See Pocket 2 (1987) for enclosure

Oct 26, 1987

ACRS/TRIP REPORT

MEMORANDUM FOR: Ronald L. Ballard, Branch Chief
Technical Review Branch
Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards

THRU: Philip S. Justus
Geology/Geophysics Section
Technical Review Branch
Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards

FROM: Keith I. McConnell
Geology/Geophysics Section
Technical Review Branch
Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards

SUBJECT: REPORT DESCRIBING ACTIVITIES ASSOCIATED WITH THE JULY 27-30, 1987, VISIT WITH THE ACRS SUBCOMMITTEE ON WASTE MANAGEMENT TO THE UNIVERSITY OF ARIZONA AND THE NEVADA TEST SITE

PURPOSE AND BACKGROUND OF TRIP

On July 27 through July 30, 1987, I accompanied the Waste Management subcommittee of the Advisory Committee on Reactor Safeguards (ACRS) and their consultants (see Attachment 1) on a field trip to the University of Arizona, the Nevada Test Site, and Yucca Mountain. The field trip consisted of three parts:

1) Briefings by Jaak Daemen (shaft sealing), Shlomo Neuman (saturated flow), Bill Greer (Oracle Ridge Mine) and Dan Evans (unsaturated flow) at the Geology Department of the University of Arizona in Tucson. [In addition to these briefings, a visit was made to the Apache Leap unsaturated zone field test site near Superior, AZ. All of the work outlined in the briefings presented this day is being funded through the Office of Research.]

2) Briefings in Las Vegas on the proposed High-Level Waste Repository Site at Yucca Mountain, Nevada, given by Paul Prestholt (NRC-OR), Carl Johnson (State of Nevada), and various DOE staff and contractors.

3) A field visit to the Nevada Test Site and Yucca Mountain which included visits to G-Tunnel, the Climax Facility, Sedan Crater, and Trench 14.

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WM Record File: 102
LPDR w/encl

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My efforts during these visits were directed towards providing technical support to the ACRS subcommittee regarding the NRC's geotechnical concerns on the proposed repository at Yucca Mountain. My observations, comments and recommendations are presented below.

SUMMARY OF DAILY ACTIVITIES:

July 28 - Morning briefings by Jaak Daemen, Shlomo Neuman, and Dan Evans - University of Arizona, Tucson.

University of Arizona

The first briefing on July 28, was on Rock Mass Sealing and Shaft Sealing by Jaak Daemen. Dr. Daemen gave an abbreviated overview of the field and laboratory research he was conducting on boreholes in basalt, granite (tuff analog), and salt using seals composed of crushed stone, cement, and bentonite. He indicated that all of his studies were limited to borehole scale tests and that the applicability of this information to shafts is unknown and untested. Pertinent points included:

1) The experimenters noted a reversal in expansion in cement seals after 250 days. In essence the sealing capabilities of cement were degraded after 250 days.

2) There is a major concern over the chemical interaction between tuff and the cement seal.

3) Allowing cement plugs to dry out (i.e., in tuff) causes shrinkage and an increase in permeability

Shlomo Neuman presented the second briefing on saturated flow. Dr. Neuman indicated that most current models involve the use of porous media and that current data suggest that geologic/geophysical studies of fractures are not sufficient to define hydrologic properties. He also indicated that geotomographic studies apparently allow for correlation with permeability, but that there is no tool currently available for determining permeability on large areas with cross-hole tests.

Bill Greer gave a short briefing on hydrologic experiments conducted in limestone at the Oracle Ridge Mine. Generally, injection tests were performed on a subhorizontal drillhole within the Oracle Ridge Mine. The results of the test are included in Attachment 1.

In the final briefing of the morning, Dan Evans outlined the studies of unsaturated flow at the Apache Leap field test site. This discussion described what we would see in the afternoon on our visit to the field site.

Apache Leap Field Site

In the afternoon of July 28, the subcommittee was taken to the Apache Leap field test site near Superior, Az. On the way to the site, we stopped near an abandoned road tunnel where some hydrologic testing had been performed. In addition, Dr. Evans pointed out that when water ponds in Clear Creek, located near Apache Leap, eddies are observed and water flows down fractures. The phenomenon causes the Magma copper mine, some 5000 ft below Clear Creek, to increase pumping in mine tunnels approximately a month after ponding is observed in Clear Creek. The implication was that the groundwater traveltime to the mine was not long.

At the Apache Leap site, we observed the spacing and angle of the holes used to test the unsaturated zone and were briefed on the results of the tests to date. Two pertinent points outlined were that there is air flow within the volcanic rocks which can be related to barometric pressure and that capillaries in the volcanic rock appear to remain saturated while larger fractures saturate and desaturate. Rudimentary tests involving plastic bags taped to borehole stems are now being used to calculate the airflow rate with more precise experiments planned for the future.

Observations

Overall, I found the Univ. of Arizona presentation to be unpolished with the absence, at the start of the briefings, of a clear statement on the purpose of the various investigations and their relationship to the waste management program somewhat disconcerting. Problems with these aspects of the presentation could possibly relate, in part, to the fact that some of the Univ. of Arizona investigators indicated that they were uncertain as to what level of briefing they should present.

ACRS subcommittee members and consultants' questions during this part of the trip concentrated on QA issues and specific technical aspects of the investigations being conducted. Dr. Daemen's presentation was the most detailed of the morning briefings and, therefore, the briefing most open to questions. The ACRS questioned Dr. Daemen on whether he was up-to-date with work being performed in similar areas at other institutions and laboratories; on whether tests were planned to evaluate seal performance after installation; and on specific aspects of sealing that were not being investigated (e.g., influences of rock chemistry on seals). Both Dr. Daemen and Tom Nicholson (NRC-RES) responded to the questions. Many of the ACRS questions seemed to relate to programmatic aspects of the investigations which required a response from the NRC contract manager.

Recommendations

It was apparent that the absence of an opening statement outlining the goals and objectives of the investigations and the relative informality of the presentation generated questions in the minds of the ACRS members as to the quality of the work and why the work was being performed (see Attachment 2). My feeling was that the unpolished presentation may have obscured the importance of the material being presented. This opinion possibly results from the fact that I had been briefed on this material prior to this trip (contrary to the impression developed by ACRS subcommittee members that the results of the contractor's work is not transfered to others in the program, see Attachment 2). Because I feel that the presentation tainted the studies, I recommend that the ACRS be given a second briefing on the program at the University of Arizona. This second briefing should be considered a formal briefing requiring polished notes and graphics and should specifically outline the goals and objectives of the program. Perhaps in this way stated concerns generated by the first briefing could be re-addressed.

July 29 - Briefings in Las Vegas from Paul Prestholt (NRC-OR), Carl Johnson (State of Nevada), and various DOE staff members.

Paul Prestholt (NRC-OR)

Paul Prestholt presented an overview of the role of the NRC On-site Representative (OR) outlining his responsibilities and the manner and extent of interactions with the DOE and the State of Nevada (Attachment 3). Questions from the ACRS subcommittee related to whether readiness reviews were being held, what the NRC's role would be in such reviews, and whether the OR was aware of an ACRS letter specifying that the NRC use the same QA standards on its contractors as applied to the DOE. Paul indicated that he was unaware of the ACRS letter.

Under questioning from the ACRS subcommittee about any problem areas that Mr. Prestholt was aware of, he mentioned the difficulty in having NRC headquarters staff travel to mission related interactions at the site and the lack of guidance from the NRC on certain key questions.

Carl Johnson (State of Nevada)

Carl Johnson (State of Nevada) presented the state's view of the proposed repository site at Yucca Mountain by defining what they term "Site Suitability Issues" (Attachment 4). Mr. Johnson indicated that some of the site suitability issues could, in the state's view, contain hidden fatal flaws. The site suitability issues presented were:

1) Characterization of moisture movement through the unsaturated zone:
   The state believes that there is not sufficient time in the Site Characterization process to develop a database to establish the manner in which moisture moves through the unsaturated zone.

2) Relationship of Yucca Mountain groundwater regime to the regional aquifer system:
   The state believes that the carbonate aquifer system under Yucca Mountain may in the future be the source of water for Las Vegas.

3) Effect of future climatic variations and resulting changes in the integrity of the site:
   The state believes that cooler and wetter climates may occur in the future.

4) Effects of future faulting or other tectonic events on the integrity of the site:
   This is considered the most important issue by the state and the issue which the state believes is the most likely to generate a fatal flaw for the site.

5) Effects of future volcanism on the integrity of the site:

6) Human interference of the site due to perceived presence of extractable natural resources:
   This issue is also of primary importance to the state.

Mr. Johnson then gave a detailed analysis of the technical issues and followed that analyses with a description of the technical programs in which the state is involved. He also mentioned that the concerns expressed by the state were not new but largely coincided with concerns expressed by the National Academy of Science and NRC staff comments on the Environmental Assessment.

Mr. Johnson was questioned on which areas contained potential disqualifiers to the site and he reiterated that faulting (including the effects on hydrology and waste cannisters), volcanism and human intrusion were prominent in the state's view. He was also questioned about interactions with the NRC since the state's concerns were similar to the NRC's. He indicated that the NRC and the state had interacted on a field trip and several contractor projects.

DOE Presentation:

Following a movie presented over lunch on the program of drilling large-diameter holes for weapons tests, the DOE and its contractors gave presentations outlining various aspects of the program (Attachment 5). The presentations were very well done, but in content were superfical and did not address the issues that have been derived from reviews of the Draft and Final Environmental Assessment.

Topics the presentations addressed included:

1) Organizing Principles for Site Characterization

2) Ground-Water Flow

3) Radionuclide Retardation

4) Tectonics

5) Volcanism

6) Potential for Hydrothermal Activity

Following the presentations, the ACRS subcommittee and their consultants discussed with DOE representatives a list of seven questions on which the DOE will provide written responses. These questions are listed in Attachment 2.

Recommendations:

My feeling at the meeting was that the ACRS subcommittee could have been better prepared for the presentations and attuned to major concerns with the Yucca Mountain site if the NRC staff had briefed the subcommittee prior to their visit. I recommend that, prior to the ACRS Waste Management subcommittee's visit to BWIP, the NRC technical staff brief the subcommittee on the history and status of major concerns.

July 30 - Field visit to the Nevada Test Site and Yucca Mountain.

Field Trip

On Thursday, July 30, the ACRS and consultants travelled to the Nevada Test Site and Yucca Mountain. After badging, the trip began with a tour of Reynolds Electrical and Enginneering Company drill yard in Yucca Flat where Patrick Rowe made a presentation on large diameter drilling.

The field visit continued with a visit to the G-Tunnel complex where Roger Zimmerman (Sandia National Laboratory) gave a walking tour of the facility pointing out that the welded tuff was 80% saturated with perched water in unwelded tuffs comprising local saturated zones. Additional stops included a fault zone from which water was dripping, heater tests and block experiments. Dr. Zimmerman made an unusual statement that fractures in the repository block at Yucca Mountain would not be any more abundant than those found in the welded tuffs in G-Tunnel because all fractures were related to cooling and the tuffs in G-Tunnel were more intensely welded than those in the repository block. I mentioned that published reports on the geology of Yucca Mountain noted that many of the fractures present there were parallel to major faults and were

probably fault related. Dr. Zimmerman stated categorically that the fractures were not tectonic.

The Climax Spent-Fuel Test Facility was the next stop on the field trip. Larry Skousen (DOE) led this portion of the trip. In the tunnel, water was observed dripping from a fault exposed near the waste-handling area.

Prior to Yucca Mountain, the field trip made a stop at Sedan Crater. At Yucca Mountain, Bill Dudley (USGS) gave an overview of the geology of the Yucca Mountain area. This was followed by a briefing on matrix flow by hydrologists from the USGS and Fenix and Scissons.

The tour continued with a visit to Trench 14 where the calcite-silica veins associated with the Bow Ridge fault were viewed. Bill Dudley gave an overview of the data currently available and the conclusion that currently available data supported a pedogenic origin. Jerry Szymanski (DOE) also discussed some of the alternative theories of origin.

Paul Prestholt, Owen Merrill and I then took a side trip to the Exploratory Shaft site in Coyote Wash. The trip then returned to Mercury.

Recommendations:

As stated previously, the ACRS subcommitte would have been better prepared to cast a critical eye on the presentations and aspects of the field trip if they had received an up-to-date briefing by the NRC staff. I recommend that, prior to the ACRS Waste Management subcommittee's visit to BWIP, the NRC technical staff brief the subcommittee on the history and status of major concerns.

OCT 26 1987

OFFICIAL CONCURRENCE AND DISTRIBUTION RECORD

MEMORANDUM FOR: Ronald L. Ballard, Branch Chief
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Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards

THRU: Philip S. Justus
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FROM: Keith I. McConnell
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DATE:

DISTRIBUTION w/o Enclosure

HLWM/SF	NMSS RF	RBrowning, HLWM	CAbrams, HLTR
MBell, HLWM	JBunting, HLSE	RBallard, HLTR	PPrestholt, HLWM
Youngblood, HLOB	KMcConnell, HLTR RF	JTrapp, HLTR	
PJustus, HLTR	HLTR RF	PDR	

CONCURRENCES

ORGANIZATION/CONCUREE	INITIALS	DATE CONCURRED
HLTR/KMcConnell		87/10/23
HLTR/JTRAPP		87/10/23

Original Hand carry 10/26/87.

ATTACHMENT 1

See memo to Bailey fm. McCormell 10/26/87 102

RESEARCH OVERVIEW for ACRS

July 28, 1987

Rock Mass Sealing: NRC Contract 04-78-271

Sealing of Boreholes and Shafts in Salt: NRC Contract 04-86-113

PI: Jaak Daemen (602)621-2501
Dept. of Mining and Geological Engineering
University of Arizona, Tucson, AZ 85721

NRC Contract Monitor: J. Philip, RES/WMBR

Agenda:

8:00 am Rock Mass Sealing

Experimental Studies on Borehole Plug Performance

Topics:

- Laboratory studies:
  - flow and strength tests on cementitious and bentonitic plugs in boreholes in basalt, granite, and welded tuff
  - drilling damage studies
  - fracture grouting
- Field testing of cement and clay borehole plugs

9:00 am Salt Repository Sealing Experiments

- Salt sample preparation and mechanical characterization testing
- Salt borehole tests: creep, closure, plug hydraulic conductivity and strength (push-out)
- Seal characterization tests

  Cement, bentonite, crushed salt
- Crushed salt characterization and consolidation

9:30 am Lab visits and informal discussions with students, as desired

Rooms: Mines 25 (Bill Greer - field testing)
Mines 13; 21 (Shoung Ouyang - crushed salt testing)
Mines 13; 119B (Kittitep Fuenkajorn - salt creep, drilling damage)
Mines 31 (Haluk Akgun - push-out testing)
Mines 29 (Robert Armstrong - rock strength testing)

7/20/87

ROCK MASS SEALING

PI: Jaak Daemen
Dept. of Mining and
Geological Engineering
University of Arizona

NRC: J. Philip, RES/WMBR

Projects

ROCK MASS SEALING (NRC-04-78-271; FIN B6627)

FIELD AND LABORATORY TESTING
BASALT; GRANITE; (TUFF)
CEMENT; BENTONITE
BOREHOLE AND FRACTURE SEALING

SEALING OF BOREHOLES AND SHAFTS IN SALT (NRC-04-86-113; FIN D1192)

ROCK SALT
CRUSHED SALT; CEMENT; BENTONITE
LABORATORY AND FIELD TESTING

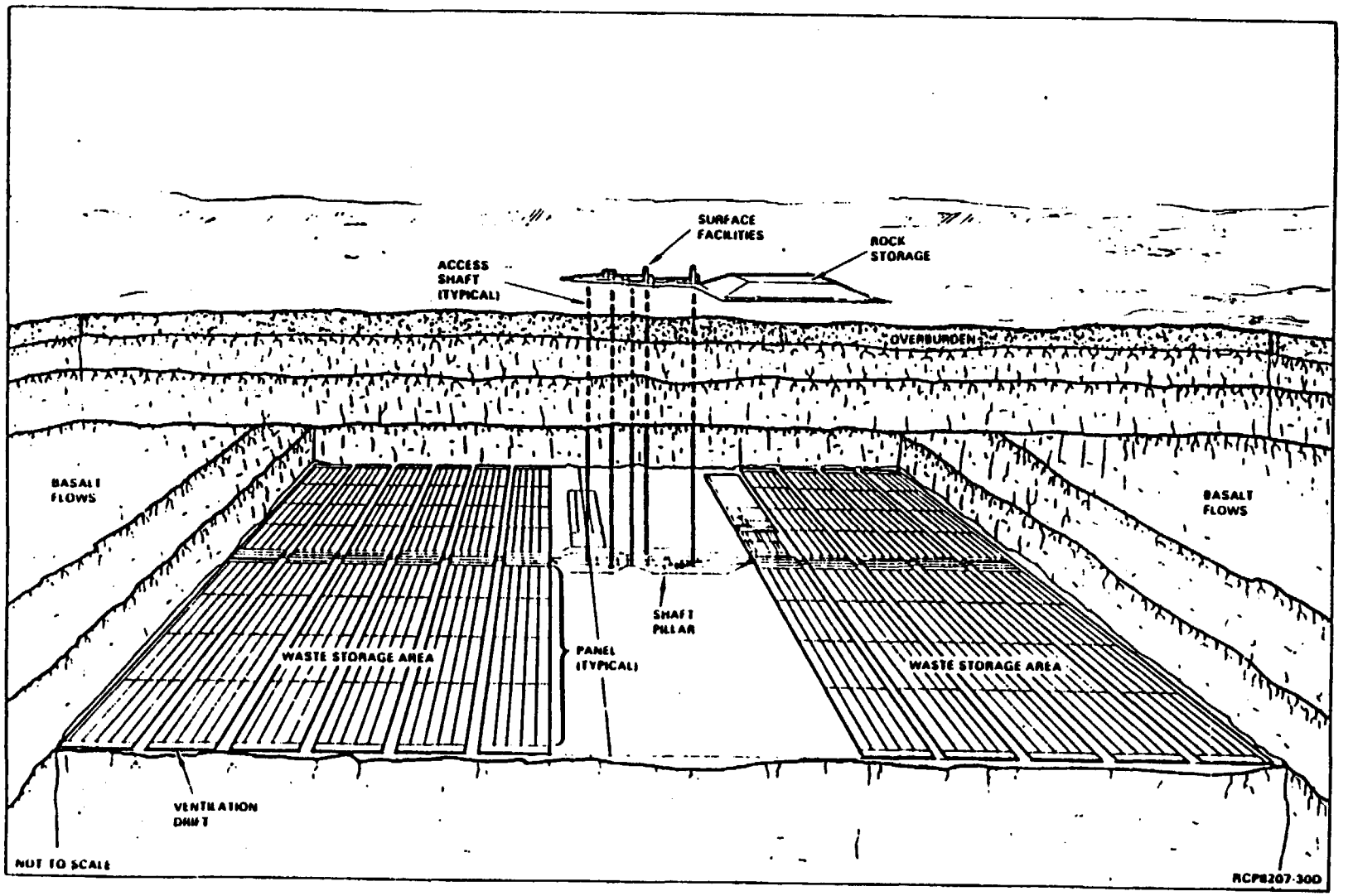


Figure 5-2. Underground layout of the reference repository location based on the 1982 Conceptual Design (RKE/PB, 1983).

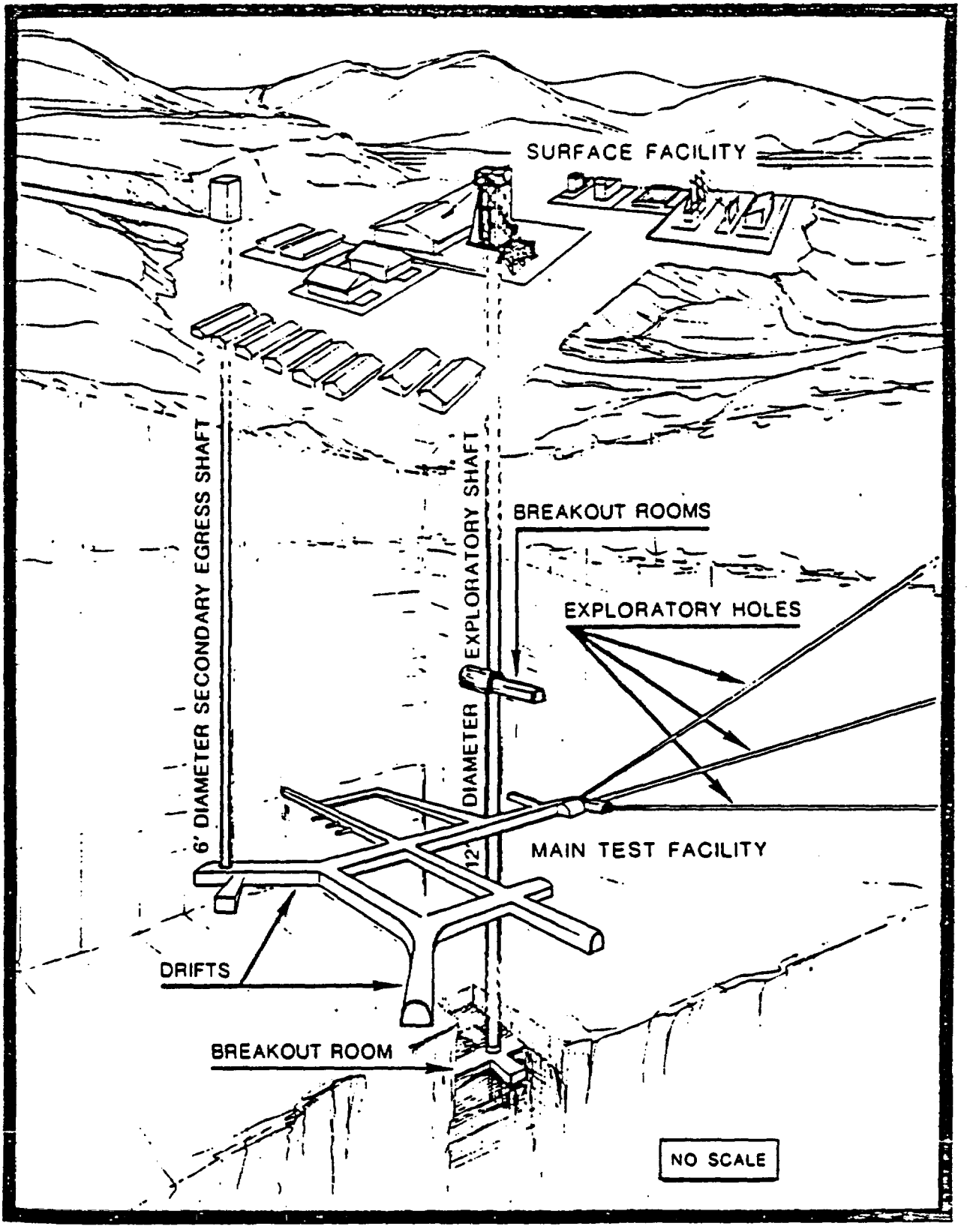


Figure 4-1. Three-dimensional illustration of the exploratory-shaft facility.

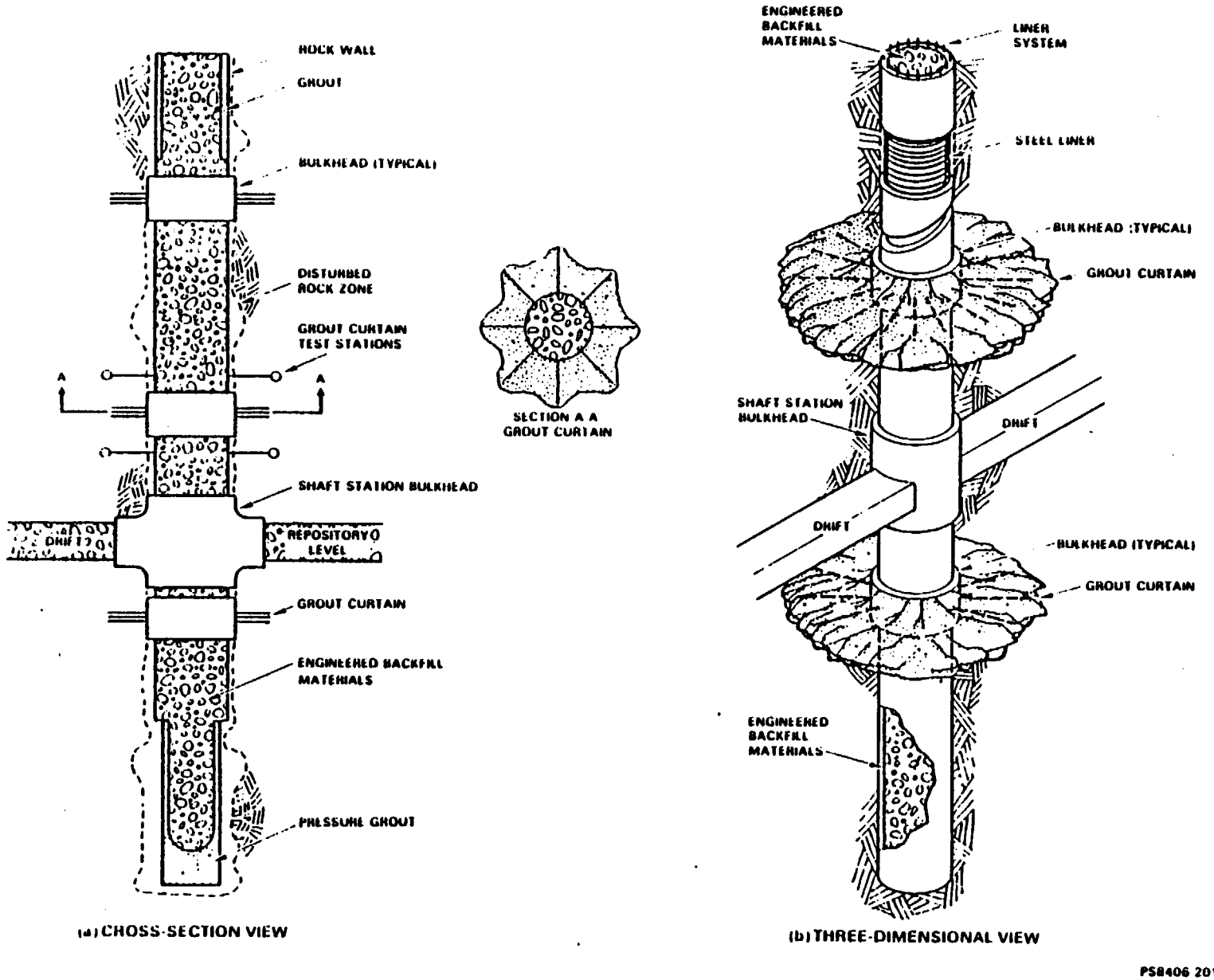


Figure 6-4. Conceptualized shaft seal design: (a) cross-section view; (b) three-dimensional view.

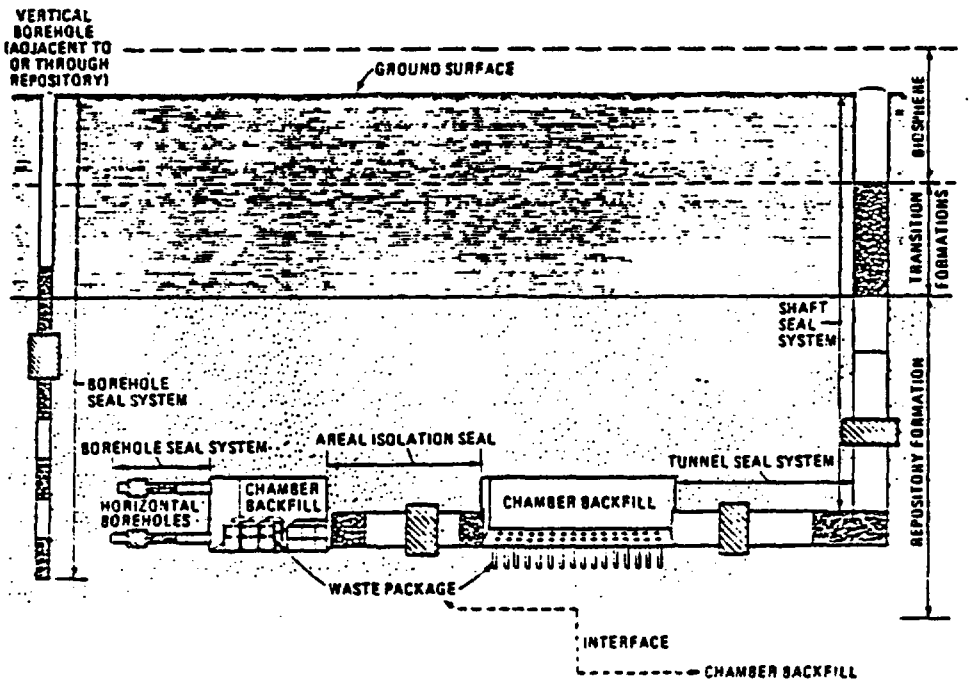


Figure 1 Penetration sealing applications. Types of seals are borehole, horizontal and vertical; shaft; tunnel, including areal isolation seals; and chamber backfill.

(Office of Nuclear Waste Isolation, 1980b), and compared the requirements for sealing shafts, tunnels, and boreholes (Office of Nuclear Waste Isolation, 1981a). An important ongoing activity has been close coordination of design with supporting field and laboratory test programs. Concurrent with the ONWI design program, preconceptual designs for penetration seals for a repository in basalt have been developed by Rockwell Hanford operations and Woodward-Clyde Consultants (Taylor et al., 1980).

Current design activities focus on developing conceptual designs for a repository in bedded salt using the Waste Isolation Pilot Plant (WIPP) site at Los Medanos in southeastern New Mexico as a reference case. This paper describes a general design approach for penetration seals which can be applied to any candidate repository site, with proper regard for site-specific geologic and design conditions. A detailed description of the interim designs developed for bedded salt is given as an initial example.

Seal Zone Components

Figure 2 shows that the seal zone consists of three potential pathways for fluid flow—the seal itself, the interface between the seal and the host rock, and a disturbed zone that may exist in the host rock. The disturbed zone is assumed to exist as a result of stress relief or damage by the excavation process or by weathering. Seal design must address all three components of the seal zone.

Interface Studies. Direct evidence regarding the importance of the

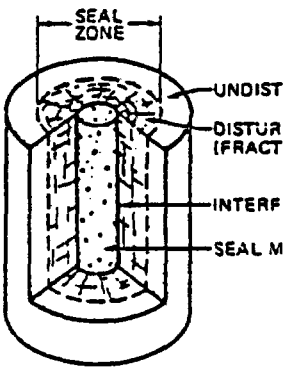


Figure 2 Seal zone

seal-host-rock interface
obtained from field and
tests on borehole plugs.
Canyon test, conducted
National Laboratories a
Science and Software at
site, involved placing a 2
cement plug in a borehol
diameter (Christensen a
1981). The plug was set i
drite formation at a dep
about 11.6 m above the
formation aquifer (Fig.
plug and an instrument
including an automatic t
were placed in the boreh
plug. Flow tests through
plug were conducted by
bridge plug, thus exposi
plug to water from the
aquifer at approximately
pressure. A packer was
plug to monitor fluid bu
pressure, and tracer arri
measured flow above the
was approximately 0.5 c
the flow velocity, estima
tracer arrival time, was

Estimating plug pern
requires knowledge of th
sectional area of flow. If
trarily take this area to
of the well bore (to inclu
turbed zone), the equival

REGULATORY CONTEXT

10 CFR PART 60 DISPOSAL OF HLW IN GEOLOGIC REPOSITORIES

60.134 DESIGN OF SEALS FOR SHAFTS AND BOREHOLES

60.133 ADDITIONAL DESIGN CRITERIA FOR THE UNDERGROUND FACILITY
(a) (1); (a) (2); (d); (h): ENGINEERED BARRIERS

LICENSE APPLICATION - SAFETY ANALYSIS REPORT
- PERFORMANCE ASSESSMENT
ALLOCATION

PERFORMANCE OBJECTIVES

60.113 ENGINEERED BARRIER SYSTEM

PERFORMANCE CONFIRMATION PROGRAM

60.142 DESIGN TESTING
(a), (c): BACKFILL
(a), (d): BOREHOLE AND SHAFT SEALS

REGULATORY CONTEXT

GTP: BOREHOLE AND SHAFT SEALING

ISSUES

- LONG-TERM STABILITY
- SHAFT AND BOREHOLE DESIGN
- INSTALLATION
- WASTE INDUCED THERMAL LOADING
- SEAL/HOST ROCK COMPATIBILITY
- LOW HYDRAULIC CONDUCTIVITY IN SEALED AREA

INFORMATION NEEDS

- ROCK CHARACTERISTICS
- SEAL MATERIAL CHARACTERISTICS
- ROCK FRACTURE SEALING
- SHAFT AND BOREHOLE DESIGN, EXCAVATION, AND CONSTRUCTION
- SEAL INSTALLATION

SEALING INVESTIGATIONS

- ORNL: MIT: SHALE/EARTHEN SEALS (1975-77)
  ORNL: CEMENT FOR SALT (± 1980)
  PSU: CEMENT (1975-9)

- ONWI: PSU: CEMENT (1979-)
  D'APPOLONIA/IT: DESIGN (1979-)
  TERRATEK: TESTING (1981-3)
  WES: CEMENT DESIGN/TESTING (1979-)
  EARTHTECHNOLOGY: SALT (1985-)

- BWIP: WOODWARD-CLYDE; PSU; D'APPOLONIA/IT;TERRATEK; BWIP

- NNWSI: LANL; PSU; WES; SNL

- WIPP: SNL; PSU; WES; IT; S^3
  IN SITU TESTING; LAB TESTING

FOREIGN:

GERMANY (ASSE): CONCRETE/CEMENT/SALT
SWEDEN (KBS): SWITZERLAND (NAGRA): BENTONITE
JAPAN: CEMENT

ROCK MASS SEALING

NRC-04-78-271

LABORATORY INVESTIGATIONS

BASALT, GRANITE, (TUFF)
CEMENT, BENTONITE

FLOW TESTING

RADIAL PERMEAMETER TESTING
UNCONFINED ROCK CYLINDERS
PIPE FLOW TESTING

PUSH OUT (STRENGTH) TESTING (CEMENT)

DYNAMIC LOAD INFLUENCE (CEMENT)

EFFECTS OF DRYING/REWETTING (CEMENT)

SIZE EFFECTS (CEMENT)

FLOW TESTING (BENTONITE)

CRUSHED BASALT/BENTONITE

DRILLING DAMAGE: GRANITE/BASALT

FRACTURE GROUTING

FIELD INVESTIGATIONS

McNARY DAM (BASALT - CEMENT - VERTICAL)
CARGADERO CANYON (GRANITE - CEMENT/BENTONITE, VERTICAL)
ORACLE RIDGE MINE (HORIZONTAL - TWIN ACCESS)

From South and Daemen, NUREG/CR-4748.

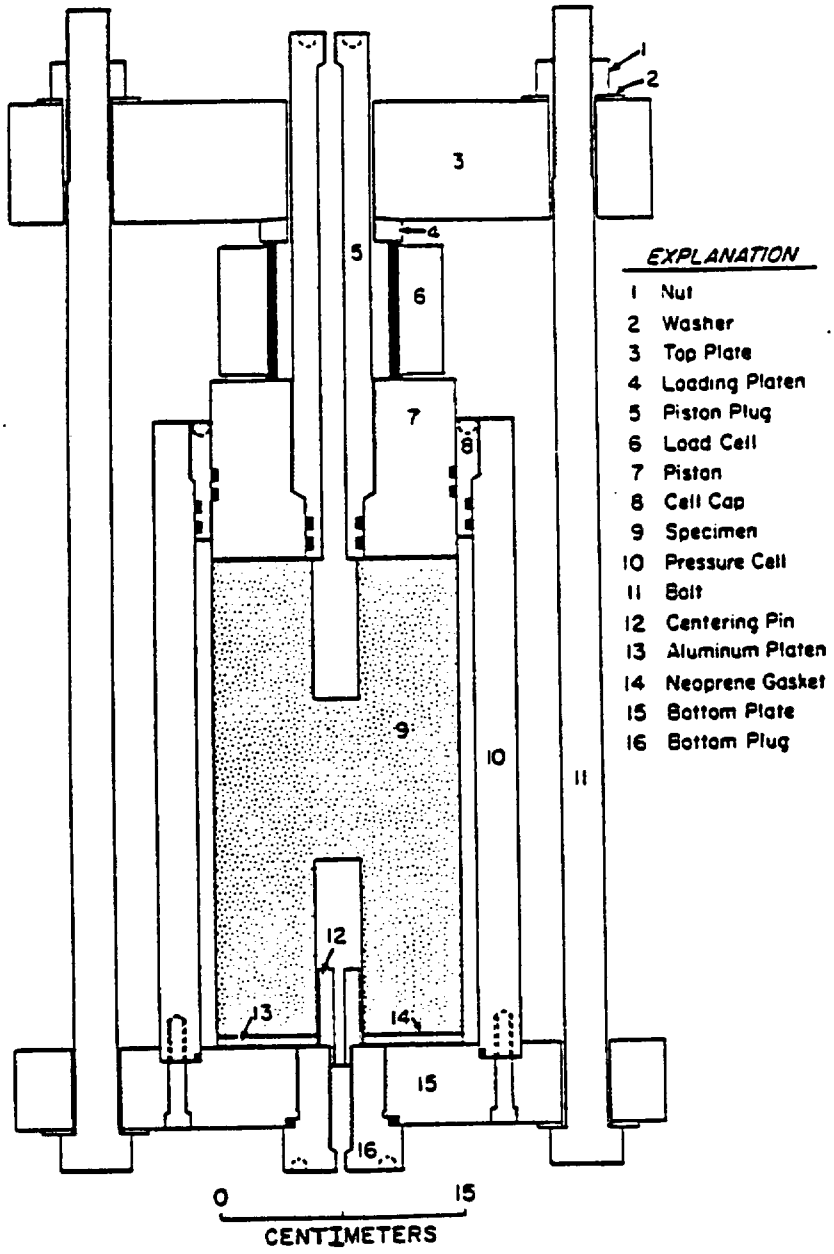


Figure 2. Radial permeameter assembly drawing. Small black rectangles indicate O-ring seals. Rock cylinder (9) is stressed axially and laterally. Water is injected through the top hole in the cylinder, and collected in the bottom hole.

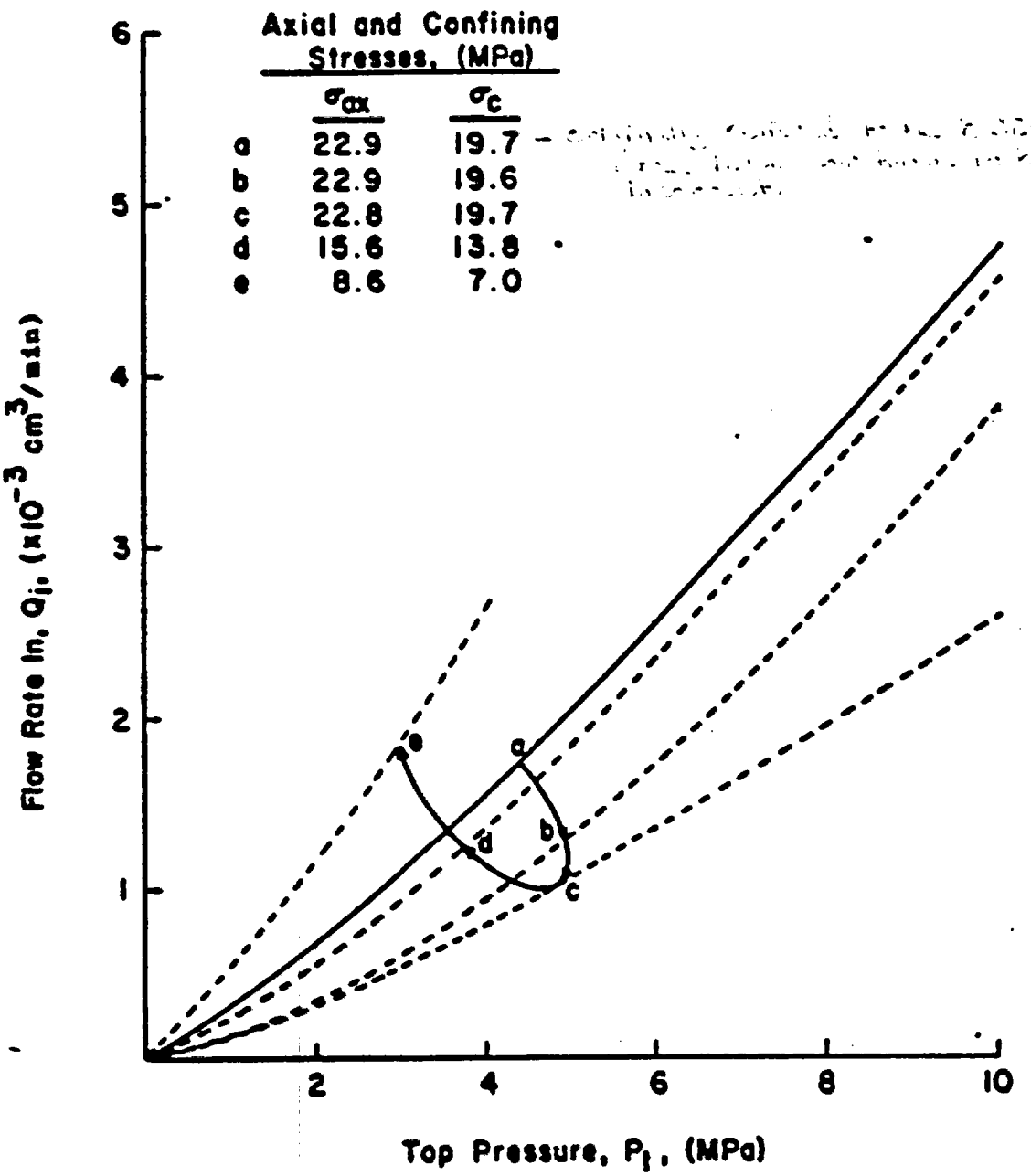
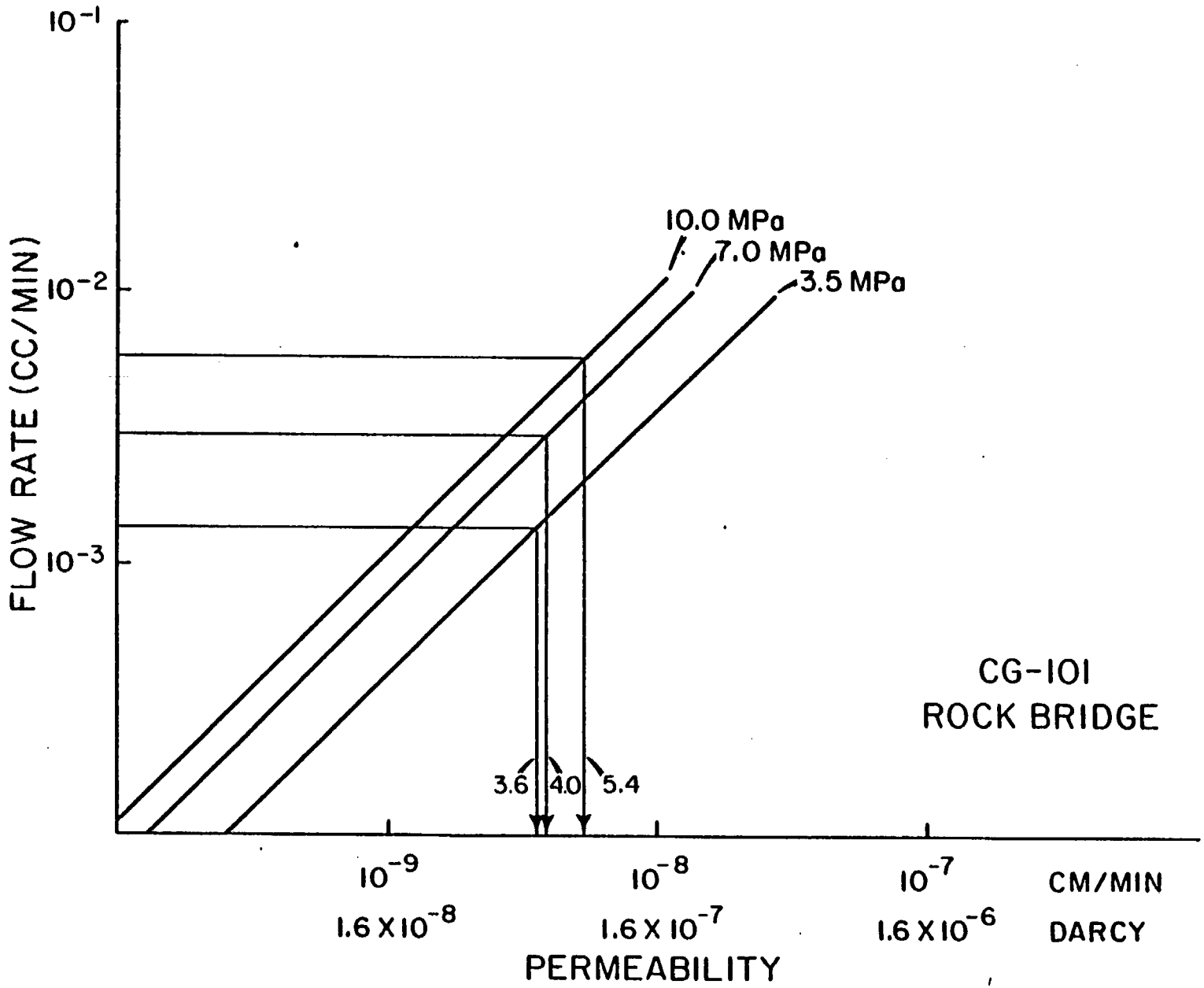
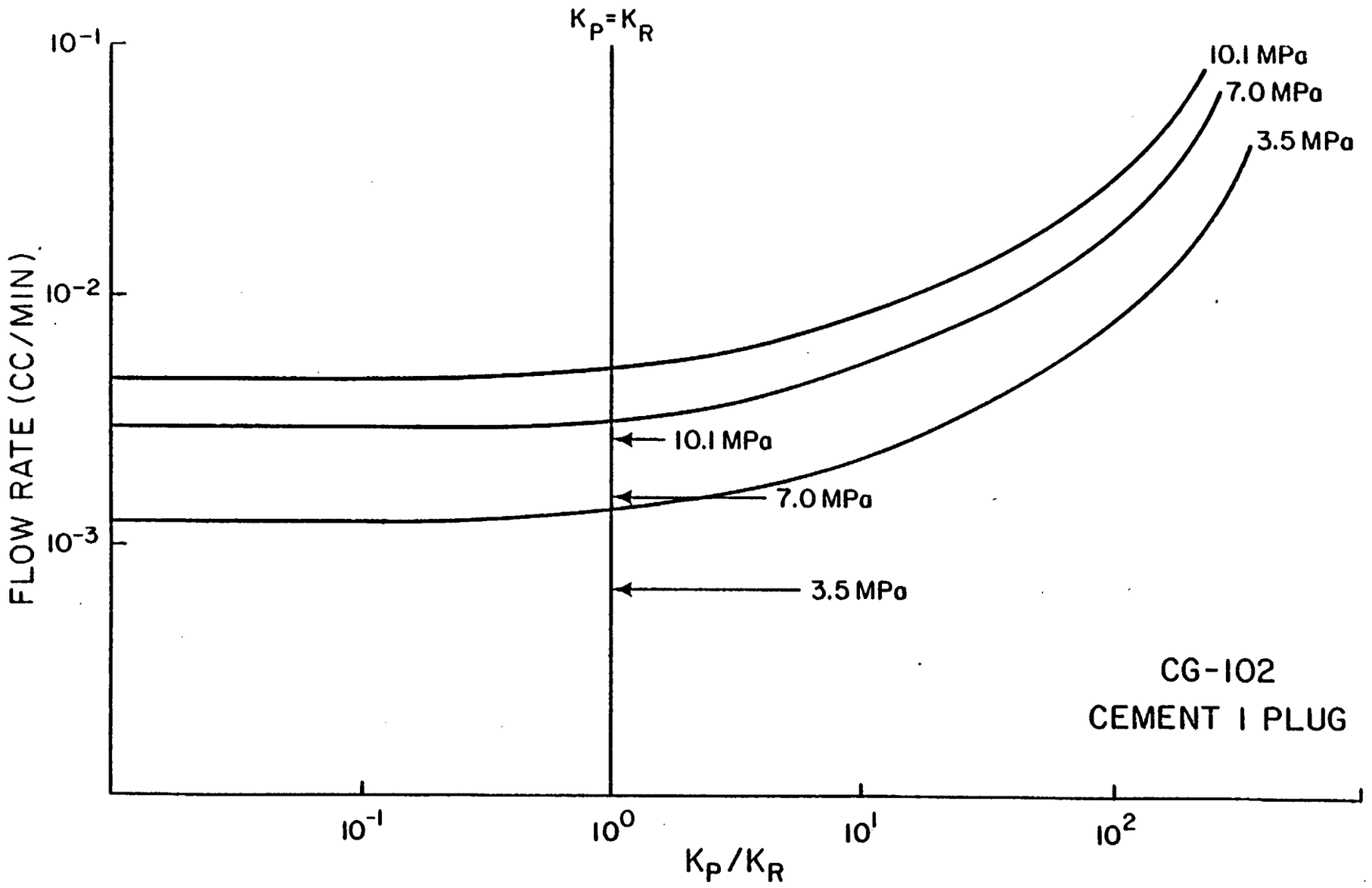
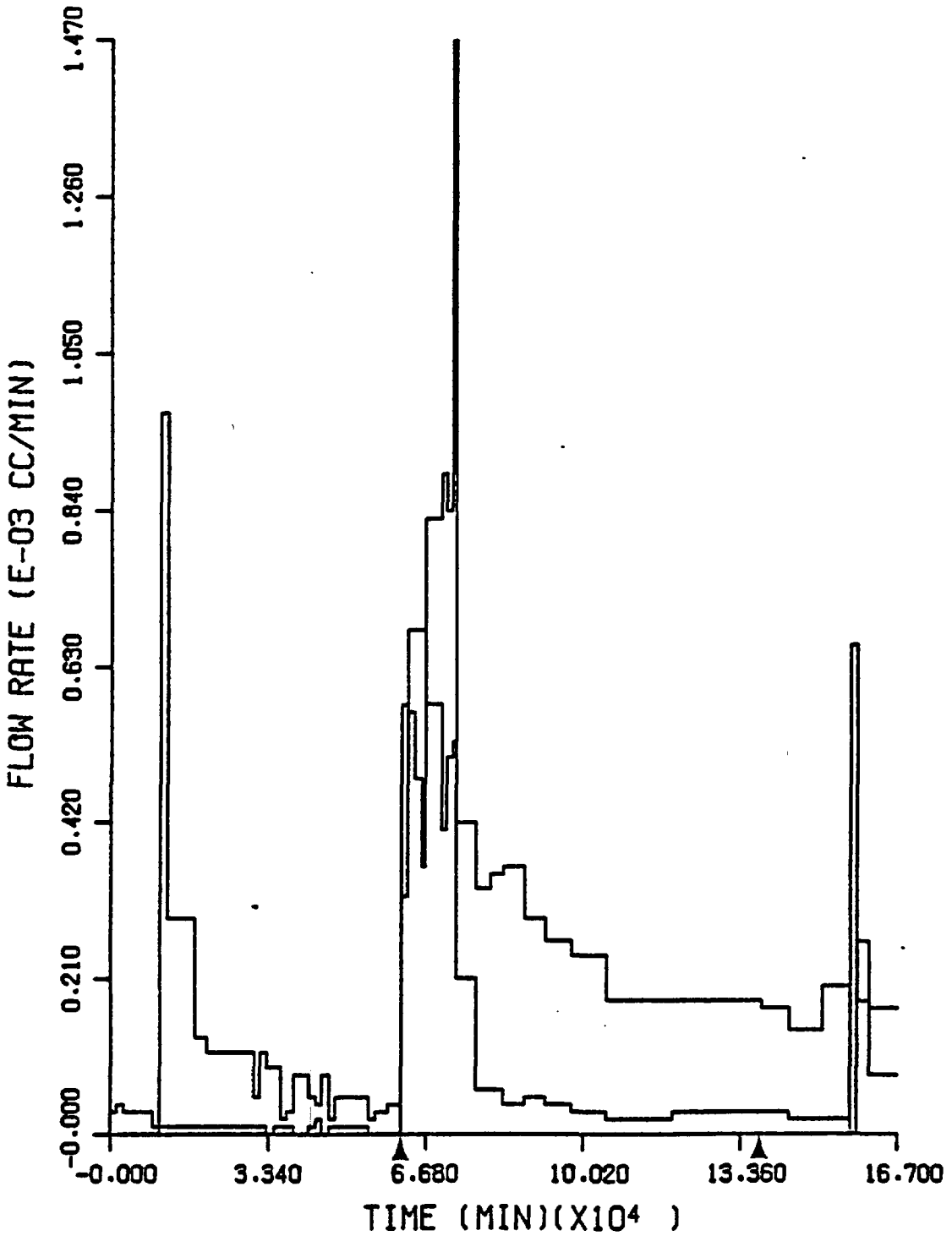


Figure 2.11 Sample CC-102, flow rate in vs. injection pressure, Charcoal Granite. Solid line indicates rock bridge, dashed lines indicate Cement 1 plug. Letters indicate order of testing.


FLOW RATE (CC/MIN)
10^{-1}
10^{-2}
10^{-3}
10.0 MPa
7.0 MPa
3.5 MPa
3.6
4.0
5.4
CG-101
ROCK BRIDGE
10^{-9}
10^{-8}
10^{-7}
CM/MIN
1.6×10^{-8}
1.6×10^{-7}
1.6×10^{-6}
DARCY
PERMEABILITY


$K_P = K_R$
10^{-1}
10^{-2}
10^{-3}
FLOW RATE (CC/MIN)
10.1 MPa
7.0 MPa
3.5 MPa
10.1 MPa
7.0 MPa
3.5 MPa
CG-102
CEMENT I PLUG
10^{-1}
10^{0}
10^{1}
10^{2}
K_P/K_R



SAMPLE NO. SGE-2-2

From South and Daemen, NUREG/CR-4748.

