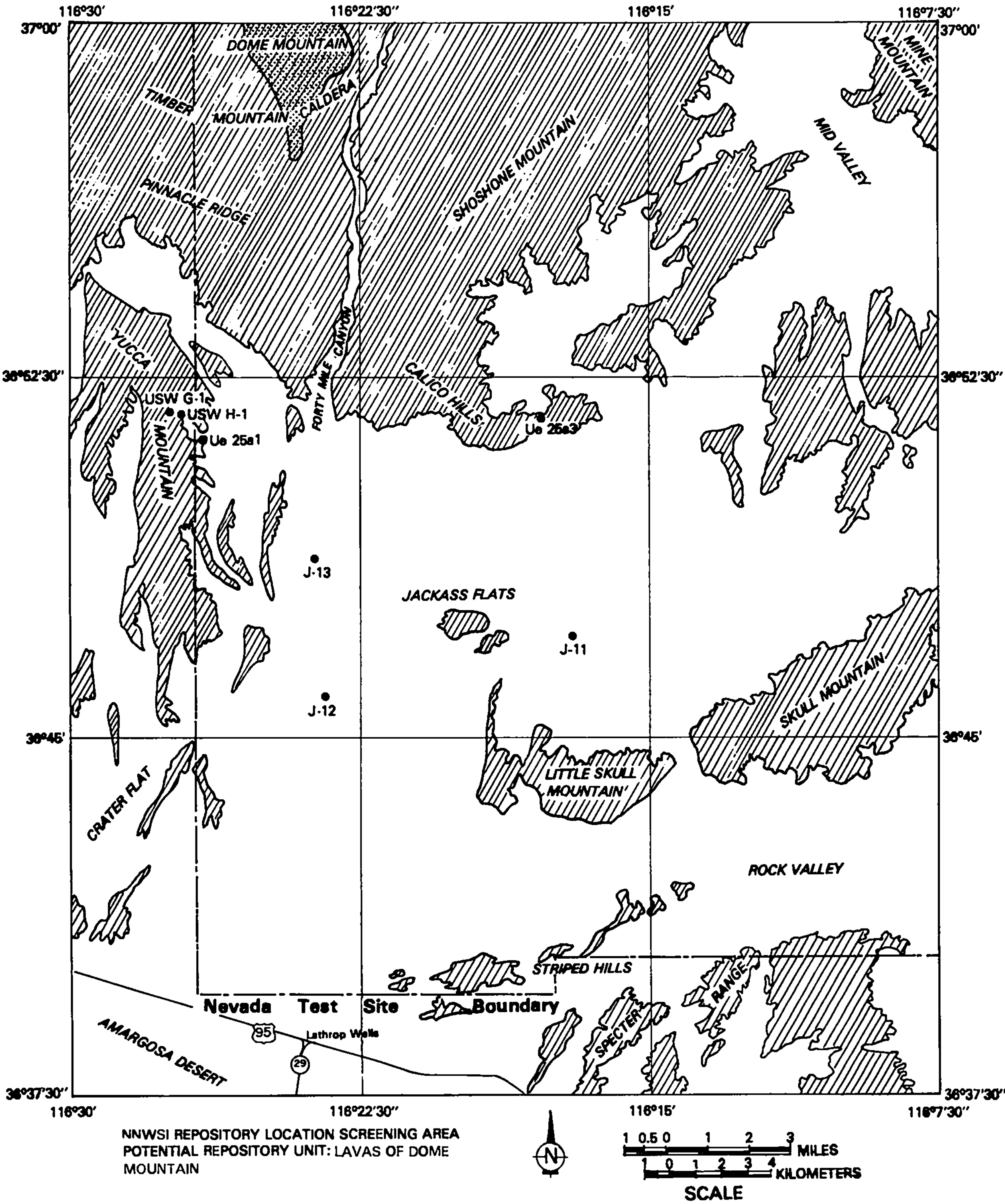
POTENTIAL REPOSITORY UNIT: BASALTS OF SKULL MOUNTAIN AND BASALTS OF KIWI MESA



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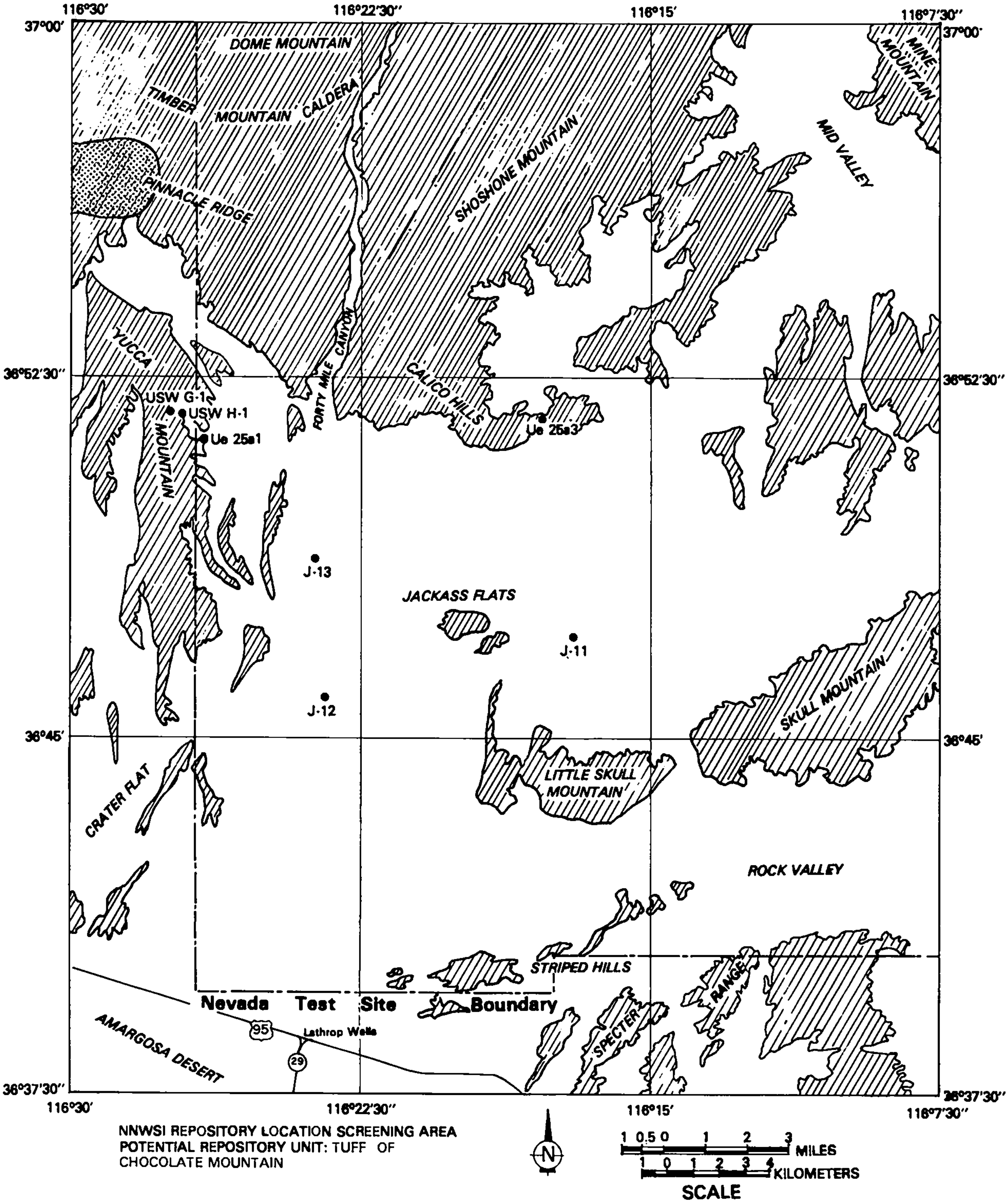
POTENTIAL REPOSITORY UNIT: LAVAS OF DOME MOUNTAIN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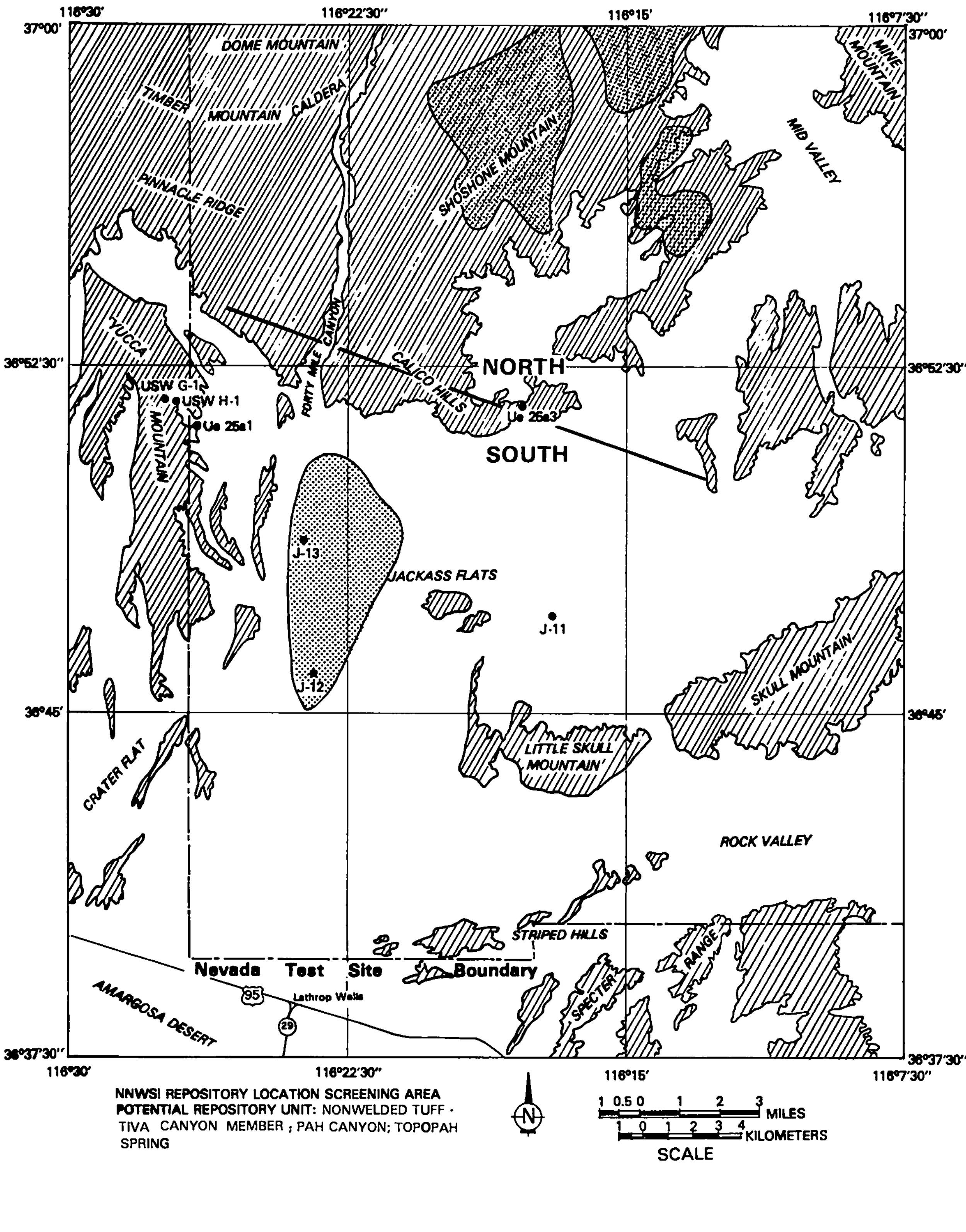
DOME MOUNTAIN
TIMBER MOUNTAIN CALDERA
PINNACLE RIDGE
SHOSHONE MOUNTAIN
MINE MOUNTAIN
MID VALLEY
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
USW G-1
USW H-1
Ue 25a1
Ue 25a3
J-13
J-12