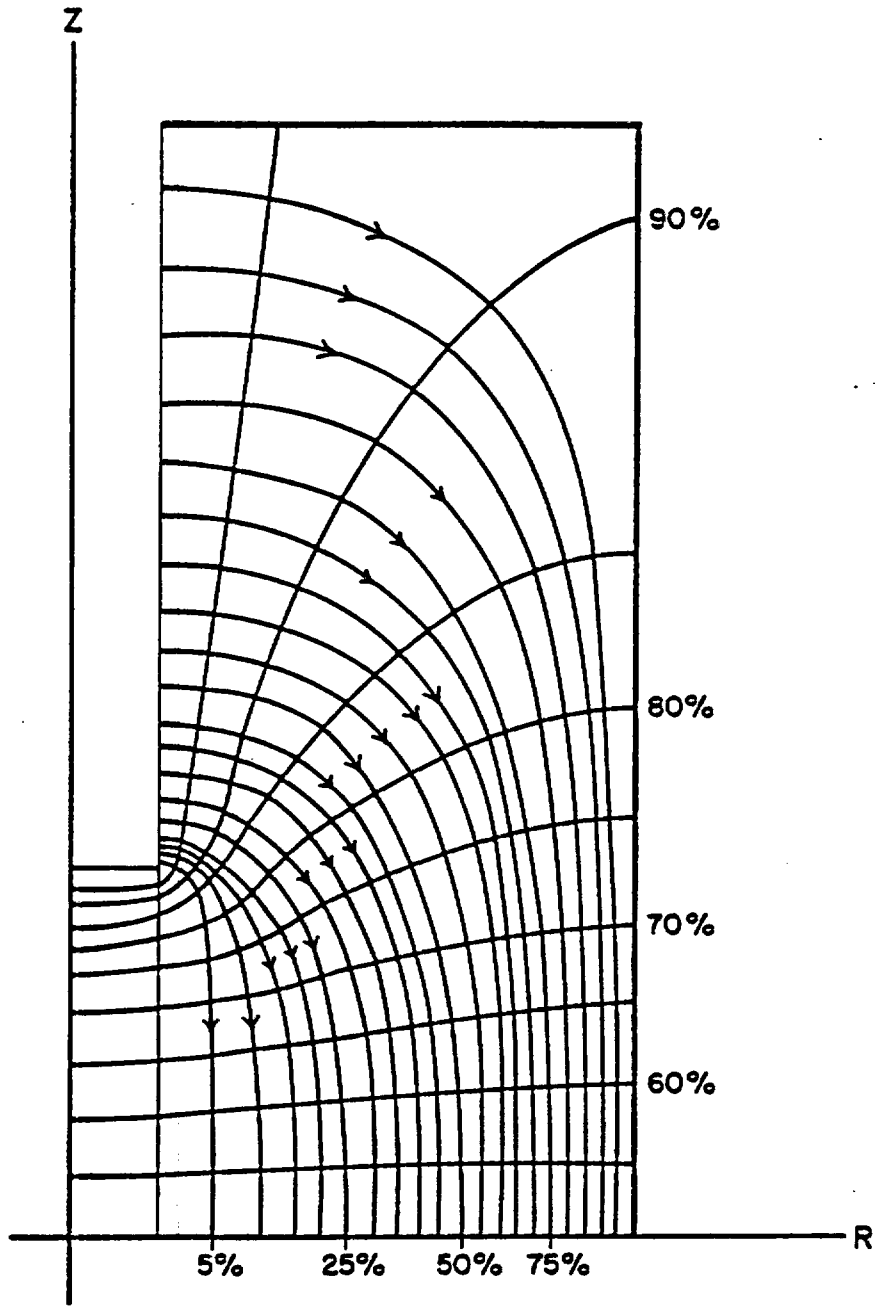


Figure 8. Flow net for intact rock, $K_P = K_R$. About 5% of the flow occurs through the "plug region". Equipotential lines show percent head with respect to center hole, which is at 100%. Stream lines show percent flow occurring between the stream line and the Z-axis. Relative flow magnitude = 1.00. Only upper half of cylinder is illustrated. Bottom hole (lower half) is at 0% head.

K_P = plug permeability; K_R = rock permeability.

From South and Daemen, NUREG/CR-4748.

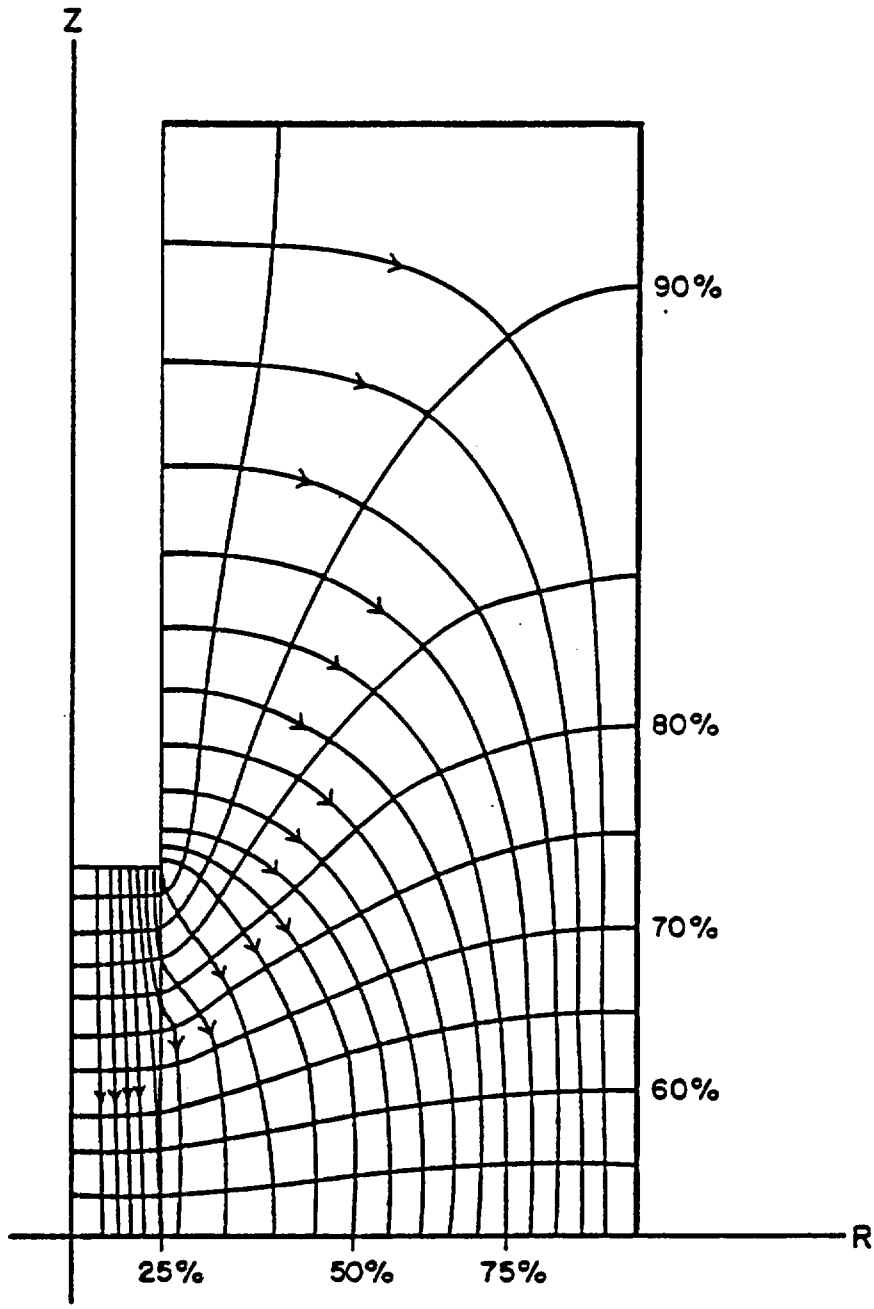


Figure 9. Flow net for plug more permeable than rock, $K_P = 10K_R$. About 25% of the flow occurs through the plug. Equipotential lines show percent head with respect to center hole. Stream lines show percent flow occurring between the stream line and the Z-axis. Relative flow magnitude = 1.50, i.e. flow is increased by 50%, as compared to the rock bridge case ($K_P = K_R$, Figure 8).

K_P = plug permeability; K_R = rock permeability.

From South and Daemen, NUREG/CR-4748.

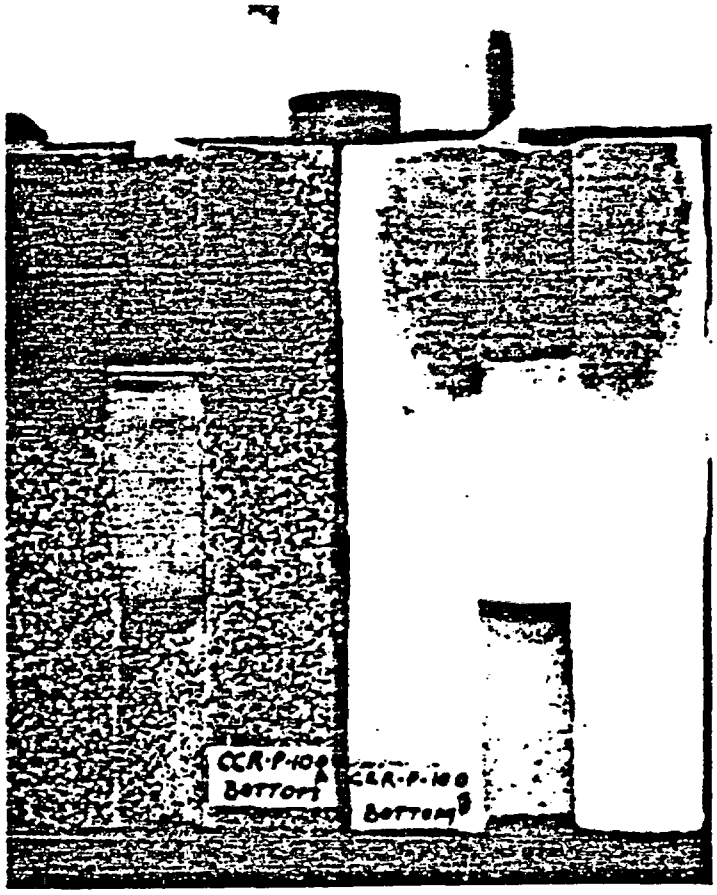


Figure 4.25 Sample CCR-P-100, dye test, showing greater penetration of the granite than of the cement plug. The dye has penetrated a 1.1 cm thick zone of laitance at the top of the plug, but has neither penetrated along the main body of the plug, nor penetrated along the rock-plug interface.

Catalina granite cylinder. Percussion drilled 3.9 cm diameter hole. Dye injected at 2 MPa for 12 days. Drying cracks appeared after sample had been cut and exposed to a room environment for several days.

From South and Daemen, NUREG/CR-4748.

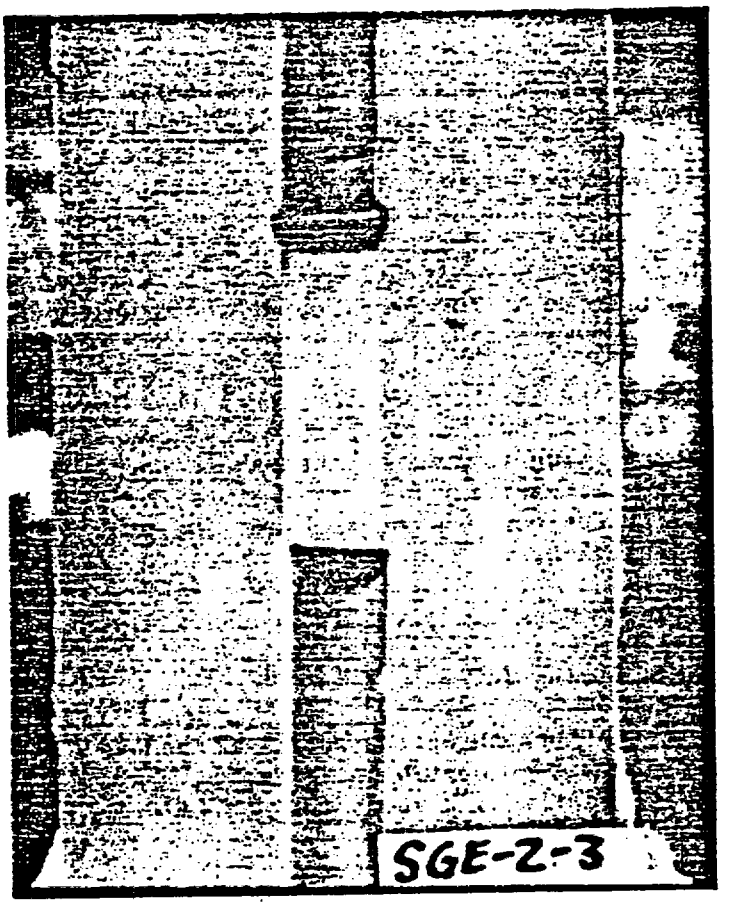


Figure 4.19 Sample SGE-2-3, dye test. Dye has been injected in top hole, at 5.1 MPa, for 24 days. Hole diameter is 2.6 cm.

From Adisoma and Daemen, report to NRC, in preparation.

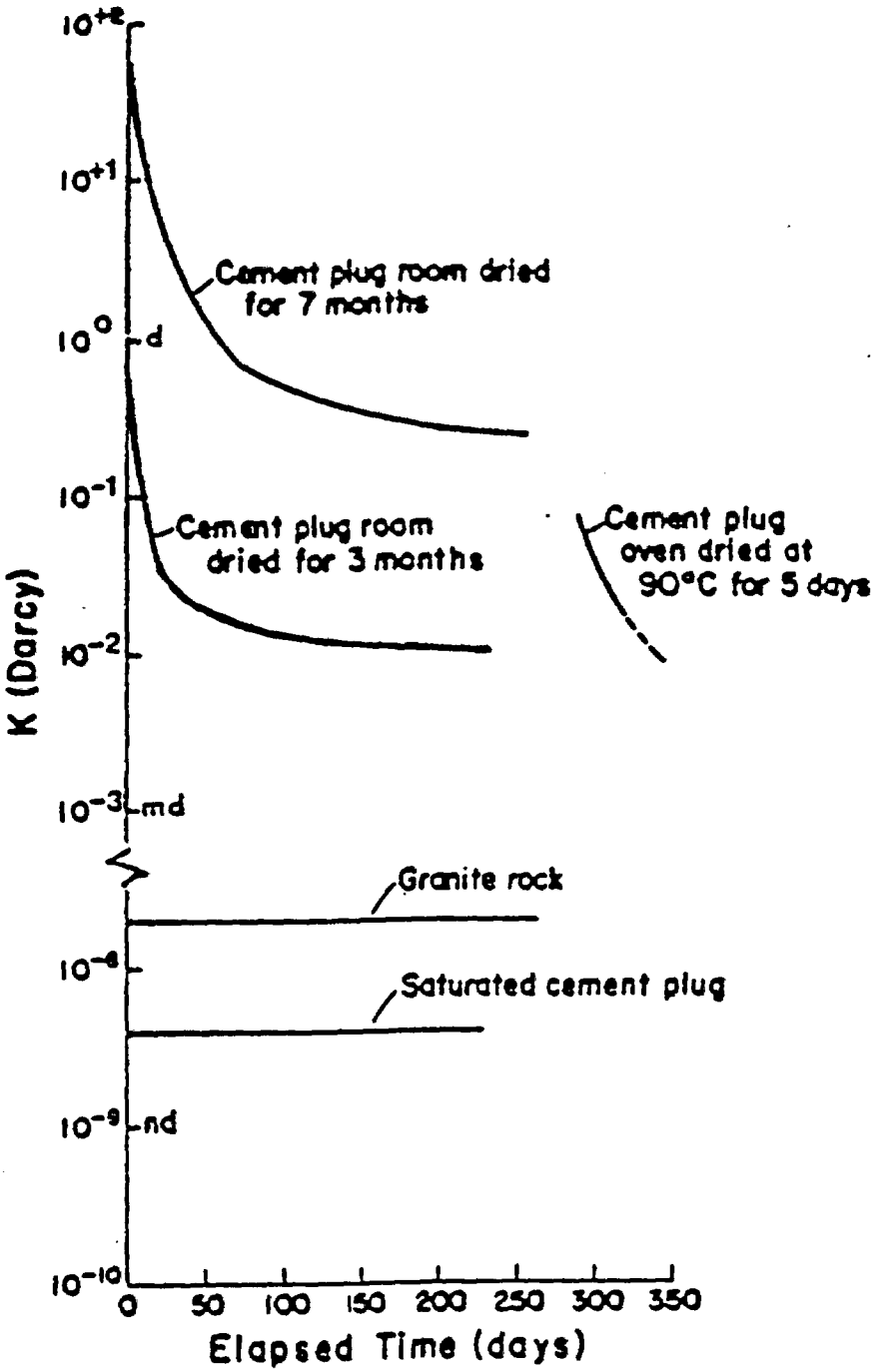


Figure 5.13 Composite permeabilities of Charcoal granite, wet and dried-out cement plugs as a function of time. Wet cement plugs are one order of magnitude less permeable than granite. Drying at long period or at high temperature increases plug permeability by many orders of magnitude and severely degrades plug performance.

From Adisoma and Daemen, report to NRC, in preparation.

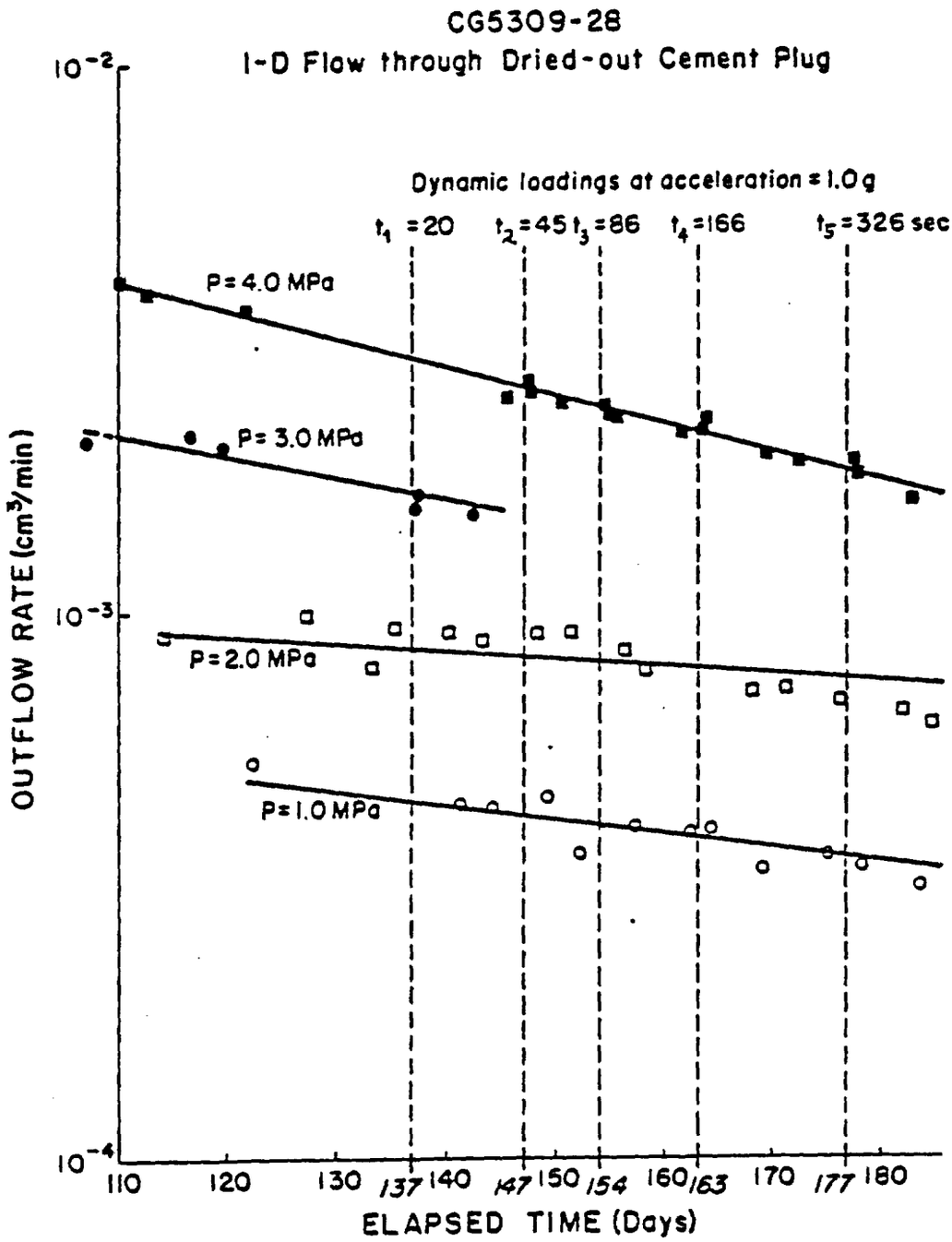


Figure 4.28 The effect of dynamic loading at a = 1 g on the longitudinal flow rate through a dried-out cement plug, specimen CG5309-28. The applied dynamic loading at durations up to 326 seconds do not change the flow rate significantly.

From Adisoma and Daemen, report to NRC, in preparation.

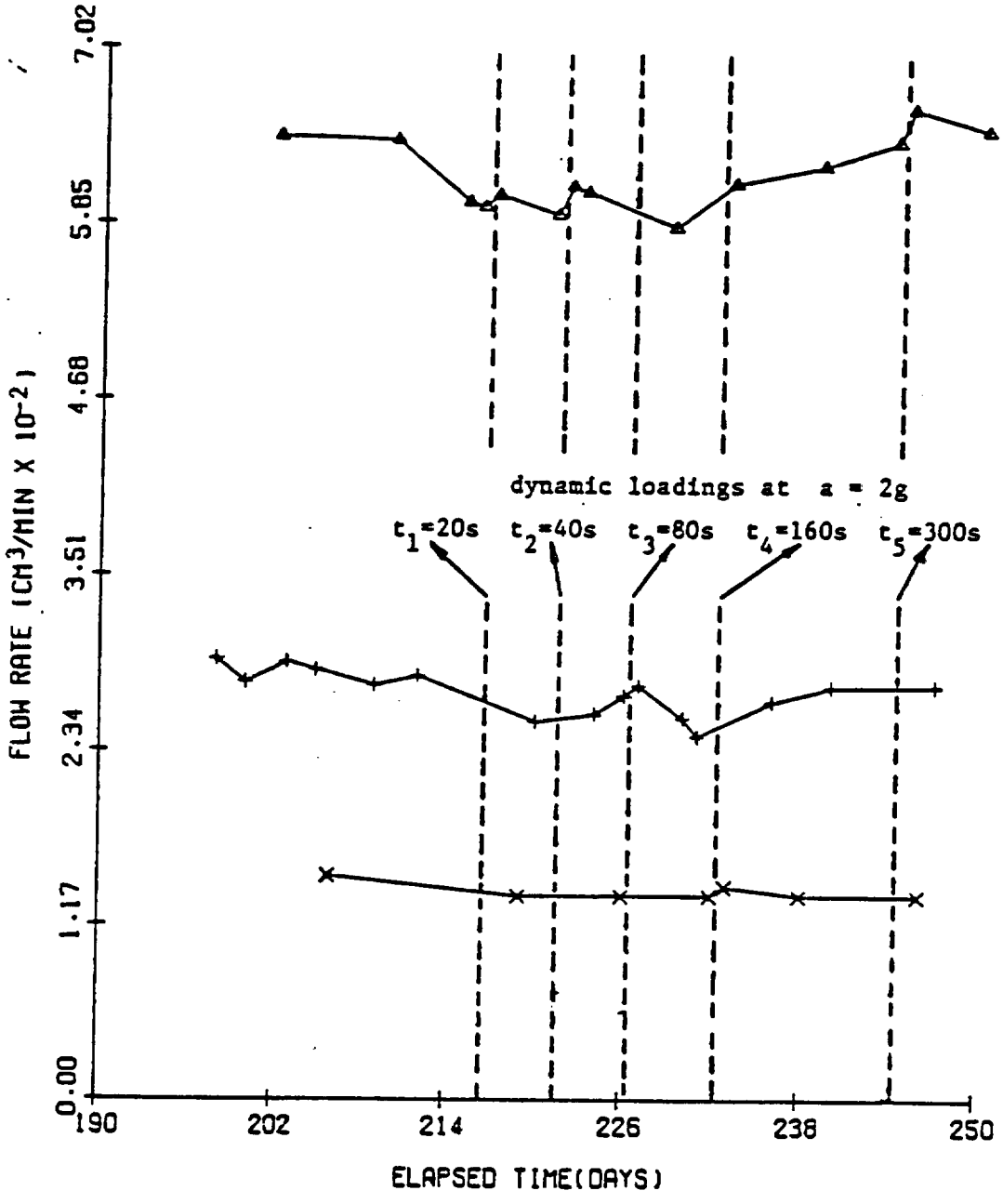


Figure 4.27 Inflow rate at various injection pressures as a function of time, specimen CG5309-08. Flow rate variation due to the dynamic loads is well within the overall flow rate variation.

Δ - Δ : injection pressure = 4 MPa
+ - + : injection pressure = 2 MPa
x - x : injection pressure = 1 MPa

From Adisoma and Daemen, report to NRC, in preparation.

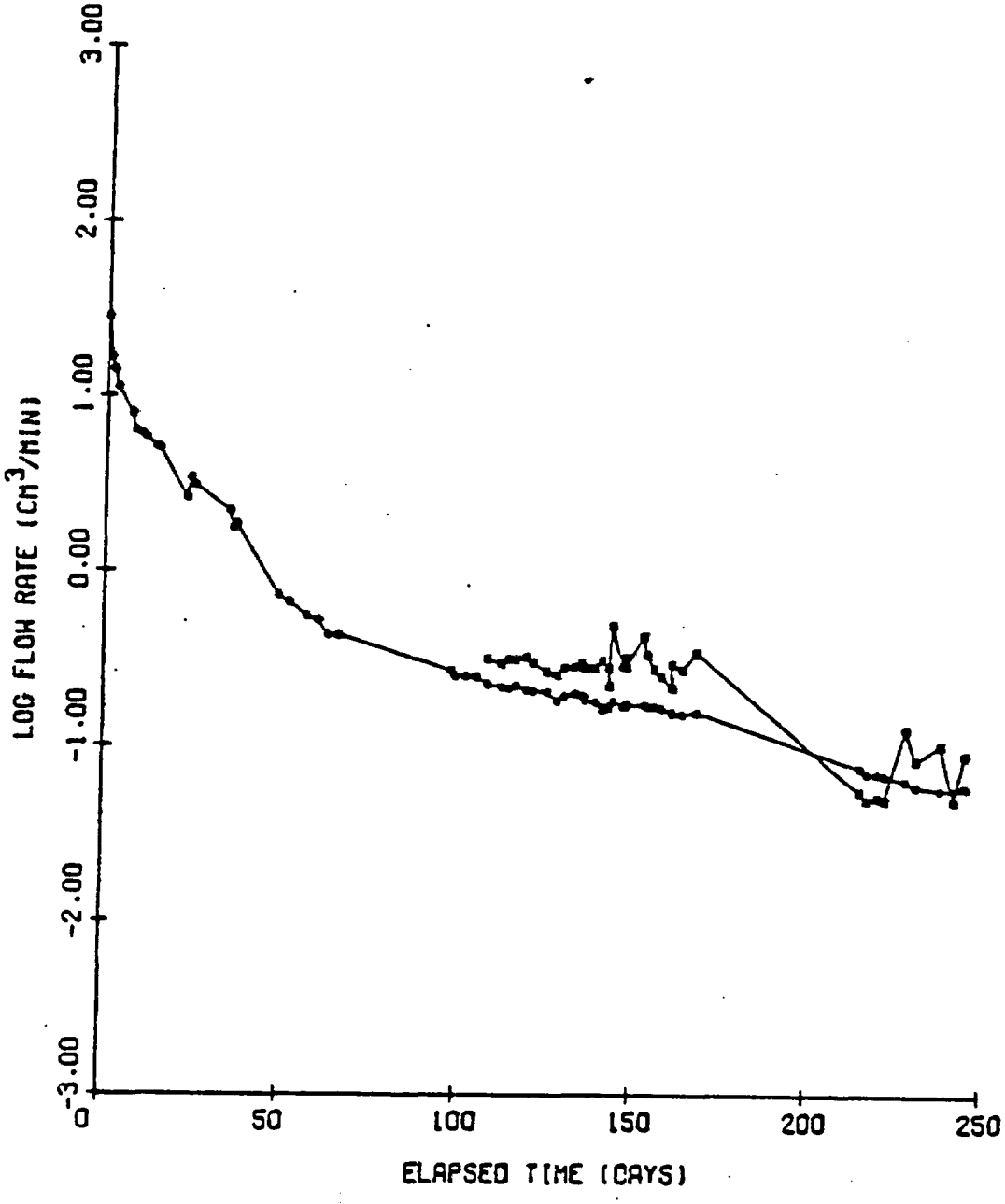


Figure 4.18 Longitudinal flow rate through a dried-out cement seal (log scale) as a function of time, specimen CG5309-01, plug length of 86 mm. The flow rate decreased rapidly as resaturation started and leveled off with time thereafter.

■ - ■ : inflow rate at 1.5 MPa
● - ● : outflow rate at 1.5 MPa

From Stormont and Daemen, NUREG/CR-3594.

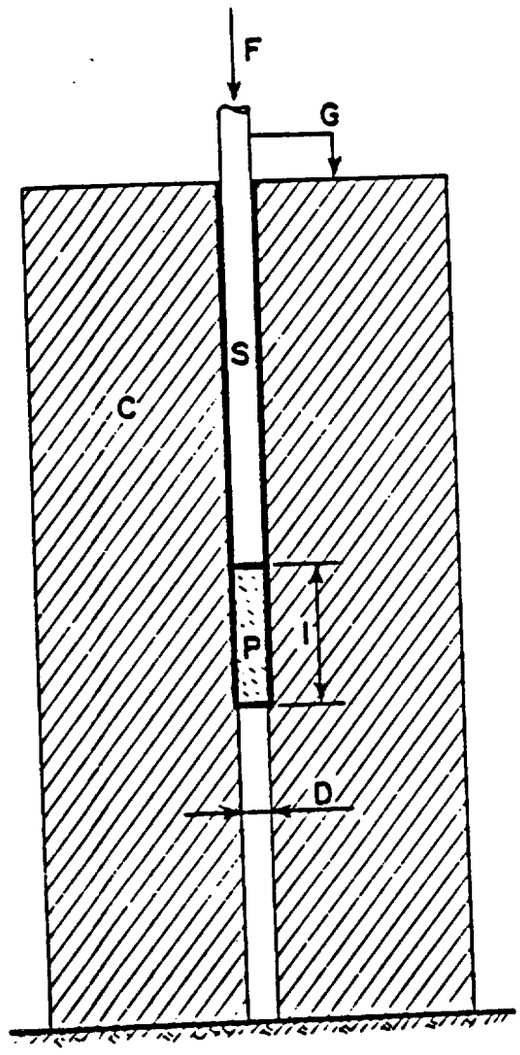


Figure 4.2 Schematic illustration of push-out experiment. A steel rod (S) applies a force (F) to a plug (P) of length (l) and diameter (D) which has been emplaced in a coaxial hole drilled in rock core (C). a gage (G) measures displacement of the rod.

From Stormont and Daemen, NUREG/CR-3594.

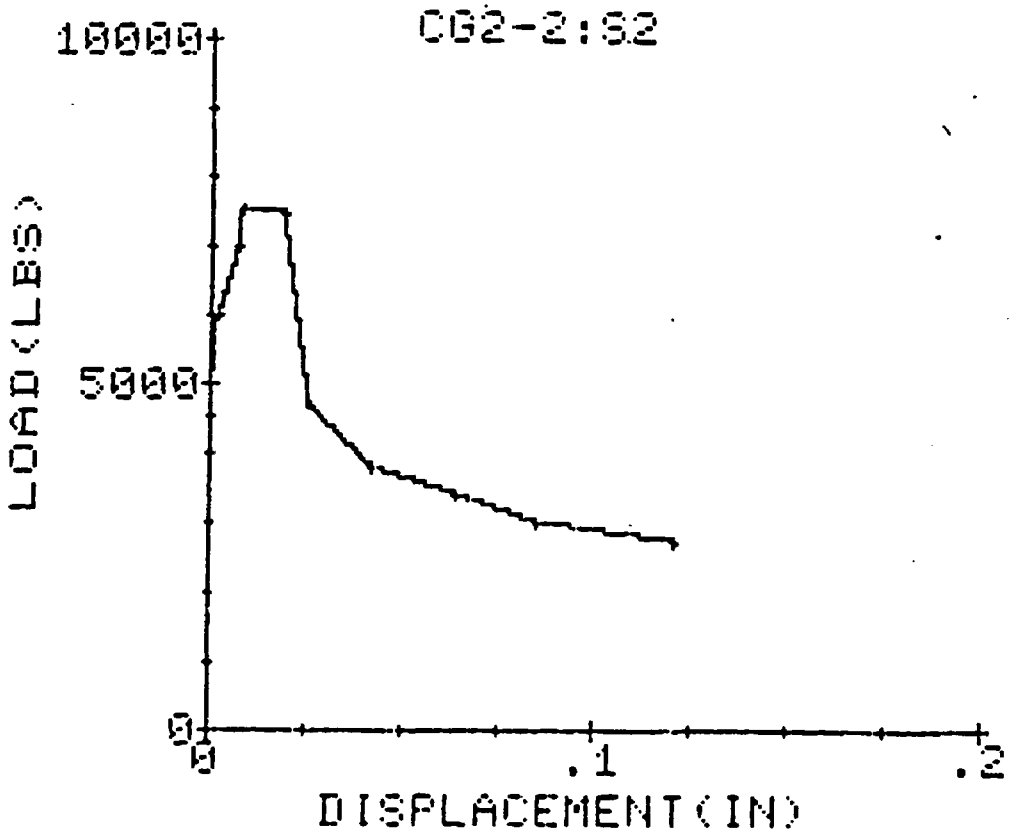


Figure 4.4 Force vs. displacement plot for 2-inch diameter, 2-inch length Cement System 2 plug in Charcoal Granite.

From Stormont and Daemen, NUREG/CR-3594.

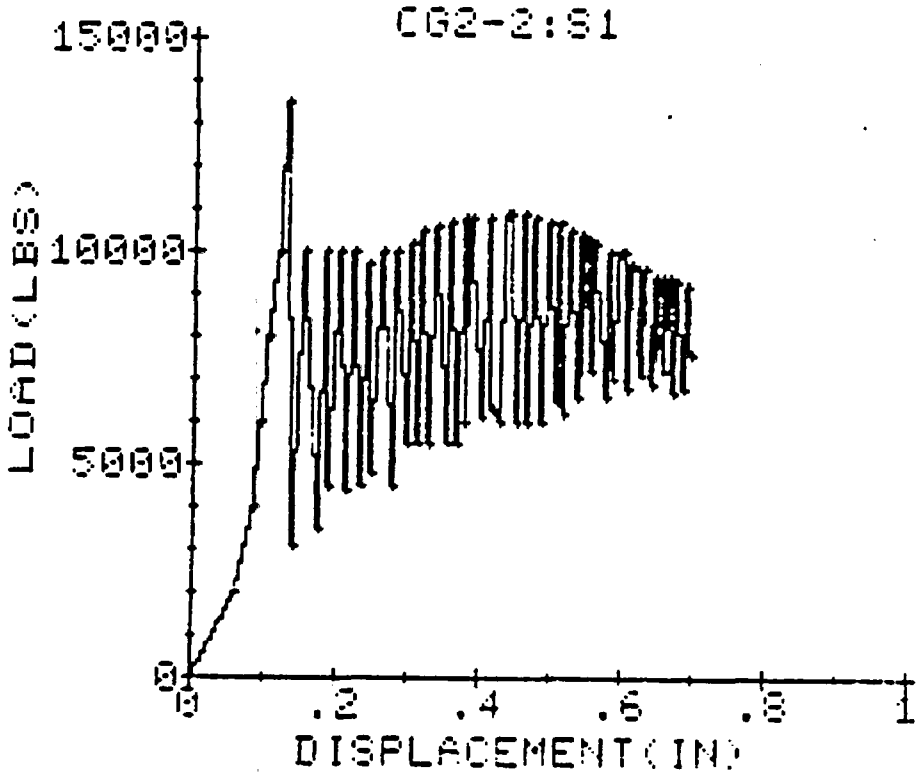


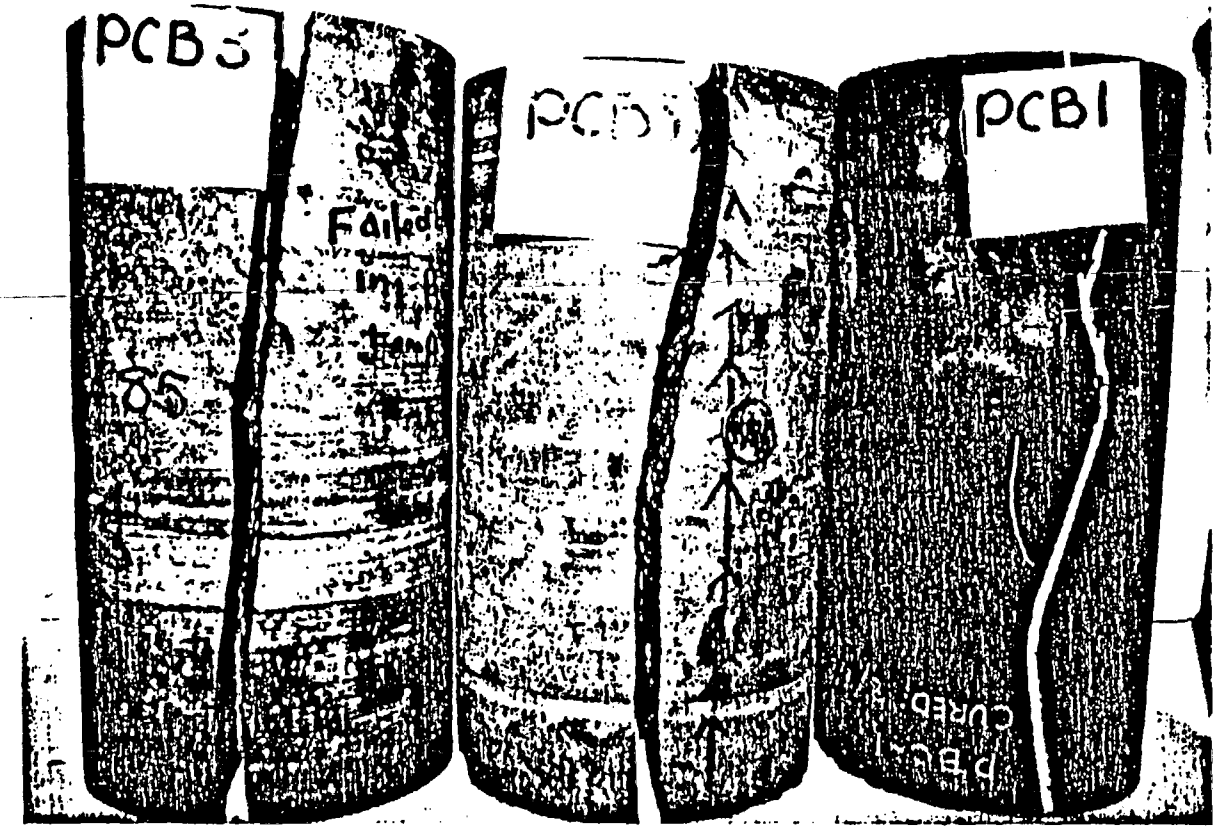
Figure 4.3 Force vs. displacement plot for 2-inch diameter, 2-inch length Cement System 1 plug in Charcoal Granite.

From Stormont and Daemen, NUREG/CR-3594.

Table 5.2 Push-Out Test Results vs. Theoretical Results from Frictional Model (Both Constant and Exponential Shear Stress Cases) for Cement System 1.

Rock Type	Radius (in.)	Length (in.)	Theoretical Strength(lb.) for constant shear stress distribution	Theoretical Strength(lb.) for exponential shear stress distribution	Experimental Results(lb.)
Hanford Basalt	.5	1	4,589	3,866	1,760, 1,760,12,402, 2,645, 1,020
Hanford Basalt	.5	2	14,205	7,769	9,500, 4,800
Hanford Basalt	.5	4	-299,412	15,540	18,800*
Hanford Basalt	1.0	1	7,776	7,405	2,800, 2,400, 6,750
Hanford Basalt	1.0	2	18,227	15,012	11,200, 7,400, 15,000
Hanford Basalt	1.0	4	55,570	30,058	6,200, 31,500
Hanford Basalt	2.0	1	14,365	14,143	--
Hanford Basalt	2.0	2	30,540	28,565	--
Hanford Basalt	2.0	4	69,885	57,213	--
Charcoal Granite	.5	1	4,546	3,894	2,580, 2,580, 2,580
Charcoal Granite	.5	2	13,795	7,844	7,600
Charcoal Granite	.5	4	-800,486	15,691	21,500, 25,000*
Charcoal Granite	1.0	1	7,741	7,421	3,900, 1,500
Charcoal Granite	1.0	2	18,038	15,102	13,500, 10,900
Charcoal Granite	1.0	4	53,858	30,263	22,000, 11,000
Charcoal Granite	2.0	1	14,324	14,138	7,600*

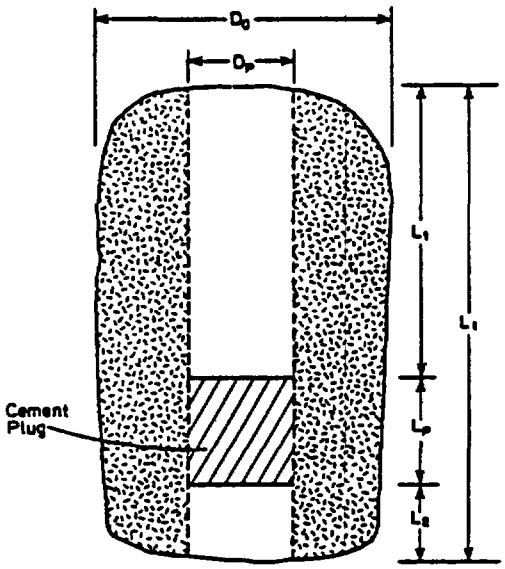
(cont.)



From Daemen et al., NUREG/CR-4642.

Figure 4.12 Axial splitting of basalt cylinders tested in the heating rock holder. Conditions at failure are listed in Table 4.8.

From Daemen et al., NUREG/CR-4642
(also in Akgun and Daemen, NUREG/CR-4738)



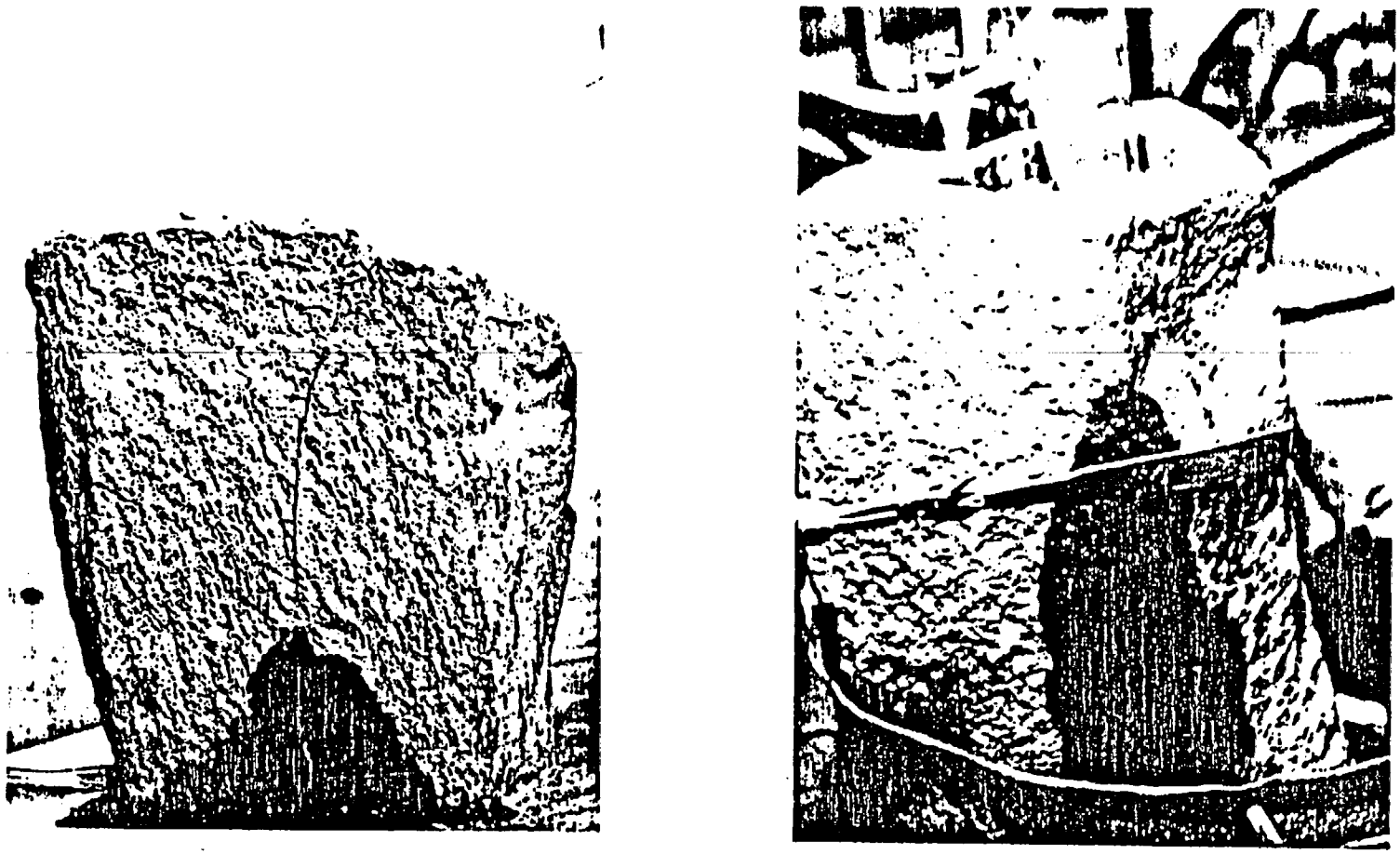
Not to scale

D_0 = maximum block diameter
D_p = plug (borehole) diameter
L_1 = top hole length
L_p = cement plug length
L_2 = bottom hole length
L_t = total hole length

Pomona Basalt Block	D_0	D_p	L_1	L_p	L_2	L_t
No. 1	584.2	196.9	400.1	203.2	107.9	711.2
No. 2	223.1	158.8	317.5	158.8	69.8	546.1
No. 3	201.0	158.8	254.0	158.8	69.8	482.6
No. 4	469.9	196.9	368.3	196.9	127.0	692.2
No. 5	330.2	158.8	266.7	158.8	203.2	628.7

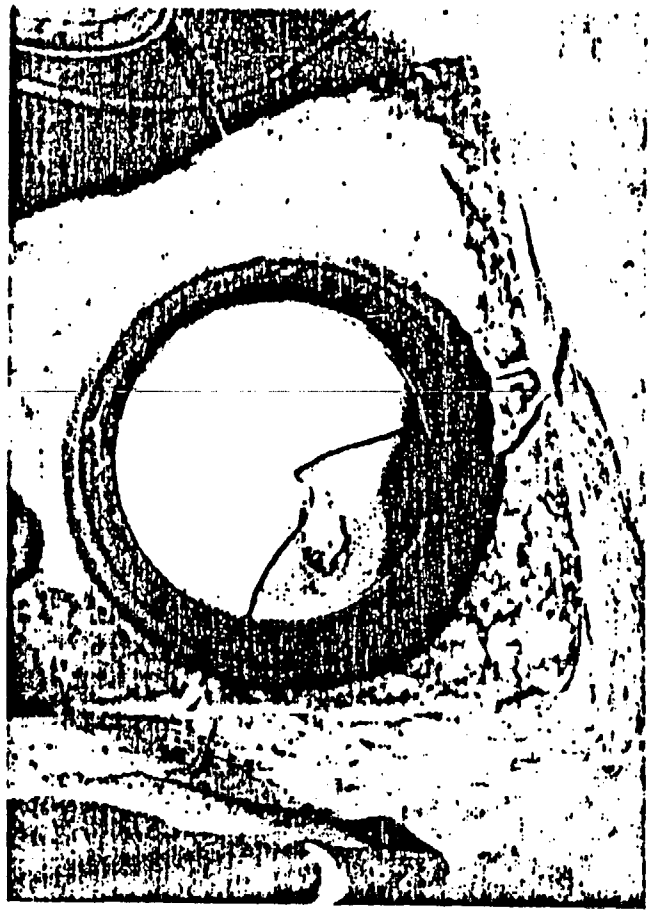
All dimensions are in mm.

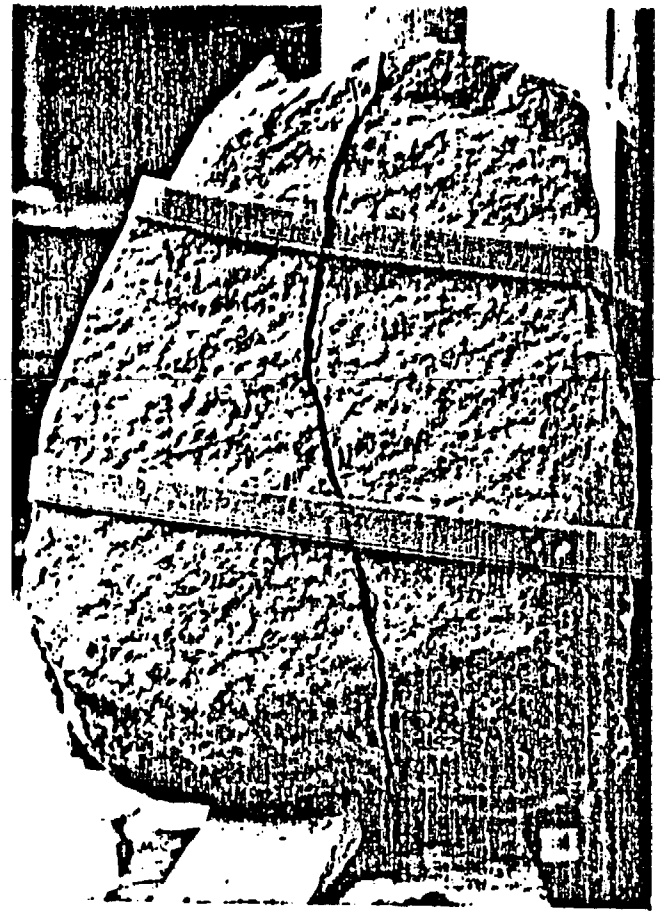
Figure 5.1 Dimensions of specimens used in block permeability tests.



From Daemen et al., NUREG/CR-4642
(also in Akgun and Daemen, NUREG/CR-4738)

Figure 5.14 Close views of the No. 4 (on the left), and No. 5 (on the right) Pomona basalt block fractures. The fractures were probably caused by cement swelling.





From Daemen et al., NUREG/CR-4642
(also in Akgun and Daemen, NUREG/CR-4738)

Figure 5.13 Fracturing of the No. 3 Pomona basalt block (with a 159 mm (6.25 in) diameter borehole) at a water injection pressure (P_t) of 0.69 MPa (100 psi). Left: top view. Right: side view. A torque of 271.16 Nm (200 ft-lb) was applied to the packer, resulting in an estimated packer pressure of 2.12 MPa (307 psi).

From Fuenkajorn and Daemen, NUREG/CR-4641.

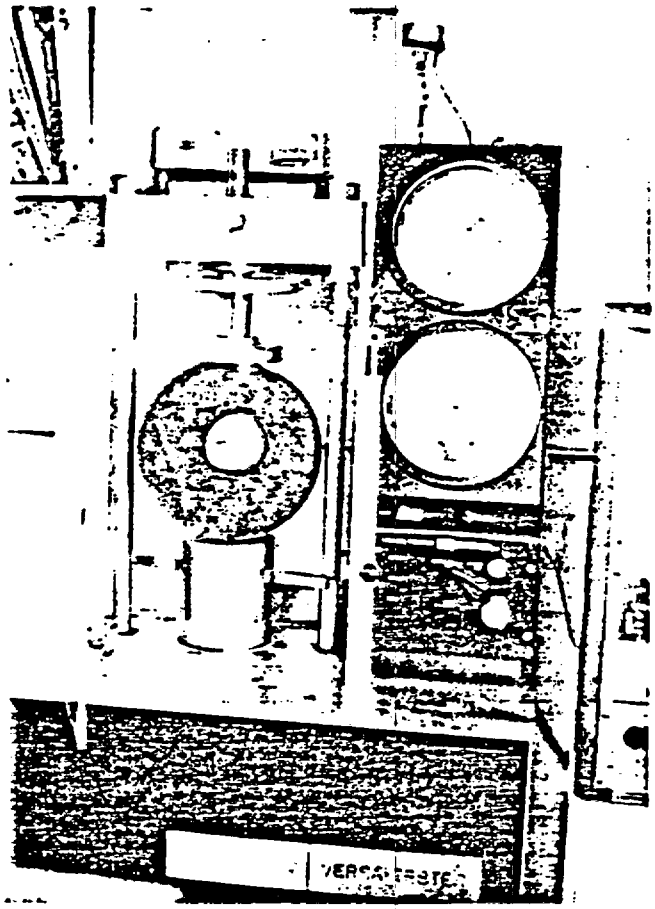


Figure 3.4 Ring test on 229 mm disk with 76 mm hole. Pomona basalt.

From Fuenkajorn and Daemen, NUREG/CR-4641.

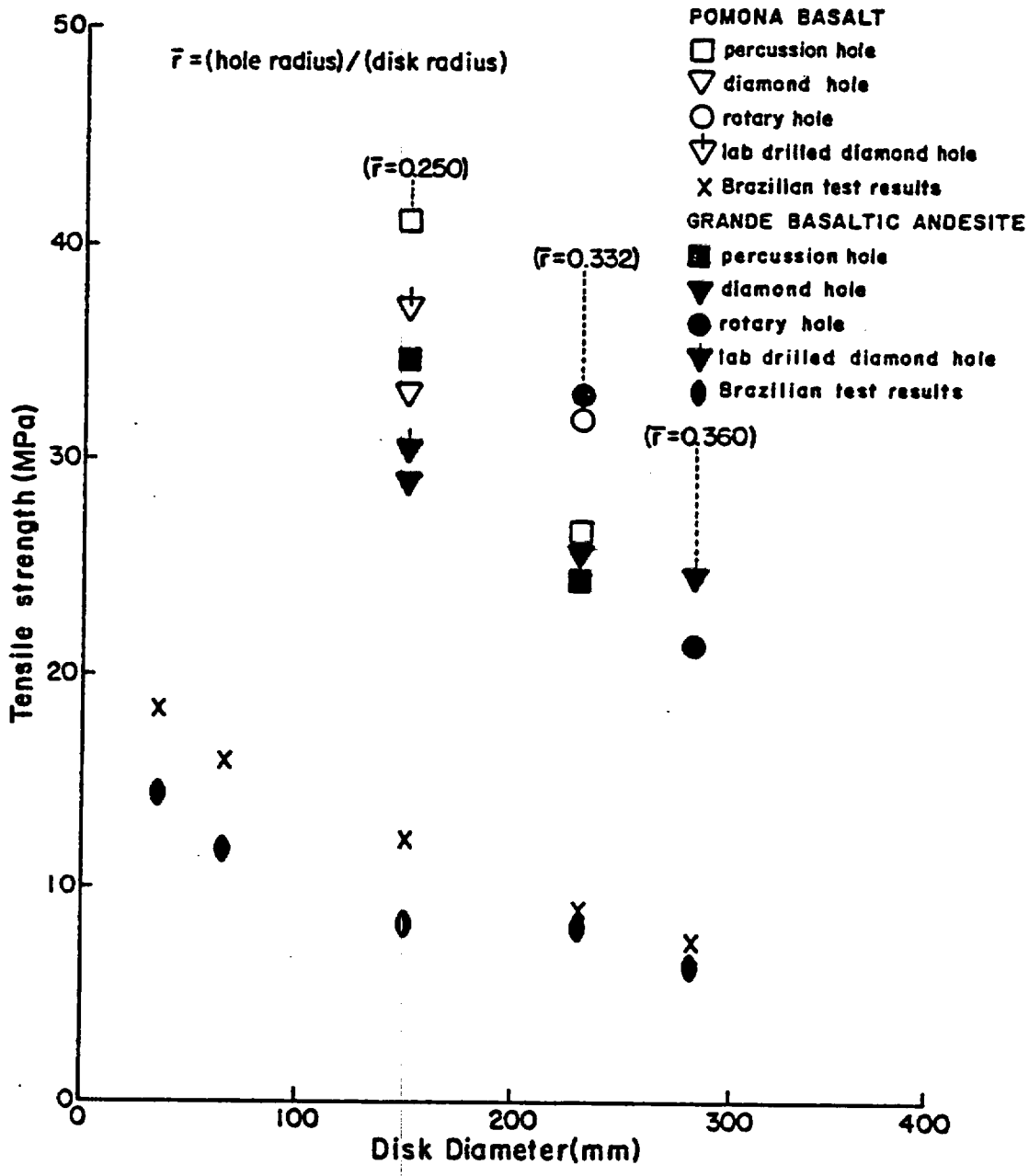


Figure 3.10 Results of ring tension tests. The tensile strengths are plotted as a function of disk diameter. Each data point is the average of at least ten samples.

From Fuenkajorn and Daemen, NUREG/CR-4641.

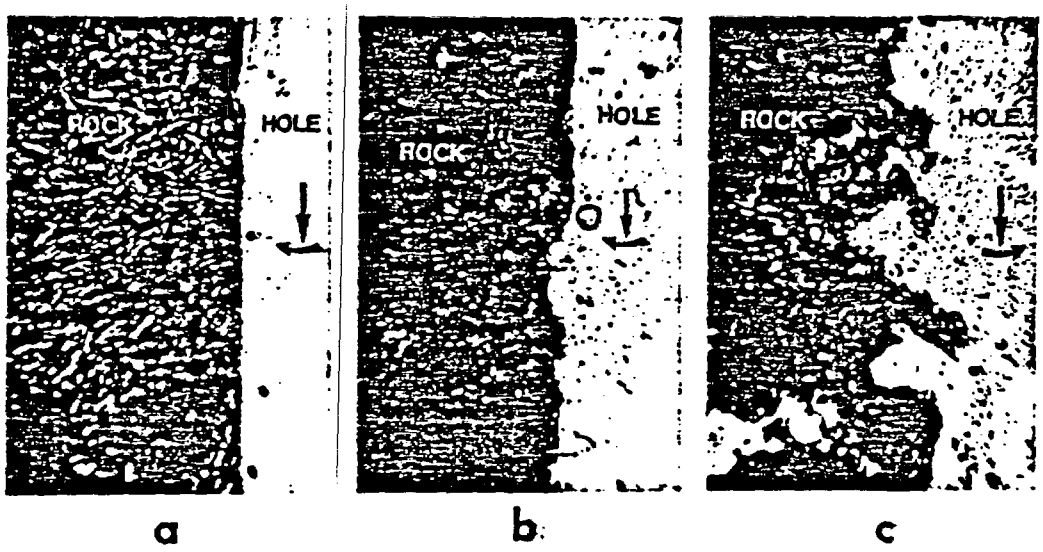
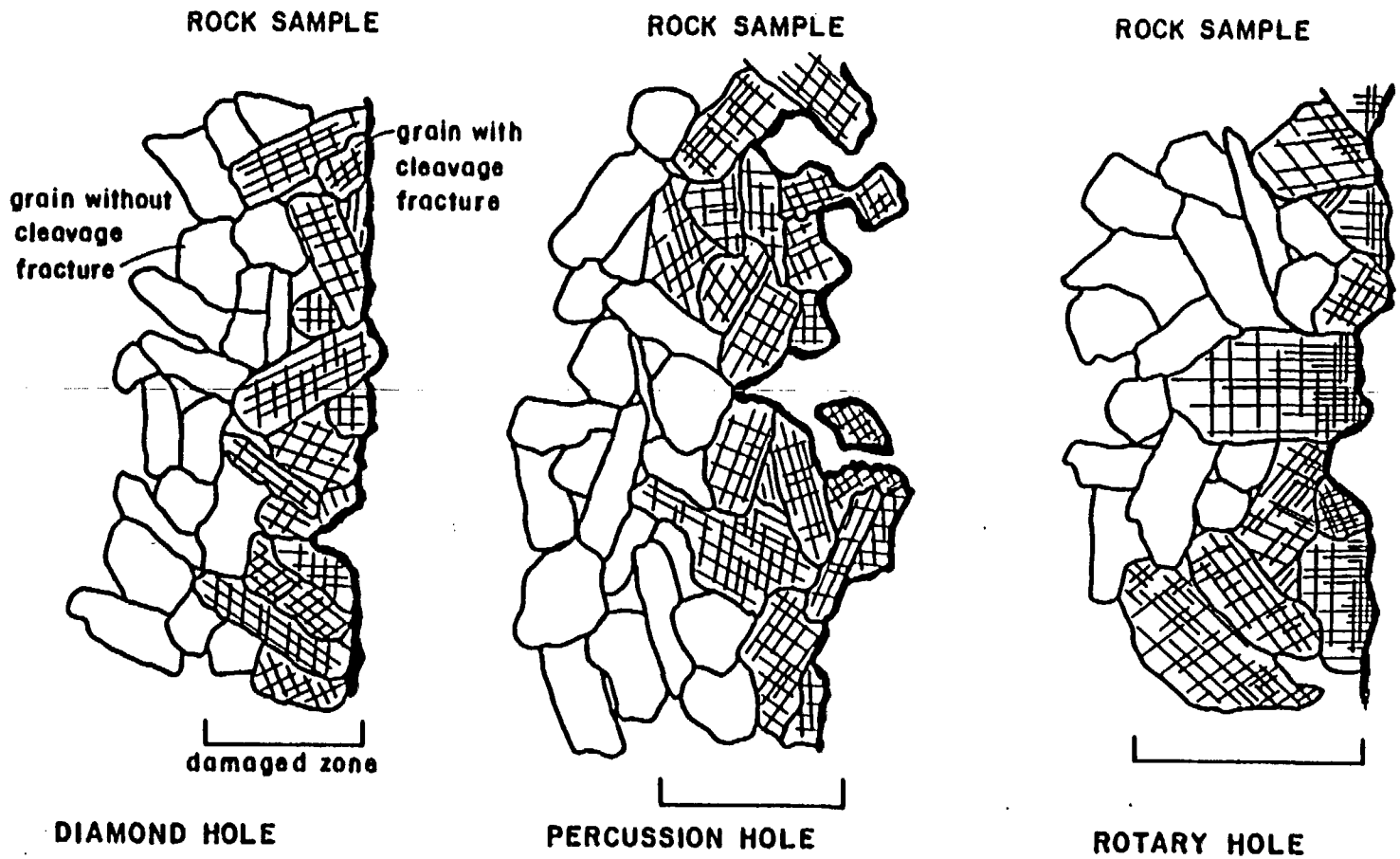


Figure 5.3 Photomicrographs of radial sections cut on the edge of 38 mm laboratory drilled diamond hole (a), field drilled diamond hole (b), and percussion hole (c) in Grande basaltic andesite. Each picture covers an area of approximately 4.00 mm x 2.50 mm. Arrows indicate direction of bit penetration and bit rotation. These pictures show the typical borehole wall roughness observed for the three drilling techniques.



From Fuenkajorn and Daemen, NUREG/CR-4641.

Figure 5.14 Typical drilling damage characteristics:

Diamond hole:	smooth wall, uniform damaged zone, few missing particles, uniform fracture density within damaged grains.
Percussion hole:	rough wall, irregular damaged zone, numerous missing particles, uniform fracture density within damaged grains.
Rotary hole:	relatively smooth wall, irregular damaged zone, higher fracture intensity closer to the hole within damaged grains

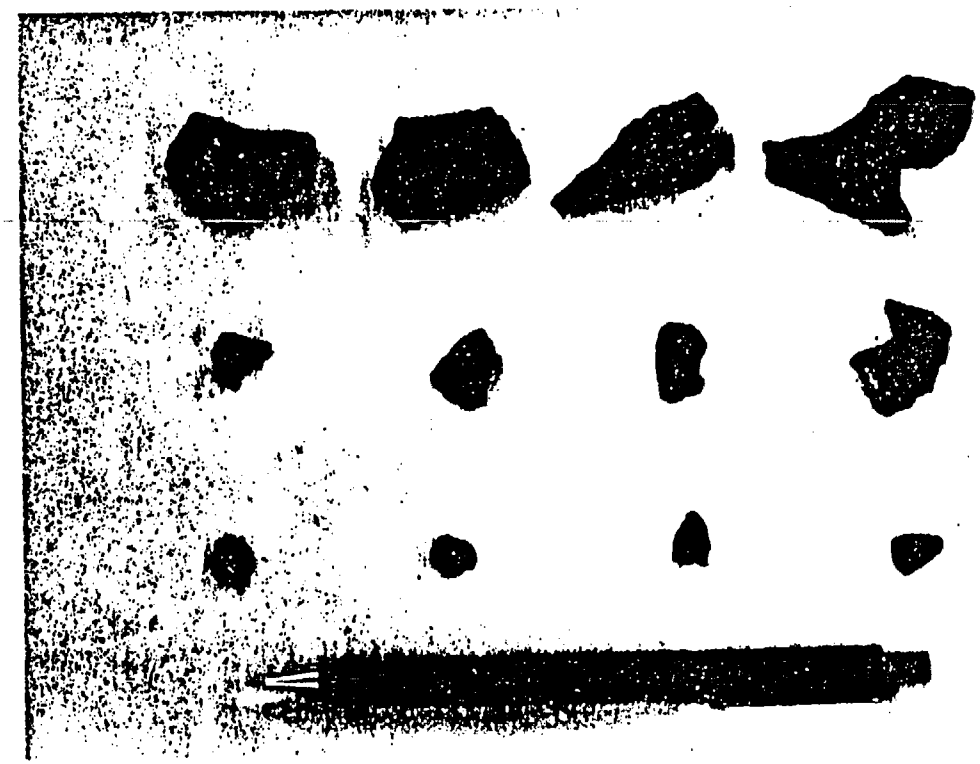
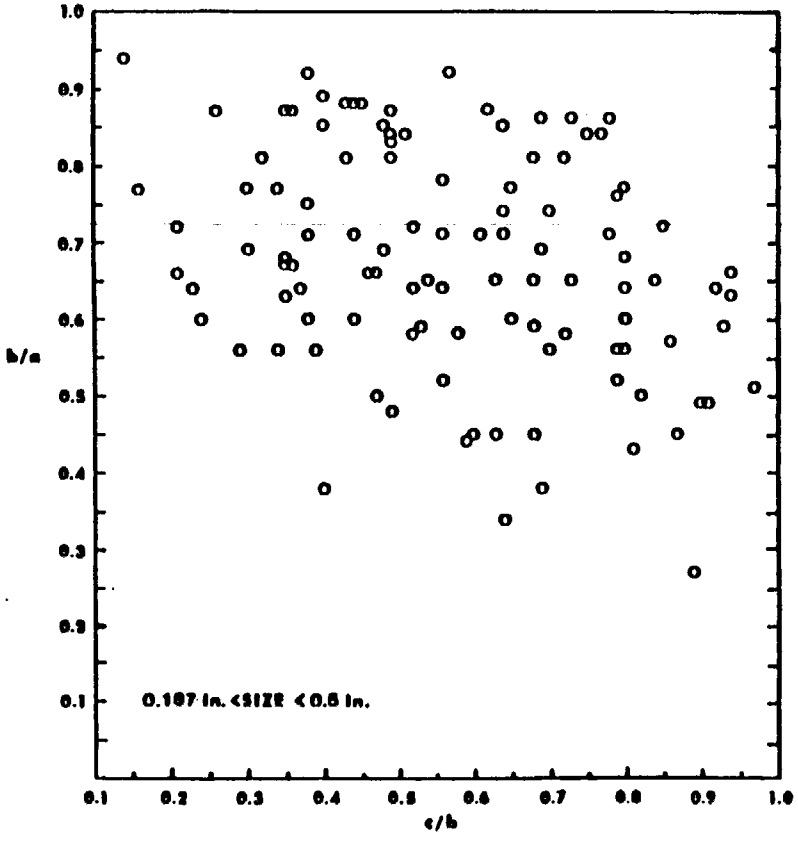
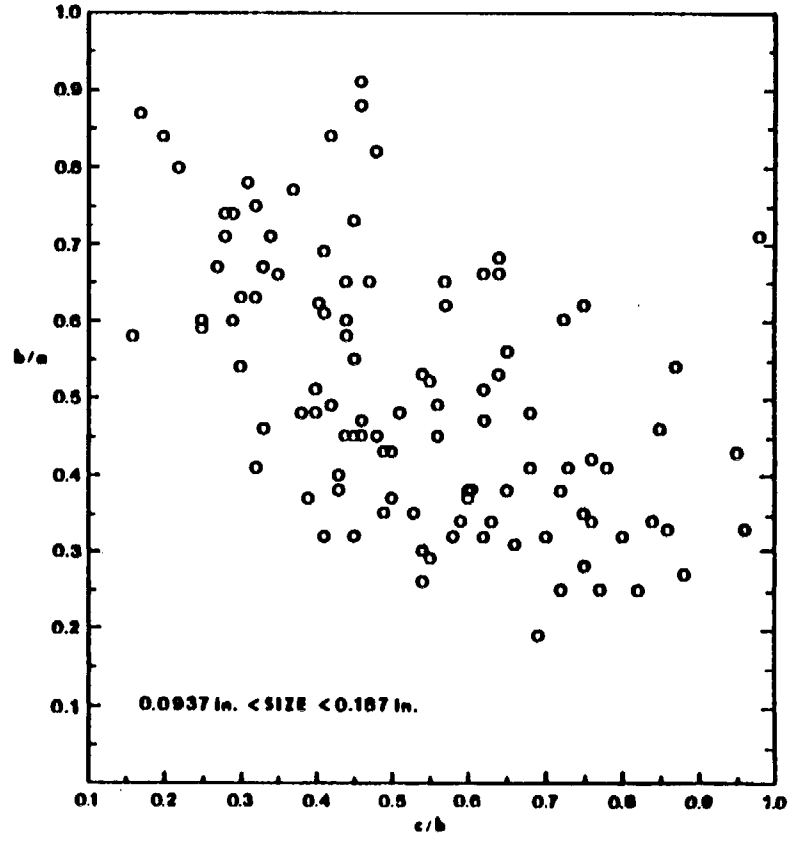


Figure 3.6 Examples of crushed basalt particles. These would be classified as very angular.



(c)



(d)

Figure 3.8 Crushed basalt plotted according to Zingg's criterion--<u>continued</u>.

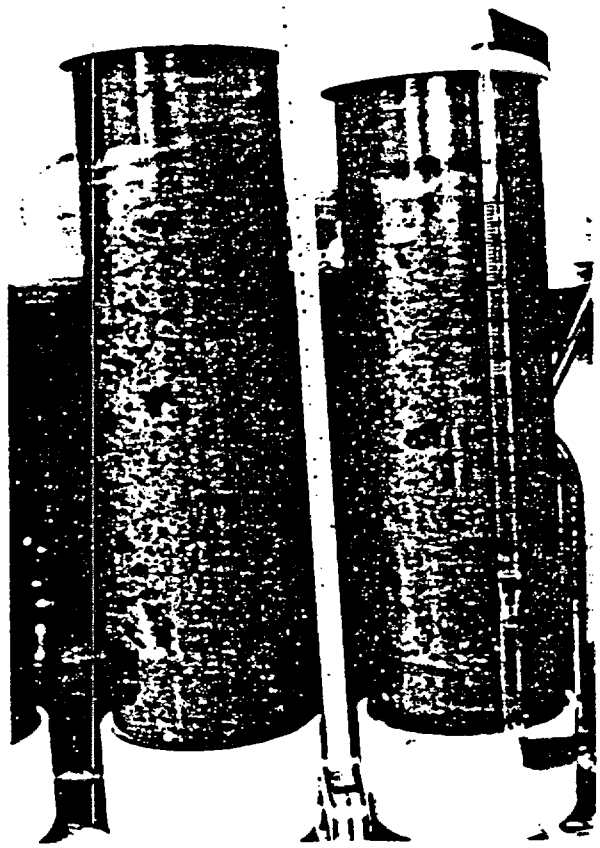


Figure 2.8 Voids in clay--continued. (c) Air- and water-filled voids in permeameters PVC 5 and PVC 6.

Table 7.1 Bimodal distribution of results.

Percent Clay	K, cm/s	
	10^{-4} to 10^{-3}	10^{-10} to 10^{-7}
35	-	4
25	2	8
15	2	2
5	2	-

Table 7.2 Classification of soils according to their coefficients of permeability (Lambe and Whitman, 1969, after Terzhagi and Peck, 1967).

Degree of permeability	Value of K (cm/s)
High	Over 10^{-1}
Medium	10^{-1} to 10^{-3}
Low	10^{-3} to 10^{-5}
Very low	10^{-5} to 10^{-7}
Practically impermeable	Less than 10^{-7}

From: M.V. Gaudette and J.J.K. Daemen, Bentonite Borehole Plug Testing, Report to NRC, in preparation.

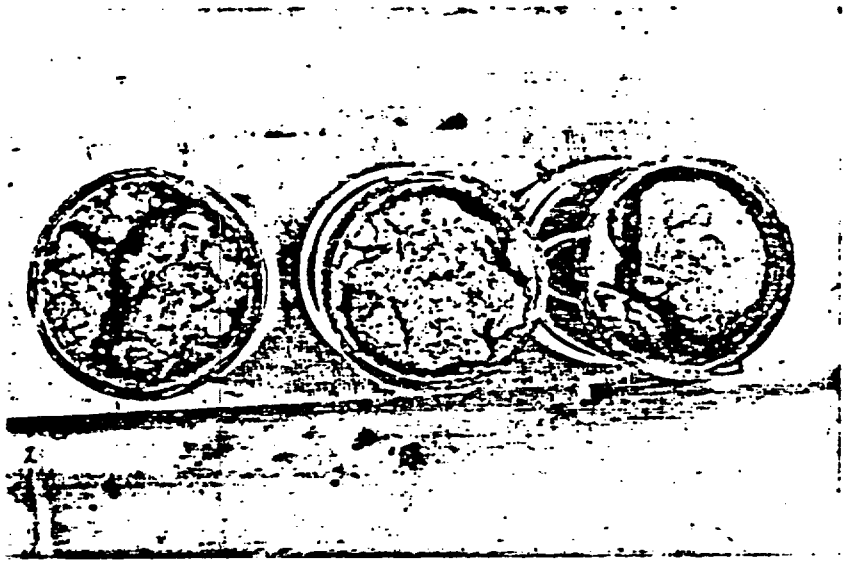


Figure 6.2 The cracks which formed in the bentonite plugs during consolidation testing.

From: M.V. Gaudette and J.J.K. Daemen, Bentonite Borehole Plug Testing, Report to NRC, in preparation.

Figure 6.1 Partially swelled bentonite tablets which make up one of the plugs used in constant pressure injection testing.

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U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC): NUREG/CR-3594

4. TITLE AND SUBTITLE (Add Volume No., if appropriate): Axial Strength of Cement Plugs in Granite and Basalt

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S): John C. Stormont and Jaak J. K. Daemen

5. DATE REPORT COMPLETED: MONTH November, YEAR 1983

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code):
Department of Mining and Geological Engineering
University of Arizona
Tucson, AZ 85721

DATE REPORT ISSUED: MONTH December, YEAR 1983

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code):
Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.: B-6627

13. TYPE OF REPORT: Topical

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

This report describes experimental and theoretical studies of the axial strength of cement plugs installed in boreholes drilled coaxially in granite and in basalt cylinders. Experimental work has consisted of loading the cement plugs to failure while measuring loads and displacements. Such tests have been performed on borehole plugs with a diameter and a length ranging from 2.5 cm to 10 cm. Results from over one hundred experiments show that the strength is high, sufficient for anticipated loads at repository depths, but very variable, complicating the design of very short plugs. Significant residual strength (thirty to fifty percent of the peak strength) is observed.

A frictional model of the interface shear strength, $\tau = c + \sigma (\tan\phi)$, in combination with the assumption of an exponential shear stress distribution or plug-rock load transfer, provides the simplest realistic model for plug strength characterization. The integrated strength thus calculated compares moderately well with experimental results. An extensive review is given of more sophisticated analysis procedures that should be of value for general plug design applications. Generic analyses and their implications for plug performance are included. Variability of experimental results complicates the assessment of their direct detailed applicability.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Borehole sealing; Borehole plugging; Repository sealing; Shaft sealing; Drift plugging; Cement plugs; Plug strength; Seal strength; Granite-cement interface strength; Basalt-cement interface strength.

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT: Unlimited

19. SECURITY CLASS (This report): Unclassified

20. SECURITY CLASS (This page): Unclassified

21. NO. OF PAGES

22. PRICE

NRC FORM 335 (7 77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)

Field Testing of Bentonite and Cement Borehole Plugs in Granite

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)

A.F. Kimbrell, T.S. Avery, and J.J.K. Daemen

5. DATE REPORT COMPLETED

MONTH March | YEAR 1987

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Department of Mining and Geological Engineering
University of Arizona
Tucson, AZ 85721

DATE REPORT ISSUED

MONTH | YEAR

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Division of Engineering Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.

NRC-04-78-271
FIN B6627

13. TYPE OF REPORT

Technical Report

PERIOD COVERED (Inclusive dates)

1985-1986

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less) This report describes in-situ flow tests on bentonite and cement borehole plugs installed in granite, and laboratory back-up experiments on similar plugs. Prior to sealing, the hydraulic conductivity of the boreholes is tested. These measurements, together with core and borehole videologs, permit the selection of seal test intervals. Commercial expansive cement and standard waterwell sealing bentonite products and emplacement procedures are used. Transient (short-term) and steady-state (long-term) tests determine the sealing performance of the plugs (premature termination of the "steady state" testing precluded full data collection).

Laboratory and field experiments confirm the difficulty of obtaining even moderately accurate performance values for bentonite plugs as installed here, due to simultaneous saturation, swelling, and consolidation. Nevertheless, conventional installation of readily available seals can provide adequate borehole seals (i.e. seals with a hydraulic conductivity of about the same magnitude as that of intact granite). Bentonite plugs of this type are heterogeneous and weak. Improved testing procedures and analyses are needed if actual conductivity values are to be obtained in a reasonable testing time (e.g. months). Laboratory investigations on failure mechanisms in cementitious and bentonitic plugs are needed to identify and prevent failure causes.

17. KEY WORDS AND DOCUMENT ANALYSIS

Borehole plugging
Borehole sealing
Rock Mass sealing.
Bentonite borehole plugs
Cement borehole plugs
Borehole plug testing
Permeability testing

17a. DESCRIPTORS

Granite hydraulic conductivity
Cement hydraulic conductivity
Bentonite hydraulic conductivity
Seal testing
Bentonite consolidation
Transient pulse testing

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT

Unlimited

19. SECURITY CLASS (This report)

Unclassified

20. SECURITY CLASS (This page)

Unclassified

21. NO. OF PAGES

22. PRICE

$

NRC FORM 335 (7-77)

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
The Sealing Performance of Bentonite/Crushed Basalt Borehole Plugs

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
J.R. Williams and J.J.K. Daemen

5. DATE REPORT COMPLETED
MONTH June YEAR 1987

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Department of Mining and Geological Engineering
University of Arizona
Tucson, AZ 85721

DATE REPORT ISSUED
MONTH YEAR

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Division of Engineering Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
NRC-04-78-271
FIN B6627

13. TYPE OF REPORT
Technical Report

PERIOD COVERED (Inclusive dates)
1985-1986

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

Mixtures of crushed rock and bentonite are considered for backfilling and sealing high-level nuclear waste repositories. Many variables affect the hydraulic conductivity of such mixtures, including the size and shape of the rock particles, method of mixing and emplacement, water content and density of the clay, and the weight ratio of rock to clay.

Mixtures of crushed basalt and bentonite have been tested in two types of permeameters, 20 cm (8 in) diameter stainless steel permeameters and 10 cm (4 in) diameter PVC permeameters. Plugs were installed as a single lift or in many lifts; the water content of the clay ranged from air-dry (in most cases) to as high as 200%.

Preliminary results show that a mixture of 75% crushed basalt and 25% bentonite has a hydraulic conductivity between 1×10^{-9} cm/s and 2.5×10^{-8} cm/s. In some cases, preferential flow paths have developed (possibly as a result of the montmorillonite washing out of the crushed rock matrix), giving hydraulic conductivities as high as 1×10^{-4} cm/s. Other ratios of rock to clay have similar bimodal results.

The probability of failure is decreased by including a higher percentage of clay in the plug, crushing the rock finer, and evenly mixing the crushed rock and clay.

17. KEY WORDS AND DOCUMENT ANALYSIS

Backfill permeability
Crushed basalt/bentonite
Hydraulic conductivity
Basalt
Bentonite

17a. DESCRIPTORS

Flow testing
Basalt crushing

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

20. SECURITY CLASS (This page)
Unclassified

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (7-77)

NRC FORM 335 (6 83) U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1 REPORT NUMBER (Assigned by TIDC add Vol. No. if any)

2 Leave blank

3 TITLE AND SUBTITLE

Experimental Assessment of the Sealing Performance of Bentonite Borehole Plugs

4 RECIPIENT'S ACCESSION NUMBER

5 DATE REPORT COMPLETED

MONTH July YEAR 1987

6 AUTHOR(S)

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7 DATE REPORT ISSUED

MONTH YEAR

8 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Department of Mining and Geological Engineering
University of Arizona
Tucson, AZ 85721

9 PROJECT/TASK/WORK UNIT NUMBER

10 FIN NUMBER

NRC-04-78-271
FIN B6627

11 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Division of Engineering Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

12a TYPE OF REPORT

Technical (Formal)

12b PERIOD COVERED (Inclusive dates)

1984-1985

13 SUPPLEMENTARY NOTES

14 ABSTRACT (200 words or less)

Bentonite, which contains the clay mineral montmorillonite, is being considered as part of a multi-component engineered barrier which will seal geological repositories of high-level radioactive wastes. Four phases of laboratory testing were conducted to quantify bentonite strength and sealing properties. Chemical analysis revealed a wide range of compositions for commercial well-sealing grade bentonites such that bentonite quality control or specifications may be necessary. Reference testing of seven bentonite samples revealed serious testing problems that make bentonite characterization difficult using standard tests. Permeability testing compared the water flow through bentonite to water flow through intact rock. Compacted bentonite seals exhibited hydraulic conductivities in the 10^{-9} to 10^{-11} cm/s range, which is one to two orders of magnitude greater than that of some intact Columbia plateau basalt specimens. Mechanical testing included direct shear strength and swelling pressure tests. Direct shearing of compacted bentonites revealed that for both unsaturated and saturated test conditions, the bentonite/basalt interface will fail in shear before the intact bentonite plug itself fails. Swelling pressures generated by hydrating bentonites depend upon dry density, mixing and saturating fluid, and method of pressure measurement. Swelling pressures in excess of 1.7 MPa (250 psi) were measured. All results, especially numerical ones, depend on numerous installation and test parameters. The sensitivity can be quite high. Variations of several orders of magnitude in hydraulic conductivity can be expected for relatively small variations in some installation or test procedure aspects.

15a KEY WORDS AND DOCUMENT ANALYSIS

Bentonite
Flow testing
Hydraulic conductivity
Permeability
Swelling

15b DESCRIPTORS

Strength
Composition
Borehole sealing

16 AVAILABILITY STATEMENT

Unlimited

17 SECURITY CLASSIFICATION (This report) Unclassified

18 NUMBER OF PAGES

19 SECURITY CLASSIFICATION (This page) Unclassified

20 PRICE

$

NRC FORM 335 (6-83)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)

2 Leave blank

3 TITLE AND SUBTITLE

Bentonite Borehole Plug Flow Testing with Five Water Types

4 RECIPIENT'S ACCESSION NUMBER

5 DATE REPORT COMPLETED

MONTH	YEAR
Sept	1987

6 AUTHOR(S)

M.V. Gaudette and J.J.K. Daemen

7 DATE REPORT ISSUED

MONTH	YEAR

8 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Department of Mining and Geological Engineering
University of Arizona
Tucson, AZ 85721

9 PROJECT/TASK/WORK UNIT NUMBER

10 FIN NUMBER

NRC-04-78-271
FIN B6627

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The hydraulic conductivity has been determined of plugs constructed with commercial precompressed bentonite pellets. Bentonite has been hydrated and tested with waters of five different chemical compositions, including one groundwater (Ogallala aquifer, Texas). The groundwater contained solids. Clay plugs constructed from bentonite tablets hydrated with unfiltered Ogallala groundwater exhibited reduced swelling and lower hydraulic conductivity than similar plugs constructed from tablets and distilled water. The differences in observed conductivities may be governed by factors including swelling characteristics and permeant colloidal matter clogging plug pore spaces. Constant pressure injection and transient pulse testing methods are used to determine hydraulic conductivity. Especially in constant pressure injection tests, outflow volumes may require adjustment to account for consolidation drainage. Attempts made here at such corrections have not been successful. Consolidation testing is characterized by the requirement of extremely long time periods to approach a constant limit. It appears probable that the flow tests have not been pursued for a sufficiently long time to assure complete determination of water chemistry effects on hydraulic conductivity.

15a KEY WORDS AND DOCUMENT ANALYSIS

Borehole sealing
Shaft sealing
Bentonite permeability
Bentonite consolidation
Hydraulic conductivity

15b DESCRIPTORS

Repository sealing
Repository closure

16 AVAILABILITY STATEMENT

Unlimited

17 SECURITY CLASSIFICATION (This report)

Unclassified

18 NUMBER OF PAGES

19 SECURITY CLASSIFICATION (This page)

Unclassified

20 PRICE

$

HYDROLOGY OF FRACTURED CRYSTALLIN
ROCKS

MAJOR OBJECTIVES:

1. STUDY EFFECT OF FRACTURES/DISCONTI
NUITIES ON

   - TRANSMISSIVE/DISPERSIVE PROPERTIE
     OF ROCK
   - FIELD/THEORETICAL/COMPUTATIONAL
     METHODS OF CHARACTERIZING
     THESE PROPERTIES

2. STUDY EFFECT OF UNCERTAINTY I
ABOVE PROPERTIES ON

   - ESTIMATION OF PARAMETERS FOR
     HYDROLOGIC MODELS
   - ERROR PROPAGATION IN SUCH MODELS
   - MODEL VALIDATION

3. DEVELOP EXPERTISE FOR SUPPORT
OF NRC LICENSING ACTIVITIES
RELATED TO HYDROGEOLOGY OF
FRACTURED CRYSTALLINE ROCKS.

FIELD WORK COMPLETED AT ORACLE EXPERIMENTAL SITE

- SURFACE GEOLOGICAL/GEOPHYSICAL INVESTIGATIONS
- CORE ANALYSES
- BOREHOLE GEOPHYSICS (ACOUSTIC TV + VELOCITY, NEUTRON, TEMPERATURE, CALIPER, FLUID VELOCITY, GAMMA, OTHE
- ELECTROMAGNETIC GEOTOMOGRAPHY
- SINGLE-HOLE STRADDLE PACKER HYDRAULIC TESTING
- CROSS-HOLE HYDRAULIC TESTING
- TRACER DILUTION TESTS
- CHEMICAL TRACER MIGRATION EXPERIMENTS
- HEAT MIGRATION EXPERIMENTS

FURTHER FIELD WORK PLANNED

- ADDITIONAL CROSS-HOLE HYDRAULI TESTS
  - USE ADDITIONAL BOREHOLES
  - VARY SCALE
  - TRY TO IDENTIFY PRESENCE OF KNOWN FAULT ZONE

THEORETICAL WORK COMPLETED

- 3-D THEORY FOR INTERPRETATION OF CROSS-HOLE HYDRAULIC TESTS TO YIEL
  - INFORMATION ABOUT FRACTURE HYDRAULIC CONNECTIVITY
  - DEGREE TO WHICH ROCK BEHAVES AS EQUIVALENT UNIFORM CONTINUU ON VARIOUS SCALES
  - S_s (SPECIFIC STORAGE) AND $\underline{\underline{K}}$ (HYDRAULIC CONDUCTIVITY TENSO WHEN SUCH BEHAVIOR EXISTS
- CORRELATION OF $\underline{\underline{K}}$ WITH FRACTURE GEOMETRIC DATA
- STATISTICAL ANALYSIS OF FRACTUR GEOMETRIC DATA
- GEOSTATISTICAL (VARIOGRAM) ANALY OF $Y = \log_{10} K$ DATA FROM SINGLE - HOLE HYDRAULIC TESTS
- 3-D KRIGING OF Y
- CORRELATION OF THE LATTER WITI GEOTOMOGRAPHIC RESULTS (LLL)
- 3-D CONDITIONAL SIMULATION OF
- USE OF THE LATTER TO IDENTIFY POTENTIAL PATHS OF HIGH K IN ROCK
- UNIFIED ANALYSIS OF K ON SMALL A LARGER SCALES (SINGLE/CROSS-HOLE TESTS) IN STOCHASTIC FRAMEWORK

- DETERMINATION OF 3-D ANISOTROPIC Y COVARIANCE FROM DATA INCLUSTERED VERTICAL BOREHOLES BY MEANS OF THE ABOVE UNIFIED THEOR
- STOCHASTIC THEORY TO COMPUTE MACRODISPERSION FROM 3-D Y COVARIANCE OBTAINED ABOVE
- IMPROVED MATHEMATICS/SOFTWARE TO ANALYZE CHEMICAL TRACER TESTS UNDER DIVERGING + TWO-WELL RECIRCULATION FLOW REGIMES
- DEVELOPMENT OF ADAPTIVE EULERIAN LAGRANGIAN FINITE ELEMENT METHO FOR ADVECTION-DISPERSION

RELEVANT WORK SUPPORTED BY OTHER SOURC

- 3-D GEOSTATISTICAL PACKAGE USING NOVEL METHODS OF DRIFT AND SEMIVARIOGRAM ESTIMATION DEVELOPE HERE
- APPLICATION OF THIS TO HYDROCHEMI CAL DATA
- NOVEL METHODS/SOFTWARE FOR PARAMETER ESTIMATION
- JOINT ANALYSIS OF HYDRAULIC AND CHEMICAL DATA.

ALL THIS HAS CULMINATED IN A PHILOSOPHY & METHODOLOGY THAT FAVORS VIEWING CERTAIN FRACTURED ROCKS AS A STOCHASTIC CONTINUUM FOR PURPOSES OF FIELD CHARACTERIZATION AND THEORETICAL/COMPUTATIONAL ANALYSIS.

WORK IN PROGRESS

- ANALYSIS OF HEAT MIGRATION EXPERIMENTS AT ORACLE. STRONG INDICATION OF CHANNELING.
- FEASIBILITY OF USING HEAT AS A TRACER
- INTRODUCTION OF OUR NEW FICKIAN MACRODISPERSION THEORY INTO A RANDOM WALK COMPUTATIONAL TRANSPORT MODEL
- EXTENSION OF THIS MODEL TO ACCOUNT FOR NON-FICKIAN DISPERSION
- ANALYSIS OF FLOW/TRANSPORT IN STRONGLY NONUNIFORM MEDIA (SUCH AS MANY FRACTURED ROCKS)
- PARAMETER ESTIMATION IN NONLINEAR MODELS

— CONTINUED JOINT ANALYSIS OF HYDRAULIC AND CHEMICAL DATA

PROPOSAL PENDING

COLLABORATION WITH NAGRA, SWITZERLAND, IN CONDUCTING TESTS AND ANALYZING TEST DATA FROM THE SEISMIC TOMOGRAPHY SITE AT GRIMSEL.

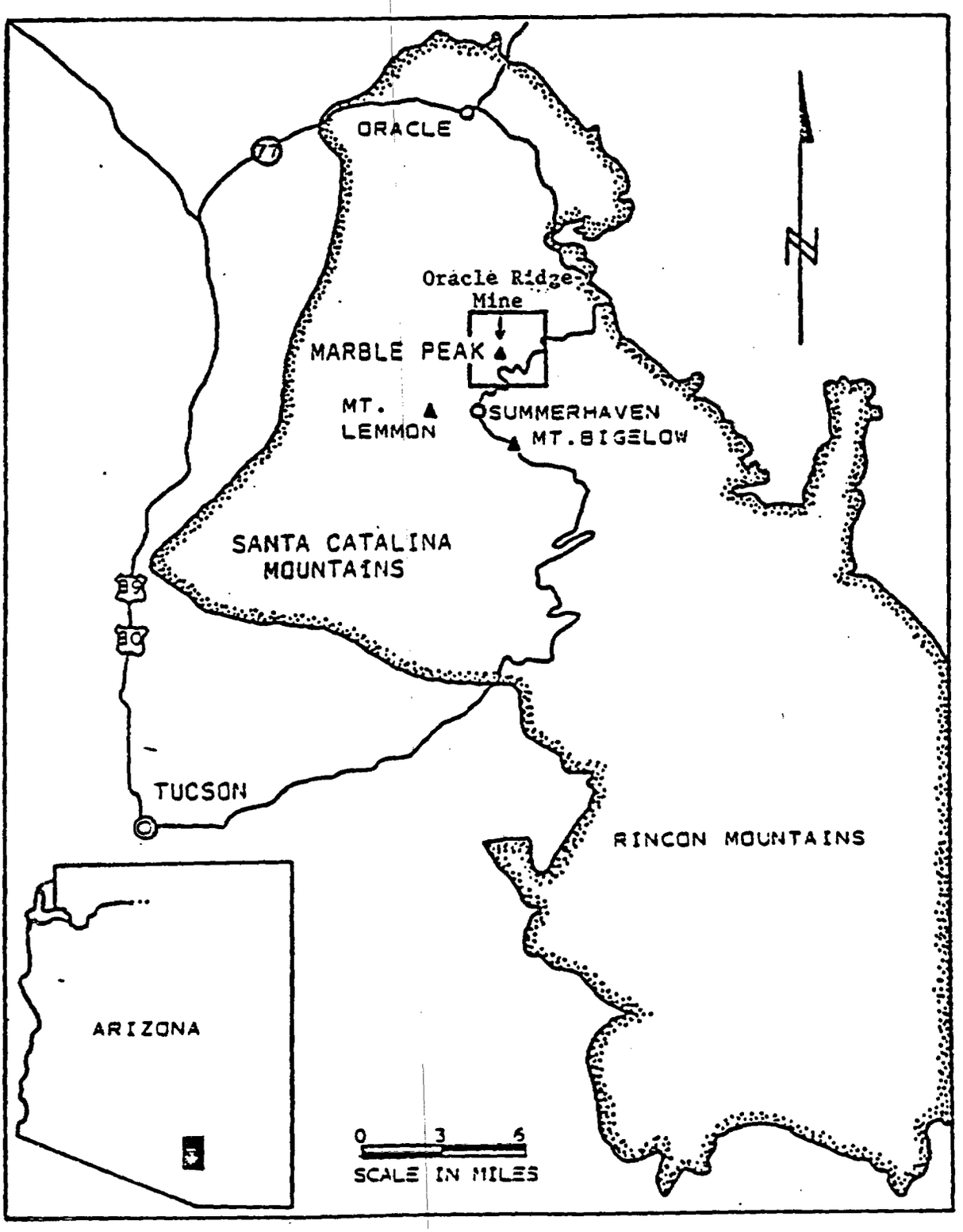

Figure 1. Location map of Oracle Ridge Mine.

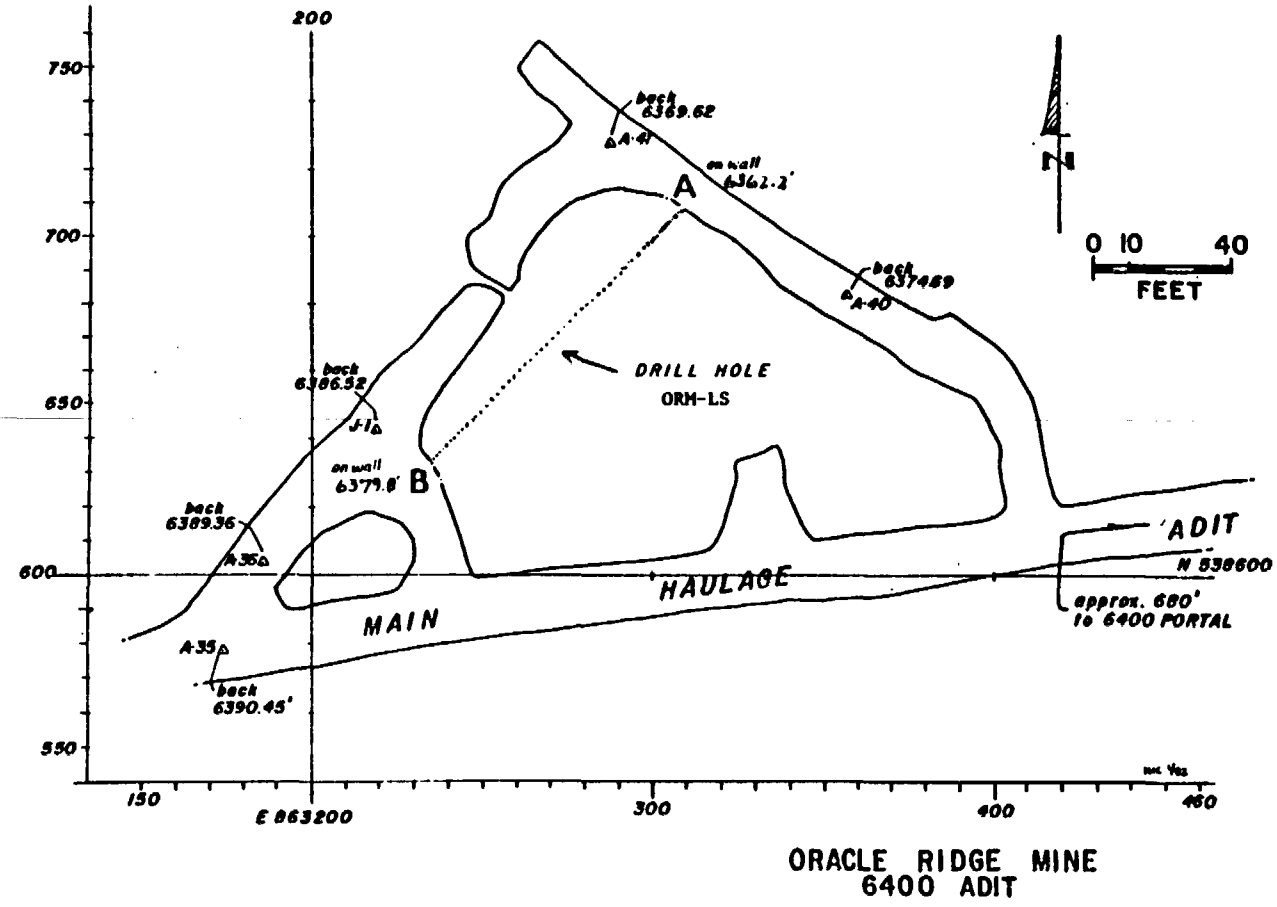

Figure 3.1 Location of hole ORM-LS, (AB) at Oracle Ridge Mine.

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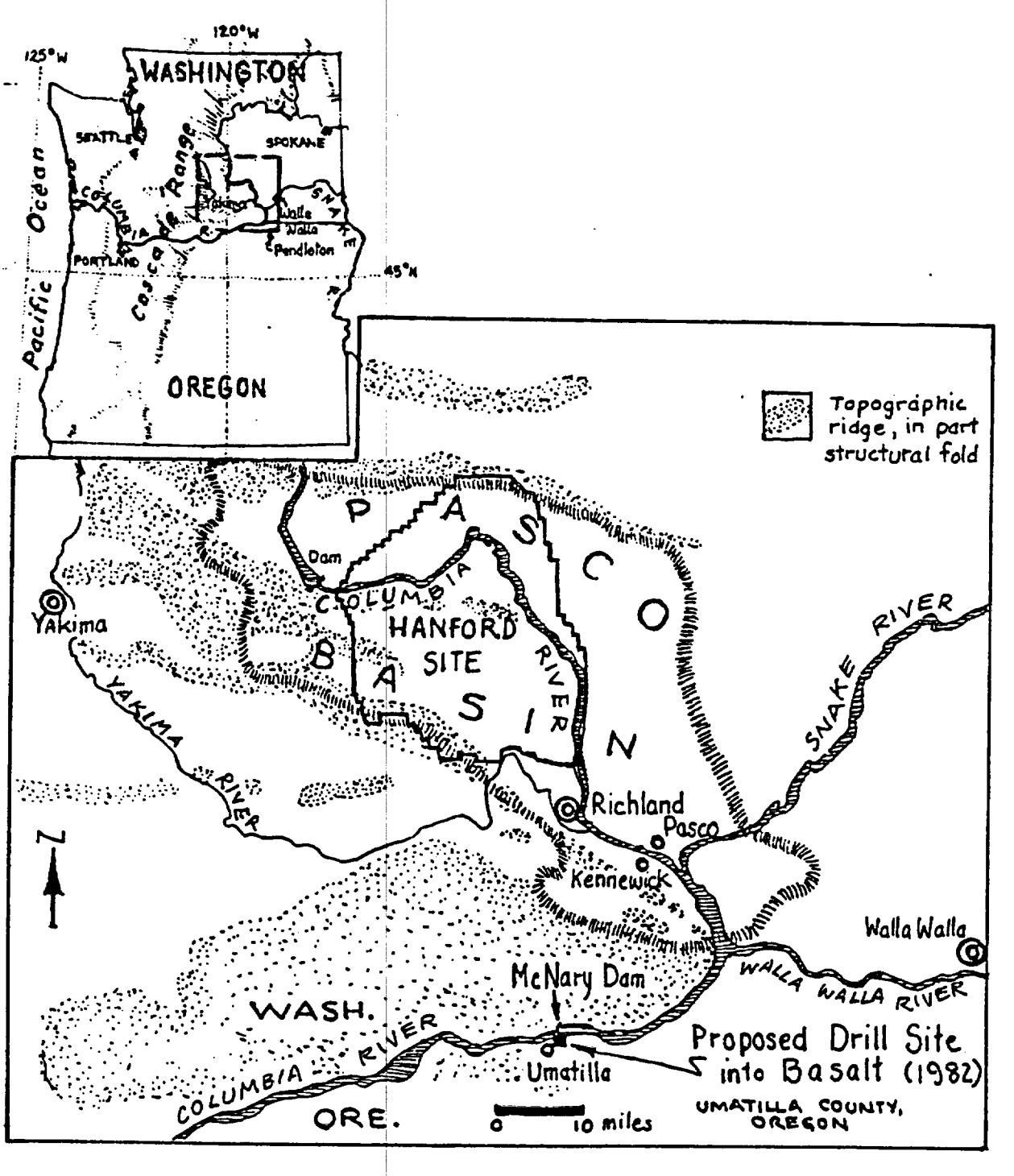

Figure 4.12 General location map of McNary Dam and the west-central portion of the Columbia River basalt plateau.

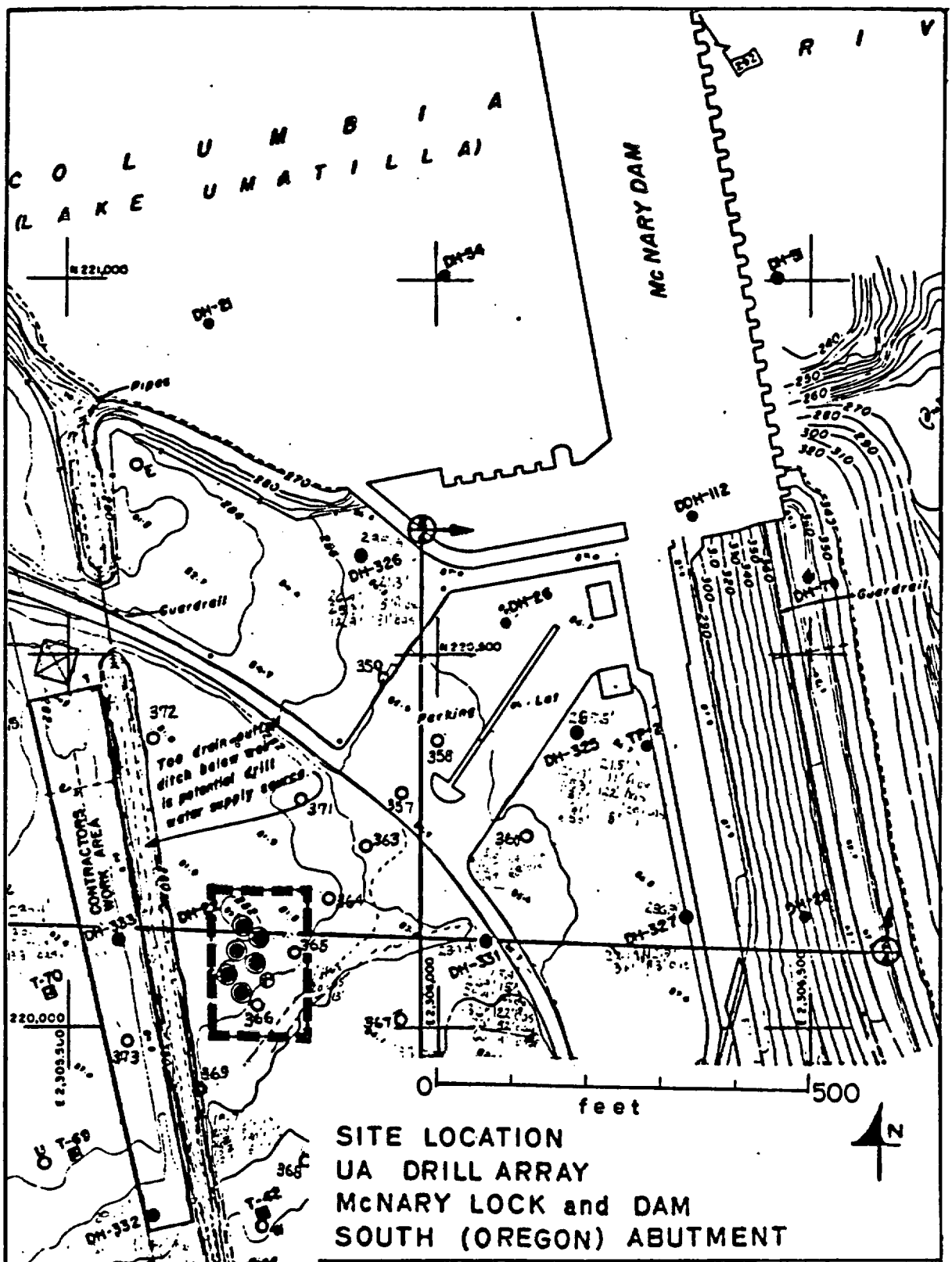

Figure 4.1 Location map of UA drill hole array sited about 1000 ft SW of McNary Dam powerhouse and 1000 ft NW of the fish-ladder viewing building.