J-11
JACKASS FLATS
SKULL MOUNTAIN
LITTLE SKULL MOUNTAIN
CRATER FLAT
ROCK VALLEY
STRIPED HILLS
SPECTER RANGE
Nevada Test Site Boundary
AMARGOSA DESERT
95
29
Lathrop Wells
NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: TUFF OF CHOCOLATE MOUNTAIN
N
MILES
KILOMETERS
SCALE



NNWSI REPOSITORY LOCATION SCREENING AREA
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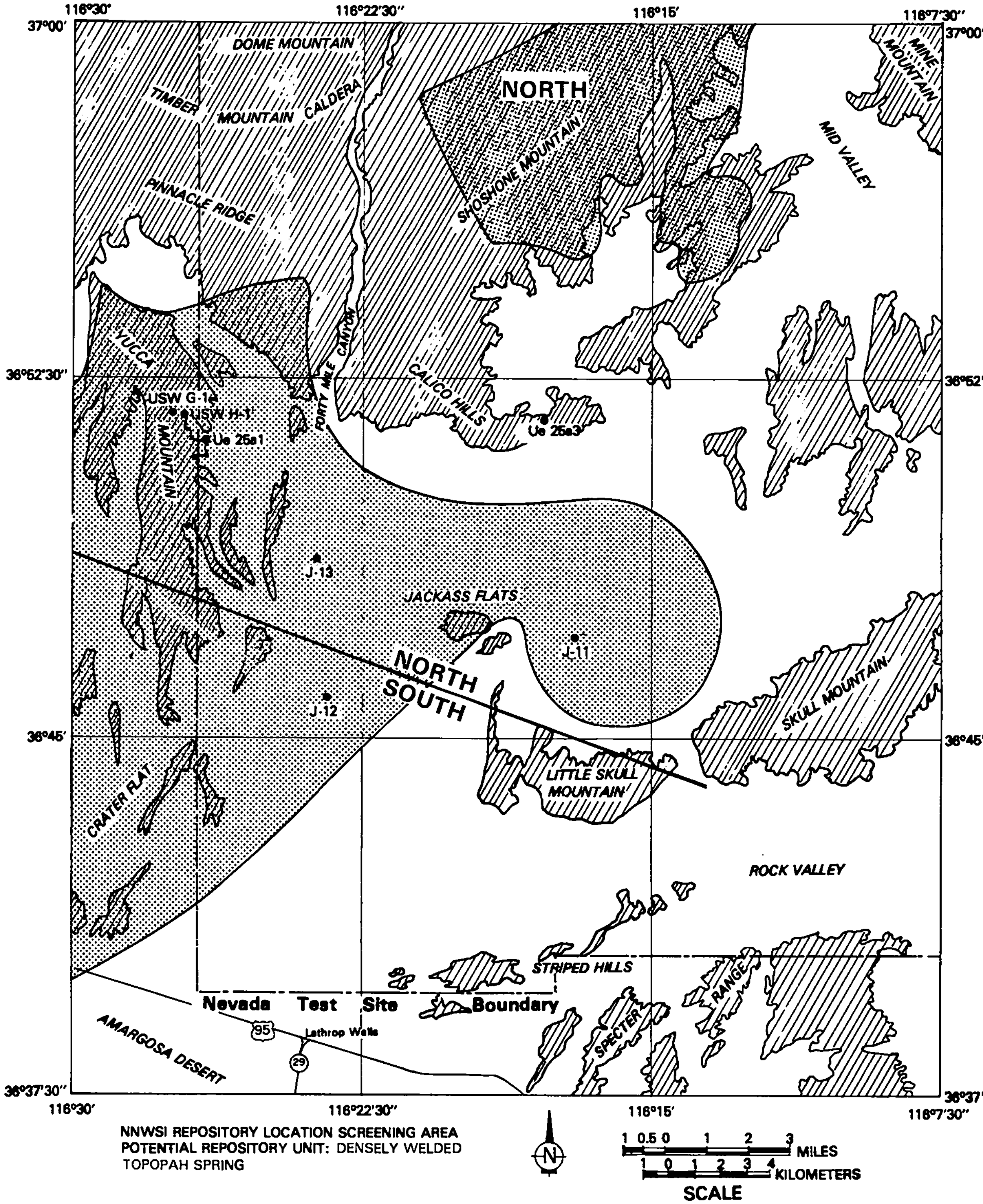
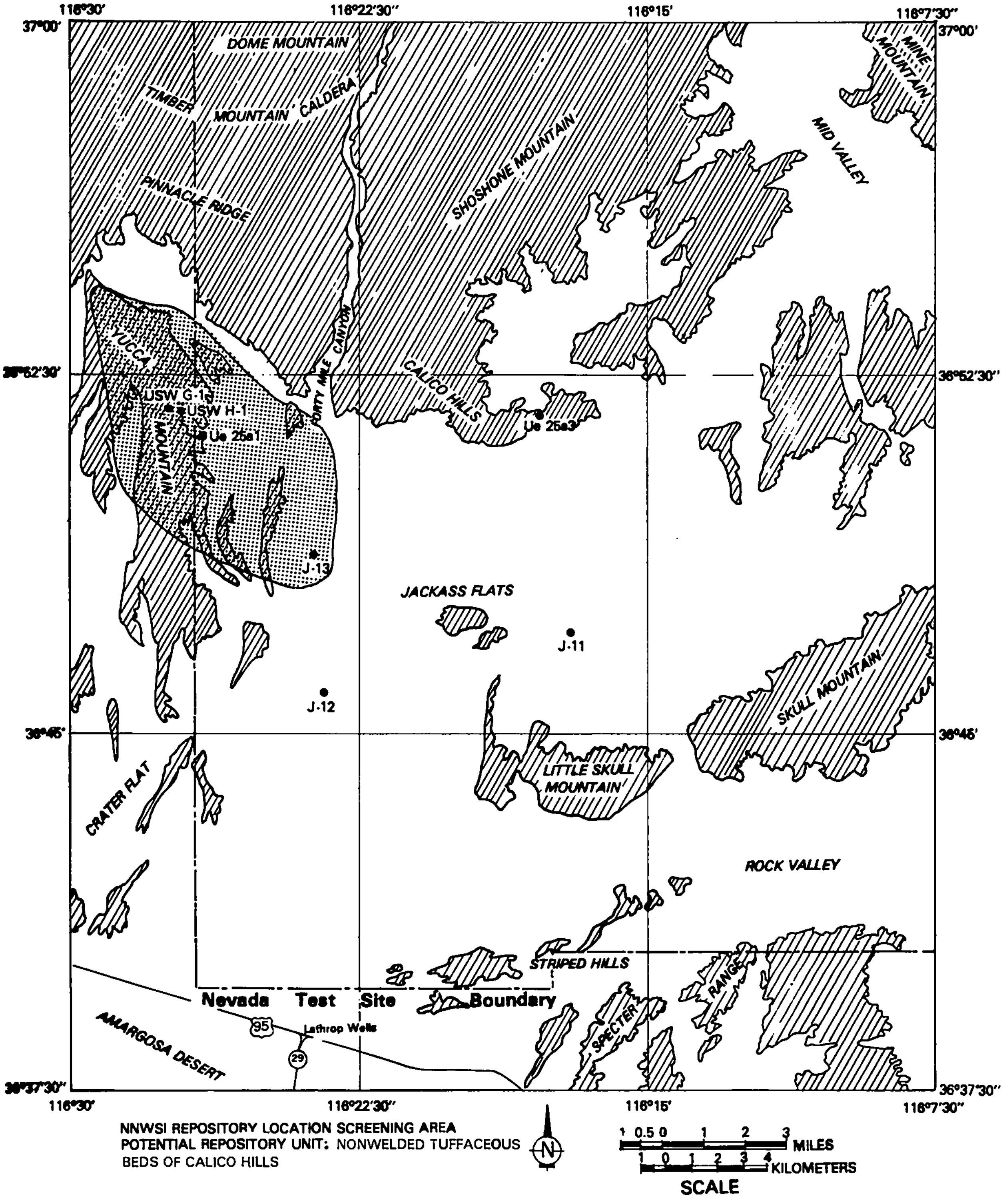

116°30'
116°22'30"
116°15'
116°7'30"
37°00'
36°52'30"
36°45'
36°37'30"
DOME MOUNTAIN