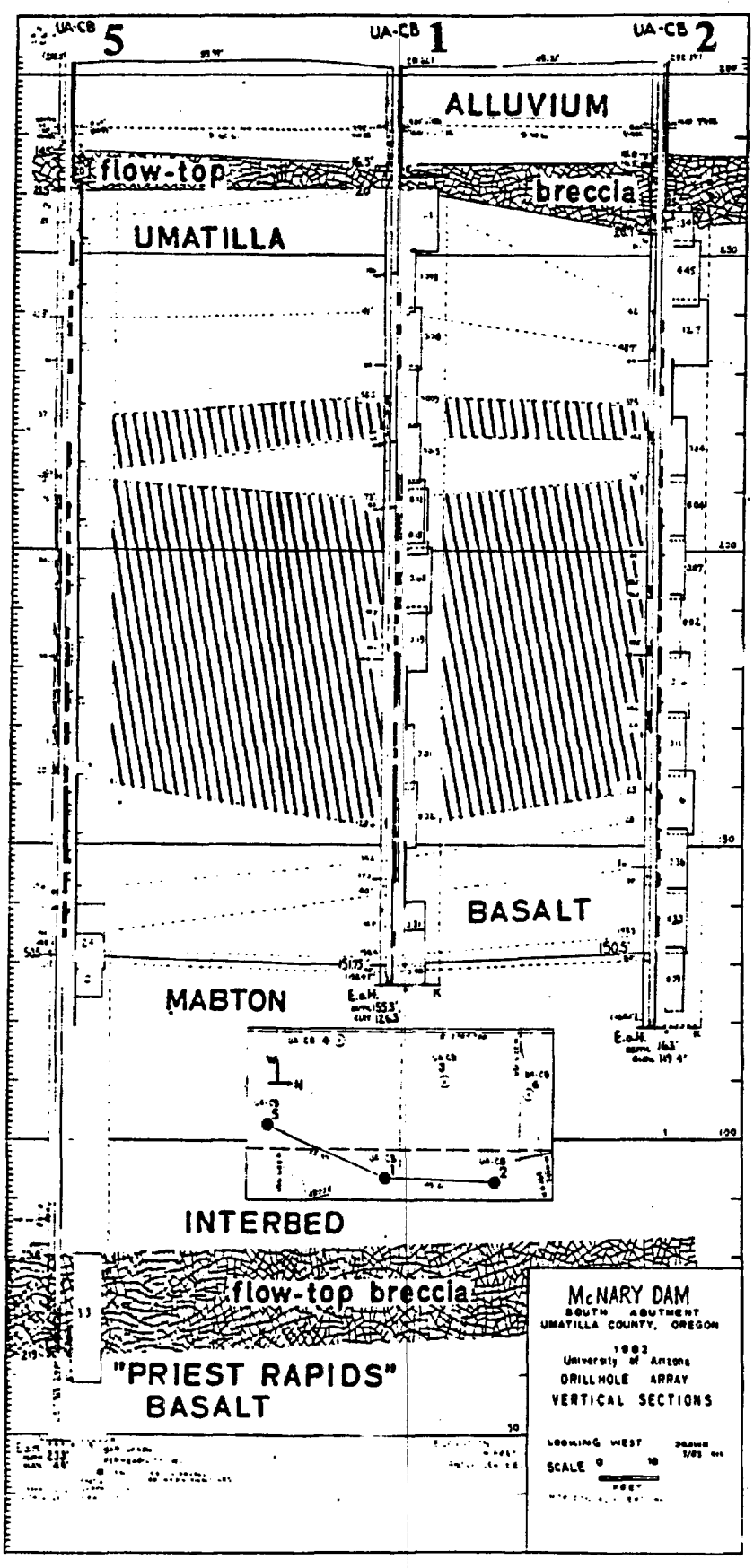

Figure 4.4a Vertical section through drill holes UA-CB-1, 2 and 5 (McNary) showing geological units and four data columns for each note from left to right; down-hole footages, trace of drill hole, zones with less than one fracture per foot (black bars), and bar graph of permeability (zero values are flush-left line).

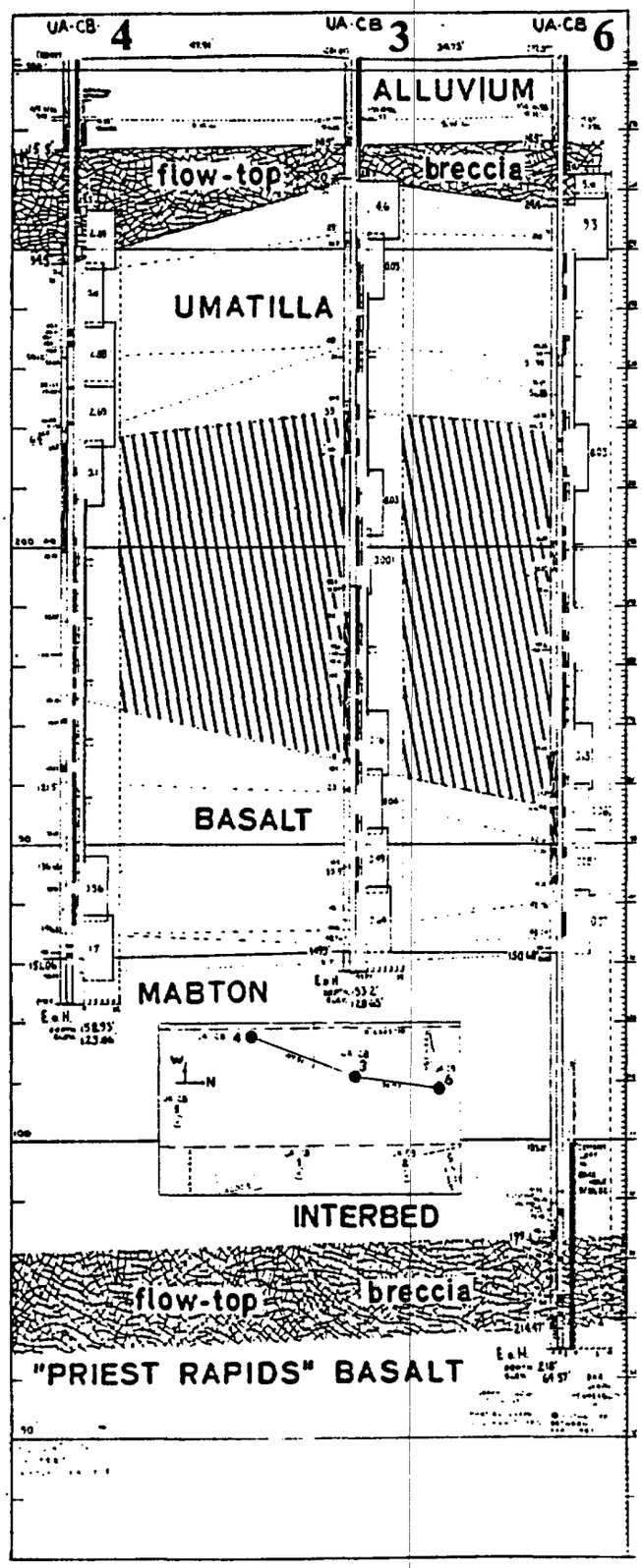

Figure 4.4b Vertical section through drills holes UA-CB-3, 4 and 6 (McNary Dam, Oregon) showing geological units. The same data is included as in Figure 4.4a, and a more detailed explanation is in the text, Section 4.1.9 . Line pattern indicates a subunit within the flow interior, characterized by <2% to no amygdules and vertical, black-chlorite filled joints, often alternating with vitric intervals. This subunit may be equivalent to the "colonnade" of weathered exposures of basalt flows.

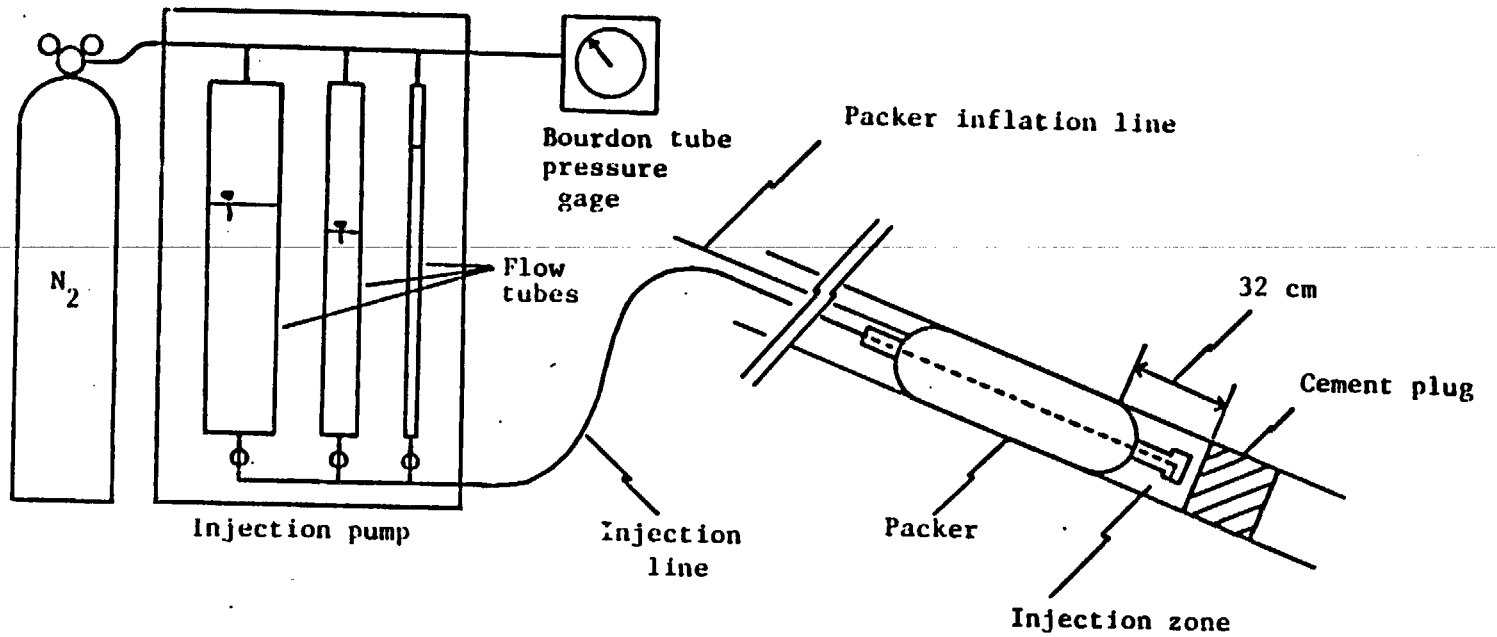

Figure 2.2 Oracle Ridge Mine injection pump and injection-side packer.

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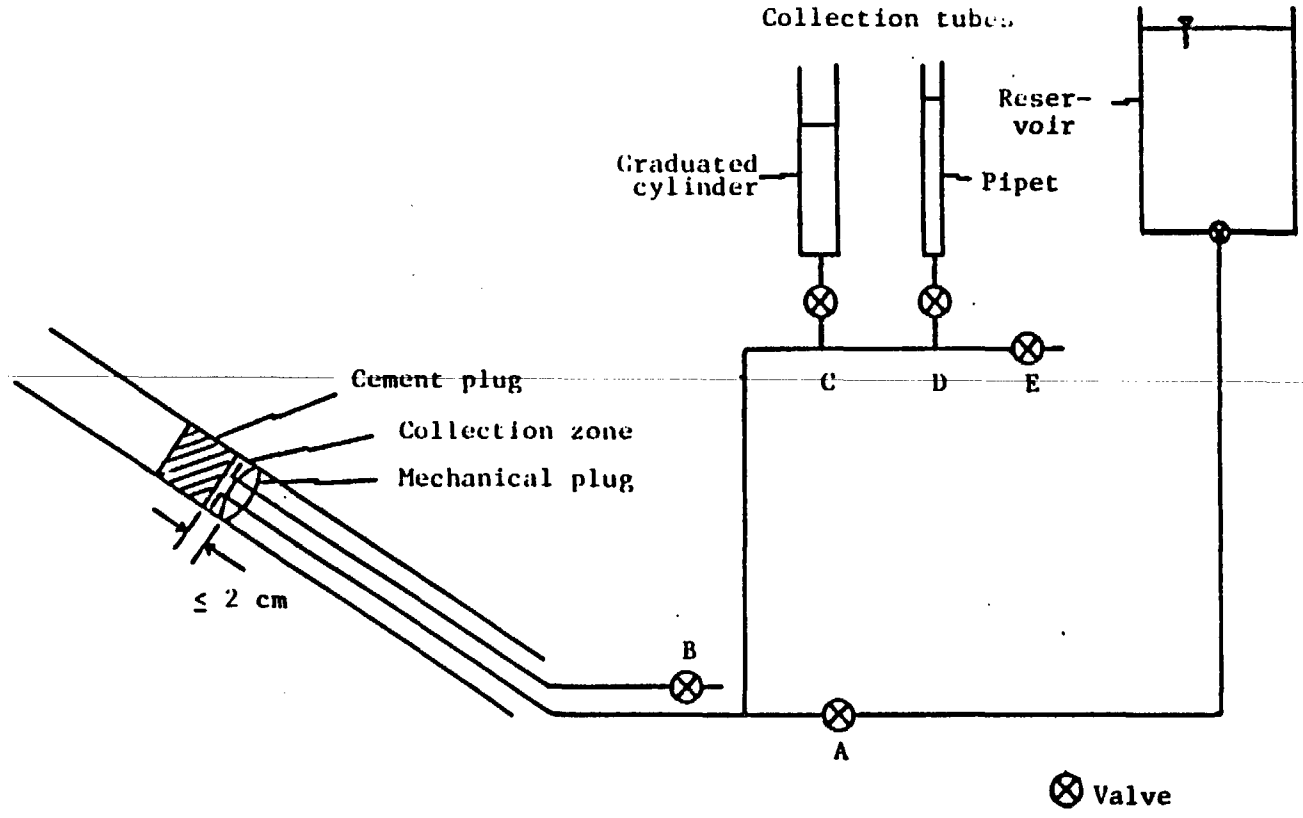

Figure 2.3 Oracle Ridge Mine collection system for constant head tests.

ORACLE RIDGE MINE CONSTANT HEAD INJECTION TEST RESULTS

Test Period Dates	Average Driving Head $\lvert h_c - h_i \rvert$ (cm)	Average Outflow Rate (cm^3/hr)	Equivalent Porous Medium Permeability of Plug ($x\ 10^{-14}\ cm^2$)
7/3/85-7/10	2570	.0910	1.7
7/10-7/18	2550	.0893	1.7
7/18-7/26	2540	.0852	1.6
7/26-8/2	2560	.0832	1.5
8/2-8/9	2550	.0832	1.5
8/9-8/15	2540	.0824	1.5
8/16	Injection zone head rasied.		
8/17-8/26	3270	.107	1.5
8/26-9/2	3250	.105	1.5
9/2-9/9	3250	.104	1.5
9/9-9/18	3230	.103	1.5
9/18-9/24	3230	.101	1.5

9/

Equivalent porous medium permeability (cm^2) calculated using the following expression:

$$k_p = \frac{Q_c \mu \ell}{900 \pi d^2 \rho g (h_i - h_c)}$$

where Q = average collection zone outflow rate (cm^3/hr)

ℓ = plug length = 10 cm

μ = dynamic viscosity of water at 10°C = 1.307×10^{-2} gm/cm-sec

d = plug diameter = 10 cm

ρ = density of water at 10°C = .9997 gm/cm^3

g = gravitational acceleration = 979.5 cm/sec^2

$h_i - h_c = |h_c - h_i|$ = driving head across plug (cm)

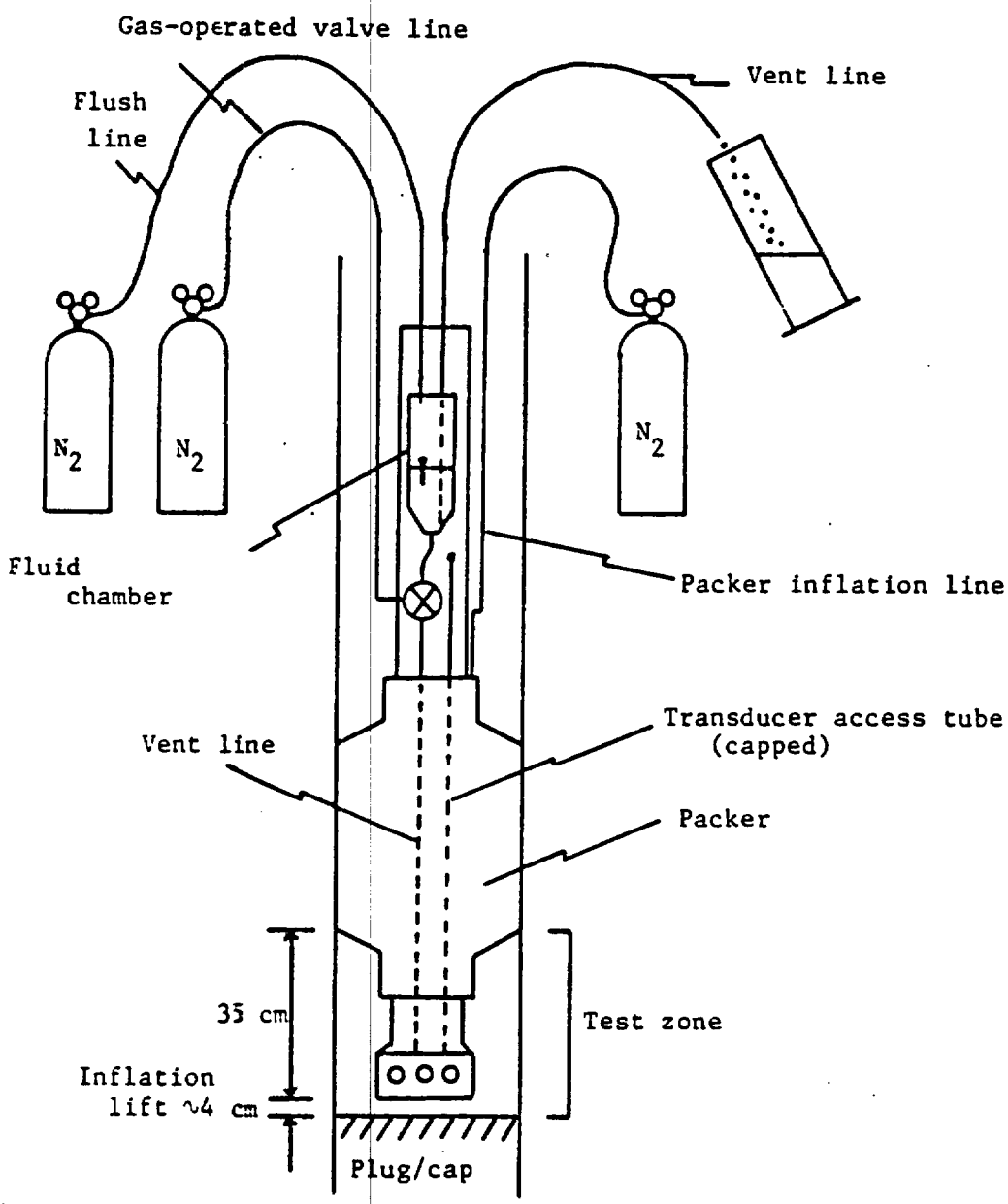

Figure 2.12 Plug tester unit with fluid collection chamber (transducer removed) for McNary Dam plugs.

From -- Southern Arizona Guidebook, 1968
Geological Society of Arizona
Ed. Spencer R. Titley

ZONED ASH–FLOW SHEET IN THE REGION AROUND SUPERIOR, ARIZONA[1]

By

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INTRODUCTION

Remnants of a thick Tertiary ash-flow sheet cover large areas in parts of Gila, Pinal, and Maricopa Counties, Arizona (Fig. 1). The ash-flow sheet is of particular local interest because it covers potential mineral exploration targets in a region that has many ore deposits. This report briefly describes the physical features of the ash-flow sheet and explains how internal zoning can help interpret its structure.

Previous Work

The ash-flow sheet was first studied in the Globe 15-minute quadrangle by Ransome (1903, p. 88-95), who described the basal tuff correctly but considered the vitrophyre and the rest of the unit to be thick, massive lava flows of dacitic composition. Short and others (1943, p. 45-49) described the sheet near Superior as alternating dacitic lava flows and tuff deposits. N. P. Peterson carefully described the deposit in the vicinity of Globe and Miami (1962, p. 38-41). He realized that lava flows of this composition would be erupted as relatively short, viscous flows with contorted flow structures. This deposit, however, actually covers hundreds of square miles and contains uncontorted, flat to moderately tilted structures, so he concluded that it was probably laid down by several ash flows or incandescent clouds (N. P. Peterson, 1962, p. 40-41).

I have made additional studies of the deposit and have concluded that it is composed of a number of ash flows erupted in rapid enough succession to form an ash-flow sheet that is, in general, a simple cooling unit. The present report, outlining this thesis, is chiefly a condensation of an earlier open-file report (D. W. Peterson, 1961a).

Terminology

The terms used in this report follow the terminology proposed by Smith (1960a, p. 800-801). Abbreviated versions of several of Smith's definitions are repeated here.

Ash flow: The basic unit of ash-flow deposits; the deposit resulting from the passage of one nuée ardente.

Ash-flow sheet: Any unspecified sheetlike unit or group of units considered to be of ash-flow origin.

Welded tuff: A rock or rock body in which vitric particles have some degree of cohesion by reason of having been hot and viscous at the time of their emplacement.

Cooling unit: A single or multiple ash-flow deposit that can be shown to have undergone continuous cooling.

Simple cooling unit: An ash flow or sequence of ash flows that has had an essentially uninterrupted cooling history.

Compound cooling unit: One that shows departures in expectable zonation and other properties which result from simple cooling, because the intervals between ash flows were too great for readjustment to a single-unit cooling gradient.

To understand the definition of " ash flow" it may be helpful to review Smith's concept of "nuée ardente". He emphasized the original observation that a nuee ardente is composed of two parts, a basal avalanche that contains the bulk of the erupted material, and an overriding cloud of expanding gas and dust (Smith, 1960a, p. 802-804). Although a nuée ardente is both a type of eruption and an agent of transport, Smith emphasized its role as an agent of transport of material from the vent to its final resting place.

The deposit in the vicinity of Superior, Miami, and Globe is an "ash-flow sheet" made up of an undetermined number of separate "ash flows" that in most places cannot be individually recognized. Part of the deposit is composed of "welded tuff," and part is non-welded. In most places the ash-flow sheet constitutes a "simple cooling unit," but locally it grades laterally into a "compound cooling unit."

In most of the literature describing the area, "dacite" has been used to designate the rock type (Ransome, 1903, 1919, 1923; Short and others, 1943; Peterson and others, 1951; N.P. Peterson, 1962, 1963), and the name is firmly established in current local usage. Dacite is defined as a volcanic rock with

1. Publication authorized by the Director, U.S. Geological Survey

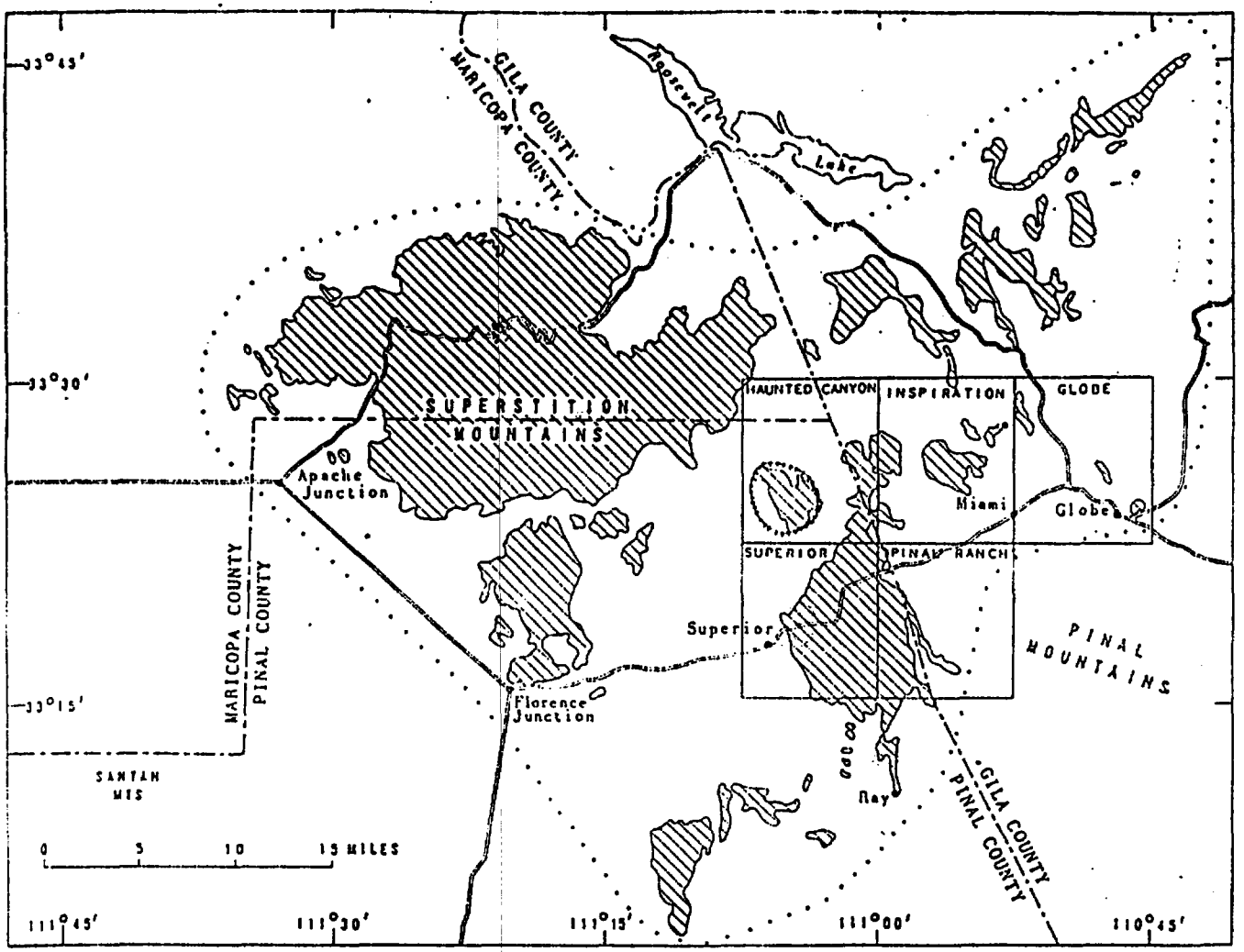

Figure 1 — Location Map of the Superior, Arizona Region

umerous quartz and feldspar phenocrysts, the feld-
ɔar phenocrysts being mostly plagioclase; on this
asis dacite is a valid name for the rock. It should be
:cognized, however, that on the basis of its chemical
ɔmposition, the rock is a quartz latite (Peterson,
961a, p. 111).

ORIGINAL EXTENT, VOLUME, AND AGE

The area in which the ash-flow sheet crops out is
ıown in Figure 1. The deposit has been recognized
om 10 miles west of the Superstition Mountains to
ıe Salt River near Cherry Creek, and from a mile
ıst of Globe to the vicinity of Ray. Outcrops of ash-
ow rocks in the Santan Mountains may be part of
ıe same sheet, but the correlation is not yet certain.
he possible original extent of the sheet is indicated
. Figure 1; this area is about 1500 square miles, but
may exceed 2000 square miles.

The maximum exposed thickness of the sheet is 2000 feet just east of Superior. Thicknesses of over 1000 feet are common in the central part of the area shown in Figure 1, and the sheet gradually thins toward its margin. The original thickness of the sheet is difficult to determine because of dissection by erosion and the irregular pre-eruption topography. However, 500 feet seems to be a reasonable estimate for the average thickness. This leads to an estimated volume for the sheet of about 150 cubic miles.

Ransome (1903, p. 94-95) assigned a Tertiary (?) age to the deposit, and this age is confirmed by isotope age dating techniques. Creasey and Kistler (1962, p. 1) determined an apparent absolute age of 20 million years on K-Ar ratios in biotite obtained from vitrophyre at the base of the deposit east of Superior. Damon and Bikerman (1964, p. 72) obtained an age of 19.9±0.9 million years on biotite from dacite about 2 miles east of Superior. (They

used a slightly different decay constant and recalculated the age obtained by Creasey and Kistler to 19.4 million years.) These dates all indicate a middle Miocene age.

FIELD DESCRIPTION

Zoning

All of the zones of welded ash flows defined and described by Smith (1960b) are present in this ash-flow sheet, and they are diagrammatically represented in Figure 2. The three fundamental zones that depend

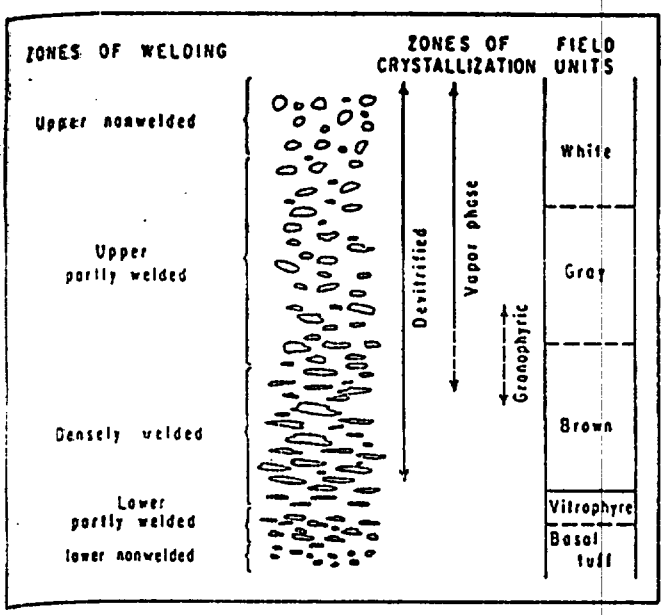

Figure 2 — Physical characteristics of the ash flow sheet

on the degree of welding include (1) upper and lower zones of no welding, (2) upper and lower zones of partial welding, and (3) the zone of dense welding. Superimposed on all but the lower part of the sheet are three zones representing the different types of crystallization that took place during the cooling of the sheet: (1) devitrification, (2) vapor-phase crystallization, and (3) granophyric crystallization. The zones of crystallization are superimposed upon the three fundamental zones of welding. In addition, the zones of crystallization overlap one another. In most vertical sections through the sheet, the successive zones in part follow the same pattern as indicated in Figure 2, without repetition or regression. This pattern indicates that, despite its great thickness, the sheet consists of a single cooling unit in most places.

The rocks of all the zones have certain features in common. Throughout the entire sheet the rocks are porphyritic with a similar phenocryst assemblage; in hand specimen phenocrysts can be identified as feldspar, quartz, biotite, accessory iron oxide, and lesser variable amounts of hornblende and sphene. Phenocrysts constitute from one-fourth to nearly one-half the volume of the rock; they range in size from barely discernible with the hand lens to 3 mm, and most are ½ to 1 mm in diameter.

Lithic inclusions are common throughout the ash-flow sheet, and generally make up 1 or 2 per cent of the rock. In the lower part of the sheet, however, they become much more abundant, generally making up about 10 per cent and locally as much as 25 per cent of the rock. All the older rocks of the district occur as inclusions. Most are angular chips a fraction of an inch in diameter, some are several inches across, and a few scattered boulders several feet in diameter have been observed.

In the field it has been convenient to map the following five units rather than the zones of crystallization or welding: (1) basal tuff, (2) vitrophyre, (3) brown unit, (4) gray unit, and (5) white unit. Some of these units have been mapped in part of the Superior quadrangle; Figure 3 shows their generalized distribution.

(1) The basal tuff includes the lower zone of no welding and part of the lower zone of partial welding. The glass shows no appreciable crystallization. The base of the ash-flow sheet consists of nonwelded crystal tuff wherever observed. The basal tuff is poorly to moderately indurated and weathers to gentle, subdued slopes. It is generally light gray to white but locally grades to shades of yellowish gray and moderate red. The basal tuff ranges in thickness from 2 to 100 feet or more, averaging about 10 to 20 feet.

The matrix of the nonwelded tuff is powdery and generally uniform; in addition to phenocrysts and lithic inclusions, it locally contains pumice lapilli and blocks. In the nonwelded tuff, orientation of constituents is random. Upward into the zone of partial welding, however, the pumice fragments and glass shards become flattened and uniformly oriented; as the tuff becomes more firmly consolidated, its specific gravity increases, and discs of black glass appear and become progressively more abundant upward. These changes all result from a progressive upward increase in the degree of welding. The zone of partial welding (the upper part of the basal tuff) ranges in thickness from a few inches to about 40 feet, averaging from 1 to 6 feet.

(2) The vitrophyre includes the lower part of the zone of dense welding that lacks superimposed crystallization. The lower part of the vitrophyre may also include the upper part of the lower zone of partial welding (Fig. 2). Most of the vitrophyre is a densely welded tuff composed of a matrix of black glass containing the normal assemblage of phenocrysts and sparse to abundant lithic inclusions. It is generally

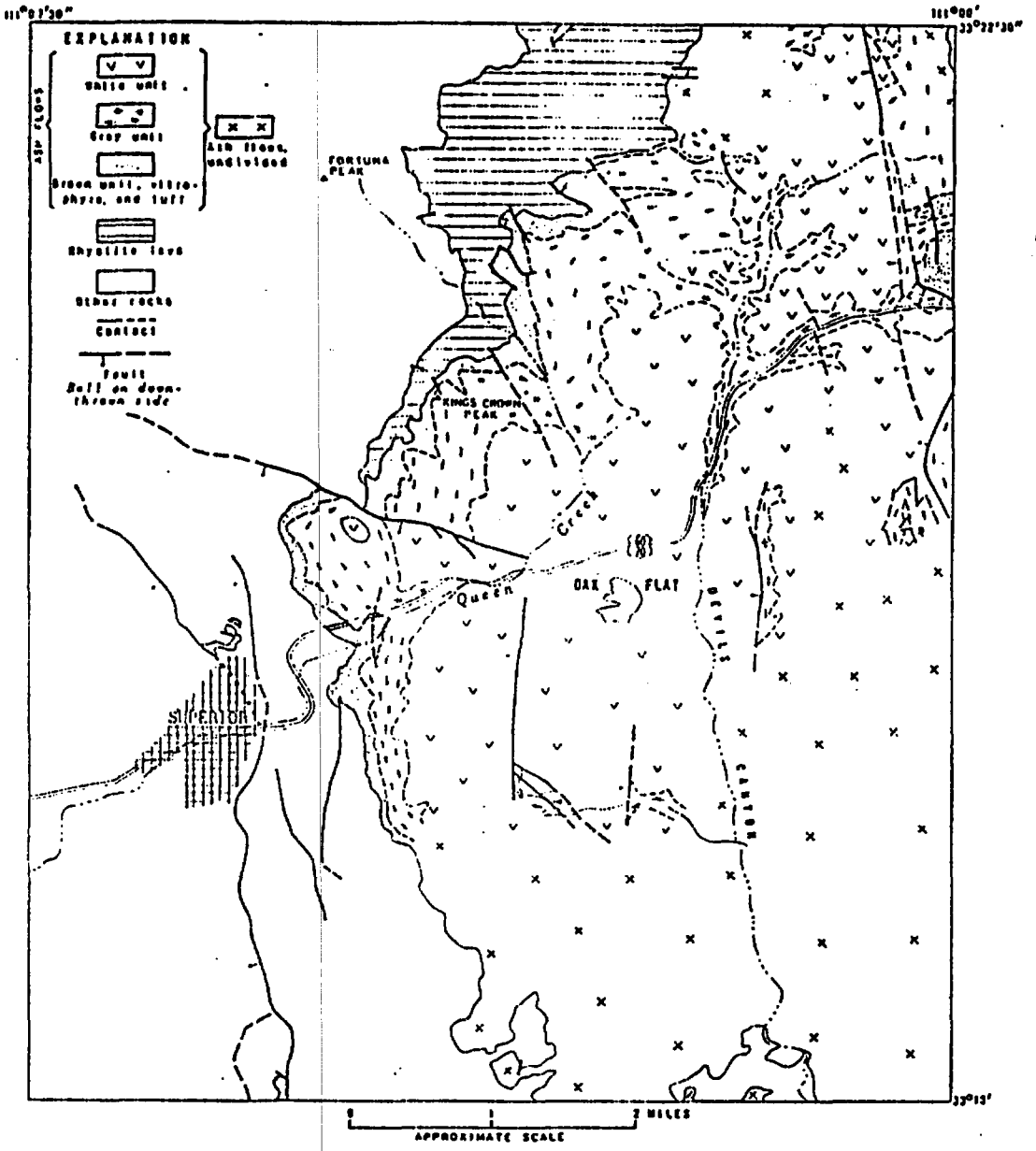

Figure 3 — Generalized geologic map of the Superior quadrangle, showing the distribution of recognized field units within the ash flow sheet. Recognition of the units has permitted identification of several faults within the sheet.

firm and resistant to weathering and stands out as a ledge above the softer basal tuff. The vitrophyre weathers to a dark gray or dark brown color that contrasts with the lighter colors of overlying and underlying rocks. It ranges in thickness from 2 to 80 feet and averages from 5 to 25 feet.

(3) The brown unit consists of the part of the zone of dense welding upon which has been superimposed the zone of devitrification. It also may include the lower part of the upper zone of partial welding, in which thin scattered lenticles that underwent vapor-phase crystallization are present. The dominant characteristic of the brown unit is a devitrification of the original glass of the groundmass to a dense, hard, flinty rock that is light brown to reddish brown in color. Careful scrutiny of the groundmass with a hand lens reveals eutaxitic structures characteristic of densely welded tuff; these structures show clearly under the microscope. The intensity of devitrification crystallization increases upward. This is expressed megascopically by a gradual change in color from brown to brownish gray to reddish gray. The thin,

light-colored lenticles in the upper part of the brown unit are flattened pumice fragments that have retained enough porosity to allow slight vapor phase crystallization; they gradually become more abundant upward into the upper zone of partial welding. The thickness of the brown unit cannot be given precisely, because of its gradational upper boundary, but it generally ranges from 20 to 200 feet. In Queen Creek Canyon the brown unit reaches its maximum thickness of about 450 feet.

(4) The gray unit lies entirely within the upper zone of partial welding, upon which the zone of devitrification crystallization has been strongly superimposed. This crystallization reaches the maximum coarseness in the gray unit, and in many places the original "welded-tuff texture" is obscured by the superimposed crystallization. The color of the rock ranges from reddish gray to medium and light gray. Pumice fragments are strongly flattened in the lower part of the unit and partly flattened in the upper part; as their flattening decreases, the amount of vapor-phase crystallization increases. However, welding of the groundmass throughout the gray unit was strong enough to confine vapor-phase crystallization chiefly to the pumice fragments. Both the lower and upper contacts of the gray unit are gradational. The unit ranges from a few feet to over a thousand feet in thickness.

(5) The white unit includes the upper part of the upper zone of partial welding and the entire upper zone of no welding. Its main characteristic is that vapor-phase crystallization not only occupies the pumice fragments but also permeates the groundmass and is there superimposed upon the devitrification crystallization. Crystallization is so intense that generally the original vitroclastic textures have been completely obliterated. The rock has an aphanitic groundmass that generally lacks planar or oriented structures. The color on the fresh surface is light gray to white; it weathers brownish gray to reddish gray, nearly the same as the gray unit. Pumice fragments range from partly flattened to nearly equidimensional in shape. On unweathered surfaces they are difficult to distinguish from the enclosing rock, but as the rock weathers to a darker color, the pumice fragments become more discernible. In most places erosion has removed a substantial part of the white unit, and only in the vicinity of Oak Flat, 4 miles east of Superior, has the original upper surface of the unit been recognized. The white unit has a maximum thickness of about 800 feet and averages perhaps 200 to 300 feet, but thicknesses are uncertain because of the gradational lower contact and the eroded upper surface.

Granophyric Crystallization

Smith (1960b, p. 152) defines granophyric crystallization as follows:

> "In silicic welded tuffs granophyric crystallization is characterized by groundmass quartz intergrown with, or as blebs associated with, alkalic feldspar and minor accessory minerals. The aggregate shows granophyric or micrographic textures similar to those shown by many slowly cooled rhyolitic flows, domes, and shallow intrusive rocks."

Granophyric textures are identified in thin section in specimens from the central part of the very thick section east of Superior. These textures occur chiefly in the centers of flattened pumice fragments in the lower part of the gray unit. The granophyric crystallization evidently took place where cooling was slowest and was promoted by the presence of residual vapors in the pumice fragments. The position of the granophyric crystallization zone illustrates well how the various zones of crystallization are superimposed on one another. This zone is thin, poorly defined, and discontinuous, and it is superimposed upon the zone of devitrification at a horizon where the zone of vapor-phase crystallization is also present.

Pumice Fragments

Light-colored cognate inclusions that are locally abundant in some parts of the ash-flow sheet have been identified as pumice fragments. They are lenticular to ovoid in shape; toward the top they are equidimensional, but downward they become progressively more flattened. Most of the inclusions range from 1 to 4 inches in their longest dimension, but both larger and smaller sizes are common. In general their light color contrasts with the slightly darker enclosing rock. Most of them carry approximately the same assemblage of phenocrysts in about the same proportions as the matrix and, except for their lighter color, appear to be practically the same rock. An important difference is that many of the phenocrysts in the enclosing rock are broken, whereas they are generally unbroken in the pumice fragments. The original pumiceous texture of the fragments has been largely obscured or obliterated by devitrification and vapor-phase crystallization, so that the fragments are now essentially a porphyritic rock with a uniform aphanitic groundmass.

The flattening of pumice fragments has been given considerable study (Peterson, 1961b). The apparent flatness of a fragment is defined as the ratio of its length to its height—a ratio which has a rather wide range of values at any given outcrop. The flattening ratio is defined as the mean value of the apparent

flatnesses of a representative number (generally 30 or 40) of fragments. This ratio can be calculated either as an arithmetical average or as the mean of the logarithms of the apparent flatnesses. These two methods yield slightly different values; the logarithmic flattening ratio is more rigorous, but the arithmetical flattening ratio is easier to calculate in the field. Figure 4

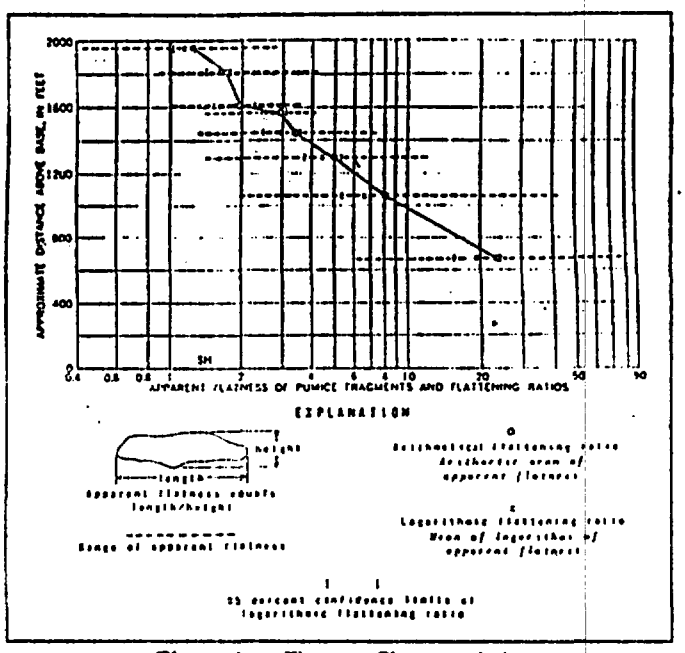

Figure 4 — Flatness Characteristics

shows the relation of the flattening ratio to the stratigraphic position in the ash-flow sheet; the flattening ratio increases as the depth of burial increases. This curve was obtained from fragments in the section of rocks exposed in roadcuts along U.S. Highway 60-70 between Superior and Oak Flat. Curves from other localities show similar relations.

Studies of flattening ratios have made it possible to estimate the amount of throw on faults in the ash-flow sheet. The flattening ratio also is a tool for estimating the distance of an outcrop below the original top of the sheet. Such applications are somewhat limited, however, because outcrops suitable for measurement of fragments are not numerous.

STRUCTURE OF THE ASH-FLOW SHEET

The term "sheet" appropriately describes the gross structure of the ash flows, inasmuch as the horizontal dimensions are many times greater than the thickness and the deposit extends over a wide area. The sheet was deposited on a surface of moderate to locally steep relief.

The attitude of most layering ranges from horizontal to dips of about 30°, but in a few places the dips are as much as 60°. The planar structure on which attitudes are measured is generally a joint system, distinct to indistinct, that lies parallel to the plane of flattening of the pumice fragments. It seems likely that the structures originally were nearly horizontal, and that the higher dips are due to post-solidification tilting. If the still-plastic rock had been deposited with an appreciable angle of dip, the rock would probably have flowed laterally, yet no evidence for such flowage has been recognized.

In earlier maps and reports, few faults were noted within the ash flows because of the uniform appearance of weathered surfaces from near the base to the top of the sheet. However, the distinct changes in lithology due to zoning and the systematic changes in the flattening ratio of pumice fragments provide the criteria that permit faults within the sheet to be recognized and mapped. A fresh surface must be obtained to identify the zone, so the work is rather slow and tedious; therefore, zones have been mapped and faults studied in detail in only a part of the Superior quadrangle (Fig. 3).

Several faults cutting the ash-flow sheet have been recognized, most of which probably belong to a single set. Most of the faults trend north to northwest, and the west or southwest side is dropped down, although a few have the opposite sense of displacement. Hammer and Peterson (in press) describe two principal sets of faults that cut the rocks of the Superior area. The older set trends principally eastward, and many of the faults are mineralized. Most of these faults are pre-Tertiary in age. The younger set trends north to northwest; its faults displace faults of the older set and offset Tertiary as well as older rocks. In general these faults are not mineralized. Most of the faults illustrated in Figure 3 belong to this second set.

Nearly everywhere the ash-flow sheet is cut by a system of vertical or nearly-vertical joints. The joints vary from clearly defined to indistinct, and from widely to closely spaced; most are from 5 to 15 feet apart. The joints commonly form distinct systems, in which parallel joints extend continuously for several hundred feet to more than a mile. In many places two joint systems intersect each other at angles from 60° to 90°. The continuity of the joints suggests that they are of tectonic origin, and are not simple cooling cracks. However, polygonal cooling joints are found in a few places, mostly in the vitrophyre.

SOURCE

The major source or sources of the ash flows have not yet been identified. Further study in areas west of the Haunted Canyon and Superior quadrangles may ultimately reveal the major eruptive center. However, a small caldera, about 3 miles in diameter, has been recognized in the southwestern part of the Haunted

outlined in Figure 1. This caldera was probably the source for part of the deposit. At most, however, it could have supplied about 10 cubic miles of material—only a fraction of the total volume of the sheet (Peterson, 1961a, p. 71-72).

The caldera is a crudely circular structure in which ash flows and underlying rhyolite are downdropped and are surrounded by rocks of Paleozoic and Precambrian age (Peterson, 1960). The relations between the volcanic rocks and the older rocks around the border of the structure are complex and chaotic, and the older rocks are locally intruded by dikes of vitroclastic material similar to that in the ash-flow sheet. Local zones of alteration are common in the ash flows and rhyolite within the caldera. Erosion has removed all traces of any original topographic expression of a collapse feature, but the foregoing evidence is considered sufficient to identify the caldera (Peterson, 1961a, p. 66-72). Similar structures, perhaps larger, may lie farther west. M. F. Sheridan has tentatively recognized caldera-like structures in the western part of the Superstition Mountains (oral communication, 1967), which may provide additional sources for the ash flows.

PETROGRAPHY AND MINERALOGY

The nature, distribution, and appearance of phenocrysts throughout most of the ash-flow sheet are remarkably constant. They are nearly uniformly distributed, and constitute from 35 to 45 per cent of the rock. Plagioclase is the most abundant phenocryst mineral, followed by lesser amounts of quartz, biotite, sanidine, and opaque oxides. Hornblende is present in some specimens and absent in others. Sphene, apatite, and zircon are common accessory minerals, and a few specimens contain a little tourmaline. Over a hundred modal analyses show that the relative proportions of the different phenocryst minerals show a slight but systematic change from the bottom to the top of the [illegible] ases slightly, and quartz and [illegible] has an intermediate structural state.

The major phenocrysts average between ½ and 1 mm in diameter, but a few are as large as 3 mm. Except for the phenocrysts in pumice fragments, a high proportion of phenocrysts throughout the sheet are broken, and tiny angular crystal fragments are scattered through the matrix.

The plagioclase crystals, constituting from 55 to 80 per cent of all phenocrysts, are generally subhedral, rarely anhedral, and are commonly twinned after one or more twin laws. Most are distinctly zoned, showing either normal or oscillatory-normal patterns. Optical and X-ray diffraction studies of the plagioclase have not shown a unique composition, but they indicate that it lies in the range from oligoclase to

The ash-flow sheet generally contains only a small number of sanidine phenocrysts, about 1/2 to 5 per cent of the phenocrysts. In the white unit, however, sanidine makes up from 6 to 15 per cent of the phenocrysts. In all units the sanidine is subhedral or euhedral, and some crystals show slight to moderate corrosion and embayment of their borders. Most are untwinned, but a few are twinned on the Carlsbad law. X-ray diffraction study indicates an approximate composition of Or_{85}-Ab_{15}.

Quartz phenocrysts are anhedral and approximately equant, and they generally have deeply embayed borders. Quartz constitutes from 5 to 14 per cent of the phenocrysts in most of the ash-flow sheet, but from 11 to 25 per cent in the white unit. Grains are clear and unaltered, and some contain liquid inclusions. The quartz in most specimens shows slightly undulatory extinction.

In all parts of the sheet biotite makes up from 5 to 13 per cent of the phenocrysts and averages about 8 per cent. Biotite phenocrysts are generally euhedral or subhedral and form tabular books and flakes; many grains are distorted and bent. "Bird's-eye" structure is common, and pleochroism is pronounced with X = yellow, Y = Z = dark brown. Biotite in the lower part of the sheet is fresh, but in the upper part of the brown unit it is slightly altered, and farther upward the alteration becomes progressively more intense. Alteration begins as bleaching at the crystal boundaries and development of small clots of opaque oxides in the bleached areas. The bleaching progresses inward with further alteration, particularly along cleavage planes, and the opaque clots enlarge. Alteration is most intense in the white unit, where biotite is either replaced by chlorite or is completely bleached and accompanied by large concentrations of opaque oxide clots.

HISTORY OF THE ASH-FLOW SHEET

The magma, with a chemical composition of quartz latite, probably originated by selective melting of sialic material at a depth of several kilometers (Peterson, 1961a, p. 113-115). As it migrated upward it cooled, and plagioclase, sanidine, quartz, biotite, and other minerals crystallized. As crystallization continued, gas pressure rose; when about 40 per cent of the magma had crystallized, it found its way explosively to the surface. The properties of the magma—such as temperature, viscosity, and gas content—were such that it erupted as nuées ardentes. Gas escaped with enough violence to disrupt the magma into ash-sized particles, and the explosively vesiculating magma rapidly spread laterally in all directions as a gas-charged avalanche.

Mobility was aided by air engulfed by the incandescent mass; the suddenly heated air expanded violently, speeding the avalanche forward along its path and creating a constant turbulence within it (McTaggart, 1960). Billowing clouds of dust undoubtedly rose to great heights, but the bulk of the material was carried by the basal avalanche.

Successive eruptions rapidly followed one another; each eruption was an individual pulse separated from the next pulse by hours or days, but each successive layer was added before the next underlying layer had cooled appreciably. Each eruptive pulse added from a few tens to several hundred feet of material to the deposit. The erupted material had sufficient energy and mobility to travel distances of as much as 20 miles. The original relief was moderate to steep, perhaps on the order of 1000 feet; the deposits filled in valleys and ultimately covered hills under depths of several hundred feet.

The first material that came to rest on the cool prevolcanic surface was quickly chilled, and the glass particles became rigid enough to resist deformation. This material (the lower nonwelded zone) formed an insulating blanket causing material above it to cool more slowly, so that shards and pumice fragments retained their plasticity long enough to be deformed and flattened by the weight of the overlying material, thereby giving rise to the lower partly welded zone. The vitrophyre represents a layer in which the particles were plastic enough to become greatly flattened and thoroughly welded together, yet were chilled quickly enough to form a glass.

In a thick layer above the vitrophyre the still-plastic particles were deformed by the overlying load and thoroughly welded. Cooling, however, was slower, and the originally glassy constituents devitrified to form the cryptocrystalline, aphanitic groundmass characteristic of the brown unit. Higher in the sheet the overlying load was smaller and the degree of welding gradually decreased, so that some porosity was retained. Escaping gases collected in these pore spaces to promote additional crystallization. The intensity of vapor-phase crystallization increased upward as the degree of welding decreased and became still more intense through the gray unit. Finally the upward-streaming gases permeated all the spaces between particles to cause vapor-phase crystallization through the entire white unit. As crystallization became more complete, the outlines of particles became more diffuse because crystals grew across shard boundaries. Near the top of the sheet the particles were essentially undeformed and nonwelded, but their original outlines were ultimately obliterated by crystallization, owing to long contact with upward-rising hot gases.

The region was either standing high or was uplifted soon after the ash-flow eruptions, for erosion deeply dissected the sheet and locally cut entirely through it. Fluvial deposition followed, and the Gila Conglomerate was deposited in local basins. In some areas air-fall tuffs and lava flows, ranging in composition from basalt to rhyolite, were erupted and locally interfinger with the Gila Conglomerate. Abundant faults cut both the ash-flow sheet and the younger rocks.

Renewed uplift halted deposition of the Gila, erosion continued to dissect the ash-flow sheet and to cut into the younger rocks, and gradually the present-day topography developed.

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ATTACHMENT 2

August 15, 1987

MEMORANDUM

TO: Mr. Owen Merrill
Senior Staff Engineer, ACRS

SUBJECT: Revised Trip Report

Enclosed for your information and use is a revised (and corrected) copy of my report of the visit by the Waste Management Subcommittee to the University of Arizona and the DOE Nevada HLW Repository Facilities last month.

Sincerely,

Dade W. Moeller,
ACRS Member

encl.

4'

D. W. Moeller
LET57 - Draft #2
August 11, 1987

SUMMARY REPORT OF ACRS WASTE MANAGEMENT FIELD TRIP TO UNIVERSITY OF ARIZONA AND THE NEVADA TEST SITE - July 28-30, 1987

I. Introduction

The field trip consisted of three parts:

1. A visit to the NRC supported HLW Management research program at the University of Arizona in Tucson. This included a visit to their field investigations at the Oracle Ridge Mine near Superior, AZ.

2. A visit to the DOE supported HLW Management research program in Las Vegas, Nevada. This visit included discussions with the NRC Onsite Representative (Paul Prestholt), the leader (Carl Johnson) of the State of Nevada review program organization, and USGS and DOE personnel (including personnel from the Lawrence Livermore Laboratory and the Los Alamos and Sandia National Laboratories).

3. A tour of HLW Management research activities and demonstration projects at the Nevada Test Site. This included a visit to Yucca Mountain and discussions with personnel of the U. S. Geologic Survey who are conducting onsite investigations there.

ACRS Committee members who participated in the tour included Carson Mark, Dade Moeller, Forest Remick, Paul Shewmon and Martin Steindler. Consultants taking part in the field trip included Melvin Carter, Konrad Krauskopf, Frank Parker, George Pinder, and Mihailo Trifunac. Also taking part in the trip were S. J. S. Parry, Senior ACRS Fellow, and Owen Merrill, Senior Staff Engineer, ACRS; Stephen Kale and James Knight of the DOE Staff Headquarters Office of Geologic Repositories; and Keith McConnell, Division of High Level Waste, and Thomas Nicholson, Office of Nuclear Regulatory Research, NRC Headquarters.

II. Visit to the University of Arizona (July 28, 1987)

Presentations to the Subcommittee included coverage of laboratory and field studies on borehole plugging, including the use of cement and bentonite plugs in basalt, granite and welded tuff, as well as the sealing of salt with cement, bentonite and crushed salt.

The visit to the Oracle Ridge Mine included examination of welded tuff in the field and a review of data obtained through the drilling of a series of nine boreholes in a tuff formation.

The laboratory studies have shown that cement borehole seals, which were initially tight, will with time (7 to 9 months) become loose. A critical factor in the success of the seal appears to be the manner (and care) with which the hole is drilled. If the walls of the borehole are damaged, this can lead to a poor seal. The field studies have shown that the tuff formation "breathes." Sometimes the air flow is into the formation; other times it is out.

One interesting item reported was the development by Lawrence Livermore Laboratory personnel of a technique for electromagnetic geotomography which yields data that closely correlate with those from hydraulic tests (of permeability). Support of further development of this technique at LLL has, however, been terminated.

The major observation noted in the University of Arizona studies is that fractures within a geologic formation will dominate the flow of water through the formation. Therefore the primary need is to understand fracture flow, as well as matrix flow.

Questions raised and comments made by the Subcommittee included the following:

1. All the studies reported appear to be exploratory; there does not seem to be a focus or delineation of clear goals for the work. For example, a number of experiments have been conducted in which a variety of materials have been tested as possible seals for a range of geologic media. If these studies had been arranged on the basis of a factorial experimental design, much more information could have been extracted from the data.

2. The possible influences of chemistry on the behavior of the seals (and their bonding to the geologic medium) do not appear to have been investigated. Although both laboratory and field tests are underway, the integration of the two appears to be absent. There is no clear indication of how either set of tests complements the other. Although they are attempting to obtain a water balance in the flow tests (outlet versus inlet), this does not appear to have been successful. The outlet flow, for example, continues for some time after the inlet flow has been terminated.

3. There were also questions as to how data based on small borehole plugging experiments can be applied to the sealing of large shafts. Plastic (flexible) seals might also be considered. Finally, little attention appears to have been given to the development of methods for testing the adequacy of borehole and shaft seals in the field. This would appear to be crucial to the confirmation of the integrity of a completed repository.

4. Other questions raised included: The adequacy of their QA program; uncertainties and limitations in the data they are obtaining; and who it is that performs independent reviews of the work they are doing. In this regard, it might be noted that the headquarters NRC Project manager appears to have had a major impact on the nature of the research they are conducting.

5. Lastly, there were questions as to how successful the University of Arizona staff has been in keeping up with related research being conducted elsewhere, and the transfer of the results of their work to others. The NRC Onsite Representative (in Las Vegas), for example, had essentially no familiarity with the work being done at the University of Arizona, even though the work was supposedly being conducted primarily in support of the proposed HLW repository being considered for location in Yucca Mountain.

III. DOE Presentations in Las Vegas (July 29, 1987)

A. Presentation by NRC Onsite Representative

The opening technical presentation was made by Paul Prestholt, the NRC Onsite Representative for the proposed Yucca Mountain repository. Mr. Prestholt has a background in geology and quality assurance and appeared to have a solid grasp of the project. He accompanied the Subcommittee throughout the meetings in Las Vegas and the tours at the Nevada Test Site. Mr. Prestholt appeared to have good working relationships with the headquarters NRC Staff, the DOE Staff and the State of Nevada personnel.

Comments and observations made as a result of contacts with Mr. Prestholt included the following:

1. Both the DOE Staff and Mr. Prestholt indicated that the NRC needs to give more attention to the guidance being provided to the DOE Staff. At present, such guidance appears to be less than effective -- certain terms are not clear or need to be better defined; in some cases the DOE Staff simply does not understand what the NRC desires be done. A clear example was the fact that the NRC regulations (which are based on EPA standards) specify limitations on groundwater travel time. What is important is the travel times of the radionuclides being transported by the water. This should be indicated and/or clarified.

2. Mr. Prestholt is hampered by a lack of funds for support of travel by NRC headquarters personnel. For example, during a recent QA review of the DOE HLW research work, he requested the assistance of a QA expert from NRC headquarters. Such help was not provided due to limitations on travel funds. Mr. Prestholt also believes the project is frequently hampered by the high turnover rate of NRC personnel. New people must receive orientation both from Mr. Prestholt and the DOE Staff, with resultant delays. There also appears to be little Commissioner interaction with NRC HLW operations in the field. Except for a trip by Chairman Zech to the BWIP site, the interaction of the Commissioners with NRC and DOE personnel at the several proposed repository sites appears to have been minimal.

3. There are also questions about the availability of written reports pertaining to the HLW repository investigations and related

work. Neither Mr. Prestholt nor any of the DOE personnel had seen any of the recent ACRS reports on the HLW repository program. This includes the recent report (letter) expressing our concerns about the associated QA program. In a similar manner, none of the ACRS Subcommittee members or consultants have seen any of the quarterly reports being submitted to NRC headquarters by Mr. Prestholt. Efforts may need to be taken to make such reports more widely available.

4. Finally, the question was raised as to whether the three sites currently proposed as possible locations for a HLW repository are receiving comparable attention in terms of laboratory and field investigations, evaluations and reviews. According the the NWPA, all three should be evaluated on a comparable basis.

B. Presentation by State of Nevada Representative

The next presentation was made by Mr. Carl Johnson, Director of the Nevada Office of Technical Programs, who is responsible for reviewing the proposed repository in Yucca Mountain. Mr. Johnson's office includes 4 to 5 technical staff members, and is supported by a seven member Citizens Advisory Committee. Also interacting with his group is a seven member committee from the State legislature. Mr. Johnson indicated that, on the basis of his work, there were six critical issues related to the proposed repository in Yucca Mountain.

1. Characterization of moisture movement through the unsaturated zone.

2. Relation of the groundwater beneath Yucca Mountain to the regional aquifer system in that area. This was considered significant because such a system may be a potential future source of drinking water for the city of Las Vegas.

3. Effects of long term climatic changes. Here Mr. Johnson stated that predictions (based on historical records) are that the climate will become wetter and cooler.

4. Future faulting and other tectonic events.

5. Future volcanism.

6. Possible human interference -- natural resource exploration.

Of these issues, Mr. Johnson stated that the last three were most critical and that any one of them could (in his opinion) represent grounds for disqualification of the Yucca Mountain site from further consideration for a HLW repository.

Mr. Johnson also indicated that he was concerned about potential impacts on the site of future underground nuclear weapons

testing at the Nevada Test Site. In response, the DOE staff indicated that limitations on the ground shaking in the city of Las Vegas should assure protection of the Yucca Mountain region. Mr. Johnson also indicated that there was some potential for hydrothermal activity within the region and this was a concern to him. Overall, he stated that he is not satisfied with the DOE research program or the directions in which it is heading.

With respect to the review activities being conducted by the State of Nevada, the Subcommittee made the following observations:

1. The Staff program is funded by the DOE. Over the past six years, it was indicated that the funds provided had totalled about $100 million, a portion of which is used to provide contracts to State organizations (for example, the University of Nevada in Las Vegas and related units in Reno).* Such contracts range on an annual basis from $150 thousand to well over $1 million. In spite of this, Mr. Johnson indicated that the funding level needed to be increased.

2. The Governor of Nevada has indicated that he is opposed to the siting of a HLW repository in his State. It is his opinion that the State of Nevada has, through the nuclear weapons testing program, contributed more than its share to the Nation's nuclear programs. Since Mr. Johnson is a political appointee and must be responsive to the Governor, the objectivity of his review may be in question.

3. Although the State of Nevada and the NRC would appear to share identical objectives -- to assure that any repository located within Nevada can be constructed and operated with full protection of the health and safety of the public and the environment, and also comply with all applicable regulations -- these two organizations do not conduct any research activities on a cooperative basis, nor do they appear to share thoughts and concerns in terms of their reviews and evaluations of the Yucca Mountain project. Since their interests and roles would appear to be identical, such cooperation might be explored.

C. Presentations by DOE Staff and Contractors

Opening remarks in this portion of the program were made by Donald Vieth, former director of DOE HLW operations in Nevada. He indicated that DOE's major goals were to determine whether the geology would support a repository and to gather sufficient scientific data either to support or deny that indication, while also striving for intellectual honesty in the pursuit of these goals. To assist in these activities, they have established an "issues hierarchy" and a system for resolving each of the issues identified.

Although in a "typical" respository, access would be through a vertical shaft drilled from the surface, the Yucca Mountain site would permit access by drilling through the side of the Mountain, as

* According to DOE's "Annual Report to Congress" (DOE/RW-0144, dated April, 1987) the funds granted to the State of Nevada for FY 1983-86 totalled $7.3 M.

well as from the top. Current thoughts are that the primary entrance will be through the side.

Individual presentations were then made by DOE representatives on each of the following subject areas:

1. Site Characterization -- the objective was to provide information on what the program was designed to accomplish. Subcommittee questions pertained primarily to the performance allocations for the various site parameters -- how the individual goals or limitations were set and the basis for the specific numbers chosen.

2. Groundwater Travel Time -- the studies are designed to determine flow through the matrix and the fractures. Dr. Steindler noted that they had observed a 300 foot hydraulic discontinuity in the water table; this is similar to observations made at the BWIP site.

3. Geologic Faults -- several have been observed in the region of Yucca Mountain. Trenches have been dug to examine them in more detail.

4. Volcanism -- recent studies indicate that a nearby calandra may have been located that has an age less than 20,000 years. However, the releases appear to have declined substantially in recent history, and calculations indicate that the population doses accompanying a volanic release of material within the repository would be minimal (millirems, at most). Nonetheless, because of the interest of the State of Nevada in these matters, the DOE Staff is continuing these studies.

5. Hydrothermal Activity -- this is being investigated. Recent data indicate some potential for such activity in the area. Accompanying releases could affect the waste containers.

Following these presentations, the Subcommittee members formulated a list of questions they thought should be addressed. These were provided to the DOE Staff who offered to provide written responses, including a list of appropriate references, on each topic. The questions included the following:

1. How will the integrity of the completed repository be determined? That is, how will the integrity of the sealed shafts be assured?

2. Which is important -- the travel time of the groundwater or the radionuclides that it contains? The DOE staff is to clarify its questions regarding this issue and the Subcommittee will seek a response from the NRC Staff.

3. How were the retardation coefficients determined? In fact, could more information be provided on all the geochemistry work from the standpoint of how it was assured that collected

samples were representative, that their analyses were accurate, and that the interpretation of the resulting data were properly conducted.

4. The same information is needed regarding measurements of stress fields in the area. Where did the numbers come from? Details of the calculations should be provided.

5. Indications are that the underground nuclear weapons tests have altered (temporarily and/or long range) the water tables in the area. Data on these changes should be provided.

6. As previously indicated, the procedures for determining the performance allocations for various parameters within the HLW repository should be carefully documented and provided to the Subcommittee.

7. Finally, the Subcommittee encouraged the DOE Staff not only to seek to meet the NRC regulations in the design, construction and operation of a HLW repository, but also to assure protection of the health and safety of the public, as well as the environment.

D. Site Tours (July 30, 1987)

The third day of the field trip was devoted to a tour of relevant work and research activities within the Nevada Test Site and at Yucca Mountain. Specific items covered included the following:

1. Drilling Rigs -- included a description and tour of rigs for constructing holes up to 12 feet or more in diameter (in a single cut). Current plans call for increasing the size up to perhaps 20 feet. Newer techniques permit more rapid drilling at far reduced cost.

2. G-Tunnel -- this includes tunnels one mile or more into the side of a mountain, including excavations within welded tuff some 1400 feet beneath the surface. The tuff (which was in a thin layer that cooled rapidly) was highly fractured and cracked. Within Yucca Mountain where the welded tuff layer is thicker and cooled more slowly, it is anticipated that far less fracturing will be present.

3. Spent Fuel Test -- Climax -- this consisted of a vertical shaft down some thousand feet or more into a granite formation. Spent fuel elements from the Turkey Point (PWR) Plant were encapsulated and remotely transported and stored here for some three years, during which extensive analyses and testing were conducted. Later the fuel elements were retrieved and the tests were subsequently terminated. This was a positive demonstration of the capability to emplace spent fuel in a granite repository at depth and later to retrieve it.

4. Sedan Crater -- the Subcommittee observed the Sedan Crater that was formed by an underground 100 KT explosion in 1962 as part of the Plowshare Program. The crater is in excess of 1200 feet in diameter and 300 feet deep.

5. Yucca Mountain -- here the Subcommittee observed the site, the local geology, and interacted with the USGS Staff who are conducting field studies in the area. The studies include measurements of the porosity of the overlying soil and welded tuff, and downward migration of surface rainfall. Nearby activities include the digging of exploratory trenches to explore faults in the area. The site is in a very remote and desolate area.

Summary Comment: The Subcommittee members and consultants were unanimous in their conclusion that the field trip had been a major success. Being provided the opportunity to observe the DOE laboratory and field facilities engaged in HLW research enhanced our understanding of the work and the associated problems.

VANDERBILT UNIVERSITY

NASHVILLE, TENNESSEE 37235 TELEPHONE (615) 322-7311

Civil and Environmental Engineering • Direct phone 322-2697

August 10, 1987

Dr. Dade Moeller
27 Wildwood Drive
Bedford, MA 01730

Dear Dade:

Though I was unable to attend the morning meeting at the University of Arizona due to the delay of the plane because of an intense electrical storm in Nashville, I have read all of the material sent to me and did participate in the visit to the geohydrology test site. In addition, I did participate in the discussions in Las Vegas, though I did not make the field visit. I have, however, previously toured most, if not all, of the sites.

Because of the lack of time on both occasions for full detailed discussions with the researchers involved, and without access to the voluminous documentation already available on the site, I shall restrict my comments to general impressions based upon the information that I have, recognizing that we did not have complete briefings, particularly on performance assessment that would indicate how they intend to meet the requirements of both 40 CFR 191 and 10 CFR 60.

Perhaps it would also be best to recall that the Environmental Assessments specifically do not address the system guidelines except in a preliminary and conservative way. It would be useful then to compare the technical guidelines for selection of sites for characterization and note that they must be met. They will be discussed in a manner corresponding to that outlined in the Guidelines and the EA Overview Document whose pages will be cited.

In the section on Geohydrology on page 22, it states that there are four major considerations:

1. ground water travel time and flux
2. effect of climatic changes
3. ease of characterizing and modeling the geo-hydrological system
4. local ground water used for consumption and irrigation

Since ease of characterization impacts all the others, I shall address this first, despite the fact that DOE says that "Since it is not an intrinsic physical characteristic of the geohydrological setting, this consideration is not as important as the first two considerations." This statement is true if one had infinite time and dollars and were willing to destroy the site in order to understand it. However, under the circumstances of tight money and time schedules, the logic of this escapes me because if the site cannot be

characterized and modelled in real time without endless scientific dispute, then one cannot get reasonable scientists to agree on the first two topics. Looking at all of the literature and even more importantly at what we learned on our field trip, such as that when rain water flows into the unsaturated zone, the impact is felt 5000 feet in the limestone aquifer below the tuff within one month. Visual observation of the tuff outcrops indicates it is highly fractured. Two of the topics in geohydrology about which there is not agreement even on the fundamentals is fracture flow and vadose zone flow. Yet this is precisely what one has at the Yucca Mountain site. Both are extraordinarily difficult problems. One cannot tell from the surface nor by geophysical means what are the number, orientation, size, connectiveness and chemical characteristics of the fractures. In the vadose zone, the hydraulic conductivity is a function of the head and the moisture content. Determining the moisture content in detail is difficult, and in addition, the conductivity varies depending upon whether the matrix is wetting or drying. Taking meaningful samples is also very difficult. Finally, the recharge is obtained by indirect means based upon the precipitation and the calculation of evapotranspiration. Evapotranspiration remains a black box with the empirical calculation of Thornthwaite in the 30's still the standard methodology, if any. The recharge is determined by the difference between precipitation and losses by runoff and evapotranspiration. Therefore, a small error in any of the input data can make a major difference in the output. The accuracy of the Thornthwaite formulation is low. Consequently, one can expect large differences in the source term. Taking all of these considerations into account, it is difficult to understand how one can fashion a credible model in the time available to do so.

Since the region around Yucca Mountain is a closed basin and the water in the vadose zone appears to move primarily in the fractures and joints, which one is not sure to intersect, it is difficult to measure flow times and be sure that the total flux is accounted for and that the fastest flow times have been included. As discussed above, a credible model is difficult to obtain, therefore determination of flow times and water flux with acceptable accuracy will be difficult to obtain. The effects of climatic changes can be calculated only if there is a credible model. As discussed above, that is difficult. Consequently, the effects of climatic change can be calculated only with a high degree of uncertainty.

This is not to imply that the work is not of high scientific caliber. Though we did not have time to make such determinations, the researchers are scientists with fine reputations. Rather the problem is one of approach. The problem cannot be solved scientifically with the time, manpower and funds available. Consequently, much higher reliance must be placed on the engineered barriers and an optimized combination of the engineered barriers with the natural barriers. The proper approach would be to determine precisely what can be said now with existing theory plus the advances that can reasonably be expected in the time available and the data already in hand and that which can reasonably be expected for use in license application, and design the engineering system to fulfill the system requirements with some degree of

safety. I am quite confident that this would indicate that the system's requirements could easily be met. It is less clear to me that all of the individual technical requirements can so easily be met. These determinations require a symbiotic relationship with the performance assessment group so that the most important parameters can be determined so that the investigations will focus on reducing the degree of uncertainty in the most critical items. While all of this may be happening, it was not clear to me that this was in fact the case.

In summary, to reach the goals of acceptance of waste at the repository in a timely fashion, an engineering approach to the problem is mandatory. We need as much as possible of the underlying theory, but will have to accept increased factors of safety to offset our uncertainty in theory and data.

Detailed comments on the individual presentations would require far more detailed information than we have available to us at this time.

Sincerely yours,

Frank L. Parker

FLP:bl

cc: Owen Merrill

Georgia Institute of Technology
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
NUCLEAR ENGINEERING AND HEALTH PHYSICS PROGRAMS
SCHOOL OF MECHANICAL ENGINEERING

Please reply to:

NUCLEAR ENGINEERING AND
HEALTH PHYSICS PROGRAMS
CHERRY EMERSON BUILDING
GEORGIA INST. OF TECH.
ATLANTA, GEORGIA 30332 U.S.A.

August 6, 1987

Dr. Dade Moeller, Chairman
ACRS Subcommittee on Waste Management
Harvard University
Kresge Center for Environmental Health
Environmental Health Sciences
665 Huntington Avenue
Boston, Massachusetts 02115

Dear Dade:

As requested, following our recent visit to the University of Arizona and certain of its research facilities, I want to provide several comments. These are based on the discussions we had with the researchers as well as the pertinent briefings.

The closure techniques they have developed are being tested on a very small scale and with a limited number of variables. I'm concerned about scaling these up to practical size and to possible effects produced over time by radiation levels, elevated temperatures, etc.

In addition, they seem to be producing more or less ideal conditions in the way that plugs are emplaced and tested. This does not appear to simulate a repository environment.

These lead to major concerns in the sealing program and its application to a repository. Can we model large opening closures and sealings on a practical basis and effectively evaluate their performance? Also, can we develop a system which will allow testing of the repository or major portions of it before use?

In Nevada, I'm concerned about the movement of radionuclides in various media and the retardation coefficients. Besides mobility and transport of radionuclides, other factors which

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must be considered are the inventories, half lives, and relative hazards. These latter factors, in fact, are what reduce tritium to a non-problem in spite of its rapid mobilization and transport.

Hopefully these brief comments and questions will be useful to you.

Sincerely,

Melvin W.Carter
Consultant

MWC/bc
cc: Mr. Owen Merrill

STANFORD UNIVERSITY

DEPARTMENT OF GEOLOGY
School of Earth Sciences
Stanford, California 94305-2115

TELEPHONE: (415) 723-2537
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31 July 1987

Mr. Owen Merrill
Senior Staff Engineer
ACRS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Owen:

Here are some random thoughts about the presentations we heard during the past three days in Tucson and Las Vegas. If you think they would be of any interest to Dade, I hope you will send them along to him.

University of Arizona. Seems to me some good research is being done, and just for the sake of scientific knowledge I'm glad to see such work supported, but I wonder if all of it is relevant to NRC's problem of judging the licensability of DOE's disposal efforts. For example, Jaak Daemen gave a good presentation of his work on seals in repositories in granite and basalt, but a major worry seemed to be the effect of wetting and drying. Such repositories, as far as I know, will be well below the water table, so I wonder if this worry is relevant? Once a repository is closed, only in extraordinary circumstances would it ever dry out. Also I doubt that finding an exact relation between flow rate and pressure is important for an actual repository situation. Shlomo Neuman's talk was an impressive analysis of the difficulties of predicting flow thru fractured rocks and of his efforts to surmount the difficulties, but I was left with the feeling (as I have been after many other discussions of this forbidding subject) that I still didn't understand how his equations and experimental results would help much in judging a real-life repository. Much the same criticism can be leveled at the work of Dan Evans and his colleagues: they have developed methods for obtaining much useful scientific information, but are they asking the right questions to get information quickly and efficiently that will apply directly to licensing problems? One other objection I had to the presentations in Tucson was the repetition in the talks of materials that we had already seen in the pre-meeting handouts.

Talk by Carl Johnson of the Nevada Agency for Nuclear Projects. It is hard to comment objectively about this talk, because the speaker took a negative attitude toward every question regarding the Yucca Mountain site.-- which I expect he was required to do by his political position. At least it is encouraging that the State and DOE are looking at the same set of questions, and I expect it is salutary for DOE to be continually reminded of the possible negative answers.

DOE - USGS presentations in Las Vegas. These talks were well organized and well presented. Seems to me the right questions are being asked, the methods of attack are reasonable, and appropriate attention is being paid to estimates of uncertainty. There is some overkill in the planned research, but much less than at Tucson. The only talk that disappointed me was the one on radionuclide retardation by K. Eggert. We were shown tables of retardation factors, and told about plans for getting additional numbers, but we heard very little about how the numbers were obtained. Retardation factors have no meaning unless the conditions of the experiments are specified very precisely -- the nature of the solid material used, the pH and Eh and chemical composition of the solution, the assurance that steady-state conditions were reached, and so on. To me, one of the major unknowns about the unsaturated zone is the oxidation potential and acidity of solutions that move thru it, and I wish more had been said about how these will be

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determined. They are essential not only in limiting retardation, but also in limiting solubility of radionuclides and in influencing the formation of colloids. Very probably the people doing the research are aware of all this, but I wish Mr. Eggert had made it clear in his talk.

John Stuckless in his talk on hydrothermal activity made it pretty clear that there is little evidence for warm solutions or mineralization at the site. Much of his talk concerned the exposures in trenches across a fault that we saw at the end of our field trip, and from the very superficial examination we could make I would certainly agree with him that the calcite-opal mixtures look like the work of pretty cold water. As I remember it, the only evidence he cited for elevated temperatures was from work on fluid inclusions in quartz from the matrix of the Tiva breccia. Just to be on the safe side, I suggest that samples of this matrix be assayed for gold and silver; if the solutions from which the matrix formed were warm, traces of the metals might be present. If the metals are completely absent (as I expect they will be), this would help to confirm that the site lacks mineral resources of any consequence. Assaying is a simple and inexpensive procedure, so it might be well to include also samples of the calcite-opal material from the fault zone and any similar material from fault- or vein-fillings elsewhere at the site.

G-tunnel. Seems to me that Roger Zimmerman is getting valuable information about the behavior of welded tuff from his in-situ experiments. The heating experiments, however, give somewhat ambiguous results because they are done with short holes drilled into a rock face that is exposed to a well-ventilated tunnel. I would like to see an experiment on a larger scale, of this general sort: seal a section of the tunnel a few tens of meters long, or drive a branch tunnel that can be sealed; put heaters in the tunnel so that its temperature can be raised to the point expected in a repository; and equip the tunnel with instruments to see what happens to water in the adjacent rock. My guess is that water moving down thru the unsaturated zone toward a heated repository would never reach the repository, but would be deflected around it by multiple vaporization-and-condensation. G-tunnel would be a fine place to see if the guess is correct.

I hope this will be of some use. You arranged a fine trip for us to Tucson and Las Vegas, and I do thank you for taking care of all the details.

Sincerely,

Konnie

Konrad B. Krauskopf

DEPARTMENT OF CIVIL ENGINEERING AND OPERATIONS RESEARCH
SCHOOL OF ENGINEERING/APPLIED SCIENCE
PRINCETON UNIVERSITY PRINCETON, NEW JERSEY 08544

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(609) 452-4602

July 31, 1987

Dr. D. Moeller
Chairman, Subcommittee on Waste Management
U. S. Nuclear Regulatory Commission
Advisory Committee on Reactor Safeguards
Washington, D. C. 20555

Dear Dr. Moeller:

This letter report on our trip to Arizona is provided at the request of O. S. Merrill. It briefly summarizes my perceptions of the ongoing NRC research program at this location.

Mission, Goals and Objectives: Because of my brief exposure to the NRC program, I have virtually no perspective on the management structure, breadth or depth of the program. My comments are therefore limited to the specific objectives documented in our pre-trip documentation and the presentations.

Overall research planning direction and structure are extremely important. I strongly recommend that a subcommittee of the newly proposed NRC committee be charged with the responsibility of working with NRC in defining the most cost-effective and technologically rewarding research objectives possible. I believe it is essential that critical problem areas, that is those that must be solved for the mission of NRC to be realized (such as the determination of site permeability), be identified and that research be focused on these areas. Certainly the activities we reviewed addressed important questions, but I am concerned that outstanding critical problems remain that require additional consideration. An interdisciplinary, highly competent oversight committee would be able to examine the overall research activity and provide guidance regarding not only areas of importance but also activities that may be either redundant or unlikely to contribute substantially to the Commission's goals.

Quality and Relevance of Research: Given my brief exposure to the Arizona activities, I believe they by and large constitute careful and relevant research. While one can criticize in retrospect some details of the various programs, they appear to be on a par with ongoing activities elsewhere in the United States and abroad. I am, however, concerned that certain high-risk,

high-return research activities, such as those associated with the now inactive field site, may have been prematurely terminated. I believe that carefully designed field programs of this kind are needed, and should be supported.

Quality of Principal Investigators: Of the principal investigators we met, I know only Dr. Neuman by scholarly reputation. He is unquestionably an outstanding researcher in the field of groundwater hydrology. His published papers document carefully executed and insightful research. I believe the NRC if fortunate to have him as a contractor.

Quality of Facilities: Regrettably, we were unable to visit the inside laboratories, but the unsaturated flow experiment was interesting. I think this is a unique facility and I believe that with careful planning and support, additional useful and important information could be obtained. It is evident that some of the results from both field studies were perhaps unanticipated, for example, the heterogeneity of the fractures in the tuff, and revealed new areas of concern for the waste repository program.

I hope these comments are helpful. I have enjoyed my participation on the subcommittee and regret I cannot devote the time needed to continue as a member.

Sincerely yours,

George F. Pinder
Professor and Chairman

GFP:dh

UNIVERSITY OF SOUTHERN CALIFORNIA

UNIVERSITY PARK • LOS ANGELES, CALIFORNIA 90089-0242

SCHOOL OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

July 20, 1987

Mr. Owen Merrill
Senior Staff Engineer
ACRS
USNRC
Washington, D.C. 20555

Dear Mr. Merrill:

On July 16, 1987, I met with the members of the NRC staff, in Silver Spring, to hear their presentation on the Yucca Mountain site and to ask questions. They were very helpful. They supplied all the important references I requested and outlined for me what they know so far about the site. During our discussion it became clear that they lack much the same technical information which I was hoping to get from them and that it is the material which is presented to them that does not have sufficient detail for further evaluation and verification. In this respect it is clear that there should be more formal communication between the NRC staff and their technical counterpart.

The NRC staff presented to me their current understanding of the proposed techtonic models for the Yucca Mountain site: right lateral slip faulting not expressed on the surface, bending of the top plate, and the variations of the extension model. We also discussed the local seismicity and how the design levels for vibratory ground motion are developed.

Again, as I indicated in my previous letter to you, I find that the NRC staff questions do appear to cover the right topics, but it is also clear that we do not have the adequate and more specific coverage of the technical material to evaluate the calculations and conclusions in the reports on this site.

Yours sincerely,

M. D. Trifunac

M. D. Trifunac

MDT:jch

REVISED: 7/28/87 P.M.

ACRS ITINERARY

JULY 29-30, 1987

VISIT TO LAS VEGAS & NEVADA TEST SITE

JULY 29

8:15 a.m.	Meet at front door of Alexis Park Hotel. Transport via DOE vans to SAIC offices.
8:30 a.m.	Arrive at SAIC offices at Valley Bank Building on Convention Center Drive. Meet in Room 450. MAY Blanchard
8:45 a.m.	Presentation by Paul Prestholt, NRC On-Site Readiness Reviews Representative.
9:30 a.m.	Presentation by Carl Johnson, State of Nevada.
11:00 a.m.	Film on Big Hole Drilling
11:30 a.m.	Break for Lunch. ← Don Vieth
1:00 p.m.	DOE/NNWSI Presentation.
5:00 p.m.	Adjourn. Transport via DOE vans to Alexis Park Hotel.

JULY 30

6:45 a.m.	Meet at front door of Alexis Park Hotel. Depart for Mercury, NTS via DOE vans.
8:15 a.m.	Arrive at Mercury Badge Office for badging.
8:45 a.m.	Depart for Area 1 Drill Yard.
9:30 a.m.	Arrive at Area 1 Drill Yard. Walk-through briefing by Patrick Rowe, Reynolds Electrical & Engineering Company (REECO).
10:00 a.m.	Depart for G-Tunnel.
10:30 a.m.	Arrive at G-Tunnel. Briefing by Roger Zimmerman, Sandia National Laboratory (SNL).
11:45 a.m.	Depart for Area 12 Cafeteria.
12:00 noon	Arrive at Area 12 Cafeteria for Lunch (No Host).

12:45 p.m.	Depart for Spent Fuel Test-Climax (SFT-C).
1:15 p.m.	Arrive SFT-C. Underground briefing by Mitch Kunich, DOE, WMPO.
2:00 p.m.	Depart for Sedan Crater.
2:10 p.m.	Arrive at Sedan Crater. View crater.
2:20 p.m.	Depart for Yucca Mountain.
3:45 p.m.	Arrive at top of Yucca Mountain. Yucca Mountain Geology/Hydrology briefing by Bill Dudley of the U.S. Geological Survey.
6:45 p.m.	Depart Yucca Mountain for Mercury.
7:45 p.m.	Arrive at Mercury Steak House. Reserved table (No Host). Mercury Cafeteria.
8:45 p.m.	Depart Mercury for Las Vegas.
10:15 p.m.	Arrive at Alexis Park Hotel, Las Vegas.

PAUL T. PRESTHOLT
SENIOR ON-SITE LICENSING REP.
JULY 28, 1987

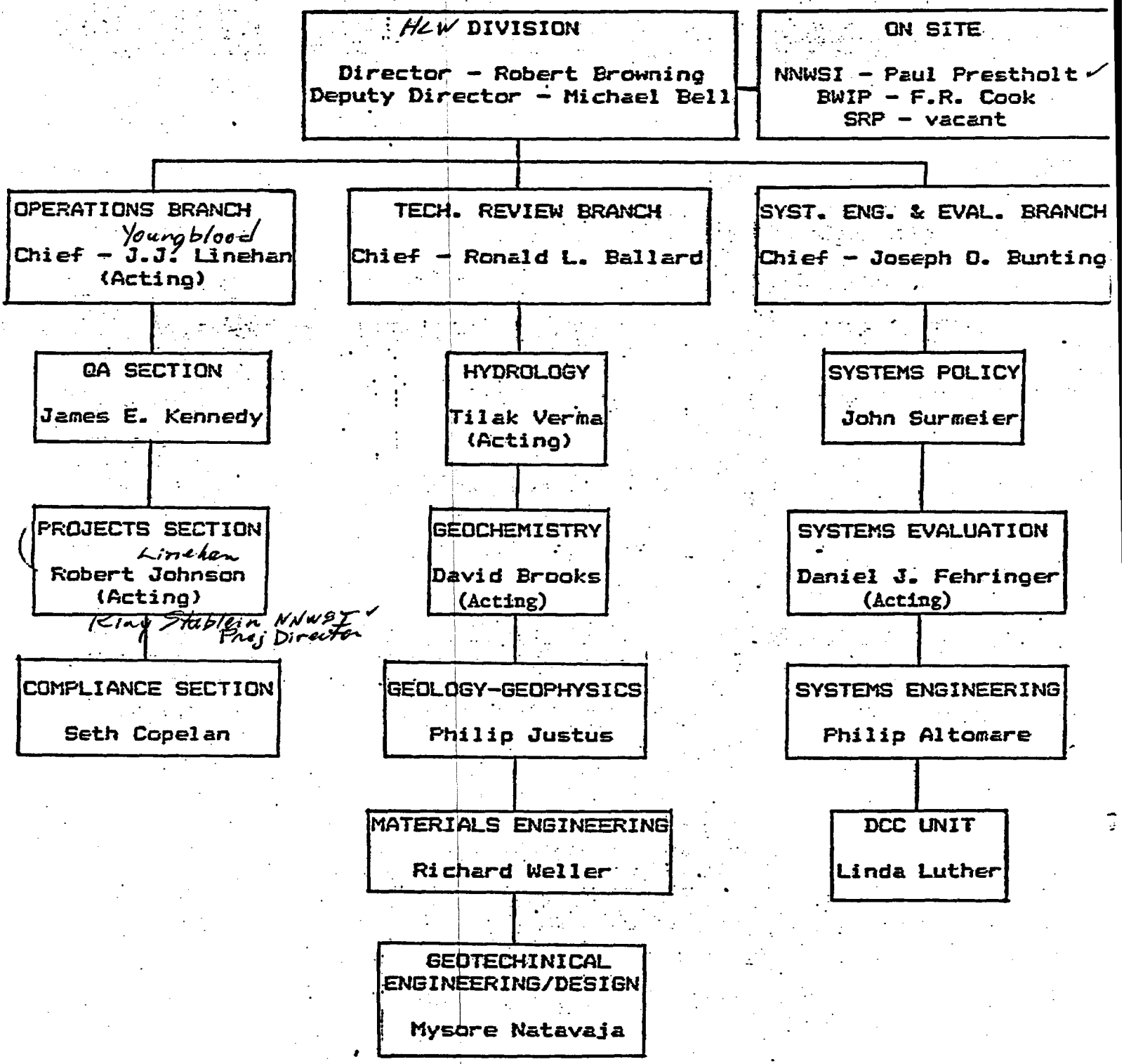
ATTACHMENT 3

FUNCTIONAL STATEMENT

As the Director of the Division of High-Level Waste Management's representative, serves at one of the selected candidate high-level waste repository sites as the principal NRC liaison with DOE staff and other parties involved with the onsite repository project in order to facilitate an effective pre-licensing interface with NRC.

DIVISION OF WASTE MANAGEMENT

✓ = Principal Points of Contact for P²



REGULAR DUTIES

- Represents the Director of the Division of High-Level Waste Management at the site for all high-level waste repository site activities relating to the most difficult projects for the potential disposal of large quantities of highly radioactive waste at the site.

- Proposes research programs, studies, safety reviews, and environmental impact assessments related to the future high-level waste repository licensing review.

- Acts as on-site liaison between the NRC and DOE Project Manager related to the HLW repository licensing review.

- Assists in the development of regulatory waste management policies, recommending improvements in procedures designed to accelerate the licensing process.

- Develops and participates in liaison mechanisms with other agencies in waste management activities, including EPA, DOE, state and local government specifically to maintain cognizance of on-going research and to assure the adequacy and appropriateness of program direction.

REGULAR DUTIES
(Continued)

- Maintains awareness and proficiency in current and developing techniques and theories of systems analysis by frequent contact with researchers in the field through site visits and professional meetings.

- Arranges meetings with senior DOE Field Office (FO) executives to discuss areas of mutual interest that may need clarification by the Division Director HLWM.

- Recommends to the Division Director HLWM improvements to NRC/DOE interaction relating to site characterization.

- Provides quality assurance (QA) reviews, as deemed necessary, in all areas of the DOE site characterization program to understand DOE's on going QA program and provide comments and recommendations to the Director HLWM as appropriate.

- Expedites the flow of facts, information and plans regarding site characterization activities between DOE's Field Office and/or contractors and the Division of High-Level Waste Management.

REGULAR DUTIES
(Continued)

- As the representative Judges to be appropriate or at the specific request of the Director, observes, reviews and evaluates onsite actions undertaken or sponsored by the DOE related to site characterization.

- Arranges and/or coordinates site visits by NRC technical staff.

- Prepares policy analysis papers and technical reports pertaining to the waste management program for use by the Division Director in developing waste management policy. As the representative Judges to be appropriate or at the specific request of the Director, reviews documents related to the characterization of the candidate repository site, including environmental assessments and site characterization plans.

- Makes specific recommendations concerning site characterization plans and activities to Division Director and/or NRC technical and project management staff.

- Develops recommendations for the Division Director concerning NRC policy and technical positions on repository licensing issues.

- Identifies and communicates pertinent information/data related to site characterization to responsible NRC technical and project management staff.

- Provides supervision for one onsite licensing staff and a part time clerical assistant.

CONTACTS

- As the Director of HLWM's representative, continuous contact with Director, Deputy Director, Branch Chiefs, and technical staff within HLWM and senior staff within the Commission.

- Continuous contact with senior DOE Field Office (FO) executives and other federal government agency representatives relating to site characterization activities.

- Frequent contact with senior State and local Government officials, and representatives of "affected Indian tribes" in coordinating the exchange of technical and policy information regarding the candidate repository site as required under NWPA (Section 117) and 10CFR60 Subpart C.

- Frequent contact with DOE and DOE contractor technical and administrative personnel to keep abreast of developments in the plans and activities involving the candidate HLW repository site.

- Occasional contact with Office Director NMSS relating to onsite licensing activities.

INDEPENDENT ACTION

- Manages and directs the efforts of the onsite licensing representatives office.

- Independently assesses effectiveness of DOE's on-site activities and based on his judgments, brings issues or potential issues which may affect NRC's licensing actions to the attention of the NRC Division Director and appropriate NRC Branch Chief.

- Independently assesses the effectiveness of NRC regulations and guidance on DOE's site characterization activities and, based on his judgment, brings issues or potential issues involving NRC regulatory actions and guidance to the NRC Division Director and appropriate NRC Branch Chief.

- Represents Division Director in meetings with DOE, State or Tribal officials relating to site project activities. Based on knowledge of Division technical, and regulatory policy positions, uses judgment to articulate NRC positions and provide clarification.

- Explores need for and establishes working liaison with multiple Federal agencies and acts as a liaison with other agencies involved in waste management activities including EPA, DOE, state and local government, especially as they deal with the Federal repository.

PRESENTATION

TO

U. S. NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

BY

CARL JOHNSON

NEVADA AGENCY FOR NUCLEAR PROJECTS

JULY 29, 1987

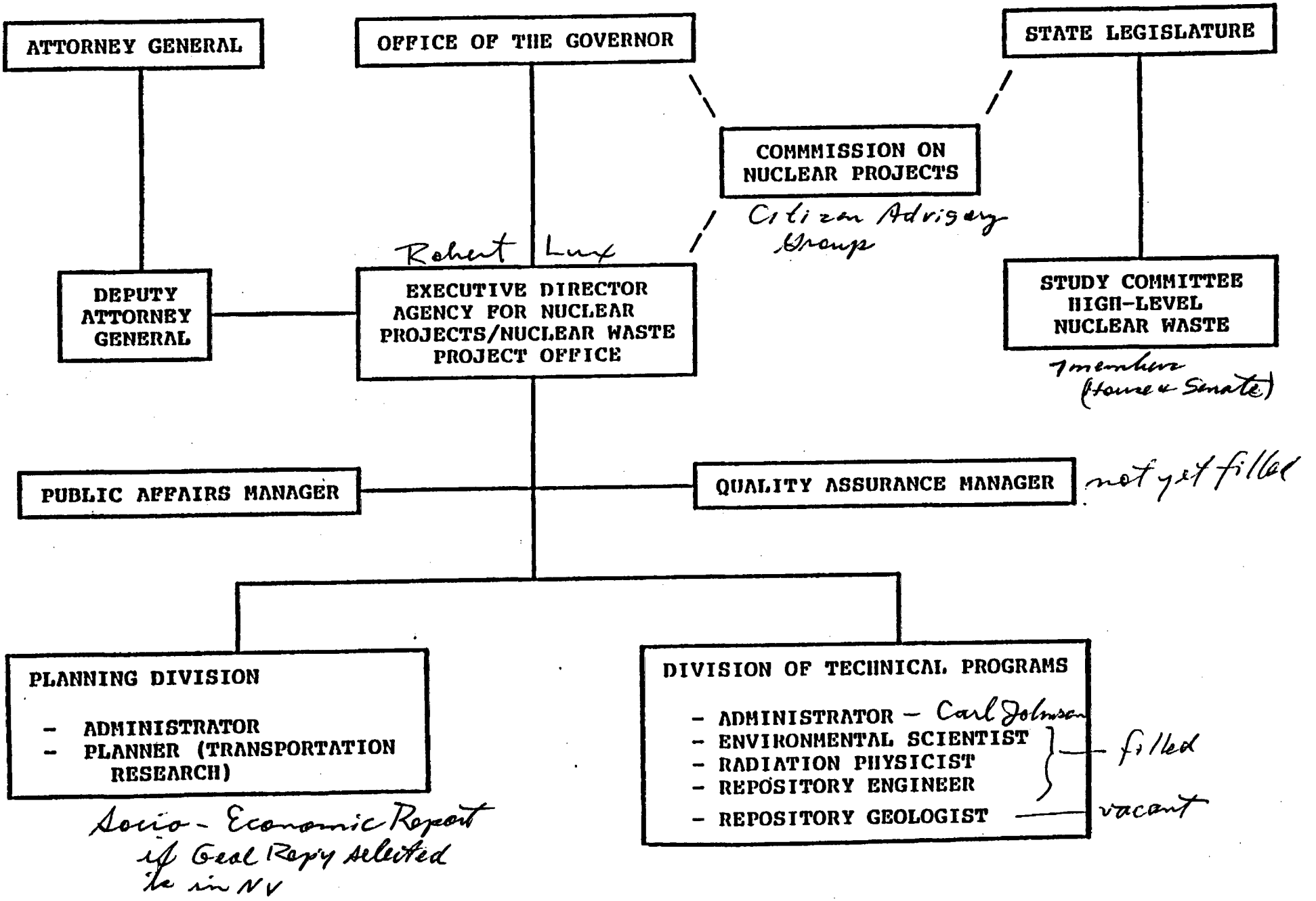
ATTACHMENT 4

AGENDA

- STATE ORGANIZATION
- STATE TECHNICAL CONCERNS
- STATE TECHNICAL PROGRAMS

STATE OF NEVADA AGENCY FOR NUCLEAR PROJECTS

ORGANIZATIONAL CHART



NUCLEAR WASTE PROJECT OFFICE
TECHNICAL PROGRAMS

Independently Appointed Experts

CARL A. JOHNSON
ADMINISTRATOR

TECHNICAL
ADVISORY GROUP

Range
$150K to 1.5M/yr
(yr to yr basis)

STAFF

JAMES GRUBB M.S.
REPOSITORY ENGINEER

5-20 yr experience each

CHARLES MALONE PhD
ENVIRONMENTAL SCIENTIST

PETER SPIEGLER PhD
RADIATION PHYSICIST

?
REPOSITORY
GEOLOGIST/HYDROLOGIST

CONTRACTORS

DESERT RESEARCH INSTITUTE
HYDROLOGY

CENTER FOR NEOTECTONIC STUDIES
UNIVERSITY OF NEVADA RENO
GEOLOGY
SEISMOLOGY

MIFFLIN & ASSOCIATES
PALEOCLIMATE
GEOCHEMISTRY

DEPARTMENT OF GEOSCIENCE
UNIVERSITY OF NEVADA-LAS VEGAS
VOLCANISM

SARGENT & LUNDY ENGINEERS
QUALITY ASSURANCE
To develop a QA Pgm for this office & Contractors

STATE PROGRAM GOALS

- TO INSURE THAT PUBLIC HEALTH AND SAFETY AND THE ENVIRONMENT ARE ADEQUATELY PROTECTED THROUGH ALL PHASES OF REPOSITORY SITING, CONSTRUCTION, OPERATIONS, CLOSURE, AND DECOMMISSIONING.
- TO ASSESS SOCIAL AND ECONOMIC IMPACTS THAT THE STATE OF NEVADA COULD EXPERIENCE AS A RESULT OF REPOSITORY SITING AND DEVELOPMENT WITH APPROPRIATE MITIGATION STRATEGY.
- TO PROVIDE FOR LOCAL GOVERNMENT COORDINATION AND FOR PUBLIC PARTICIPATION IN THE PROJECT.
- TO PROVIDE FOR EFFECTIVE POLICY GUIDANCE TO THE GOVERNOR AND OTHER STATE LEADERS.
- TO PROVIDE FOR SOUND AND EFFICIENT ADMINISTRATION AND MANAGEMENT OF THE STATE EVALUATION PROGRAM.

Agency started in 1983 following passage of NWPA

This Office (HLW) has no responsibility for Beatty LLW Rpsty.

Bullfrog Co. 12 mi sq. ~~to~~ to be created to ~~have~~ include YMtn Site only – no people – ∴ $ from DOE to B/F Co. will go to state & then be ~~equa~~ distributed to all other counties. Gov. has not yet appointed 3 commissioners to adm. the Co. Co seat presently

HEALTH AND SAFETY OBJECTIVES

- DETERMINE TECHNICAL ISSUES CRITICAL TO THE HEALTH AND SAFETY OF NEVADANS AND THEIR ENVIRONMENT.

- REVIEW RELEVANT U.S. DEPARTMENT OF ENERGY (DOE) PROGRAM PLANS, TECHNICAL STUDIES, AND OTHER DOCUMENTS TO ASSURE INTEGRATION OF NEVADA CONCERNS, ONGOING AWARENESS OF FEDERAL ACTIVITIES, INPUT INTO PROGRAM DESIGNS AND COORDINATION OF THE SCHEDULE OF ACTIVITIES.

- PROVIDE FOR STATE INITIATED, INDEPENDENT STUDY OF TECHNICAL ISSUES THAT HAVE BEEN IDENTIFIED AS CRITICAL AND THAT (A) ARE NOT BEING ADDRESSED BY D.O.E. AND THEIR CONTRACTORS, OR (B) THAT THE METHODS OR RESULTS USED BY THE D.O.E. AND THEIR CONTRACTORS ARE IN QUESTION BY THE STATE OF NEVADA, OR (C) THE AREAS OF STUDY ARE SO CRITICAL THAT DUPLICATIVE STUDIES ARE WARRANTED.

- PROVIDE ON-SITE MONITORING OF ALL FEDERAL TECHNICAL FIELD AND LABORATORY ACTIVITIES WITH REGARD TO SITE SCREENING AND CHARACTERIZATION IN ORDER TO MAKE COMMENTS AND RECOMMENDATIONS AND TO UNDERSTAND HOW THESE TECHNIQUES AND METHODS AFFECT THE OVERALL STUDY.

ISSUES CRITICAL TO

HEALTH, SAFETY AND THE ENVIRONMENT

SITE SUITABILITY ISSUES

□ 1) CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH THE UNSATURATED ZONE.

2) RELATIONSHIP OF YUCCA MOUNTAIN GROUNDWATER REGIME TO THE REGIONAL AQUIFER SYSTEM. future L.V. water supply source.

3) EFFECT OF FUTURE CLIMATIC VARIATIONS AND RESULTING CHANGES IN THE HYDROGEOLOGIC REGIME ON THE INTEGRITY OF THE SITE. → unsatuat. will site eventually become saturated.

✓ 4) EFFECTS OF FUTURE FAULTING OR OTHER TECTONIC EVENTS ON THE INTEGRITY OF THE SITE.

✓ 5) EFFECTS OF FUTURE VOLCANISM ON THE INTEGRITY OF THE SITE.

✓ 6) HUMAN INTERFERENCE OF SITE DUE TO PERCEIVED PRESENCE OF EXTRACTABLE NATURAL RESOURCES.

St of NV Feels that fatal flaws in some of the above (may) (would) disqualify the proposed site. [v 4,5+6 above]

□ - #1 has some potential of disqualifying

vertical emplacement mode preferable to horizontal " " ; less chance for canister rupture/damage.