TIMBER MOUNTAIN CALDERA
PINNACLE RIDGE
NORTH
SHOSHONE MOUNTAIN
MINE MOUNTAIN
MID VALLEY
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
USW G-1
USW H-1
Ue 25a1
Ue 25a3
J-13
JACKASS FLATS
J-11
J-12
NORTH
SOUTH
SKULL MOUNTAIN
LITTLE SKULL MOUNTAIN
CRATER FLAT
ROCK VALLEY
STRIPED HILLS
SPECTER RANGE
Nevada Test Site Boundary
AMARGOSA DESERT
95
Lathrop Wells
29
NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: DENSELY WELDED TOPOPAH SPRING
N
MILES
KILOMETERS
SCALE



116°30'
116°22'30"
116°15'
116°7'30"
37°00'
36°52'30"
36°45'
36°37'30"
DOME MOUNTAIN
TIMBER MOUNTAIN CALDERA
PINNACLE RIDGE
SHOSHONE MOUNTAIN
MID VALLEY
MINE MOUNTAIN
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
USW G-1
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Ue 25a1
Ue 25a3
J-13
J-11
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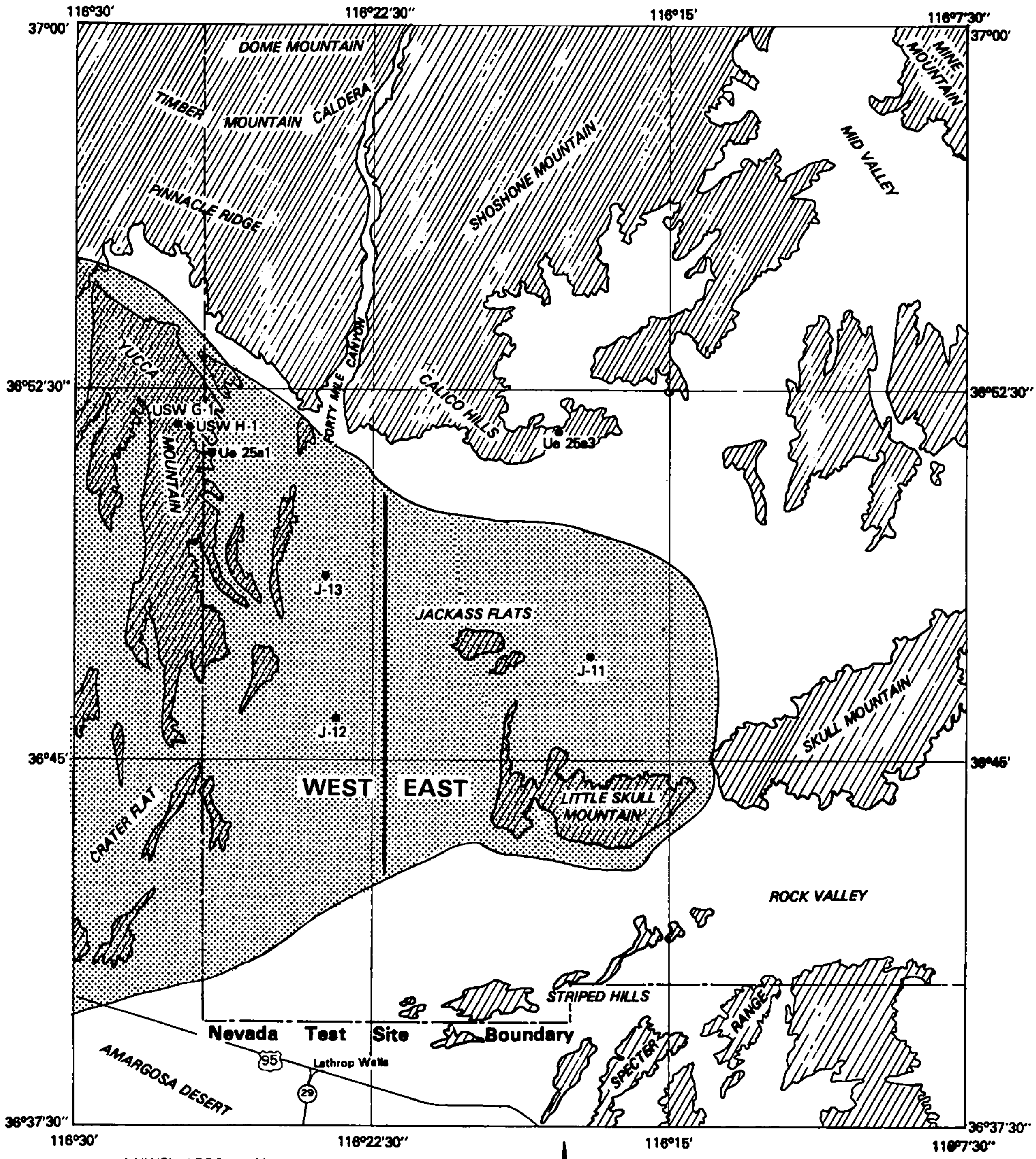
JACKASS FLATS
SKULL MOUNTAIN
LITTLE SKULL MOUNTAIN
CRATER FLAT
ROCK VALLEY
STRIPED HILLS
SPECTER RANGE
Nevada Test Site Boundary
95
29
Lathrop Wells
AMARGOSA DESERT
NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: NONWELDED TUFFACEOUS BEDS OF CALICO HILLS