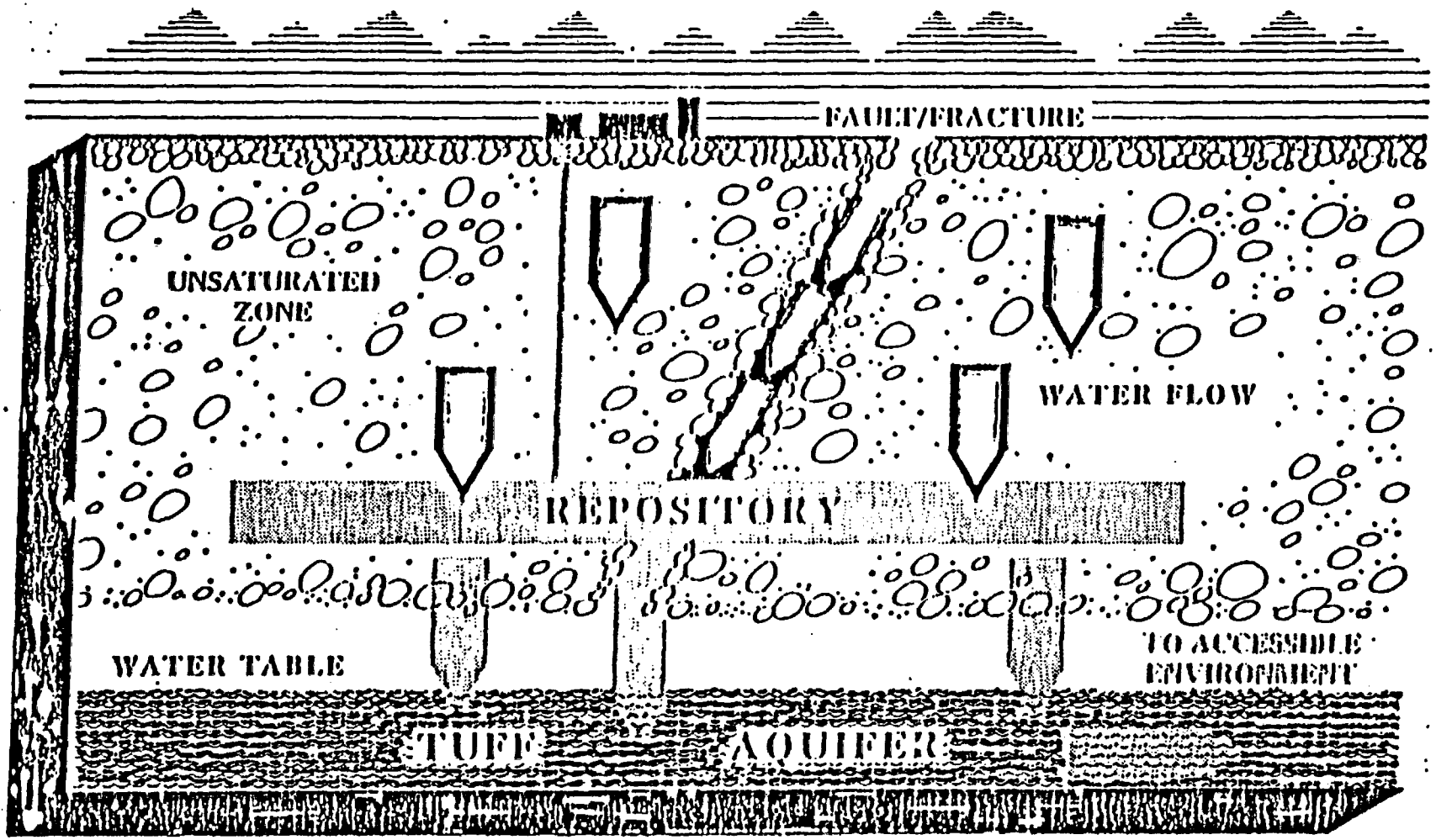
MOISTURE MOVEMENT THRU UNSATURATED ZONE

EVIDENCE

- TUFF ROCKS HIGHLY FRACTURED
- ROCK MATRIX PERMEABILITY LOW
- ROCK MATRIX SATURATION 40 PERCENT TO 90 PERCENT
- RAINER MESA DATA SUGGESTS LARGE COMPONENT OF FRACTURE FLOW
- PERCHED WATER DATA IN DRILL-HOLE WASH MAY SUGGEST FRACTURE FLOW
- MANY IN-SITU HYDROLOGIC PARAMETER VALUES UNKNOWN
- CONTRIBUTION OF MATRIX FLOW VS. FRACTURE FLOW CRITICAL TO CALCULATION OF GROUND WATER TRAVEL TIMES
- PRESENT STATE-OF-THE-ART HYDROLOGIC CODES DO NOT REALISTICALLY MODEL SITE UNSATURATED ZONE

CONCLUSION

- SITE UNSATURATED ZONE HYDROGEOLOGIC CONDITIONS COMPLEX
- USING CONSERVATIVE DATA, SITE DOES NOT MEET GROUND WATER TRAVEL TIME REQUIREMENTS


FAULT/FRACTURE
UNSATURATED ZONE
WATER FLOW
REPOSITORY
WATER TABLE
TO ACCESSIBLE ENVIRONMENT
TUFF AQUIFER

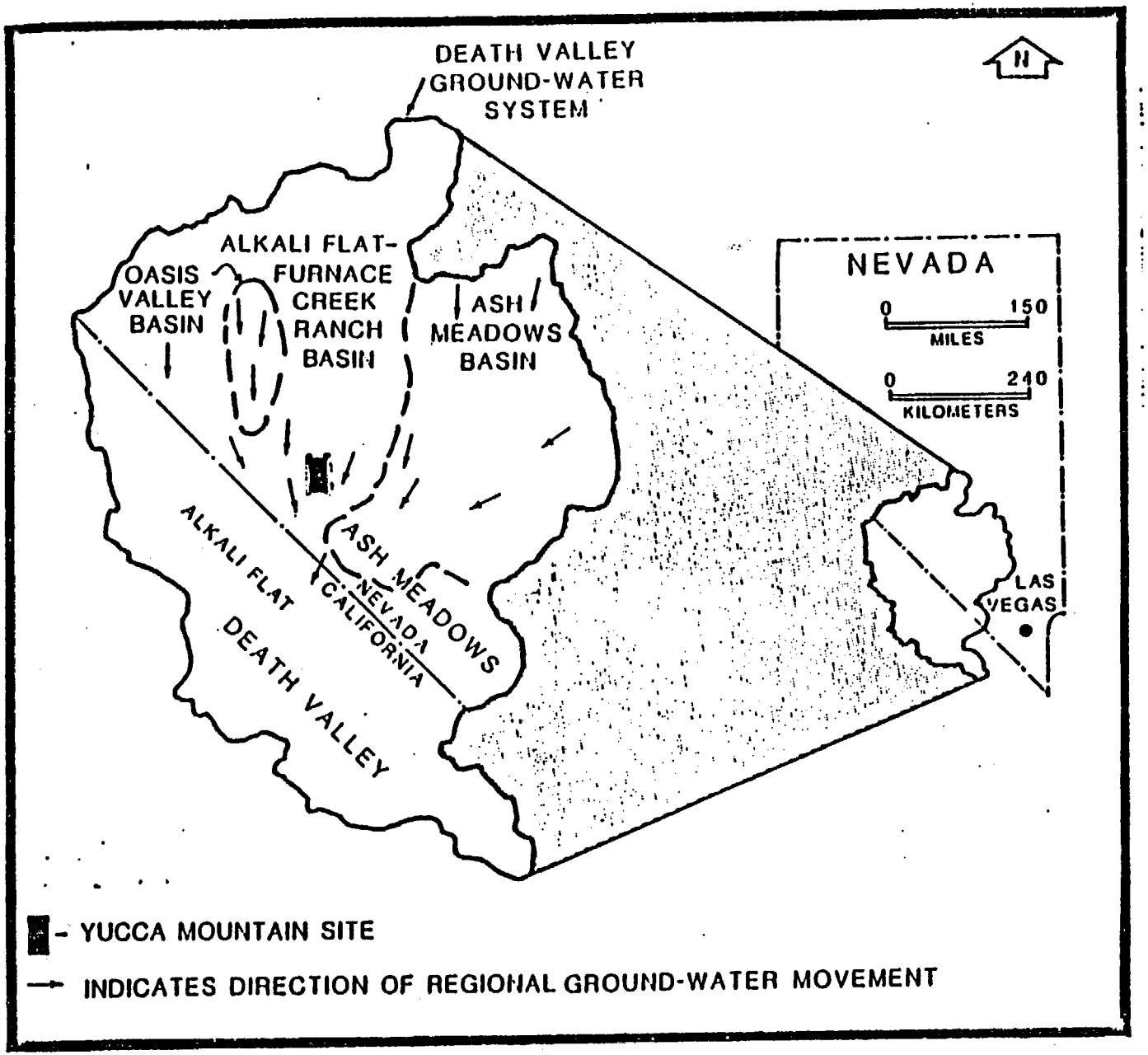
MOVEMENT THRU SATURATED ZONE

EVIDENCE

- TUFF-ALLUVIAL AQUIFER BENEATH SITE AND AMARGOSA VALLEY
- WATER TABLE GRADIENT NEARLY FLAT BENEATH SITE, BUT SUBSTANTIALLY HIGHER NORTH AND WEST OF SITE
- TUFF-ALLUVIAL AQUIFER FLOW RATES OF 300 METERS/DAY
- REGIONAL CARBONATE AQUIFER DEEP BENEATH SITE
- CONTINUITY BETWEEN TUFF-ALLUVIAL AQUIFER AND REGIONAL CARBONATE AQUIFER UNKNOWN

CONCLUSION

- TUFF-ALLUVIAL AQUIFER MAY NOT SATISFY GROUND WATER TRAVEL TIME REQUIREMENTS
- POTENTIAL FOR CONTAMINATION OF CARBONATE AQUIFER, A POSSIBLE FUTURE WATER SUPPLY SOURCE


DEATH VALLEY
GROUND-WATER
SYSTEM
N
NEVADA
0
150
MILES
0
240
KILOMETERS
OASIS
VALLEY
BASIN
ALKALI FLAT-
FURNACE
CREEK
RANCH
BASIN
ASH
MEADOWS
BASIN
ALKALI FLAT
DEATH VALLEY
ASH MEADOWS
NEVADA
CALIFORNIA
LAS
VEGAS
- YUCCA MOUNTAIN SITE
INDICATES DIRECTION OF REGIONAL GROUND-WATER MOVEMENT

FUTURE CLIMATE CHANGES

EVIDENCE

- PAST CLIMATE COOLER AND WETTER THAN PRESENT
- DRILL HOLE AND REGIONAL MAPPING DATA SUGGESTS SUBSTANTIALLY HIGHER WATER TABLES IN PAST
- DRILL HOLE DATA SUGGESTS NUMEROUS PERCHED WATER ZONES IN PAST
- MAPPING SUGGESTS PAST SPRING DISCHARGE OCCURRENCES AT SITE

CONCLUSION

- POTENTIAL FOR INCREASED RECHARGE AND SIGNIFICANT RISE IN WATER TABLE IF AREA RETURNS TO PLUVIAL CLIMATIC CONDITIONS IN FUTURE

ACTIVE FAULTING AND TECTONICS

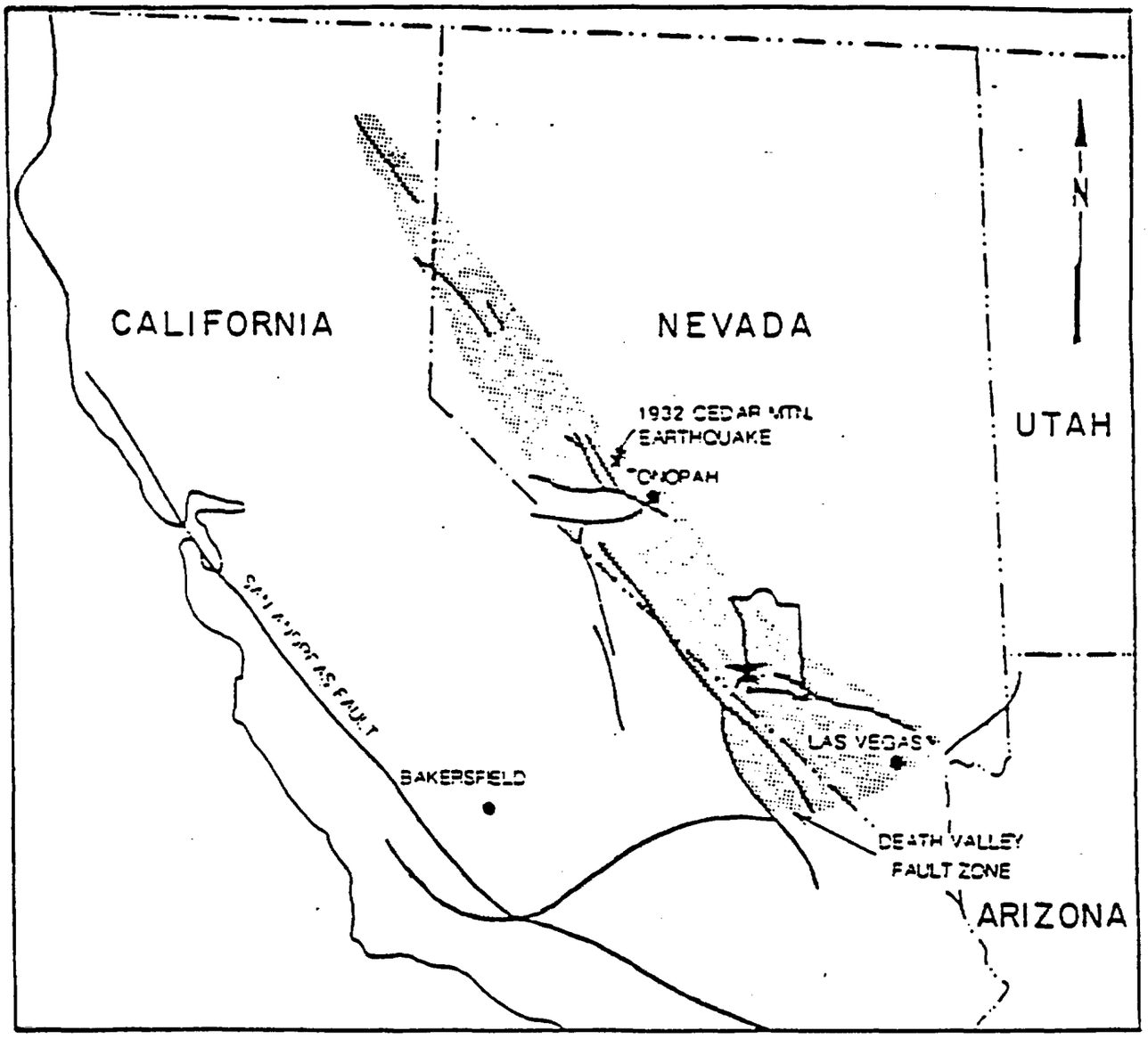
EVIDENCE

- SITE WITHIN WALKER-LANE STRUCTURAL ZONE
- REGION OF HIGH SEISMIC ACTIVITY
- STRESS DATA SUGGEST FAULTS NEAR FAILURE
- FAULTS PREDOMINANTLY STRIKE-SLIP MOTION
- FAULT MOVEMENT AS YOUNG AS 3,000 YEARS AGO
- MAGNITUDE 6.5 - 7.3 EARTHQUAKE POSSIBLE AT SITE
- 1.1 M OF DISPLACEMENT POSSIBLE
- PEAK GROUND ACCELERATION EXCEEDING 1.0 G POSSIBLE AT SITE
- NUCLEAR TESTING COULD PRODUCE SIGNIFICANT VIBRATORY GROUND MOTION AT SITE

CONCLUSION

- FAULTS AT SITE CONSIDERED ACTIVE
- REPOSITORY COULD EXPERIENCE LARGE EARTHQUAKE, WITH SIGNIFICANT GROUND DISPLACEMENT AND HIGH GROUND ACCELERATION

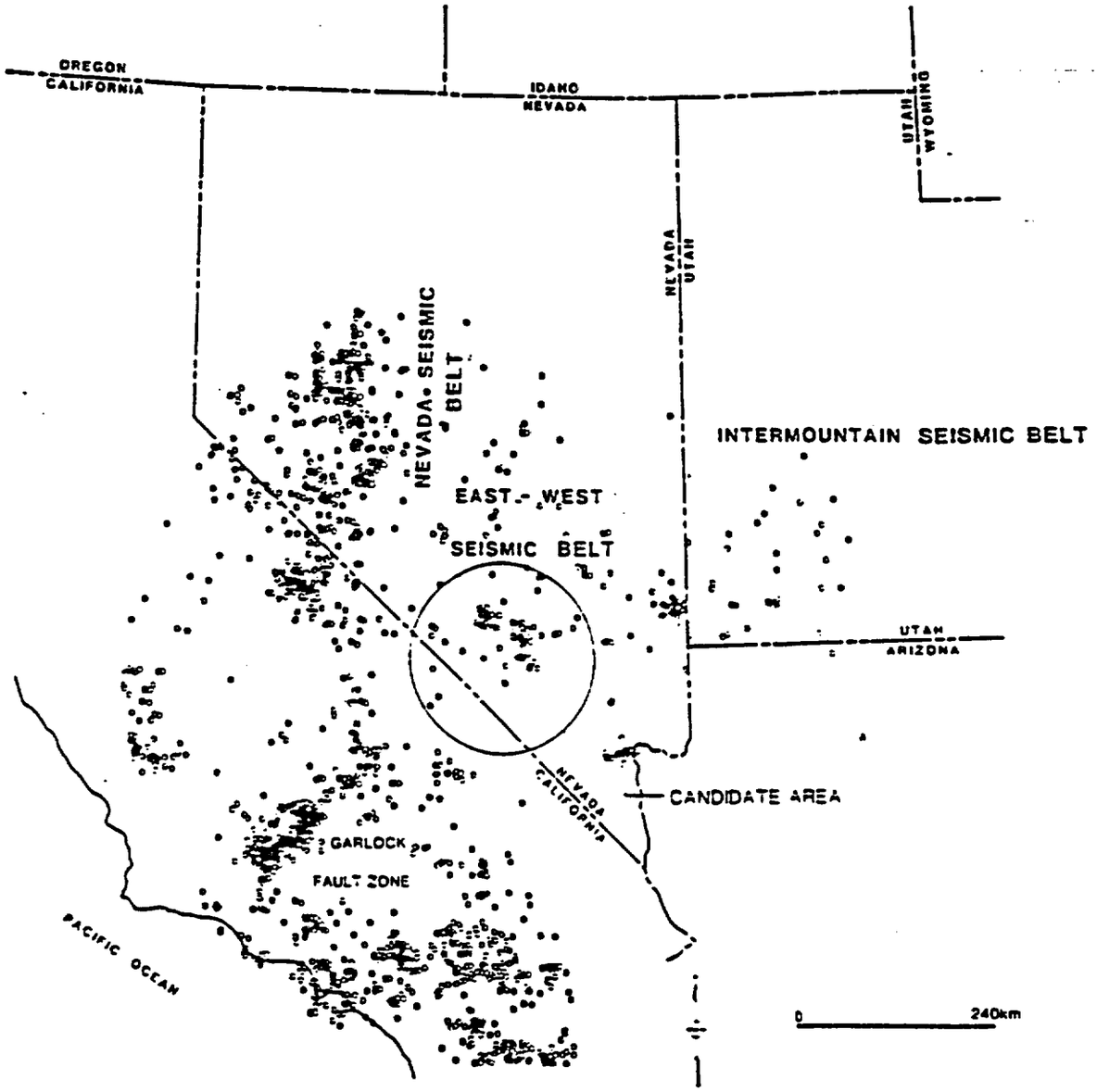
WALKER LANE STRUCTURAL ZONE



WALKER LANE ZONE

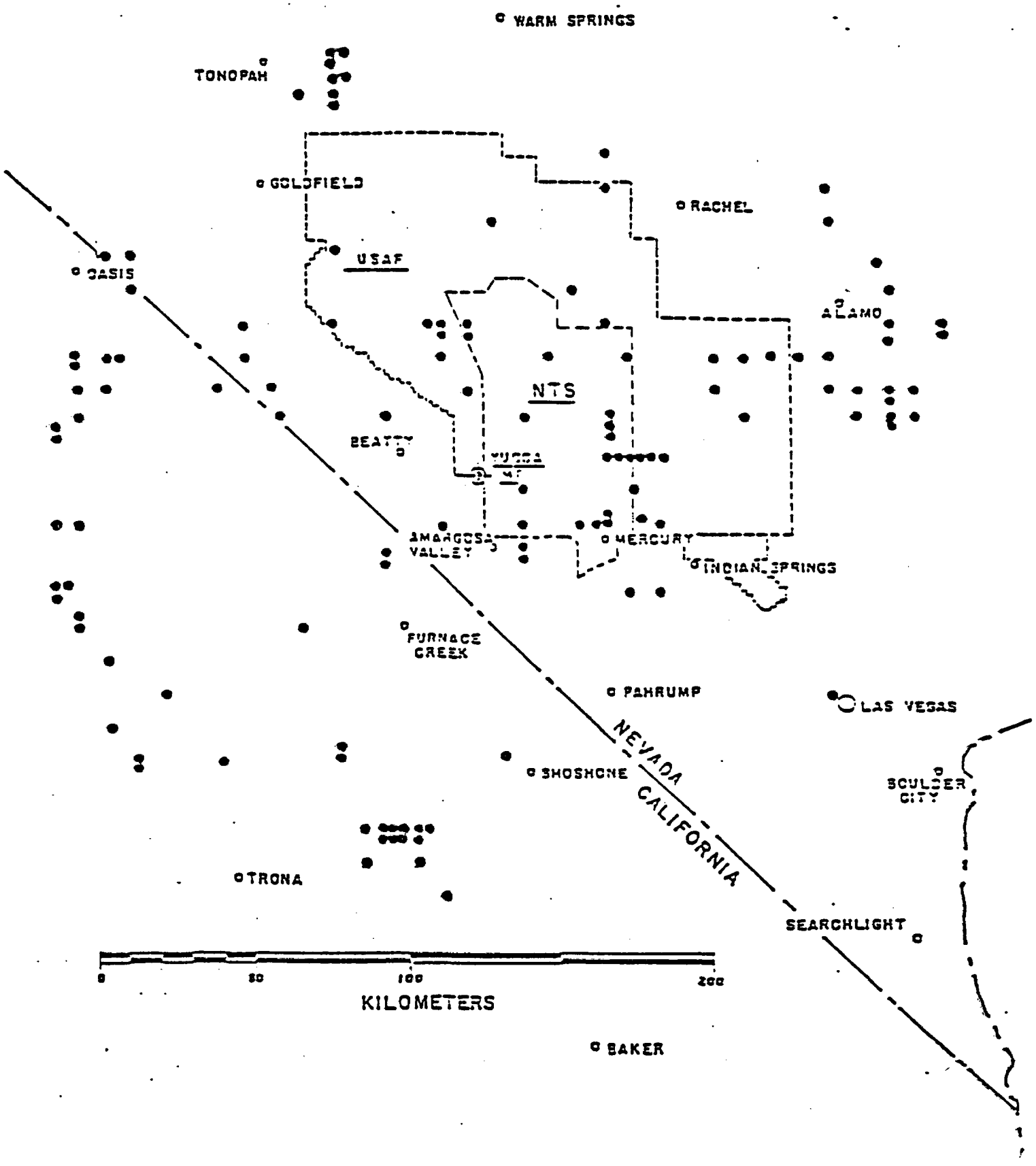
0 100 200 300 KILOMETERS

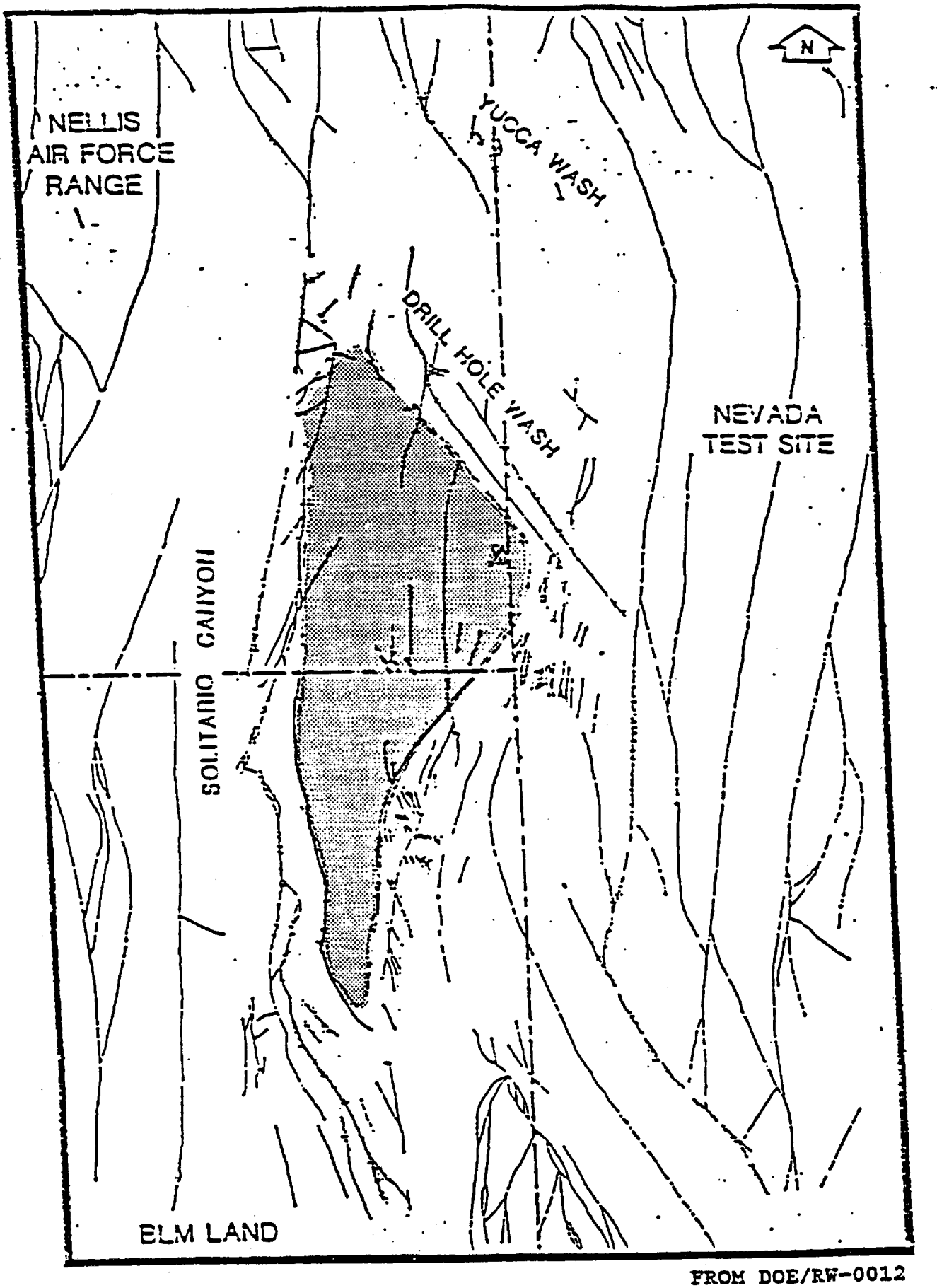
★ YUCCA MOUNTAIN AREA



HISTORIC EARTHQUAKES OF MERCALLI INTENSITY ≥ V OR MAGNITUDE ≥ 4.0
WITHIN 400 KM OF THE CANDIDATE AREA THROUGH 1974

EARTHQUAKE EPICENTERS WITHIN 150 KM OF YUCCA MT.





FROM DOE/RW-0012

YUCCA MOUNTAIN
AREA FAULTS

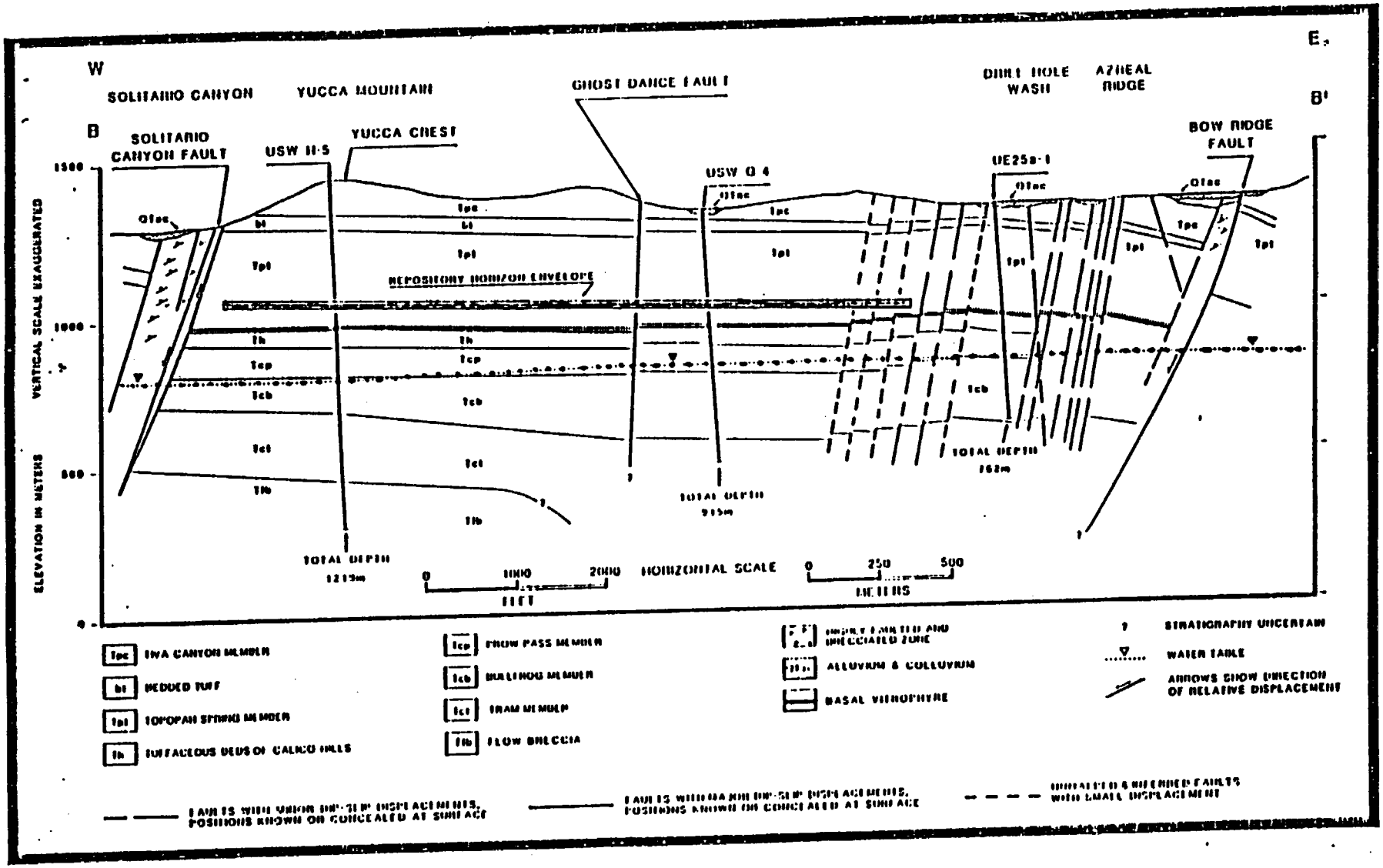
0 10,000
FEET

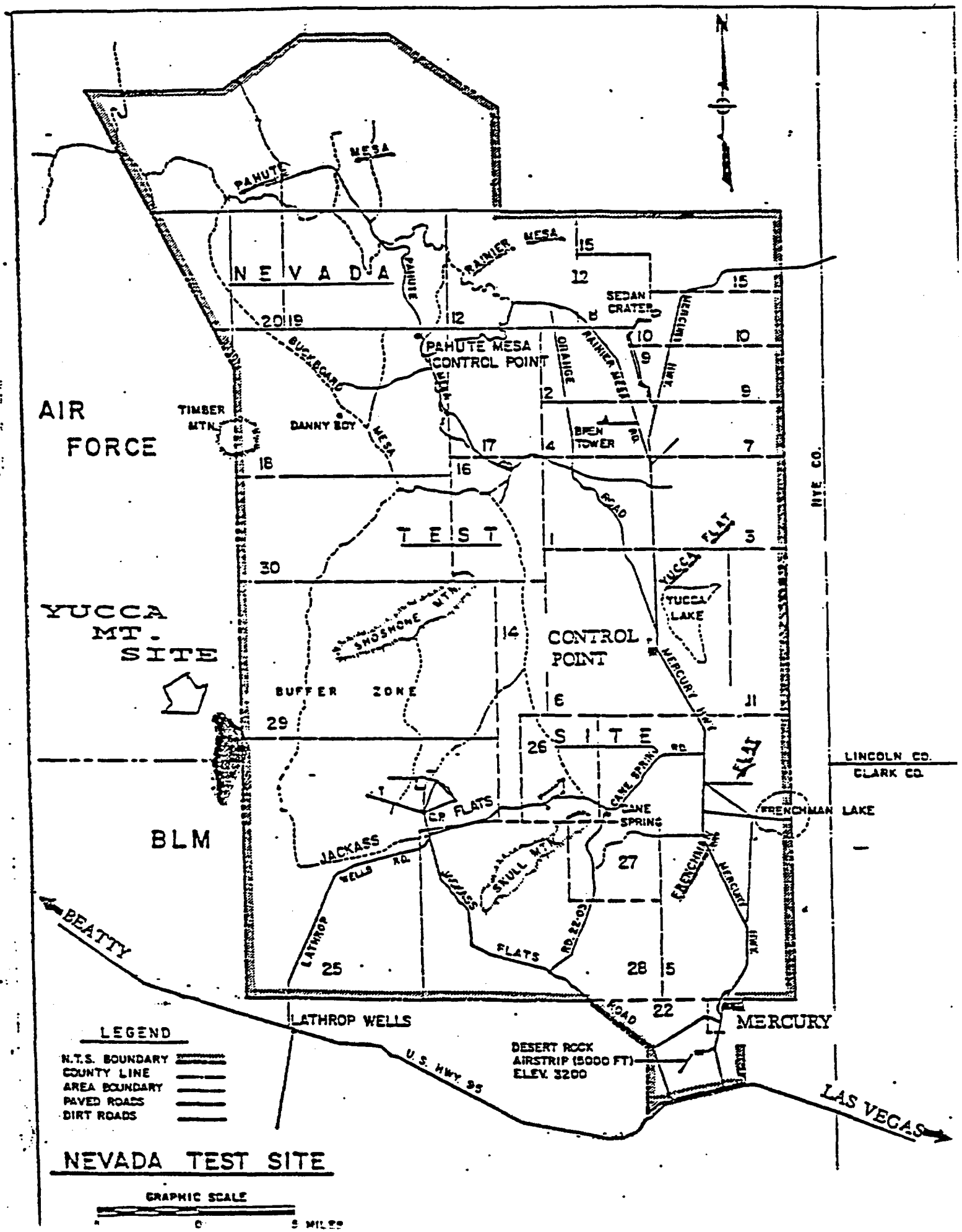
0 2,000
METERS

PRIMARY REPOSITORY AREA

SURFACE LOCATION OF FAULTS

BLM - BUREAU OF LAND MANAGEMENT


W
E
B
B'
SOLITARIO CANYON
YUCCA MOUNTAIN
GHOST DANCE FAULT
DIRT HOLE WASH
AZHEAL RIDGE
SOLITARIO CANYON FAULT
USW H-5
YUCCA CREST
USW G-4
UE25a-1
BOW RIDGE FAULT
REPOSITORY HORIZON ENVELOPE
TOTAL DEPTH
HORIZONTAL SCALE
FEET
METERS
VERTICAL SCALE EXAGGERATED
ELEVATION IN METERS
INYO CANYON MEMBER
BEDDED TUFF
TOPOPAH SPRING MEMBER
TUFFACEOUS BEDS OF CALICO HILLS
PROW PASS MEMBER
BULLFROG MEMBER
TRAM MEMBER
FLOW BRECCIA
ALLUVIUM & COLLUVIUM
BASAL VITROPHYRE
STRATIGRAPHY UNCERTAIN
WATER TABLE
ARROWS SHOW DIRECTION OF RELATIVE DISPLACEMENT
FAULTS WITH MINOR DIP-SLIP DISPLACEMENTS, POSITIONS KNOWN OR CONCEALED AT SURFACE
FAULTS WITH MAJOR DIP-SLIP DISPLACEMENTS, POSITIONS KNOWN OR CONCEALED AT SURFACE


N
NEVADA
TEST
SITE
AIR
FORCE
YUCCA
MT.
SITE
BLM
PAHUTE MESA
CONTROL POINT
SEDAN
CRATER
TIMBER
MTN.
DANNY BOY
BUCKBOARD
MESA
PAHUTE
RAINIER
MESA
OILFIELD
RAINIER WEST
MERCURY
HWY.
BREN
TOWER
RD.
ROAD
YUCCA
FLAT
YUCCA
LAKE
SHOSHONE
MTN.
CONTROL
POINT
MERCURY HWY.
BUFFER
ZONE
NYE CO.
LINCOLN CO.
CLARK CO.
FRENCHMAN LAKE
CANE SPRING
CANE SPRING RD.
C.P. FLATS
JACKASS
WELLS RD.
SKULL MTN.
JACKASS
FLATS
RD. 22-02
FRENCHMAN
MERCURY
HWY.
LATHROP
WELLS
BEATTY
LATHROP WELLS
U.S. HWY. 95
DESERT ROCK
AIRSTRIP (5000 FT)
ELEV. 3200
MERCURY
LAS VEGAS
LEGEND
N.T.S. BOUNDARY
COUNTY LINE
AREA BOUNDARY
PAVED ROADS
DIRT ROADS
NEVADA TEST SITE
GRAPHIC SCALE
0
5 MILES

VOLCANISM

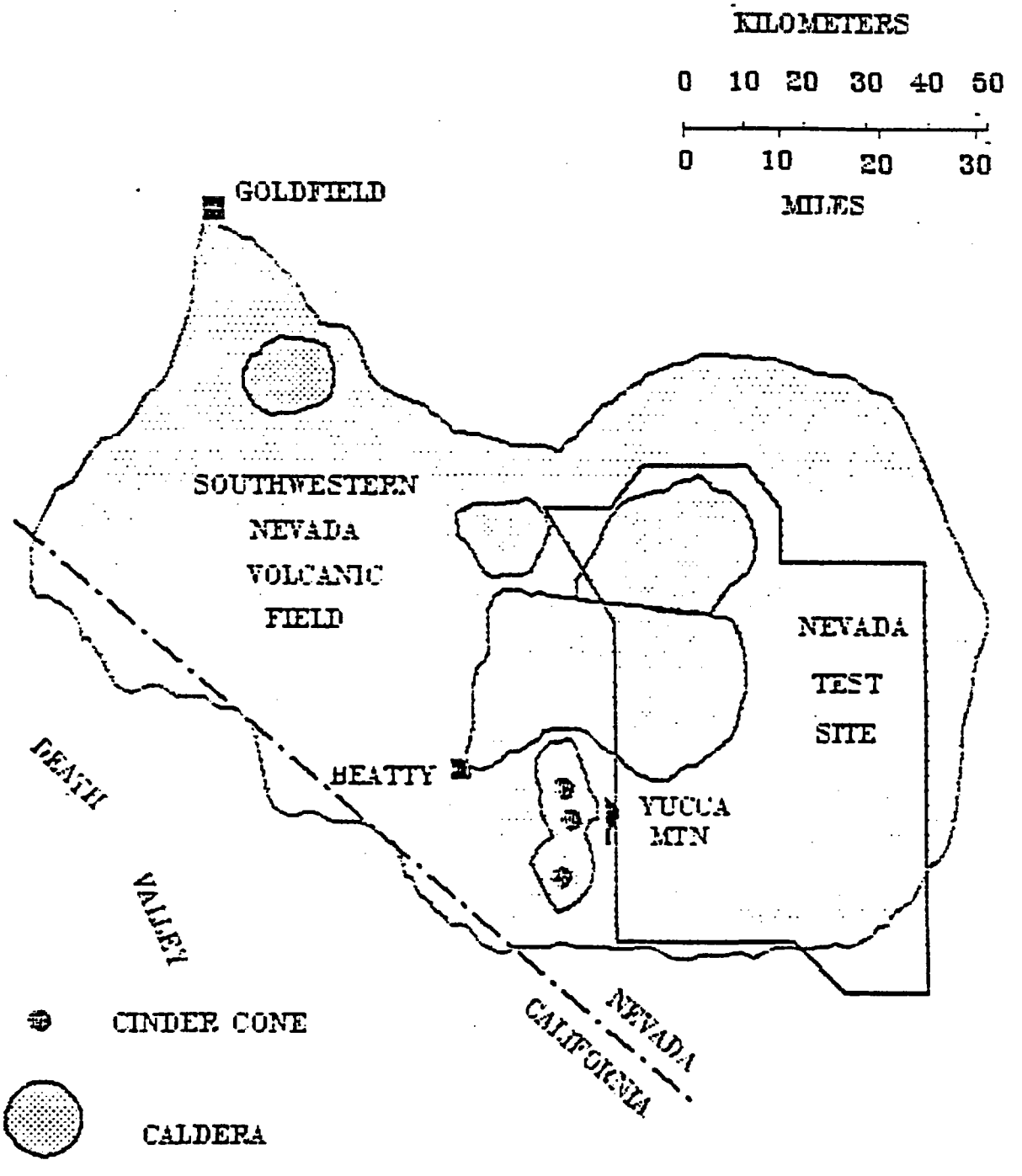
EVIDENCE

- SITE LOCATED WITHIN SOUTHWESTERN NEVADA VOLCANIC FIELD
- SITE LOCATED ALONG DEATH VALLEY-PANCAKE RANGE VOLCANIC BELT
- CENTERS OF BASALTIC VOLCANISM IN CRATER FLAT ADJACENT TO SITE
- YOUNGEST BASALTIC ERUPTION IN CRATER FLAT LESS THAN 20,000 YEARS AGO
- VEIN FILLINGS ENCOUNTERED IN DRILL HOLES AND TRENCHES SUGGEST POSSIBLE HYDROTHERMAL ORIGIN
- ABOVE-NORMAL GROUND-WATER TEMPERATURES SUGGEST GEOTHERMAL SOURCE

CONCLUSION

- VOLCANIC ERUPTION POSSIBLE
- SOME POTENTIAL OF HYDROTHERMAL ACTIVITY

VOLCANIC FIELDS



NATURAL RESOURCES

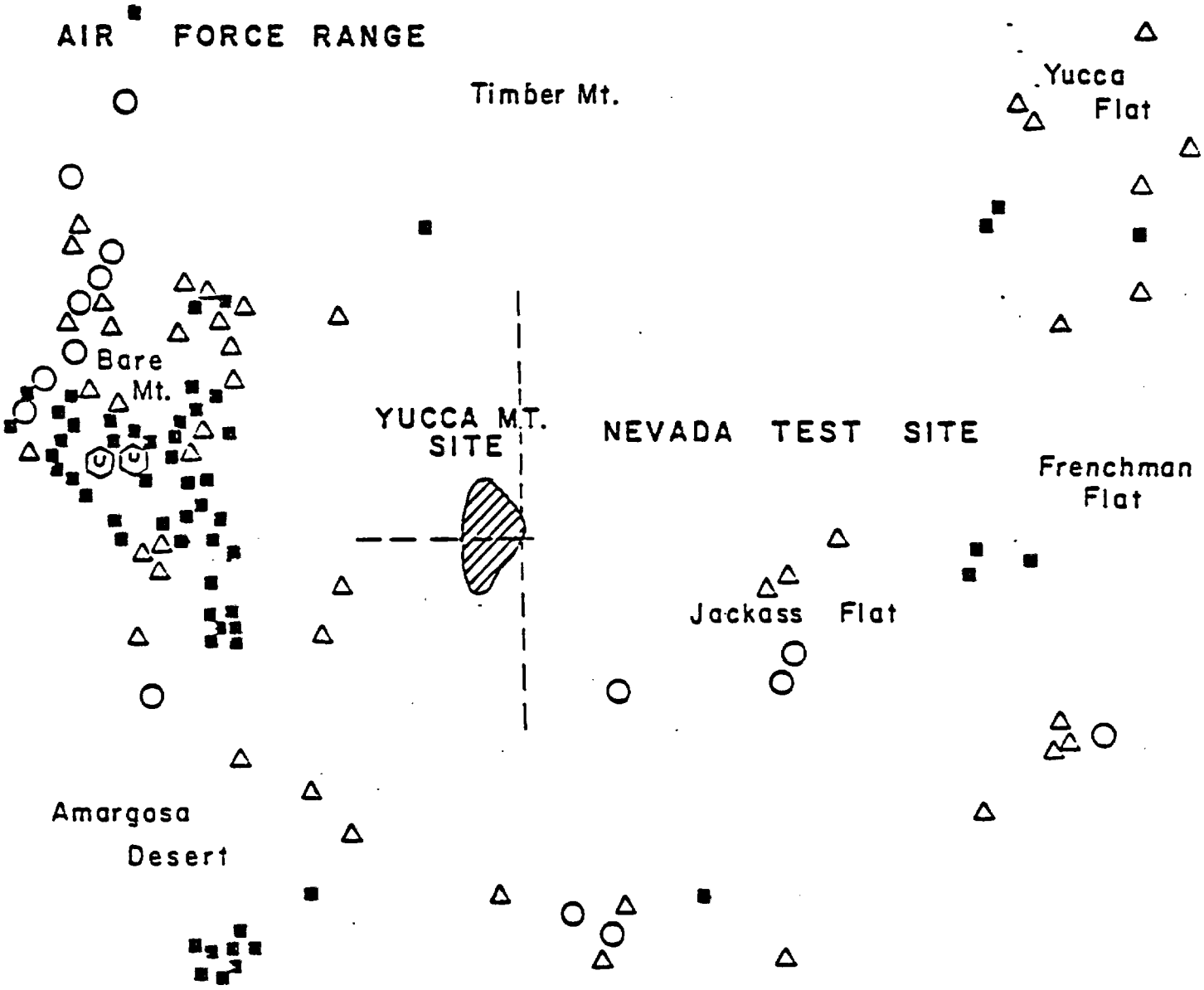
EVIDENCE

- VOLCANIC CALDERAS CENTERS OF MINERALIZATION IN GREAT BASIN
- MINING ACTIVITY PROMINENT IN REGION
- SITE LOCATED ON EDGE OF MINERALIZED CALDERA
- BURIED TUFFS DISPLAY ALTERATION AND SECONDARY PYRITE
- GOLD AND SILVER ENCOUNTERED IN SITE DRILL-HOLE
- HISTORIC PLACER GOLD MINING IN FORTY MILE WASH
- PROJECTION OF OVERTHRUST BELT IN PALEOZOIC ROCKS BENEATH SITE SUGGEST PETROLEUM POTENTIAL
- REGIONAL CARBONATE AQUIFER IS POTENTIAL WATER SUPPLY SOURCE

CONCLUSION

- POTENTIAL FOR EXTRACTABLE NATURAL RESOURCES BENEATH SITE

NATURAL RESOURCE LOCATIONS IN VICINITY OF YUCCA MT.



LEGEND

- ■ BASE & PRECIOUS METALS
- △ INDUSTRIAL MINERALS
- ○ GEOTHERMAL RESOURCES
- (U) URANIUM OCCURRENCES

MILES: 0 — 6 — 12

KILOMETERS: 0 — 10 — 20

WATER RESOURCES CENTER - DESERT RESEARCH INSTITUTE

TECHNICAL STUDY PROGRAMS

- REGIONAL GROUNDWATER FLOW AND CHEMISTRY
- UNSATURATED ZONE MOISTURE SAMPLING
- APPLICATION OF FRACTAL MATHEMATICS IN FRACTURE FLOW MODELS
- APPLICATION OF ISOTOPE FLOW MODELS TO ANALYSIS OF GROUND WATER FLOW SYSTEMS
- ORIGIN OF CARBONATE/SILICA VEIN DEPOSITS
- PACKRAT MIDDEN CLIMATOLOGY
- INFLUENCE OF CLIMATIC PATTERNS ON HYDROLOGIC CONDITIONS

Areas of disagreement with DOE, principally at mgmt level not so much between PIs of NV & DOE Conti's who are in good agreement

Most are being addressed by DOE

Not happy w/ results

" " with direction DOE's efforts are going.

NV addressing these more vigorously than DOE

DWM - your objectives more closely in agreement w/ NRC than w/ DOE

REGIONAL GROUNDWATER FLOW

OBJECTIVE

- TO DEFINE REGIONAL GROUNDWATER FLOW AND HYDRAULIC CONTINUITY BETWEEN YUCCA MOUNTAIN AND ADJACENT AREAS

RATIONALE

- SITE SUITABILITY ISSUE: DEFINE RELATIONSHIP OF YUCCA MOUNTAIN GROUNDWATER SYSTEM TO REGIONAL AQUIFER SYSTEM
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT, AND TO CLASS 1 GROUNDWATER SUPPLIES

APPROACH

- COLLECT PERIODIC WATER SAMPLES FROM WELLS AND SPRINGS
- ANALYZE SAMPLES FOR WATER CHEMISTRY
- DEVELOP TIME-SERIES HYDROCHEMICAL MODEL

UNSATURATED ZONE MOISTURE SAMPLING

OBJECTIVE

- TO OBTAIN PORE WATER SAMPLES FROM UNSATURATED ZONE

RATIONALE

- SITE SUITABILITY ISSUE: CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH UNSATURATED ZONE
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT
- NRC LICENSING CRITERIA (10 CFR PART 60): GROUNDWATER TRAVEL TIME FROM DISTURBED ZONE TO ACCESSIBLE ENVIRONMENT SHALL BE AT LEAST 1,000 YEARS

APPROACH

- DRILL 200' - 300' BOREHOLE USING ODEX DRILLING METHOD
- INSTALL SUCTION LYSIMETER AND DOWNHOLE SAMPLER
- ANALYZE SAMPLES FOR CHEMISTRY AND ENVIRONMENTAL AND TRACER ISOTOPES

FRACTURE FLOW MODELS

OBJECTIVES

- TO EVALUATE USE OF FRACTAL MATHEMATICS TO CATEGORIZE DEGREE OF IRREGULARITY OF FRACTURES
- TO DEVELOP FLOW MODELS IN FRACTURED MATERIALS BASED ON FRACTAL GEOMETRY

RATIONALE

- SITE SUITABILITY ISSUE: CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH UNSATURATED ZONE
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT
- NRC LICENSING CRITERIA (10 CFR PART 60): GROUNDWATER TRAVEL TIME FROM DISTURBED ZONE TO ACCESSIBLE ENVIRONMENT SHALL BE AT LEAST 1,000 YEARS

APPROACH

- REVIEW OF FRACTAL MATHEMATICS THEORY AND APPLICATION OF FLOW IN FRACTURED ROCK
- DEFINE GEOMETRIES OF FRACTURES
- DEVELOP NEW FLOW AND TRANSPORT MODELS FOR FLOW IN FRACTURED ROCK

ISOTOPES IN GROUNDWATER FLOW SYSTEMS

OBJECTIVES

- TO DELINEATE GROUNDWATER FLOW PATHS
- TO ASSESS MIXING PROPERTIES OF FLOW SYSTEMS
- TO DEFINE GROUNDWATER RESIDENCE TIME

RATIONALE

- SITE SUITABILITY ISSUE: DEFINE RELATIONSHIP OF YUCCA MOUNTAIN GROUNDWATER SYSTEM TO REGIONAL AQUIFER SYSTEM
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT, AND TO CLASS 1 GROUNDWATER SUPPLY

APPROACH

- SYNTHESIS OF ALL AVAILABLE GROUNDWATER ISOTOPE DATA
- SAMPLING AND ISOTOPE ANALYSIS OF ADDITIONAL POINTS
- CALIBRATE POSSIBLE MODELS WITH ISOTOPE DATA
- ANALYZE AND INTERPRET INTERACTION OF GROUNDWATER FLOW SYSTEMS

CARBONATE/SILICA VEIN DEPOSITS

OBJECTIVE

- TO DEFINE ORIGIN OF CARBONATE/SILICA VEIN DEPOSITS

RATIONALE

- NRC LICENSING CRITERIA (10 CFR PART 60):
  - POTENTIAL CHANGE IN HYDROLOGIC DISCHARGE CONDITIONS THAT COULD AFFECT MIGRATION OF RADIONUCLIDES (COLD WATER SPRING)
  - IGNEOUS ACTIVITY WHICH COULD AFFECT INTEGRITY OF SITE (THERMAL WATER)

APPROACH

- REVIEW FIELD LOGS OF DEPOSITS
- SAMPLE CARBONATE/SILICA DEPOSITS FOR ELEMENT CHEMISTRY, PETROLOGY, ISOTOPE CHEMISTRY, AND MINERALOGY
- SAMPLE ASH FILINGS FOR MINERALOGY, MICRO FOSSIL ANALYSIS, AND AGE DATING
- EXAMINE AND SAMPLE WALL ROCK FOR EVIDENCE OF ALTERATION

PACKRAT MIDDEN CLIMATOLOGY

OBJECTIVES

- TO ESTABLISH PAST PRECIPITATION AND VEGETATION AT YUCCA MOUNTAIN
- TO DEFINE PAST CLIMATIC REGIME AT YUCCA MOUNTAIN

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE CLIMATIC VARIATIONS AND RESULTING CHANGES IN HYDROGEOLOGIC REGIME ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): POTENTIAL FOR CHANGES IN HYDROLOGIC CONDITIONS RESULTING FROM FORESEEABLE CLIMATIC CHANGES

APPROACH

- MAP AND SAMPLE PACKRAT MIDDENS ALONG FORTY MILE AND YUCCA WASHES
- ANALYZE SAMPLES FOR VEGETATION COMPONENTS
- RADIOCARBON AGE DATING OF SELECTED SAMPLES
- CORRELATE PLANT ASSOCIATIONS WITH CLIMATIC AND HYDROLOGIC FACTORS
- DEVELOP CLIMATIC HISTORY

INFLUENCE OF CLIMATIC PATTERNS ON HYDROLOGIC CONDITIONS

OBJECTIVE

- TO EVALUATE PAST CLIMATIC PATTERNS AND MAGNITUDES OF VARIATION, AND INFLUENCE ON HYDROLOGIC CONDITIONS

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE CLIMATIC VARIATIONS AND RESULTING CHANGES IN HYDROGEOLOGIC REGIME ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): POTENTIAL FOR CHANGES IN HYDROLOGIC CONDITIONS RESULTING FROM FORESEEABLE CLIMATIC CHANGES
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT

APPROACH

- ANALYZE PAST CLIMATIC DATA FOR PATTERNS AND TRENDS
- MODEL WET CYCLES FOR DIFFERENT TIME FRAMES

MIFFLIN & ASSOCIATES

TECHNICAL STUDY PROGRAMS

- UNSATURATED ZONE DRILLING AND MONITORING
- REGIONAL GROUNDWATER PALEODISCHARGE
- CHEMICAL AND PHYSICAL-CHEMICAL BEHAVIOR OF CLINOPTILOLITE AND VOLCANIC GLASS
- PEDOGENIC OPAL ANALOG

Paleoclimates and Geochemistry

UNSATURATED ZONE DRILLING AND MONITORING - PHASE I

OBJECTIVE

- TO ASSESS MOISTURE TRAVEL MECHANISMS IN UNSATURATED ZONE
- IN PHASE I, ESTABLISH DIRECT MOISTURE METHODOLOGY

RATIONALE

- SITE SUITABILITY ISSUE: CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH UNSATURATED ZONE
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT
- NRC LICENSING CRITERIA (10 CFR PART 60): GROUNDWATER TRAVEL TIME FROM DISTURBED ZONE TO ACCESSIBLE ENVIRONMENT SHALL BE AT LEAST 1,000 YEARS

APPROACH

- DRILL HOLES NEAR YUCCA MOUNTAIN USING DRY DRILLING TECHNIQUE
- EMPLACE MOISTURE SENSING INSTRUMENTATION
- MONITOR MOISTURE MOVEMENT

REGIONAL GROUNDWATER PALEODISCHARGE

OBJECTIVE

- TO EVALUATE PAST PLUVIAL CLIMATIC GROUNDWATER CONDITIONS AS AN INDICATOR OF FUTURE GROUNDWATER CONDITIONS

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE CLIMATIC VARIATIONS AND RESULTING CHANGES IN HYDROGEOLOGIC REGIME ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): POTENTIAL FOR CHANGES IN HYDROLOGIC CONDITIONS RESULTING FROM FORESEEABLE CLIMATIC CHANGES
- EPA STANDARD (10 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT

APPROACH

- MAP PAST GROUNDWATER DISCHARGE AREAS (SPRINGS AND LAKES) AROUND NEVADA TEST SITE
- ANALYZE PACKRAT MIDDENS FOR PHREATIC VEGETATION
- DEVELOP MODEL OF PAST GROUNDWATER LEVEL MAXIMUMS

CHEMICAL BEHAVIOR OF CLINOPTILOLITE AND VOLCANIC GLASS

OBJECTIVES

- TO UNDERSTAND SORPTION CHARACTERISTICS OF CLINOPTILOLITE WITH RESPECT TO RADIONUCLIDE RETARDATION
- TO ASSIST IN DEFINING UNSATURATED ZONE HYDROGEOCHEMISTRY

RATIONALE

- SITE SUITABILITY ISSUE: CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH UNSATURATED ZONE
- EPA STANDARD (40 CFR PART 191): RELEASE AND TRANSPORT OF RADIONUCLIDES FROM WASTE PACKAGE TO ACCESSIBLE ENVIRONMENT
- NRC LICENSING CRITERIA (10 CFR PART 60): GROUNDWATER TRAVEL TIME FROM DISTURBED ZONE TO ACCESSIBLE ENVIRONMENT SHALL BE AT LEAST 1,000 YEARS

APPROACH

- REVIEW OF THERMODYNAMICS OF VOLCANIC GLASS AND TRANSFORMATION TO ZEOLITE SPECIES
- ANALYZE SAMPLES FOR CATION SPECIES
- COMPARE SAMPLES TO HECTOR, CA CLINOPTILOLITE
- ESTABLISH SPECIES SELECTIVITY AS A FUNCTION OF CATION CONCENTRATIONS IN AQUEOUS PHASE

PEDOGENIC OPAL ANALOG

OBJECTIVES

- TO ASSIST IN GENESIS OF OPAL IN CARBONATE/SILICA VEIN DEPOSITS
- TO ASSIST IN UNDERSTANDING DISSOLUTION OF SILICATE MINERALS IN WEATHERIZING ZONE

RATIONALE

- SITE SUITABILITY ISSUE: CHARACTERIZATION OF MOISTURE MOVEMENT THROUGH UNSATURATED ZONE
- NRC LICENSING CRITERIA (10 CFR PART 60):
  - POTENTIAL CHANGE IN HYDROLOGIC DISCHARGE CONDITIONS THAT COULD AFFECT MIGRATION OF RADIONUCLIDES (COLD WATER SPRING)
  - IGNEOUS ACTIVITY WHICH COULD AFFECT INTEGRITY OF SITE (THERMAL WATER)

APPROACH

- SILICATE RINDS FROM PAH CANYON TUFF WILL BE SAMPLED AND ANALYZED FOR MAJOR, MINOR AND TRACE ELEMENT GEOCHEMISTRY
- VOLCANIC GLASS IN TUFF WILL BE ANALYZED FOR LEACHING ZONE CHEMISTRY
- COMPARE RESULTS WITH CARBONATE/SILICA VEIN DEPOSITS ANALYSES

CENTER FOR NEOTECTONIC STUDIES - UNIVERSITY OF NEVADA-RENO

TECHNICAL STUDY PROGRAMS

- ACTIVE FAULTING AND QUATERNARY GEOLOGY
- REGIONAL TECTONICS
- SEISMOLOGY
- REMOTE SENSING
- NATURAL RESOURCES ASSESSMENT
- TUFF GEOCHEMISTRY
- TUFF-ROCK STABILITY

ACTIVE FAULTING

OBJECTIVE

- TO EVALUATE RECENCY AND FREQUENCY OF FAULT ACTIVITY IN THE SITE AREA
- TO EVALUATE PROBABILITY OF RECURRING FAULT MOVEMENT WITHIN NEXT 10,000 YEARS

RATIONALE

- SITE SUITABILITY ISSUE: EFFECTS OF FUTURE FAULTING OR OTHER TECTONIC EVENTS ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): STRUCTURAL DEFORMATION SUCH AS UPLIFT, SUBSIDENCE, FOLDING, AND FAULTING DURING QUATERNARY PERIOD (LAST 2 MILLION YEARS)