N
1 0.5 0 1 2 3 MILES
1 0 1 2 3 4 KILOMETERS
SCALE



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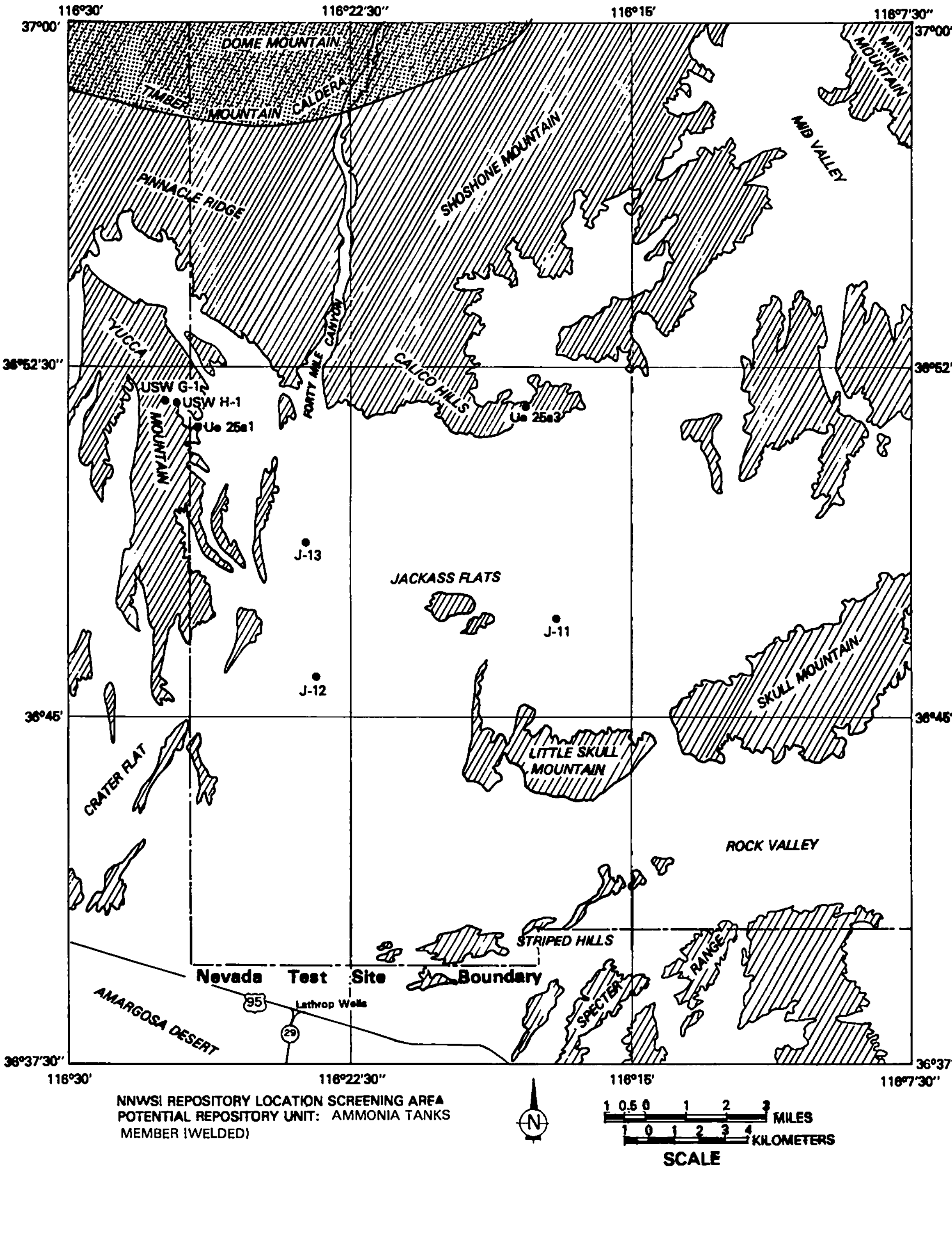
POTENTIAL REPOSITORY UNIT: CRATER FLAT TUFF
AT YUCCA MOUNTAIN


116°30'
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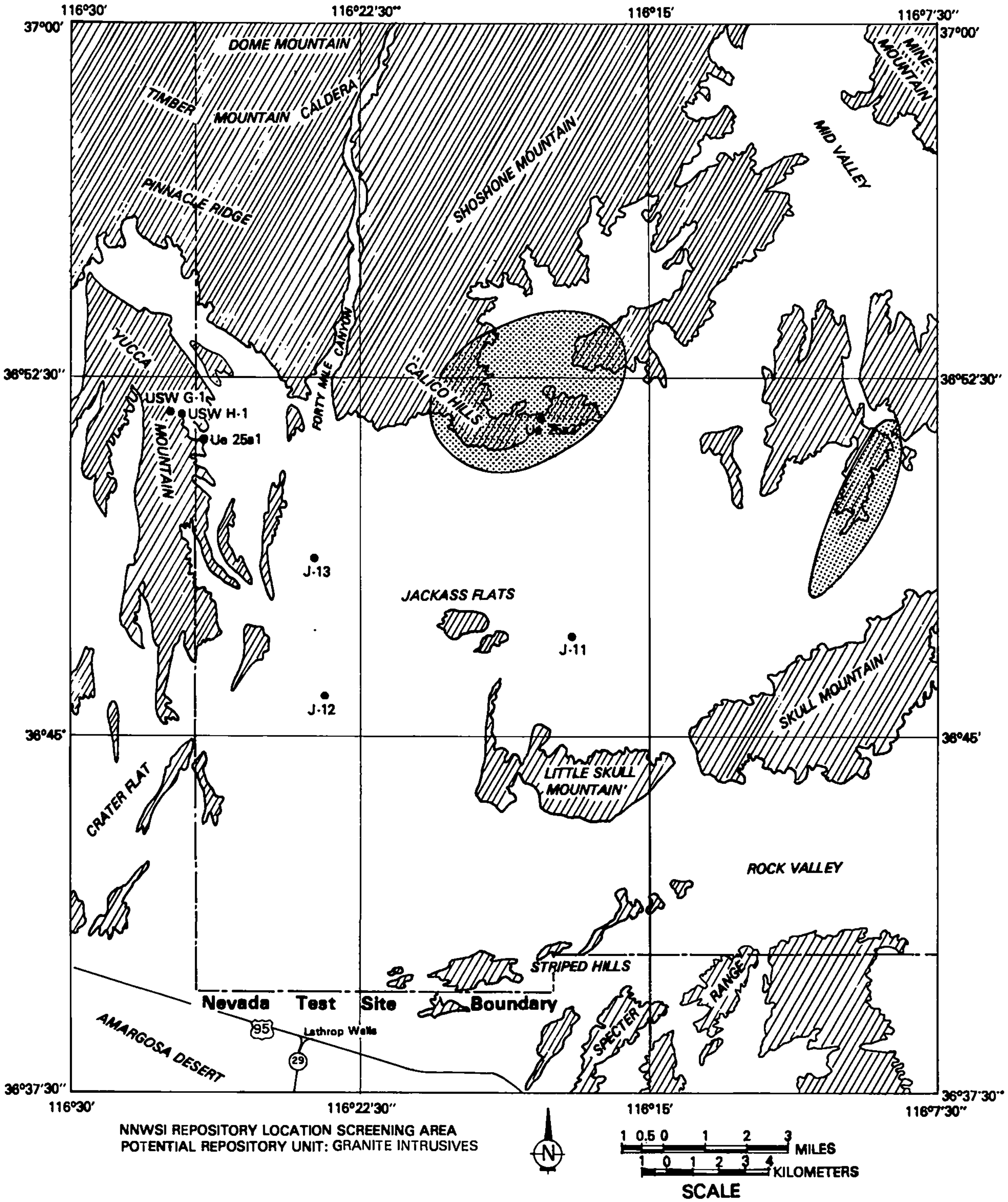
116°15'
116°7'30"
37°00'
37°00'
DOME MOUNTAIN
TIMBER MOUNTAIN CALDERA
MINE MOUNTAIN
MID VALLEY
SHOSHONE MOUNTAIN
PINNACLE RIDGE
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
36°52'30"
36°52'30"
USW G-1
USW H-1
Ue 25a1
Ue 25a3
J-13
JACKASS FLATS
J-11
J-12
SKULL MOUNTAIN
36°45'
36°45'
CRATER FLAT
LITTLE SKULL MOUNTAIN
ROCK VALLEY
STRIPED HILLS
Nevada Test Site Boundary
SPECTER RANGE
AMARGOSA DESERT
95
Lathrop Wells
29
36°37'30"
36°37'30"
116°30'
116°22'30"
116°15'
116°7'30"
NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: AMMONIA TANKS MEMBER (WELDED)
N
1 0.5 0 1 2 3 MILES
1 0 1 2 3 4 KILOMETERS
SCALE



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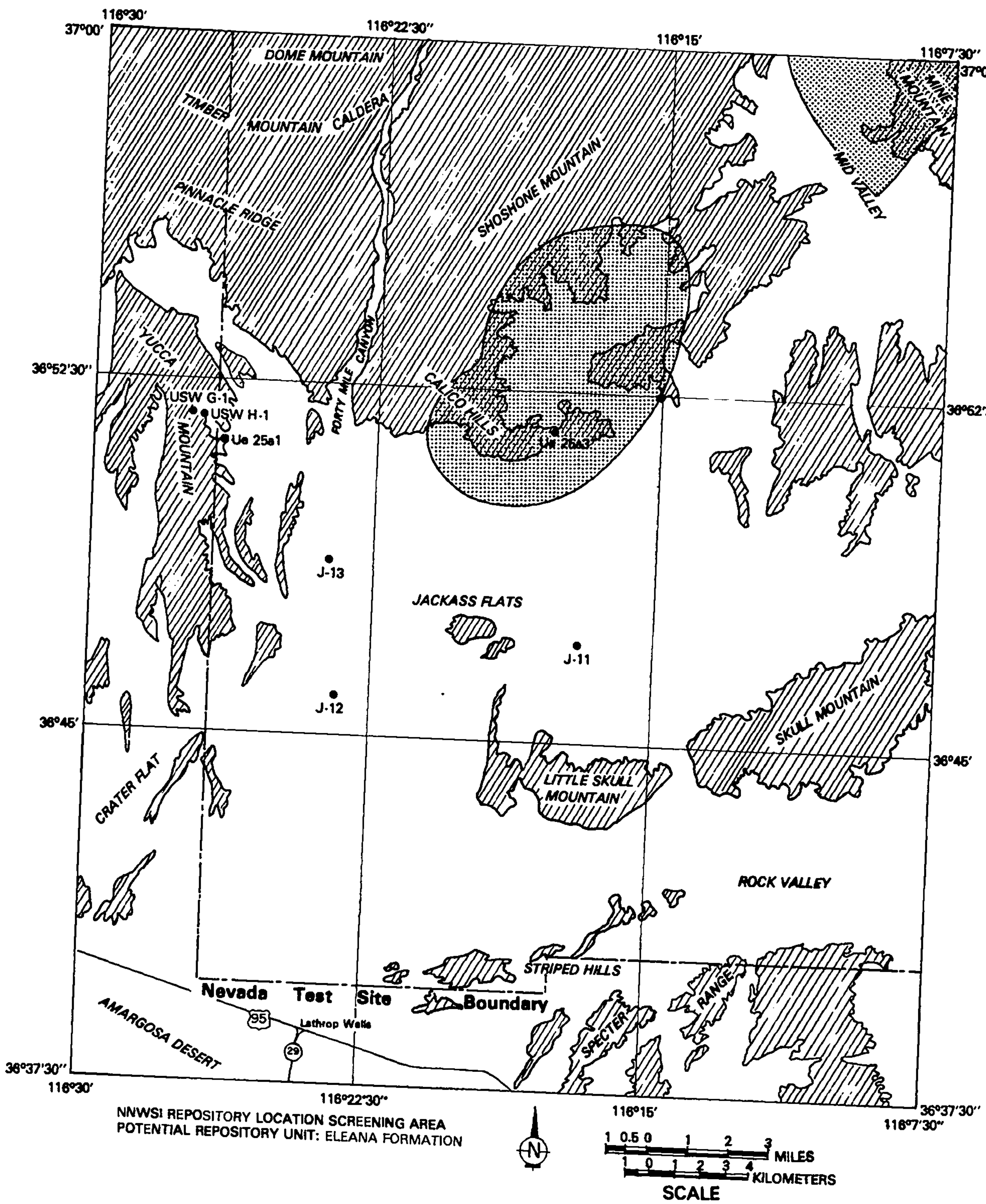