APPROACH

- PROCURE LOW-SUN ANGLE PHOTOGRAPHY OF SITE AREA
- ANALYZE LOW-SUN ANGLE PHOTOGRAPHY, VERTICAL AERIAL PHOTOGRAPHY, AND REMOTE-SENSING IMAGERY FOR EVIDENCE OF FAULT ACTIVITY
- EVALUATE FIELD EVIDENCE FOR RECENT FAULTING AND AGE DATING OF FAULT MOVEMENT
- MAP AND AGE DATE QUATERNARY GEOLOGIC UNITS

REGIONAL TECTONICS

OBJECTIVE

- TO EVALUATE THE TECTONIC SETTING, CRUSTAL STRUCTURE, AND SEISMOTECTONIC POTENTIAL OF YUCCA MOUNTAIN REGION

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE FAULTING OR OTHER TECTONIC EVENTS ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): NATURE AND RATES OF TECTONIC PROCESSES OPERATING WITHIN THE GEOLOGIC SETTING WHICH COULD AFFECT THE INTEGRITY OF SITE

APPROACH

- EXAMINE LISTRIC AND DETACHMENT FAULT DOMAINS
- REEVALUATE WALKER-LANE STRUCTURAL ZONE
- STUDY MINE MOUNTAIN STRUCTURAL ZONE
- REVIEW TECTONICS AND STRESS INDICATORS OF DEATH VALLEY FAULT ZONE
- ANALYZE REMOTE-SENSED STRUCTURAL GEOLOGY
- EXAMINE SITES OF HOLOCENE FAULT ACTIVITY
- DEVELOP MODEL OF TECTONIC SETTING AND REGIONAL STRESS

SEISMOLOGY

OBJECTIVE

- TO ASSESS PAST AND PRESENT EARTHQUAKE PATTERNS IN SOUTHERN NEVADA
- TO ASSESS GROUND MOTION FROM NUCLEAR TESTING

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE FAULTING OR OTHER TECTONIC EVENTS ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): EARTHQUAKES WHICH HAVE OCCURRED HISTORICALLY THAT IF REPEATED COULD SIGNIFICANTLY AFFECT SITE

APPROACH

- REVIEW LITERATURE AND EARTHQUAKE CATALOGS
- ANALYZE GEOPHYSICAL SURVEYS AND CRUSTAL MODELS OF SOUTHERN NEVADA
- LINK FEDERAL GOVERNMENT SEISMIC NETWORK IN SOUTHERN NEVADA WITH SEISMOLOGY LABORATORY AT UNR
- DEFINE EARTHQUAKE SOURCE PARAMETERS
- DEFINE NUCLEAR TESTING GROUND MOTION PARAMETERS
- DEVELOP EARTHQUAKE SOURCE MODEL AND ESTIMATES OF INTENSITY, PEAK ACCELERATION, AND EXPECTED DAMAGE PATTERNS

REMOTE SENSING

OBJECTIVE

- TO DEFINE REGIONAL STRUCTURAL SETTING UTILIZING REMOTE SENSING DATA

RATIONALE

- DEFINITION OF REGIONAL STRUCTURAL RELATIONSHIPS WILL ASSIST IN ASSESSING TECTONICS, VOLCANISM, HYDROGEOLOGY, AND NATURAL RESOURCE POTENTIAL

APPROACH

- MULTITEMPORAL LANDSAT THEMATIC MAPPER DATA
- FRENCH SPOT STEREO PANCHROMATIC IMAGERY
- DIGITAL GRAVITY, MAGNETIC, AND TOPOGRAPHIC DATA
- DEVELOPMENT OF REGIONAL STRUCTURE AND LINEAMENT MAPS

MINERAL RESOURCES

OBJECTIVE

- TO ASSESS MINERAL RESOURCE POTENTIAL AT YUCCA MOUNTAIN
- TO ASSESS HYDROCARBON POTENTIAL AT YUCCA MOUNTAIN

RATIONALE

- SITE SUITABILITY ISSUE: POTENTIAL FOR HUMAN INTERFERENCE OF SITE DUE TO PERCEIVED PRESENCE OF EXTRACTABLE NATURAL RESOURCES
- NRC LICENSING CRITERIA (10 CFR PART 60): PRESENCE OF NATURALLY OCCURRING MINERALS, WHETHER IDENTIFIED OR UNDISCOVERED, IN A FORM THAT ECONOMIC EXTRACTION IS FEASIBLE OR POTENTIALLY FEASIBLE IN FORESEEABLE FUTURE

APPROACH

- EXAMINE GEOLOGIC DRILL CORE FOR EVIDENCE OF MINERALIZATION OR ALTERATION ZONES
- REVIEW GEOLOGY AND MINERALIZATION CHEMISTRY OF MINING SITES IN AREA
- DEVELOP MODEL OF MINERAL RESOURCE POTENTIAL
- MAP POTENTIAL HYDROCARBON SOURCE AND RESERVOIR ROCKS
- EVALUATE STRUCTURAL GEOLOGY AND HYDROCARBON MATURATION MODELS
- DEVELOP MODEL OF HYDROCARBON POTENTIAL

TUFF GEOCHEMISTRY

OBJECTIVE

- TO ASSESS CHEMICAL CONDITIONS WITHIN HOST ROCK, CHEMICAL REACTIONS ANTICIPATED, AND SOLUBILITY OF HOST ROCK

RATIONALE

- NRC LICENSING CRITERIA (10 CFR PART 60): NATURE AND RATES OF GEOCHEMICAL PROCESSES WHICH COULD AFFECT THE ABILITY OF THE REPOSITORY TO ISOLATE WASTE

APPROACH

- EVALUATE TUFF GEOCHEMISTRY AND RANGE OF GEOCHEMICAL PROPERTIES ANTICIPATED
- EXAMINE ANTICIPATED MINERAL-SOLUTION REACTIONS, CRITICAL EQUILIBRIUM AND KINETICS OF PHASE CHANGES

TUFF-ROCK STABILITY

OBJECTIVE

- TO ASSESS REPOSITORY HOST ROCK STABILITY
- TO EVALUATE STRUCTURAL INTEGRITY OF YUCCA MOUNTAIN

RATIONALE

- NRC LICENSING CRITERIA (10 CFR PART 60): GEOMECHANICAL PROPERTIES THAT DO NOT PERMIT DESIGN OF UNDERGROUND OPENINGS THAT REMAIN STABLE THROUGH PERMANENT CLOSURE
- FEDERAL AND STATE MINE SAFETY REGULATIONS: PROTECTION OF WORKERS UNDERGROUND FROM CAVE-IN, COLLAPSE, OR ROCK BURST

APPROACH

- DESCRIPTION OF ROCK MASS FEATURES
- CHARACTERIZE ROCK MASS FRACTURES UTILIZING FRACTAL DIMENSIONS
- DEFINE CHANGES IN ROCK MASS FEATURES DUE TO MAJOR DISCONTINUITIES
- DEFINE IN-SITU ROCK STRESS

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TECHNICAL STUDY PROGRAM

- REGIONAL VOLCANISM

VOLCANISM

OBJECTIVE

- TO ASSESS POTENTIAL OF VOLCANIC ERUPTION AT OR NEAR YUCCA MOUNTAIN

RATIONALE

- SITE SUITABILITY ISSUE: EFFECT OF FUTURE VOLCANISM ON INTEGRITY OF SITE
- NRC LICENSING CRITERIA (10 CFR PART 60): EVIDENCE OF IGNEOUS (VOLCANIC) ACTIVITY AT SITE SINCE START OF QUATERNARY PERIOD

APPROACH

- STUDY YOUNG VOLCANISM IN TERMS OF REGIONAL STRUCTURAL AND MINERALOGIC SETTING
- MAP VOLCANIC FEATURES, ANALYZE GEOCHEMISTRY OF VOLCANIC ROCK SAMPLES, AGE DATE VOLCANIC FEATURES
- DEVELOP MODEL OF PAST VOLCANIC ACTIVITY

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Nevada Nuclear Waste Storage Investigations PROJECT

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Nevada
Nuclear Waste
Storage Investigations Project

NNWSI PROJECT
BRIEFING FOR THE
ACRS SUBCOMMITTEE
ON WASTE MANAGEMENT

JULY 29, 1987

United States Department of Energy
Nevada Operations Office/Waste Management Project Office

ATTACHMENT 5

Nevada
Nuclear Waste
Storage Investigations Project

NNWSI PROJECT

BRIEFING FOR THE

ACRS SUBCOMMITTEE

ON WASTE MANAGEMENT

JULY 29, 1987

United States Department of Energy
Nevada Operations Office/Waste Management Project Office

INTRODUCTION

M. BLANCHARD

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YUCCA MOUNTAIN

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INTRODUCTION

- ENCLOSURE 3, SECY-87-137
- OBJECTIVES FOR BRIEFINGS
- SCHEDULE-PROGRAM SCP
- AGENDA
- SITE DESCRIPTION

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"TECHNICAL CONCERNS" (ENCLOSURE 3, SECY-87-137)

- PRESENCE OF POTENTIALLY ACTIVE FAULTS IN THE VICINITY OF YUCCA MOUNTAIN
- POTENTIAL FOR HYDROTHERMAL ACTIVITY IN THE VICINITY OF YUCCA MOUNTAIN
- GROUNDWATER FLOW
- EFFECTIVENESS OF THE POTENTIAL RADIONUCLIDE RETARDATION MECHANISMS AVAILABLE AT YUCCA MOUNTAIN
- POTENTIAL FOR VOLCANISM IN THE VICINITY OF YUCCA MOUNTAIN

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PERSPECTIVE ON "TECHNICAL CONCERNS"

1. THE ENVIRONMENTAL ASSESSEMENTS (ESs) WERE BASED ON DATA BASES THAT PRECEEDED SITE CHARACTERIZATION

2. THE ENVIRONMENTAL ASSESSMENTS CONTAINED PRELIMINARY FINDINGS ABOUT THE SUITABILITY OF THE SITE

3. THE "AREAS OF THE TECHNICAL CONCERN" IDENTIFIED IN SECY-87-137 CORRESPOND TO THE NRC STAFF COMMENTS ON THE YUCCA MOUNTAIN EA

4. THE NRC-EA COMMENTS IDENTIFY CONCERNS "PRINCIPALLY RELATED TO:

   (A) NOT IDENTIFYING THE RANGE OF UNCERTAINTIES ASSOCIATED WITH THE EXISTING LIMITED DATA BASE,

   (B) NOT IDENTIFYING THE RANGE OF ALTERNATIVE INTERPRETATIONS AND ASSUMPTIONS THAT CAN BE REASONABLY SUPPORTED BY EXISTING DATA, AND

   (C) NOT INCORPORATING A REASONABLE RANGE OF UNCERTAINITES AND ALTERNATIVE INTERPRETATIONS INTO EVALUATIONS AND CONCLUSIONS"

5. THE COMMENTS WERE OFFERED TO "ASSIST DOE IN PREPARING HIGH QUALITY SCPs"

6. "AREAS OF TECHNICAL CONCERN" DO NOT INCLUDE NRC STAFF REACTIONS TO ISSUE RESOLUTION STRATEGIES CONTAINED IN THE SCP

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OBJECTIVE FOR BRIEFING

A COMMON THEME FOR THESE FIVE TOPICS:

PROJECT WILL TRY TO SHOW YOU THE LINKAGE OF PERFORMANCE AND DESIGN REQUIREMENTS TO THE SITE CHARACTERIZATION ACTIVITIES

EACH SPEAKER WILL INCLUDE SOME ASPECTS OF:

- RELEVANCE OF CHARACTERIZATION TO DESIGN/PERFORMANCE
- SUMMARY OF CURRENT UNDERSTANDING AND UNCERTAINTY

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PROGRAM SCHEDULE: CURRENT STATUS

- DOE HAS ISSUED GUIDELINES REQUIRED BY NWPA, SECTION 112(A)
- DOE HAS ISSUED MISSION PLAN REQUIRED BY NWPA, SECTION 114(C)
- DOE HAS ISSUED ENVIRONMENTAL ASSESSMENTS (EAs) REQUIRED BY NWPA, SECTION 112(B)(1)(E)
- NRC HAS COMMENTED ON DRAFT AND FINAL EAs
- DOE IS PREPARING SITE CHARACTERIZATION PLANS (SCPs) REQUIRED BY NWPA, SECTION 113(B)

LICENSING A REPOSITORY WILL BE DIFFERENT THAN LICENSING A NUCLEAR POWER PLANT IN AT LEAST ONE VERY FUNDAMENTAL WAY. ALTHOUGH, WE EXPECT TO ACHIEVE CONTAINMENT BY A CAREFULLY ENGINEERED REPOSITORY AND WASTE PACKAGES LONG-TERM ISOLATION WILL RELY UPON THE CHARACTERISTICS OF THE SITE ITSELF (e.i., GEOLOGY, HYDROLOGY, GEOCHEMISTRY, ROCK THERMAL/MECHANICAL PROPERTIES)

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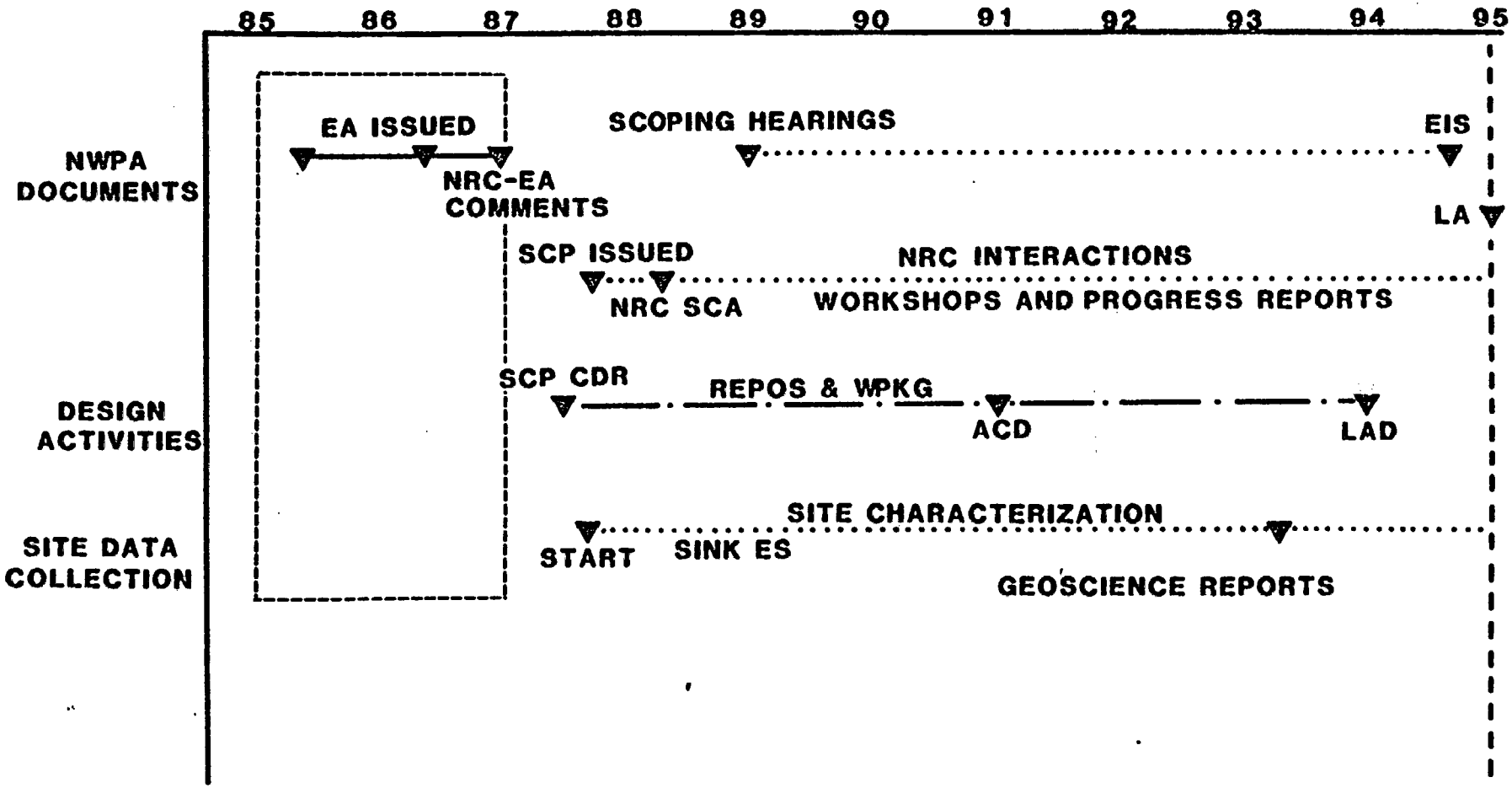
NNWSI PROJECT SCHEDULE



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ORGANIZING PRINCIPLES FOR SITE CHARACTERIZATION

F. BINGHAM
J. TILLERSON

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ORGANIZING PRINCIPLE

To make the site-characterization program provide the information that will be needed for demonstrating compliance with regulations

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THE ORGANIZING PROCESS

("Performance allocation")

("Establishment of repository design parameters")

1. Select system elements to be relied on.

2. For each element, select features on which reliance will be made. ("Performance measures," "goals," "indications of confidence").

3. Define the "parameters" to be measured or derived from measurements. Explain how well and over what ranges they must be measured.

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IMPORTANT FEATURES OF THE PROCESS

- All the steps use available information
- The allocations may (probably will) change as more information becomes available
- Because uncertainties exist in the available data, the allocations are made conservatively; the performance of elements is underestimated
- NNWSI has used multidisciplinary teams to make the allocations

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ASSESSING POSTCLOSURE PERFORMANCE OF THE TOTAL SYSTEM

(releases to accessible environment)

- CCDF will show compliance
- Making CCDF requires modeling of future performance
- Future events and processes are grouped into
  - "Nominal-case scenario"
  - "Exceptional-case scenario classes"
- Performance is allocated for each class of scenario

NNWSI PROJECT

HYDROLOGIC SECTION
YUCCA MOUNTAIN SITE

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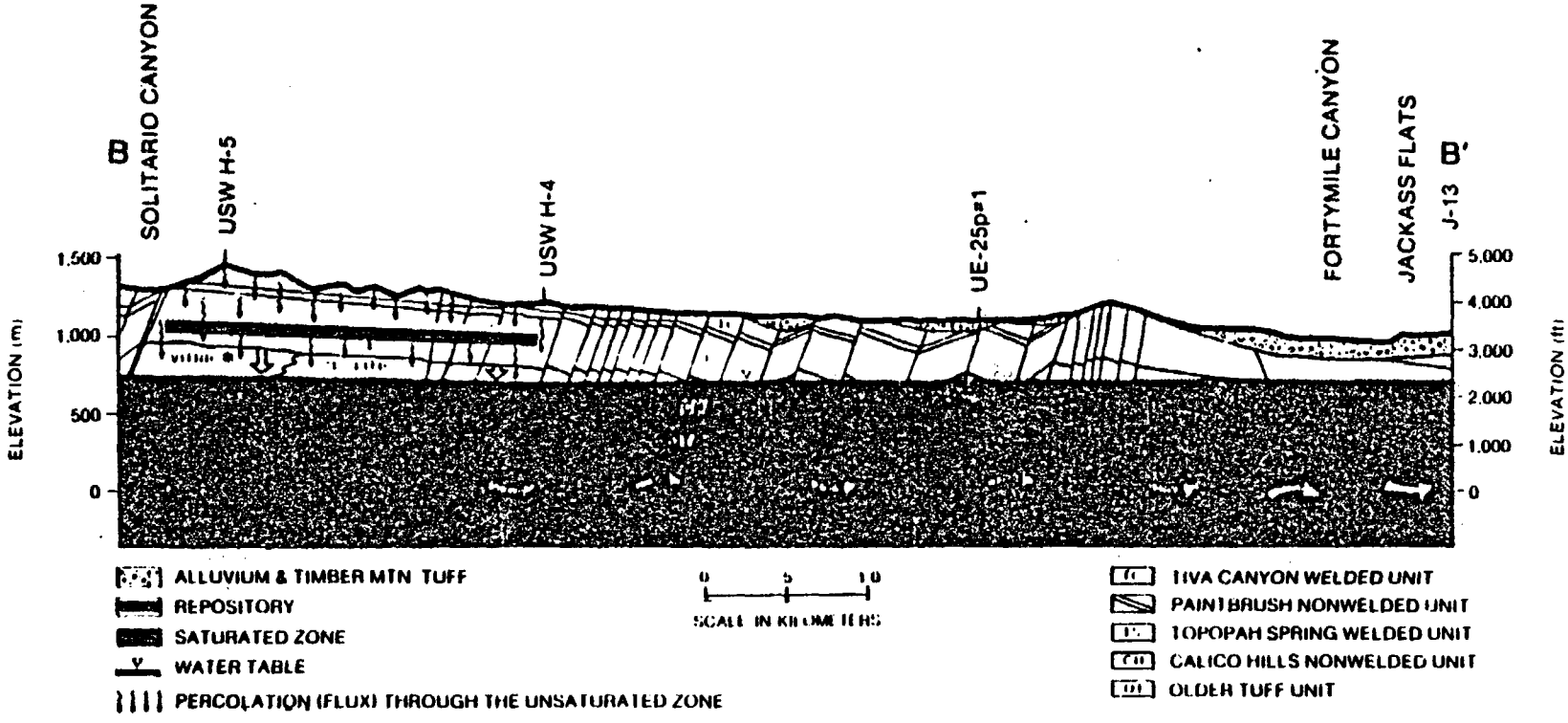
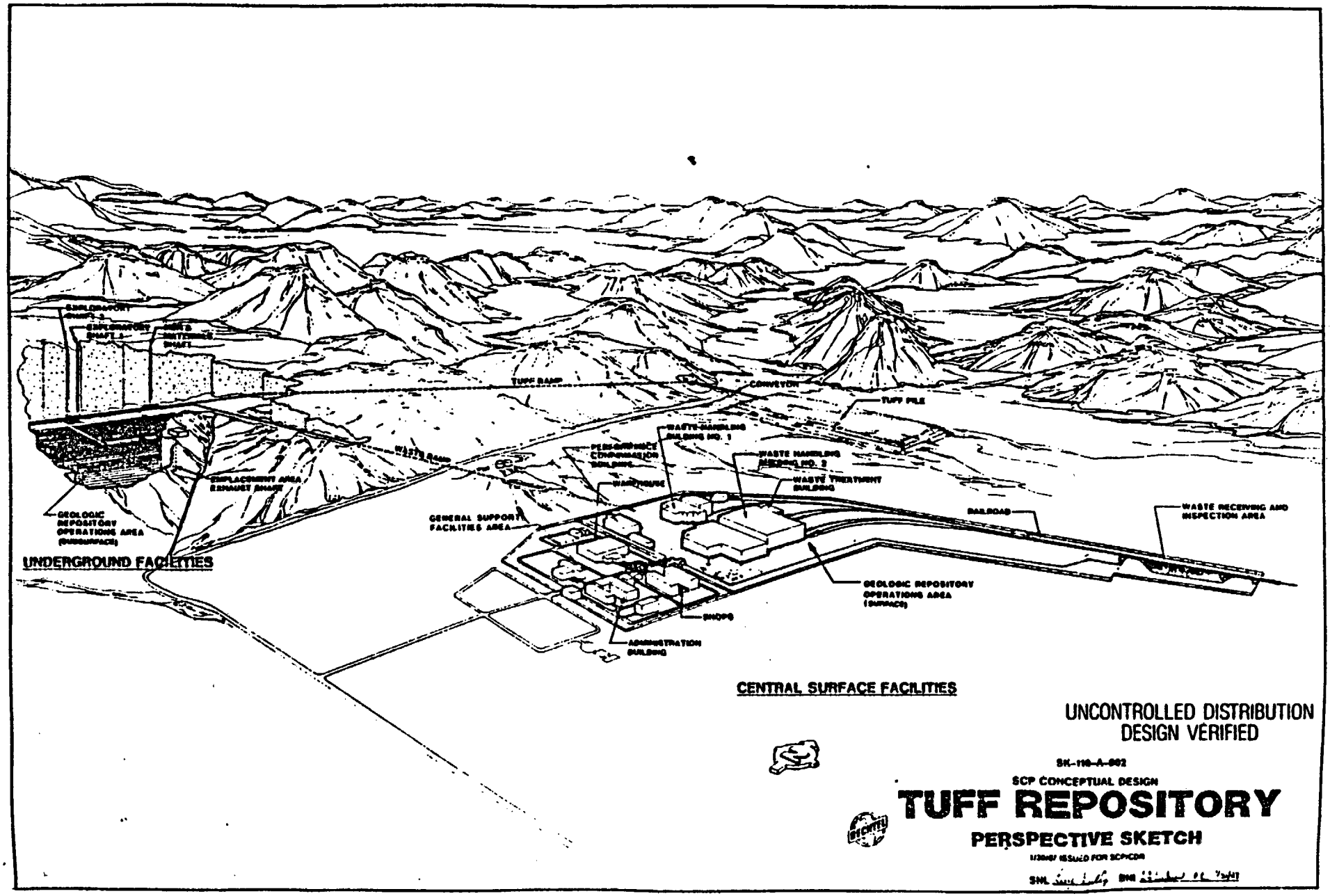


SELECTED PARAMETERS FROM ALLOCATION FOR NOMINAL-CASE SCENARIO

SYSTEM ELEMENT	PERFORMANCE PARAMETER	TENTATIVE PERFORMANCE GOAL	
UNSATURATED ZONE (UZ) (PRIMARY BARRIER)	AVERAGE FLUX	< 0.5 mm/yr	NUMEROUS MORE-DETAILED PARAMETERS
	AVERAGE EFFECTIVE MATRIX POROSITY	> 0.1	
	AVERAGE CHEMICAL RETARDATION FACTOR FOR I^{th} SPECIES	≥ 1	
	AVERAGE THICKNESS BETWEEN REPOSITORY AND WATER TABLE	> 100 m	
SATURATED ZONE (SZ) (BACKUP BARRIER)	AVERAGE FLUX	< 32 mm/yr	
	⋮	⋮	
	AVERAGE LENGTH OF FLOW PATH	> 5000 m	
ENGINEERED-BARRIER SYSTEM (BACKUP BARRIER)	FRACTIONAL MASS RELEASE RATE FOR EACH SPECIES	$< 10^{-4}$/yr	

SELECTED PARAMETERS FROM ALLOCATION FOR EXCEPTIONAL-CASE SCENARIOS

INITIATING EVENT OR PROCESS	PERFORMANCE PARAMETER	TENTATIVE PERFORMANCE GOAL	
IGNEOUS INTRUSION OR OFFSET ON FAULT CAUSES WATER-TABLE RISE	PROBABILITY OF INTRUSION WITHIN AREA	$< 10^{-5}$/yr	NUMEROUS MORE-DETAILED PARAMETERS
	PROBABILITY OF OFFSET > 1 m WITHIN AREA	$< 10^{-1}$ IN 10,000 yr	
	⋮	⋮	
VOLCANIC ERUPTION PENETRATES REPOSITORY	PROBABILITY FOR SUCH ERUPTION	$< 10^{-6}$/yr	
	DISRUPTED AREA	< 0.1% OF REPOSITORY AT CONDITIONAL PROBABILITY	
		< 0.1 IN 10,000 yr	
⋮	⋮	⋮	



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DESIGN VERIFIED

SK-110-A-002

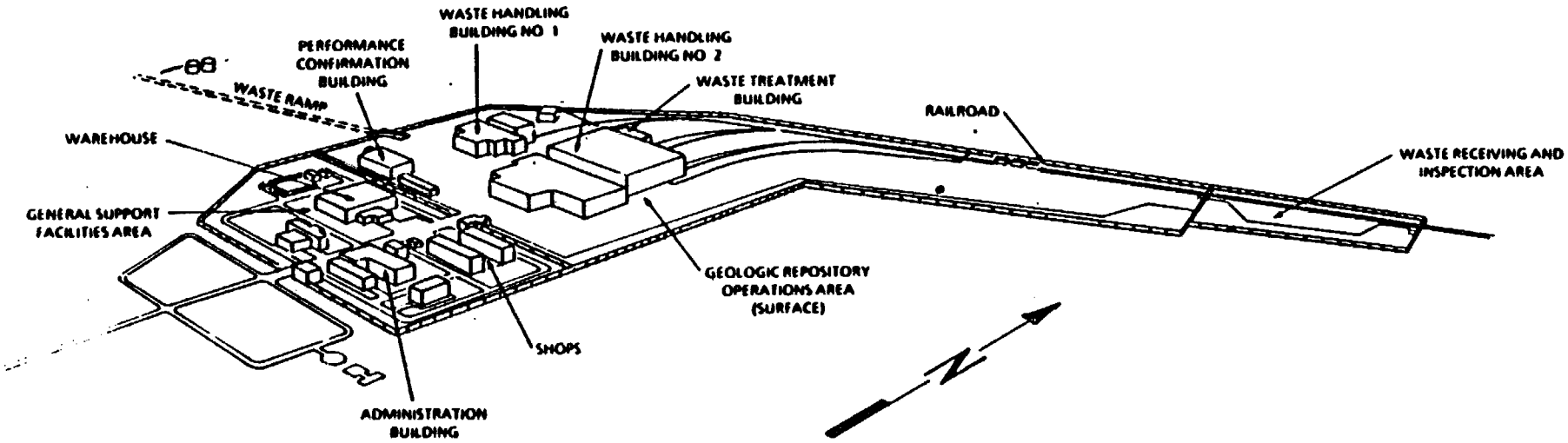
SCP CONCEPTUAL DESIGN

TUFF REPOSITORY

PERSPECTIVE SKETCH

ISSUED FOR SCP/CDR

SURFACE FACILITIES

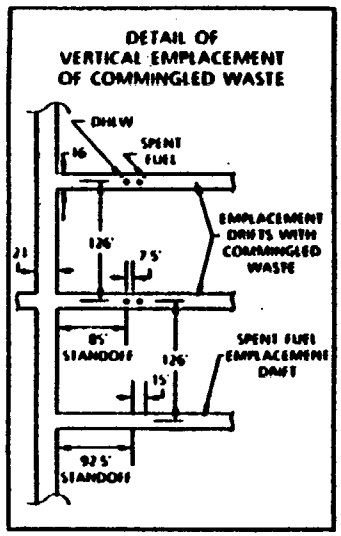


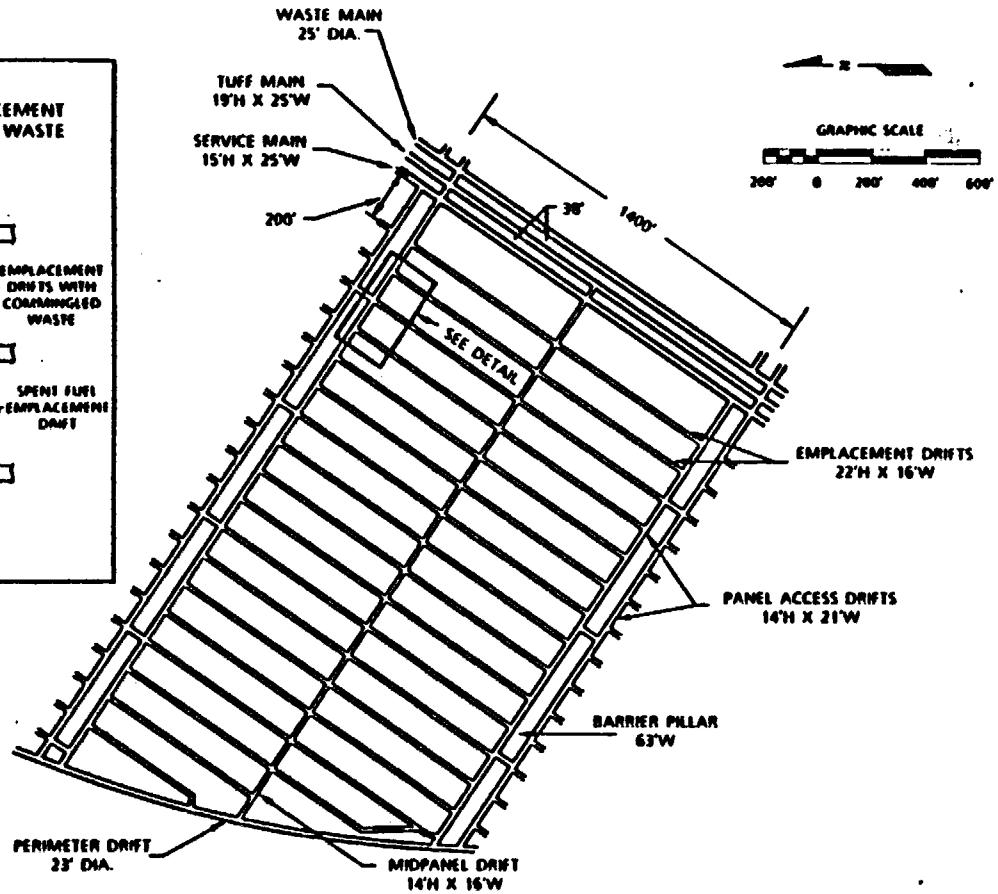
CENTRAL SURFACE FACILITIES

SELECTED CONSIDERATIONS:

- SPENT FUEL, DHLW & WVHLW
- RAIL & TRUCK ACCESS
- AVOID FAULTS WITH SIGNIFICANT DISPLACEMENT POTENTIAL
- COMPARTMENTALIZATION OF FACILITIES
- ZONED VENTILATION SYSTEMS
- LOW-PROFILE BUILDINGS
- NEGATIVE PRESSURE HOT CELLS

UNDERGROUND LAYOUT





PANEL LAYOUT - VERTICAL EMPLACEMENT

SELECTED CONSIDERATIONS:

- VERTICAL (REF. CASE) AND HORIZONTAL EMPLACEMENT DESIGNS
- THERMAL LOAD - 57 kW/acre
- PANEL EXTRACTION RATIO -
  - 16% - VERTICAL
  - 5% - HORIZONTAL
- RAMP FOR WASTE DELIVERY
- SEPARATE EMPLACEMENT & DEVELOPMENT VENTILATION
- SLOPE FROM DRIFTS TO EMPLACEMENT EXHAUST SHAFT
- DESIGN LIFETIME ~ 100 yrs.
- ACCESS DRIFT TEMPERATURE - <50°C for 50 yr.

AREAS OF DESIGN CONSTRAINTS

POSTCLOSURE

- Sealing of Shafts, Ramps and Boreholes
- Postclosure Design Constraints (layout, waste package environment, water usage, thermal loading)

PRECLOSURE

- Radiological Health and Safety
- Retrievability
- Non-Radiological Health and Safety
- Technical Feasibility (reasonably available technology)

EXAMPLES OF CHARACTERIZATION DATA NEEDED FOR REPOSITORY DESIGN CONCERNS

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POSTCLOSURE CONCERN:

FUNCTION	PROCESS	PERFORMANCE MEASURE
SELECT ORIENTATION, GEOMETRY LAYOUT AND DEPTH OF UNDERGROUND FACILITY TO CONTRIBUTE TO CONTAINMENT AND ISOLATION, TAKING INTO ACCOUNT FLEXIBILITY TO ACCOMMODATE SITE SPECIFIC CONDITIONS ⋮	• VARY DEPTH, DIP, ORIENTATION AND LATERAL EXTENT OF UNDERGROUND FACILITY TO PROVIDE HOST ROCK WITH FAVORABLE CONTAINMENT AND ISOLATION CHARACTERISTICS ⋮	USABLE AREA ADEQUATE FOR 70,000 MTU OF WASTE ⋮
TENTATIVE GOAL	**PERFORMANCE PARAMETER**	**TENTATIVE GOAL**
AREA AVAIL. >> AREA NEEDED > 200 m OVERBURDEN STAY IN TSw2 STAY > 70 m ABOVE WATER TABLE	⋮	⋮
PROBABILITY < 0.1 IN 1000 YR THAT > 0.5 % OF WASTE PACKAGES WILL BE BREACHED BY TECTONIC PROCESSES OR EVENTS →	FAULT DESCRIPTION ⋮ RECURRENCE TIME FOR 5 cm DISP.	⋮ GREATER THAN 1000 YEARS

EXAMPLES OF CHARACTERIZATION DATA NEEDED FOR REPOSITORY DESIGN CONCERNS

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PRECLOSURE CONCERN:

SYSTEM ELEMENT	FUNCTION/ PROCESS	PERFORMANCE MEASURE
SURFACE	PROVIDE FACILITY SITES NOT JEOPARDIZED BY NATURAL OR MANMADE PHENOMENA	ACCEPTABILITY OF LOCATION OF SURFACE FACILITIES

TENTATIVE GOAL	PERFORMANCE PARAMETER	TENTATIVE GOAL
FACILITIES IMPORTANT TO SAFETY (FITS) NOT LOCATED OVER POTENTIALLY ACTIVE GEOLOGICAL STRUCTURES	PROBABILITY OF EXCEEDING 5 cm DISPLACEMENT UNDER FITS	LESS THAN 0.001 IN 100 YEARS
ACCEPTABLE POTENTIAL FOR VIBRATORY GROUND MOTION	PROBABILITY OF EXCEEDING DESIGN BASIS GROUND MOTION AT FITS	LESS THAN 0.1 IN 100 YEARS

GROUND-WATER FLOW

S. SINNOCK
W. WILSON

PERSPECTIVE ON INFORMATION NEEDS FOR GROUNDWATER FLOW AT NNWSI SITE

- Mathematical basis for parameter needs
- Geographic basis for parameter needs
- Treatment of parameter uncertainty
- Treatment of conceptual uncertainty

MATHEMATICAL BASIS FOR SELECTED PARAMETER NEEDS

(groundwater travel time)

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MATHEMATICAL BASIS FOR MODELING

GWTT = d/v

WHERE

$$v = \frac{q}{n_e} = \frac{K \times \delta h/\delta l}{n_e}$$

IN UNSATURATED ZONE

$K = f(\psi_c)$

$\psi_c = f(\theta, S)$

PARAMETER NEEDS

d = STRATIGRAPHIC GEOMETRY[1] (HYDROGEOLOGIC UNITS)

q = WATER FLUX[1], [2]

K = PERMEABILITY[1], [2]

$\delta h/\delta l$ = PRESSURE FIELD[1], [2]

n_e = POROSITY[1], [2]

ψ_c = CAPILLARY MATRIC POTENTIAL[2]

θ = MOISTURE CONTENT[2]

S = SATURATION[2]

FOOTNOTES:

[1] UNSATURATED AND SATURATED ZONES

[2] FRACTURES AND MATRIX

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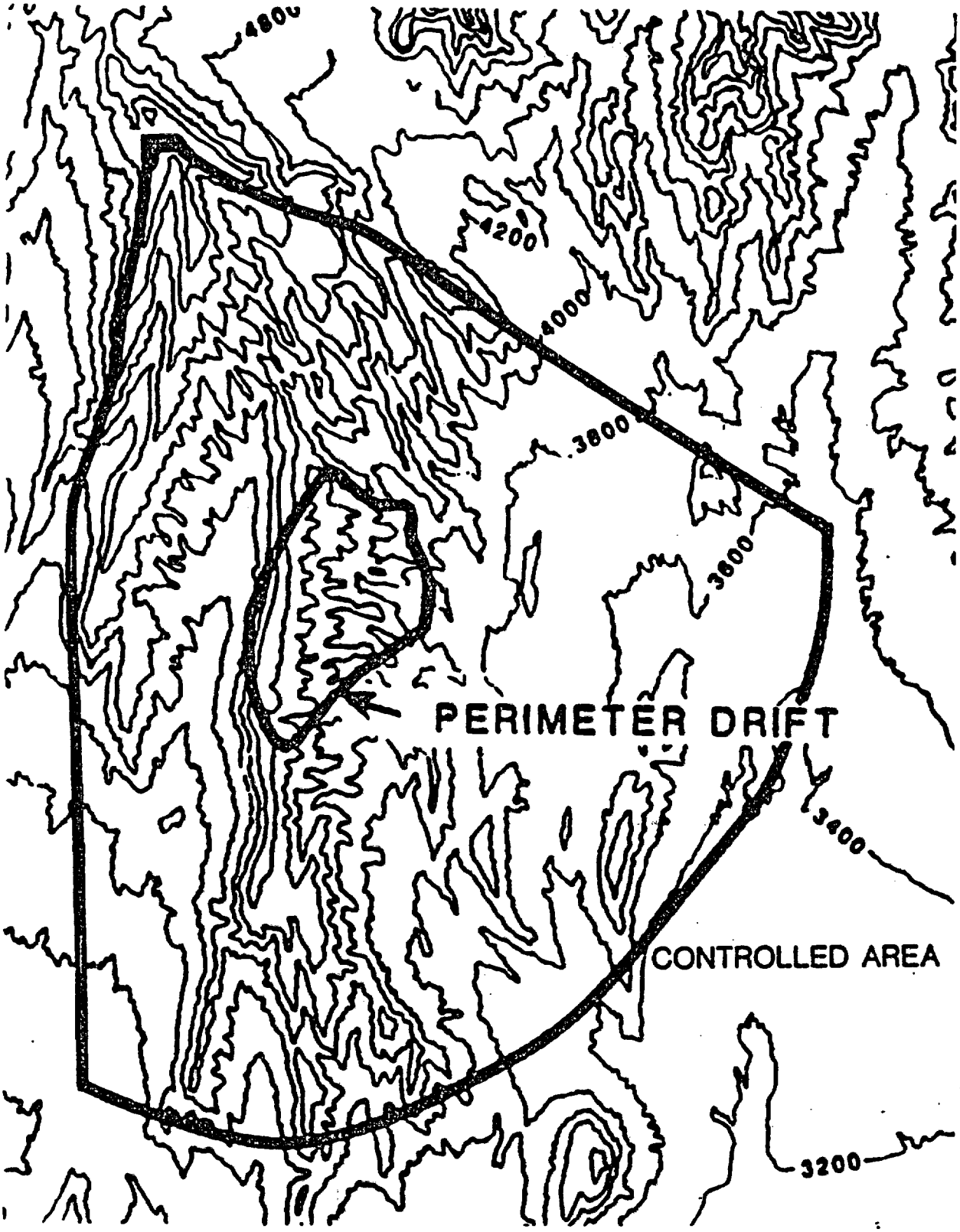
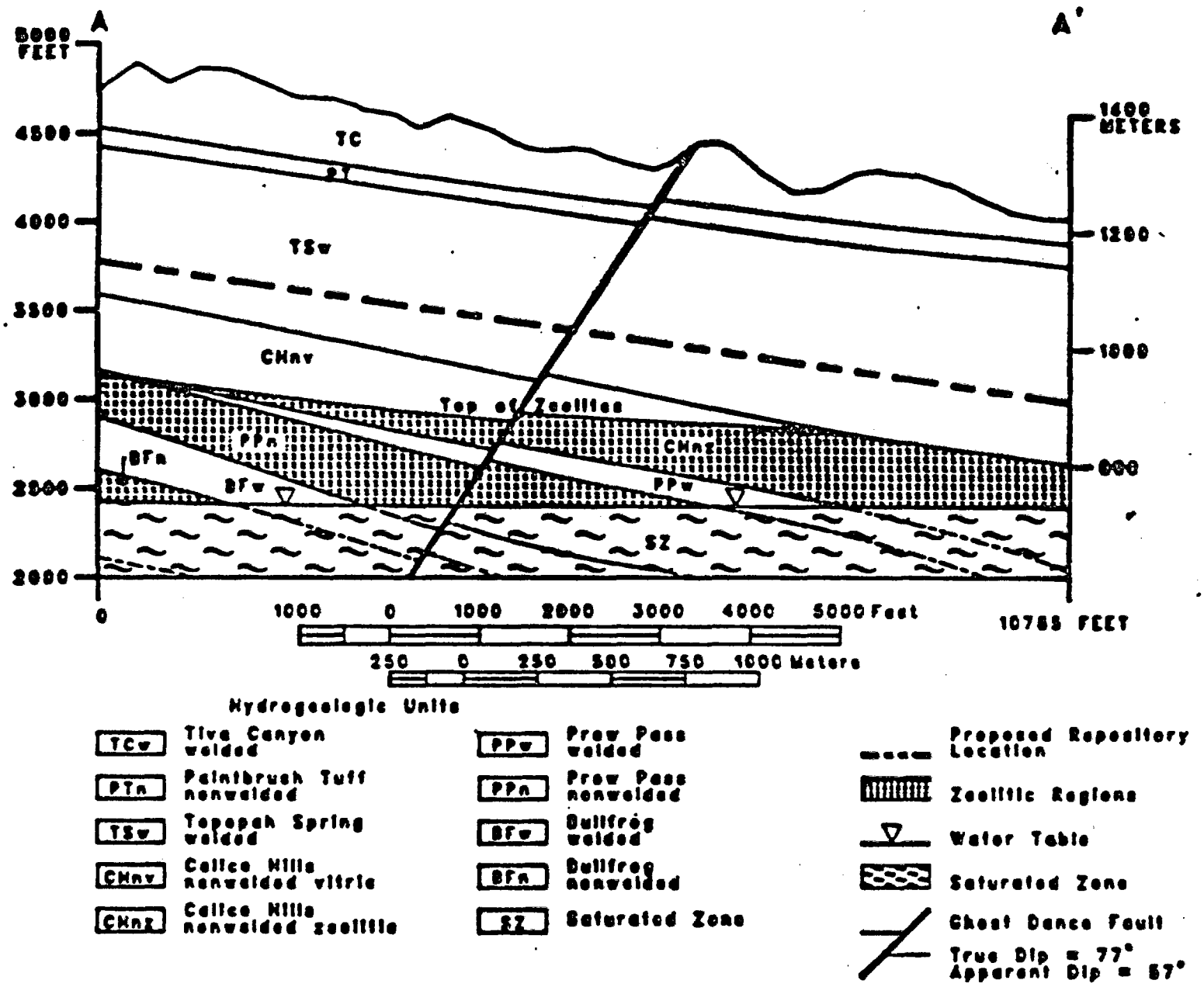
GEOGRAPHIC BASIS FOR SELECTED PARAMETER-NEEDS

(Groundwater Flow)

Performance or Design Usage	Area of Concern
▪ Groundwater Travel Time	Disturbed Zone to Accessible Environment * (Unsaturated Zone Emphasis)
▪ Total System Releases	Repository to Accessible Environment * (Unsaturated Zone Emphasis)
▪ Underground Facility Design	Vicinity of Sealed Shafts Vicinity of Drifts, Ramps (Unsaturated Zone Only)
▪ Water Supplies	Site Vicinity Aquifers (Saturated Zone Only)


4800
4200
4000
3800
3600
PERIMETER DRIFT
3400
CONTROLLED AREA
3200


A
A'
5000 FEET
4500
4000
3500
3000
2500
2000
1400 METERS
1200
1000
800
TC
TSw
CHnv
Top of Zeolites
PPn
CHnz
BFn
BFw
PPw
SZ
0
1000
0
1000
2000
3000
4000
5000 Feet
10755 FEET
250
0
250
500
750
1000 Meters
Hydrogeologic Units
TCw Tiva Canyon welded
PTn Paintbrush Tuff nonwelded
TSw Topopah Spring welded
CHnv Calico Hills nonwelded vitric
CHnz Calico Hills nonwelded zeolitic
PPw Prow Pass welded
PPn Prow Pass nonwelded
BFw Bullfrog welded
BFn Bullfrog nonwelded
SZ Saturated Zone
Proposed Repository Location
Zeolitic Regions
Water Table
Saturated Zone
Ghost Dance Fault
True Dip = 77°
Apparent Dip = 57°

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EXAMPLE OF EXPLICIT PARAMETER NEEDS FOR ASSESSING GROUNDWATER FLOW IN UNSATURATED ZONE

PARAMETER	MATERIAL TYPE	SPATIAL LOCATION	CHARACTERIZATION GOAL
PERMEABILITY	MATRIX	BELOW REPOSITORY	HIGH CONFIDENCE IN MEAN VALUE
•	•	•	• • • STANDARD DEVIATION
•	•	•	• • • SPATIAL CORRELATION
•	FRACTURES	•	MEDIUM • • MEAN VALUE
⋮			
POROSITY	MATRIX	BELOW REPOSITORY	HIGH • • MEAN VALUE
⋮			
CONTACT ALTITUDE		BELOW REPOSITORY	HIGH • • MEAN VALUE
⋮			
ETC (150 PARAMETERS)			

TREATMENT OF PARAMETER UNCERTAINTY

Sensitivity Analysis

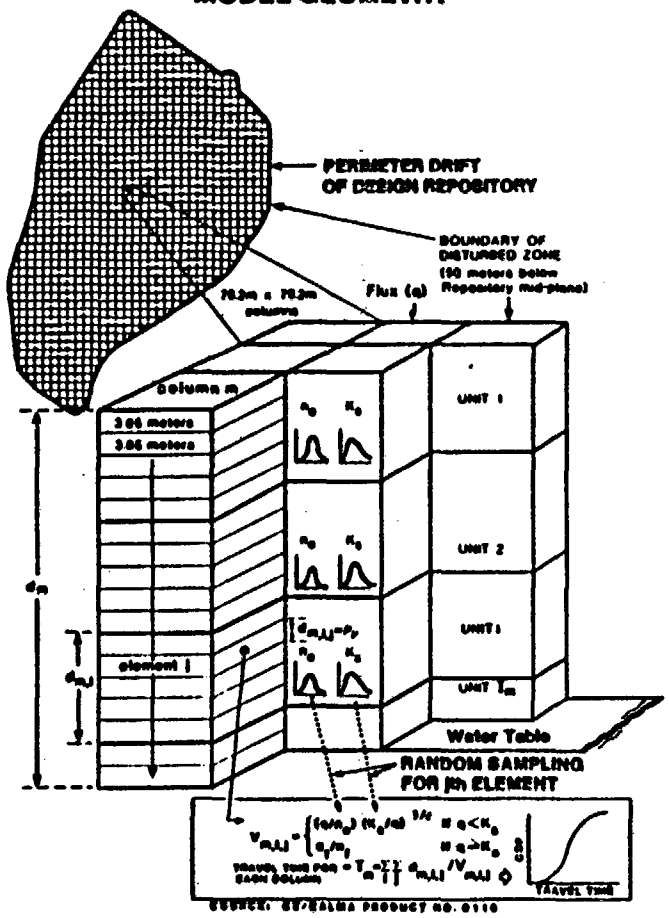
- Identify most influential variables

Uncertainty Analysis

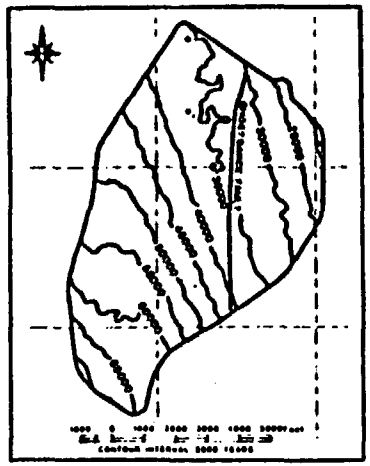
- Treat sensitive input variables as random distributions
- Probabalistic Prediction of GWTT
  - Monte Carlo
  - Direct Stochastic Simulation

GROUNDWATER TRAVEL TIME AT YUCCA MOUNTAIN

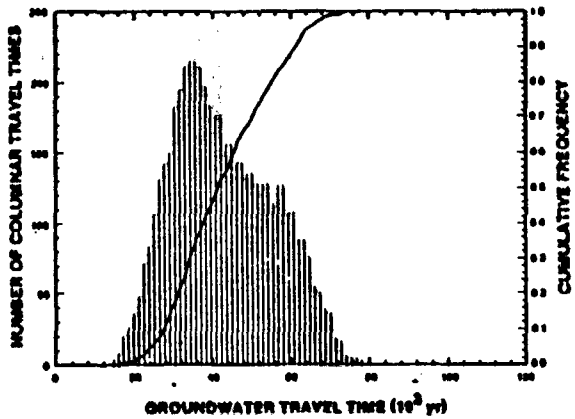
MODEL GEOMETRY



GEOGRAPHIC DISTRIBUTION



HISTOGRAM & CUMULATIVE-FREQUENCY DISTRIBUTION



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TREATMENT OF CONCEPTUAL UNCERTAINTY

- Less Amenable to Quantification

- Addressed by Consideration of Alternative Conceptual Models
  - Weighting by Professional Judgment
  - Extensive Dialogue with State, NRC, Expert Consultants

- Validation of Modeling Approaches
  - Calibration with respect to field observations (ψ, S, $\delta h/\delta \ell$)
  - Comparison to controlled field experiments
  - Comparison to controlled laboratory experiments
  - Periodic Formal Peer Review

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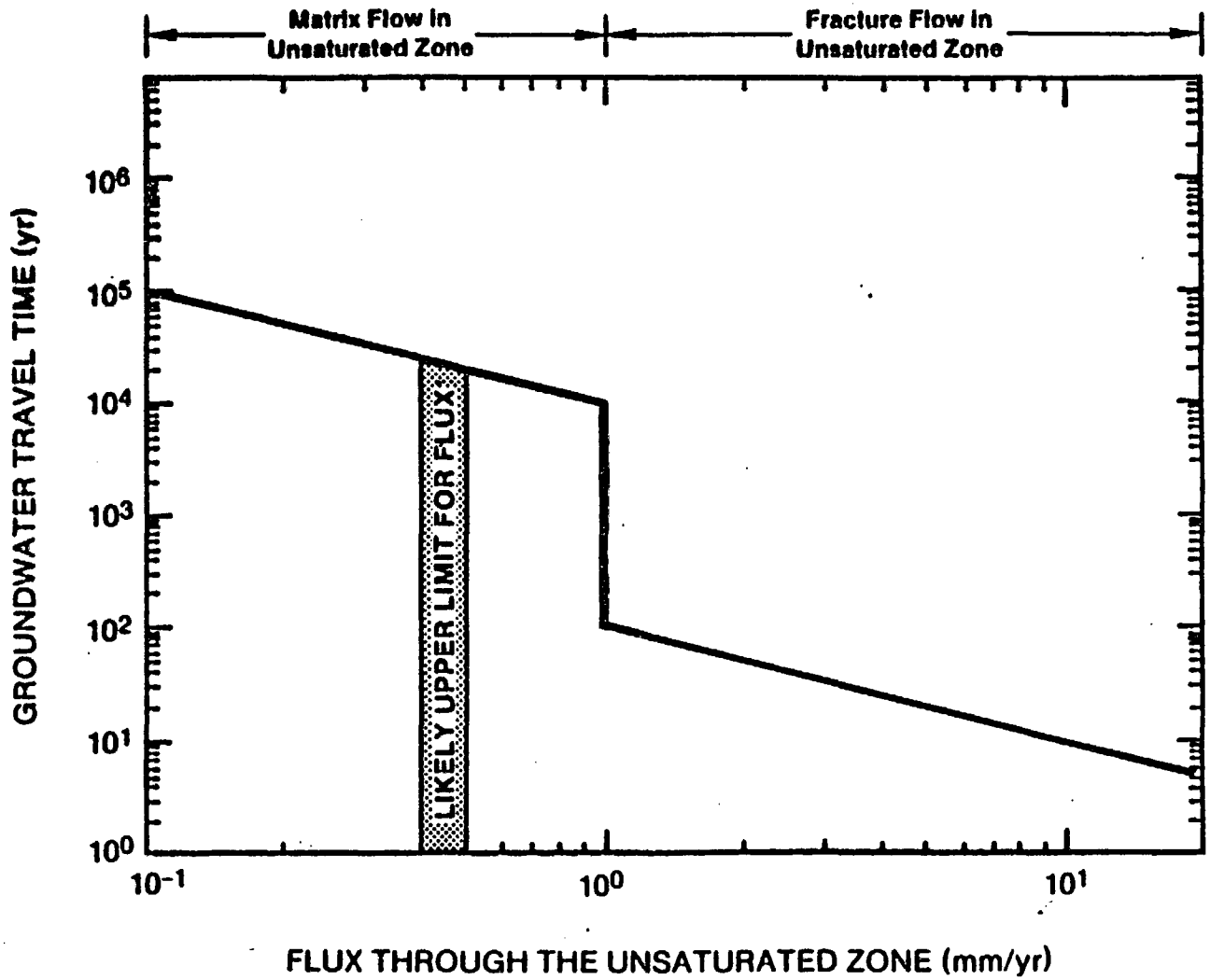
GROUNDWATER FLOW TIMES