POTENTIAL REPOSITORY UNIT: GRANITE INTRUSIVES


116°30'
37°00'
116°22'30"
116°15'
116°7'30"
37°00'
DOME MOUNTAIN
TIMBER MOUNTAIN CALDERA
MINE MOUNTAIN
SHOSHONE MOUNTAIN
MID VALLEY
PINNACLE RIDGE
YUCCA MOUNTAIN
FORTY MILE CANYON
CALICO HILLS
36°52'30"
36°52'30"
USW G-1
USW H-1
Ue 25a1
J-13
JACKASS FLATS
J-11
J-12
SKULL MOUNTAIN
36°45'
36°45'
CRATER FLAT
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95
Lathrop Wells
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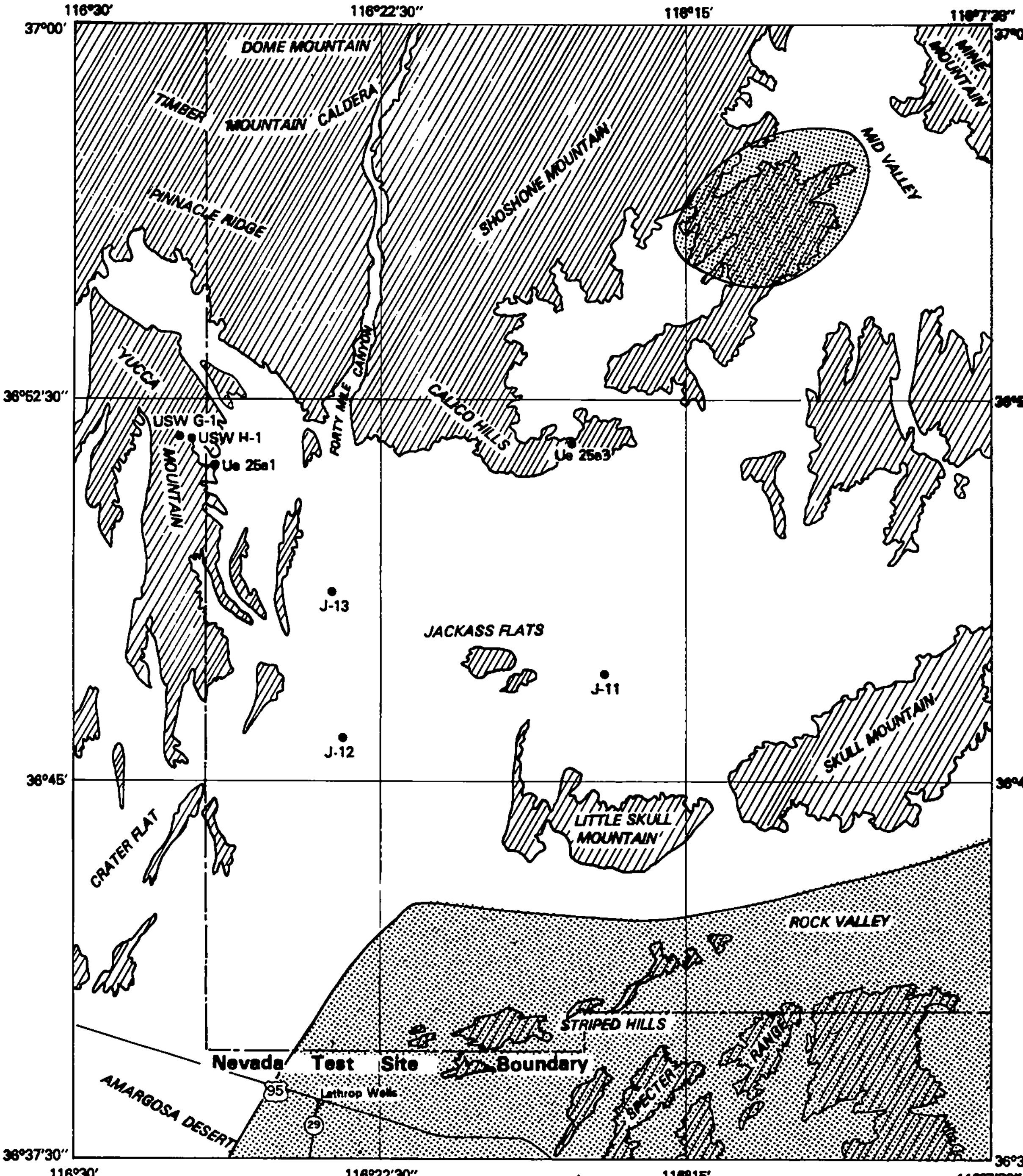
AMARGOSA DESERT
SPECTER RANGE
36°37'30"
116°30'
116°22'30"
116°15'
36°37'30"
116°7'30"
NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: ELEANA FORMATION
N
1 0.5 0 1 2 3 MILES
1 0 1 2 3 4 KILOMETERS
SCALE



NNWSI REPOSITORY LOCATION SCREENING AREA
POTENTIAL REPOSITORY UNIT: CARBONATE ROCKS
OF PALEOZOIC AGE

N

1 0.5 0 1 2 3 MILES
1 0 1 2 3 4 KILOMETERS
SCALE

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983-0-676-026/52

Printed in the United States of America
Available from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

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