Sandia National Laboratories



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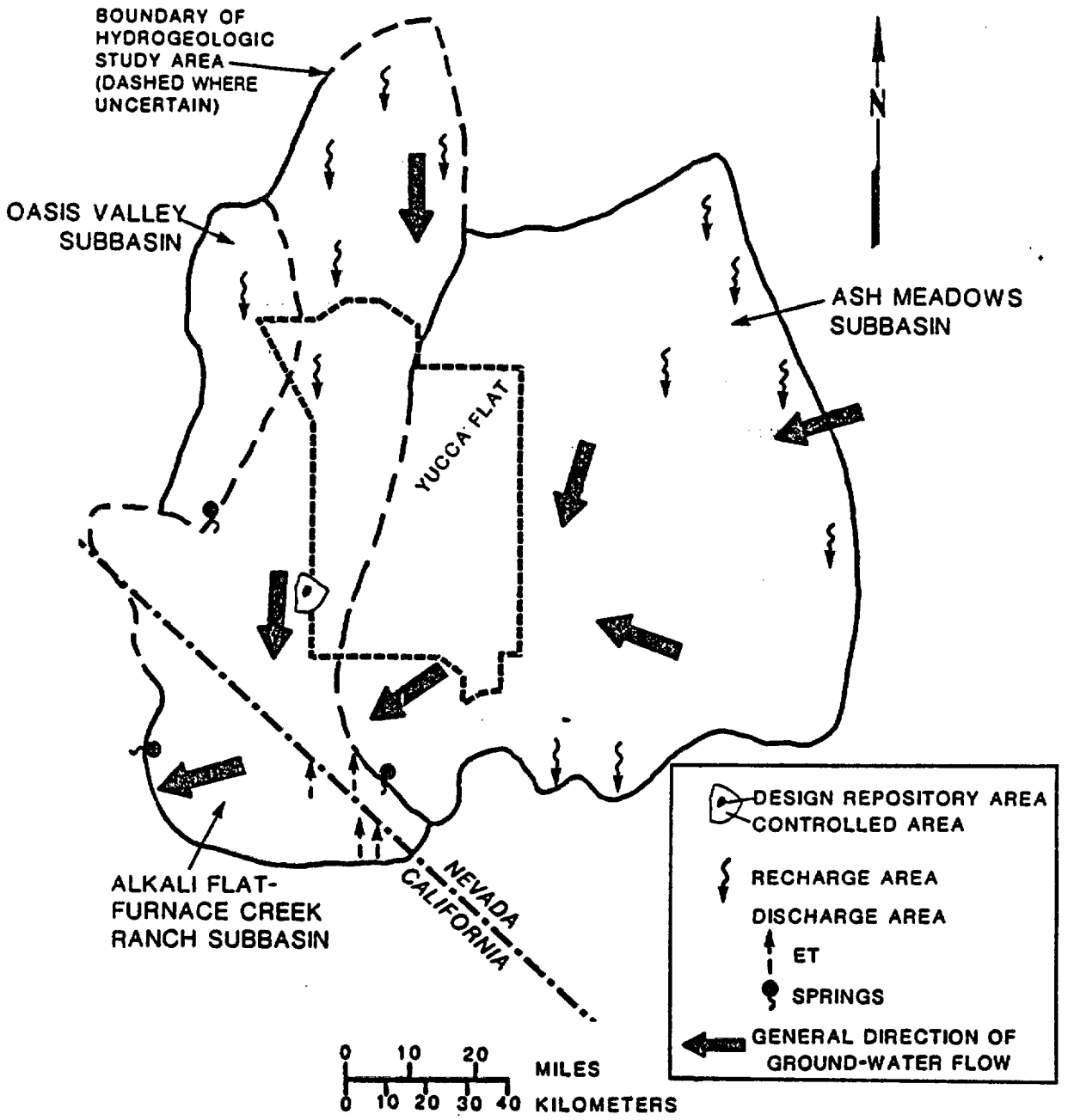
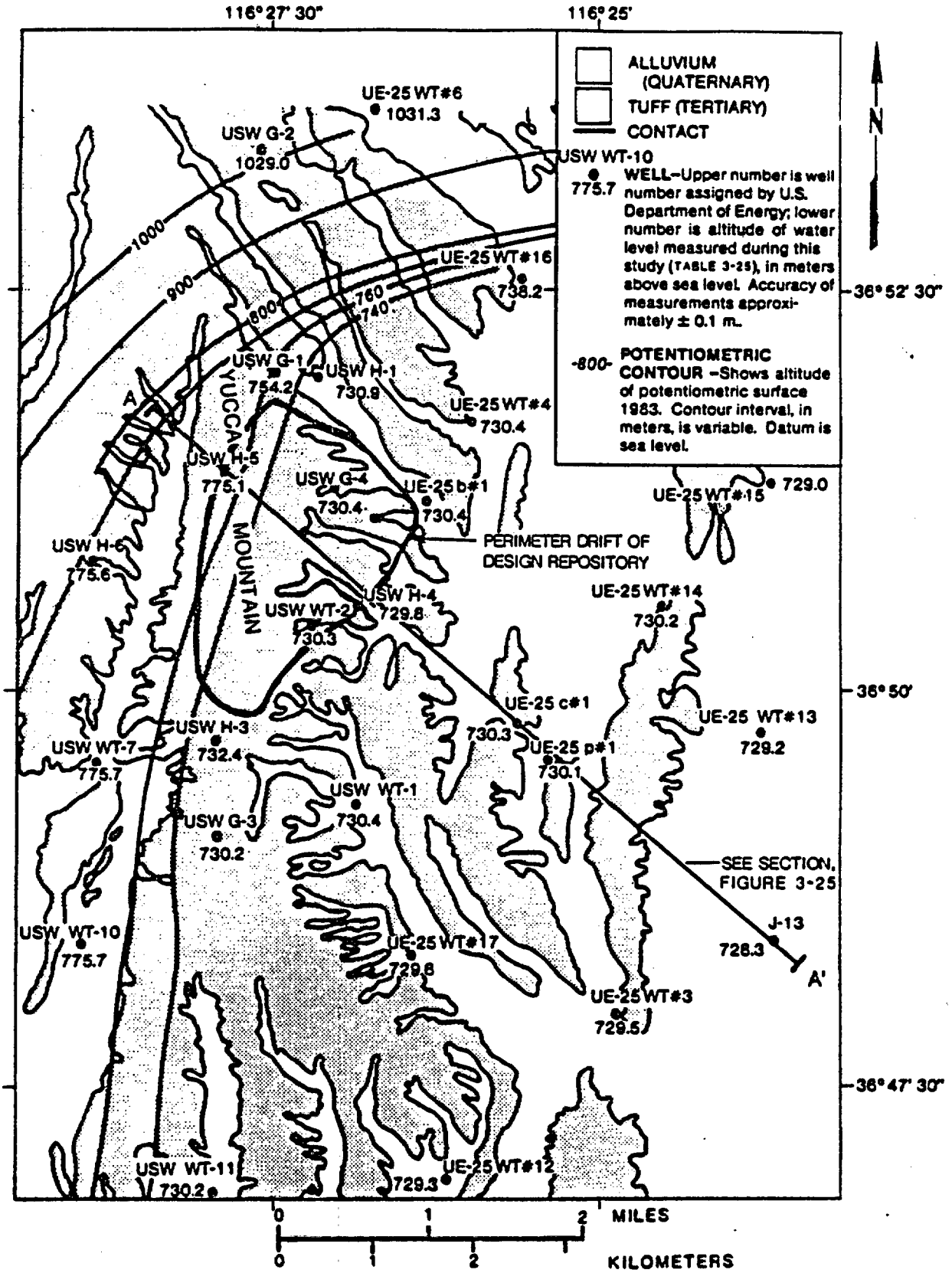
HYDROLOGIC REGIMES

- UNSATURATED-ZONE (UZ) HYDROLOGY
  - -- SITE
- SATURATED-ZONE (SZ) HYDROLOGY
  - -- SITE
  - -- REGION

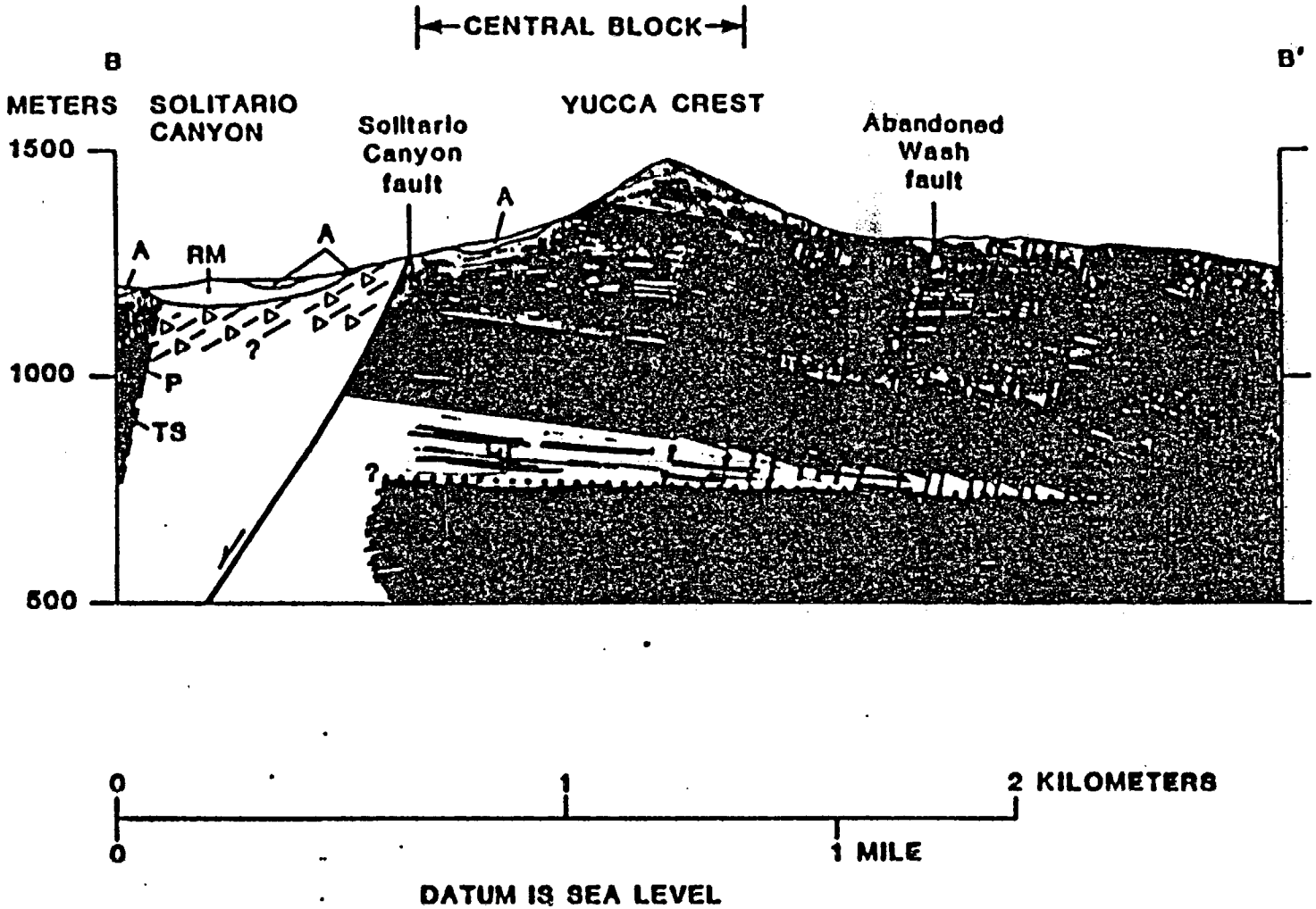

BOUNDARY OF HYDROGEOLOGIC STUDY AREA (DASHED WHERE UNCERTAIN)
OASIS VALLEY SUBBASIN
ASH MEADOWS SUBBASIN
YUCCA FLAT
ALKALI FLAT-FURNACE CREEK RANCH SUBBASIN
NEVADA
CALIFORNIA
N
DESIGN REPOSITORY AREA
CONTROLLED AREA
RECHARGE AREA
DISCHARGE AREA
ET
SPRINGS
GENERAL DIRECTION OF GROUND-WATER FLOW
0 10 20 MILES
0 10 20 30 40 KILOMETERS

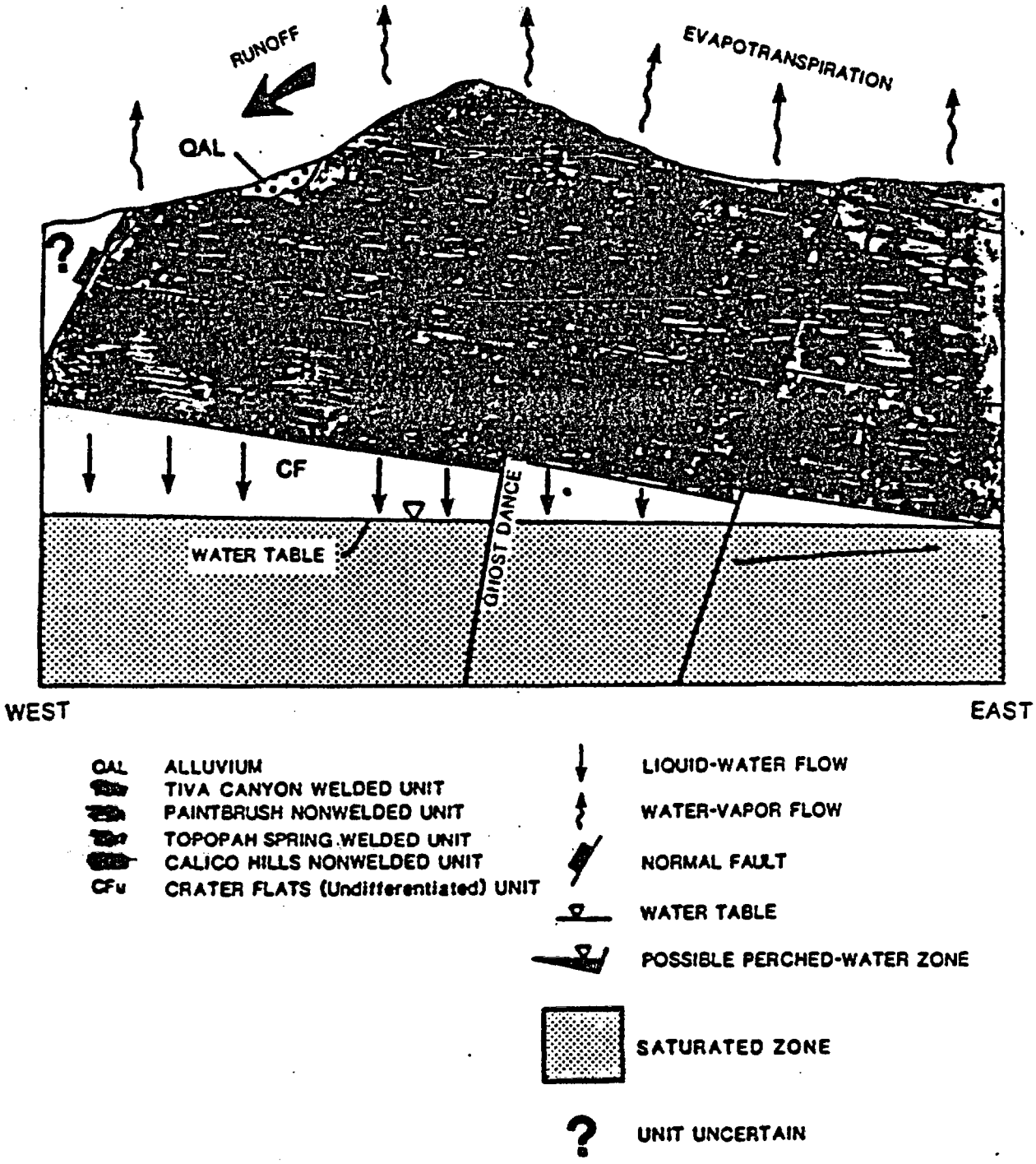

116° 27' 30"
116° 25'
36° 52' 30"
36° 50'
36° 47' 30"
ALLUVIUM (QUATERNARY)
TUFF (TERTIARY)
CONTACT
N
775.7 WELL–Upper number is well number assigned by U.S. Department of Energy; lower number is altitude of water level measured during this study (TABLE 3-25), in meters above sea level. Accuracy of measurements approximately ± 0.1 m.
-800- POTENTIOMETRIC CONTOUR –Shows altitude of potentiometric surface 1983. Contour interval, in meters, is variable. Datum is sea level.
UE-25 WT#6
1031.3
USW G-2
1029.0
USW WT-10
775.7
1000
900
800
760
740
UE-25 WT#16
738.2
USW G-1
754.2
USW H-1
730.9
UE-25 WT#4
730.4
YUCCA MOUNTAIN
A
USW H-5
775.1
USW G-4
730.4
UE-25 b#1
730.4
UE-25 WT#15
729.0
PERIMETER DRIFT OF DESIGN REPOSITORY
USW H-6
775.6
USW H-4
729.8
USW WT-2
730.3
UE-25 WT#14
730.2
UE-25 c#1
730.3
UE-25 WT#13
729.2
USW H-3
732.4
USW WT-7
775.7
UE-25 p#1
730.1
USW WT-1
730.4
USW G-3
730.2
SEE SECTION, FIGURE 3-25
J-13
728.3
A'
USW WT-10
775.7
UE-25 WT#17
729.8
UE-25 WT#3
729.5
USW WT-11
730.2
UE-25 WT#12
729.3
0 1 2 MILES
0 1 2 KILOMETERS

UZ FLOW AT YUCCA MOUNTAIN

SPECIAL ASPECTS

- APPLICABILITY OF EXISTING CONCEPTS AND THEORIES
- NONSTANDARD FIELD AND LAB TECHNIQUES
- MULTIPLE FLUIDS
- VARIABLE HYDRAULIC CONDUCTIVITY
- FRACTURE vs MATRIX FLOW
- SPATIALLY VARIABLE FLUX


CENTRAL BLOCK
B
B'
METERS
SOLITARIO CANYON
Solitario Canyon fault
YUCCA CREST
Abandoned Wash fault
1500
1000
500
A
RM
A
A
?
P
TS
?
0
1
2 KILOMETERS
0
1 MILE
DATUM IS SEA LEVEL


RUNOFF
EVAPOTRANSPIRATION
QAL
?
CF
GHOST DANCE
WATER TABLE
WEST
EAST
QAL ALLUVIUM
TIVA CANYON WELDED UNIT
PAINTBRUSH NONWELDED UNIT
TOPOPAH SPRING WELDED UNIT
CALICO HILLS NONWELDED UNIT
CFu CRATER FLATS (Undifferentiated) UNIT
LIQUID-WATER FLOW
WATER-VAPOR FLOW
NORMAL FAULT
WATER TABLE
POSSIBLE PERCHED-WATER ZONE
SATURATED ZONE
UNIT UNCERTAIN

RADIONUCLIDE RETARDATION

K. EGGERT

Radionuclide Retardation:

Slowing of Radionuclide Movement Along Transport Paths Through the Porous or Fractured Porous Media by Mechanical or Chemical Processes Relative to the Movement That Would be Expected in the Absence of Those Processes.

Examples of Retardation Processes Thought to be Significant at Yucca Mountain Include:

1. **Sorption**
   - **In Matrix**
   - **Along Fracture Surfaces**
2. **Precipitation**
3. **Matrix Diffusion**

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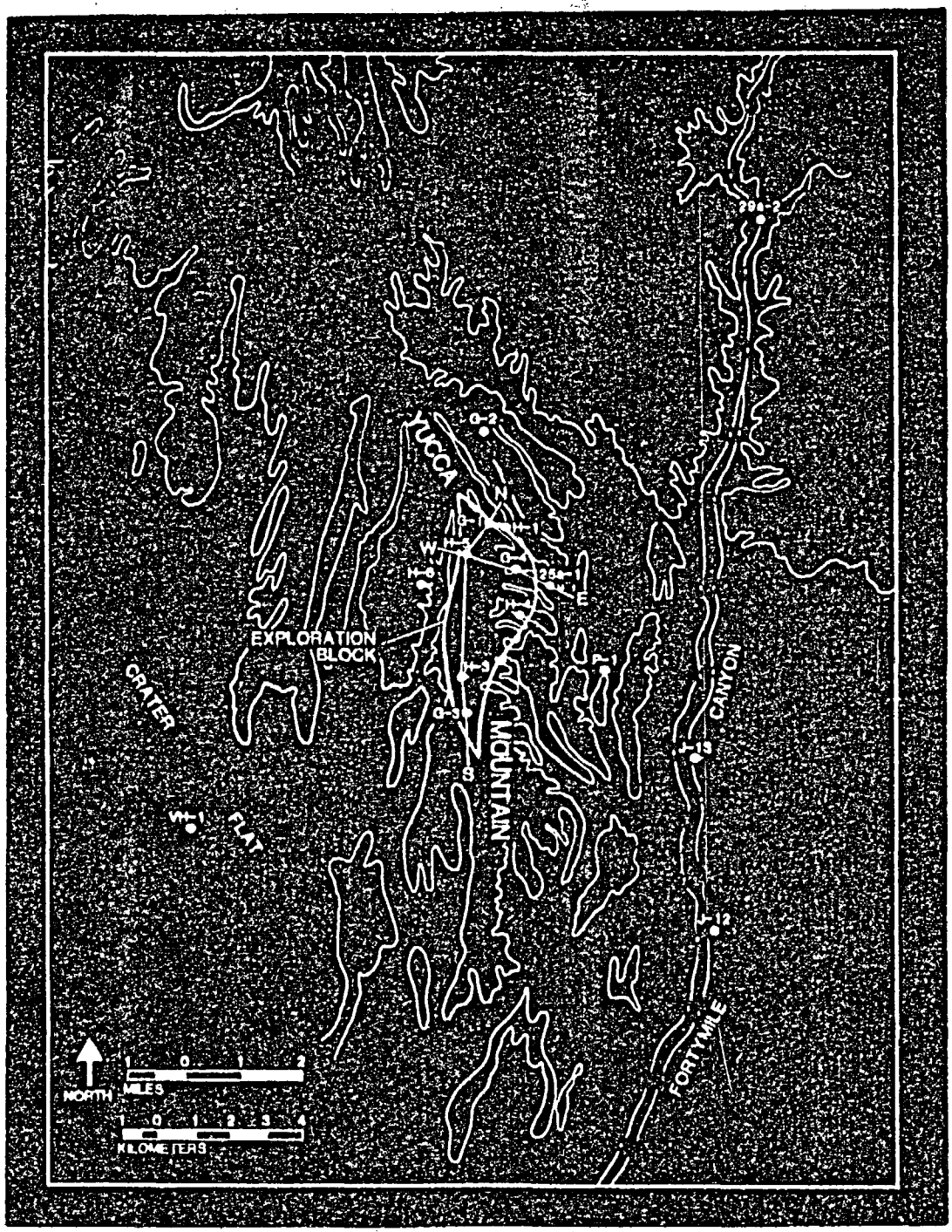

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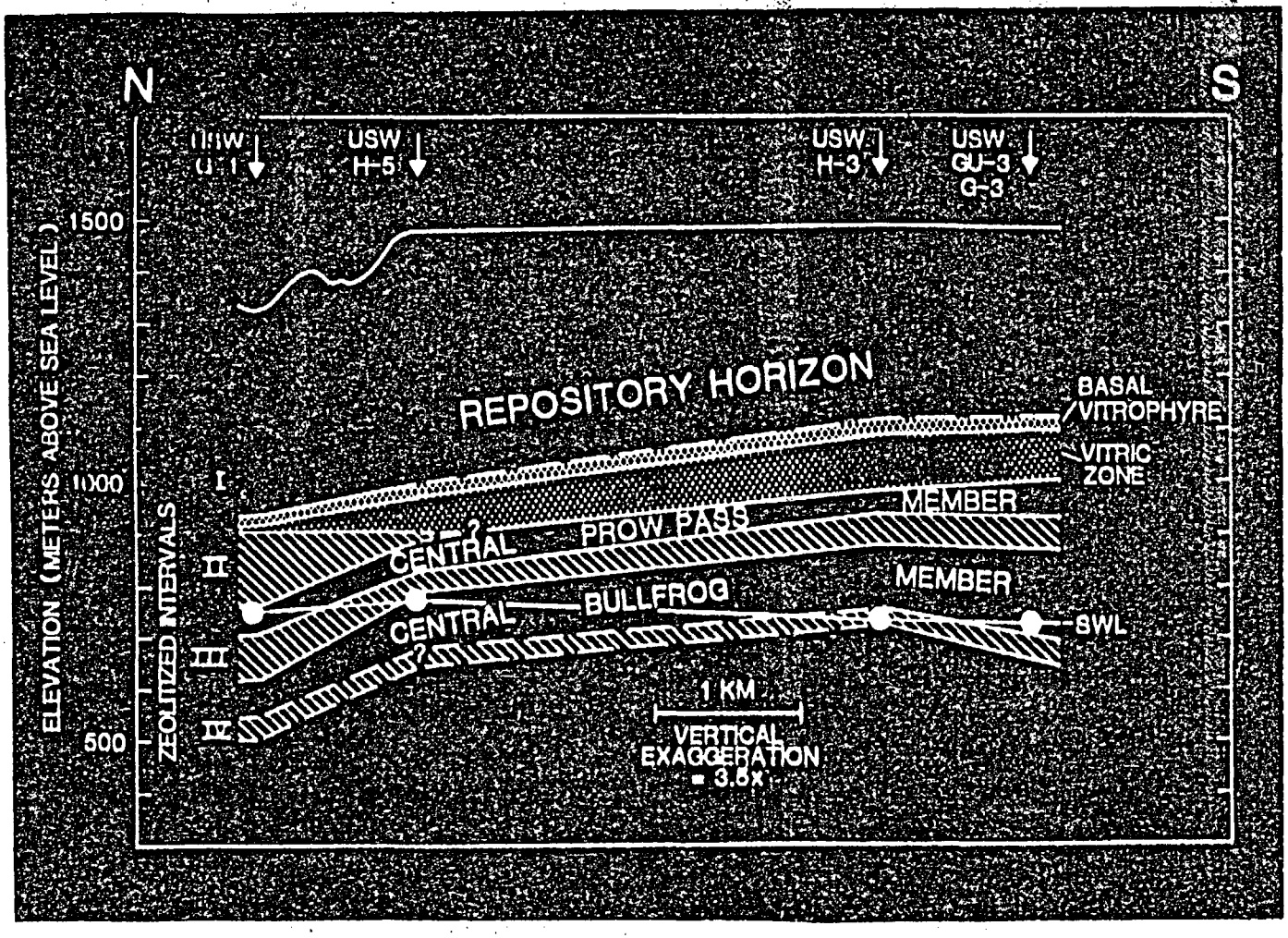

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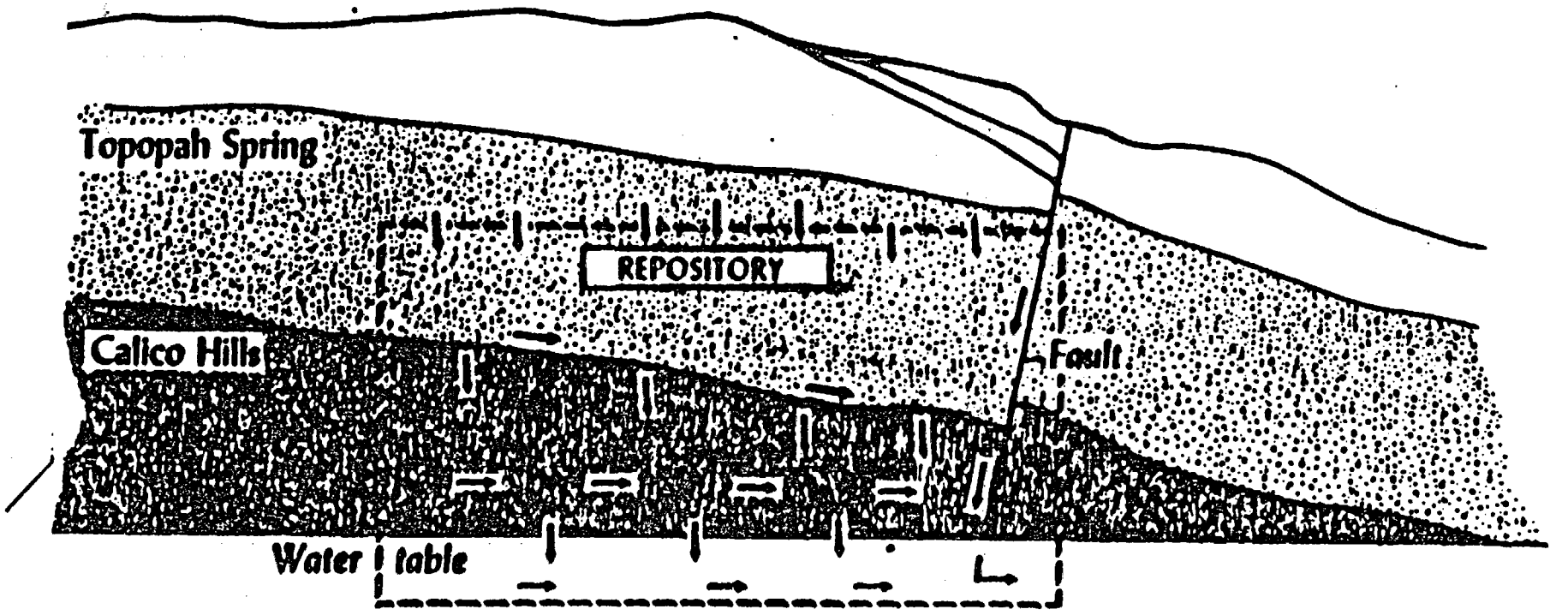
YUCCA MOUNTAIN



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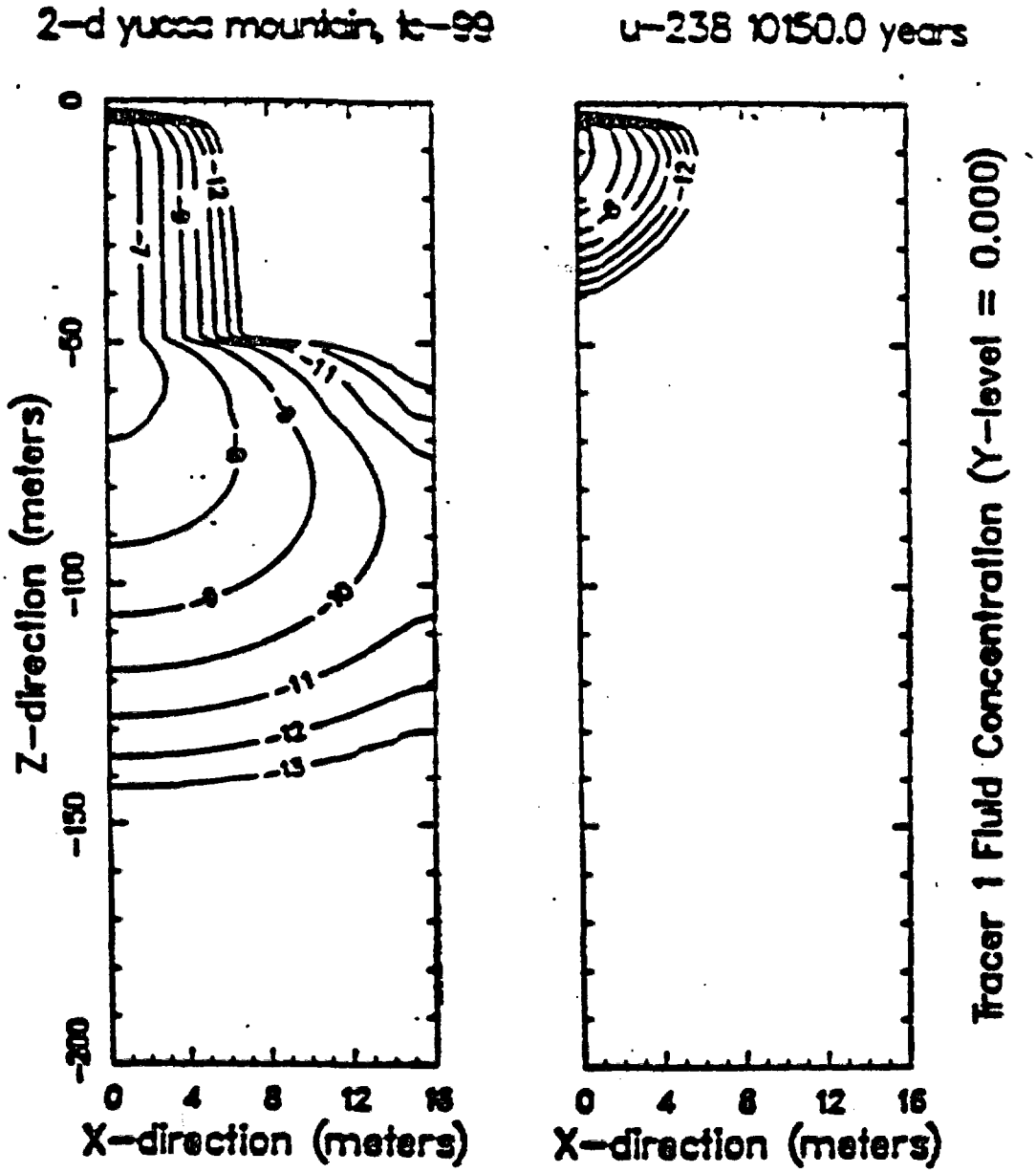
Transport Calculations from a Single Waste Package



Relevance of Retardation to Performance

- There is a significant potential for radionuclide retardation to affect transport of Yucca Mountain.
- The total system performance assessment calls for retardation coefficients for radionuclides in the inventory of EBS releases.
- Under currently assumed expected conditions, groundwater travel time alone may be sufficient to meet release limits at the accessible environment.
- However, transport mechanisms must be studied in order to justify these assumptions; and,
- under unexpected conditions, retardation may be required.

- CHEMISTRY IN UNSATURATED SOIL/ROCK
  vapor–rock interactions
  (hydro–thermo–chemical)

- FRACTURE FLOW – Is it important in unsaturated rock?

- COLLOID migration
  precipitates
  particulates

- STOCHASTIC BEHAVIOR
  need mean $c = c(x_1, x_2, \ldots, x_n)$
  and variance $c = f(x_1, \ldots, x_n, \sigma_1, \ldots, \sigma_n)$
  where x_i = variable, σ_i = uncertainty in x_i

- COUPLED PROCESSES
  flux $J_i = \sum_j L_{ij} F_j$ where F_j are driving forces

  what are L_{ij} ?, especially what are L_{ij}, $i \neq j$?

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Radionuclide Retardation Related Studies Underway at LANL

1. Groundwater Chemistry
2. Retardation by Sorption Mechanisms (Sorption)
3. Retardation by Precipitation (Solubility)
4. Effective Retardation by Transport Mechanisms (Dynamic Transport)
5. Integrated Modeling of Transport at Yucca Mountain (Retardation Sensitivity)

Sorption

- Recent work has concentrated on the derivation of basic thermodynamic data for from site specific sorption data from batch sorption experiments.

- Technique is based on deconvoluting a Fredholm integral representing total concentration of an adsorbed species as the sum of the adsorbed concentrations and specific sites.

- The potential use of this inverse method is to allow prediction of effective partition coefficients associated with mineral assemblages.

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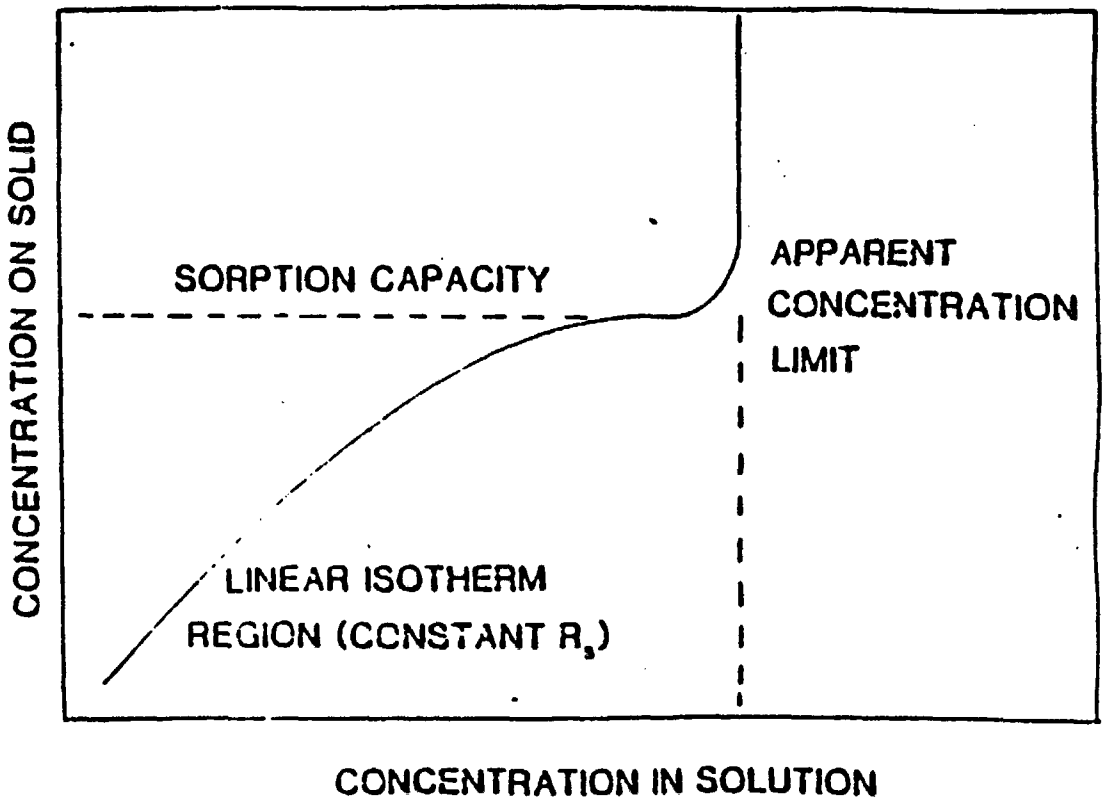
SCHEMATIC SORPTON ISOTHERM



Representative sorption ratios (distribution coefficients) and retardation factors for eight radionuclide elements with Yucca Mountain tuff[a]

Waste element	Welded tuff Topopah Spring Member porosity = 11%		Bedded tuff Topopah Spring Member porosity = 35%		Bedded tuff - tuffaceous beds of Calico Hills porosity = 35%	
	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]
Americium (Am)	1,200	25,000	180	820	4,600	21,000
Cesium (Cs)	290	6,000	16,000	73,000	7,800	35,000
Neptunium (Np)	7	150	ND[d]	ND	11	50
Plutonium (Pu)	64	1,300	120	540	140	630
Strontium (Sr)	53	1,100	17,000	77,000	3,900	17,000
Technetium (Tc)	0.3	7	2.5[e]	12	ND	ND
Uranium (U)	1.8	37	2.5	12	5.3	26
Barium (Ba)	900	18,000	38,000	180,000	94,000	440,000

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Yucca Mountain

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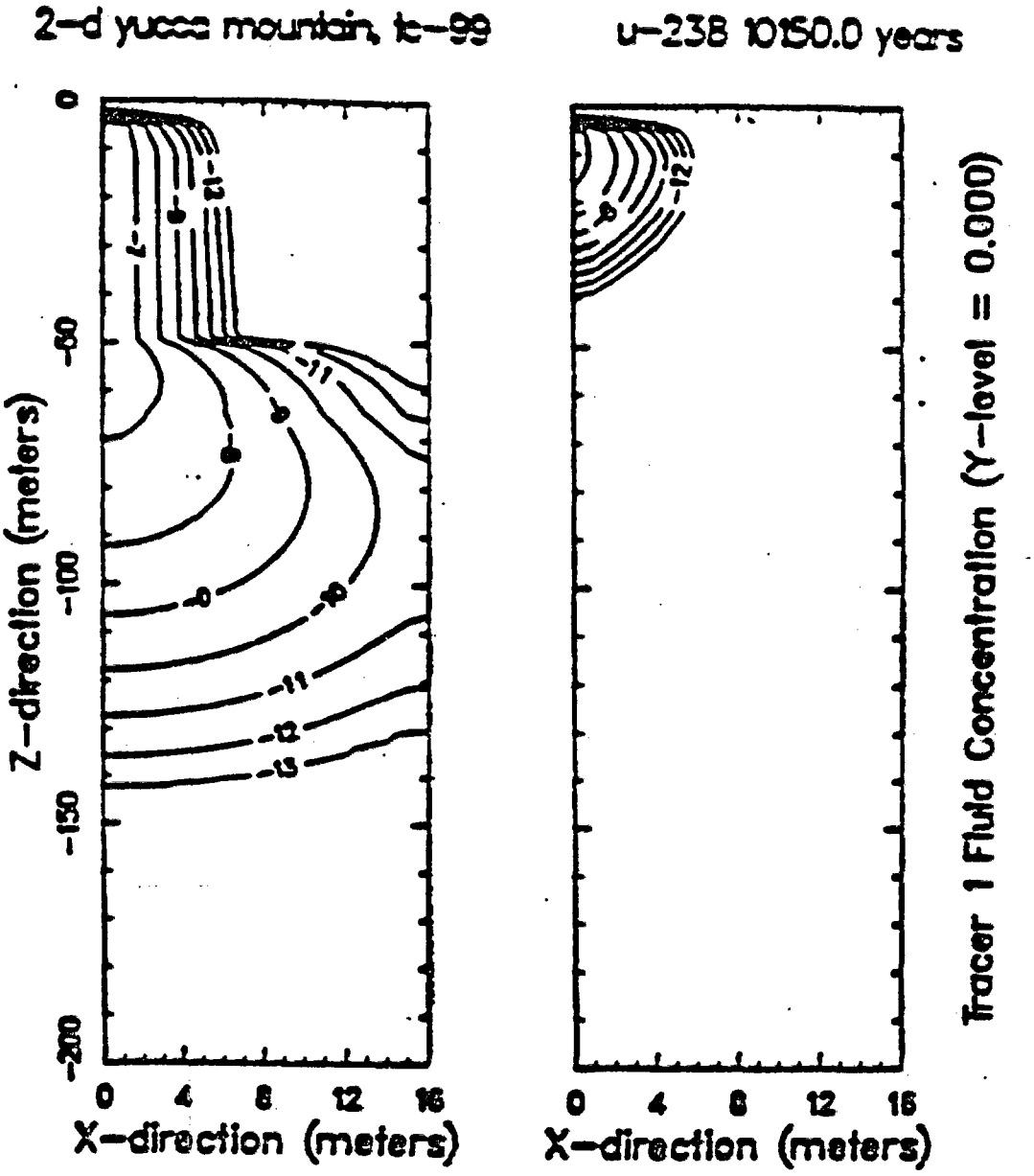
Transport Calculations from a Single Waste Package



Transport Dynamics

Based on J-13 water, transport in the form of psuedo colloids is not expected to be a problem due to the lack of colloidal material in undisturbed J-13 water; however, if colloids are formed:

- The larger colloids appear to move at rates consistent with the hydraulic aperture of the fractures, while smaller colloids are slowed by mixing with "dead" water in the fractures.

- Column experiments have yielded a rapidly moving fraction (~1%) of sorbing tracers that may require a colloidal explanation, eg. anomolies in break through curves indicate that Am behaves like a colloidal material.

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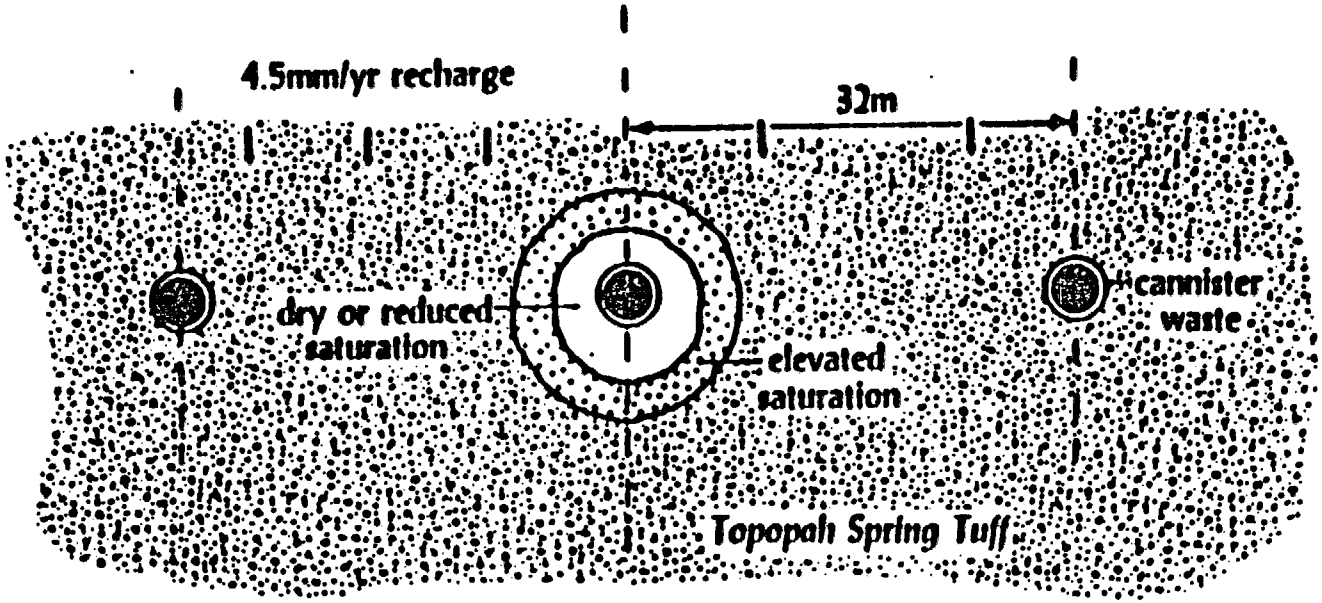
Coupled Hydrothermal Transport Processes Near a Horizontally Emplaced Waste Package



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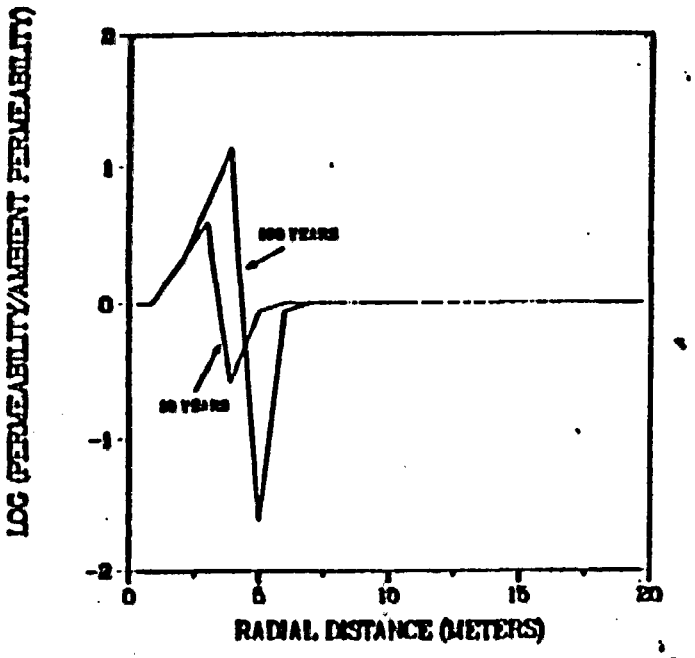
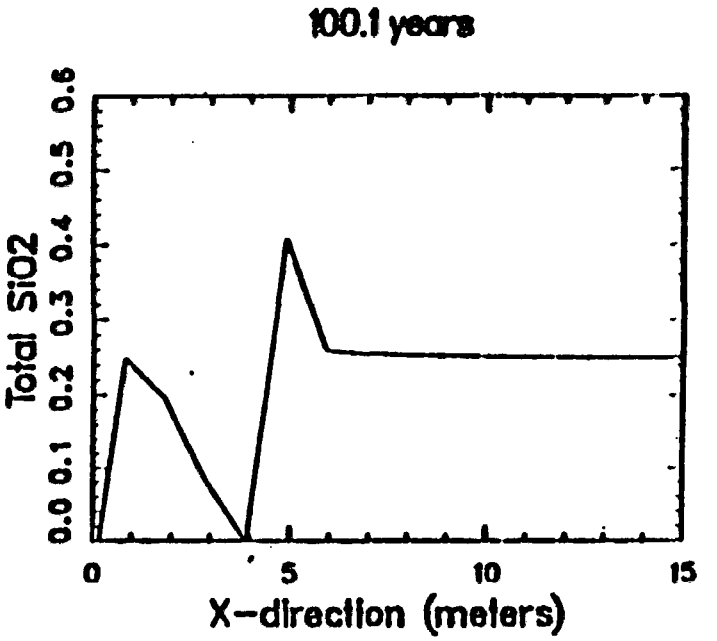
Coupled Hydrothermal and Transport Calculations

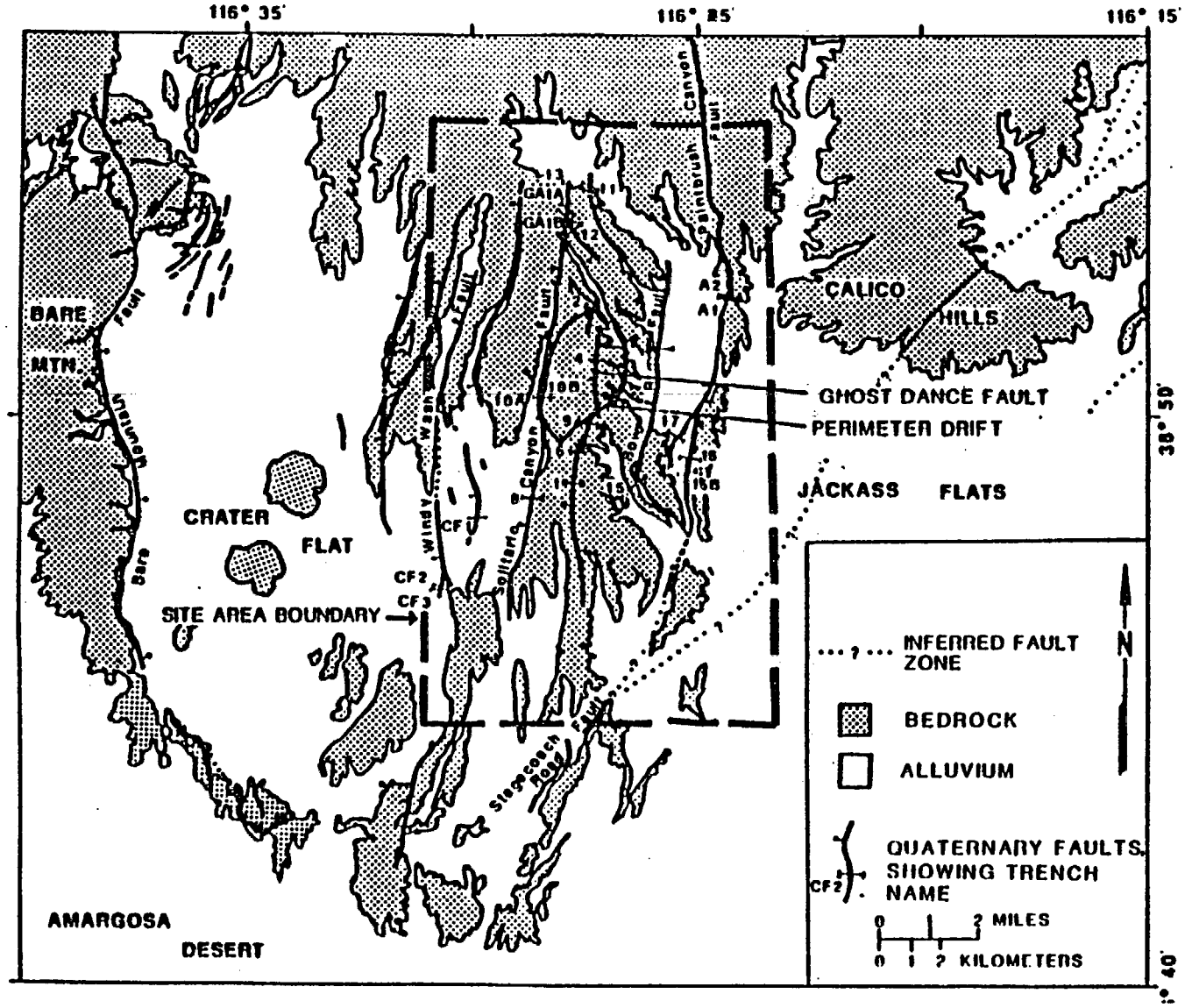


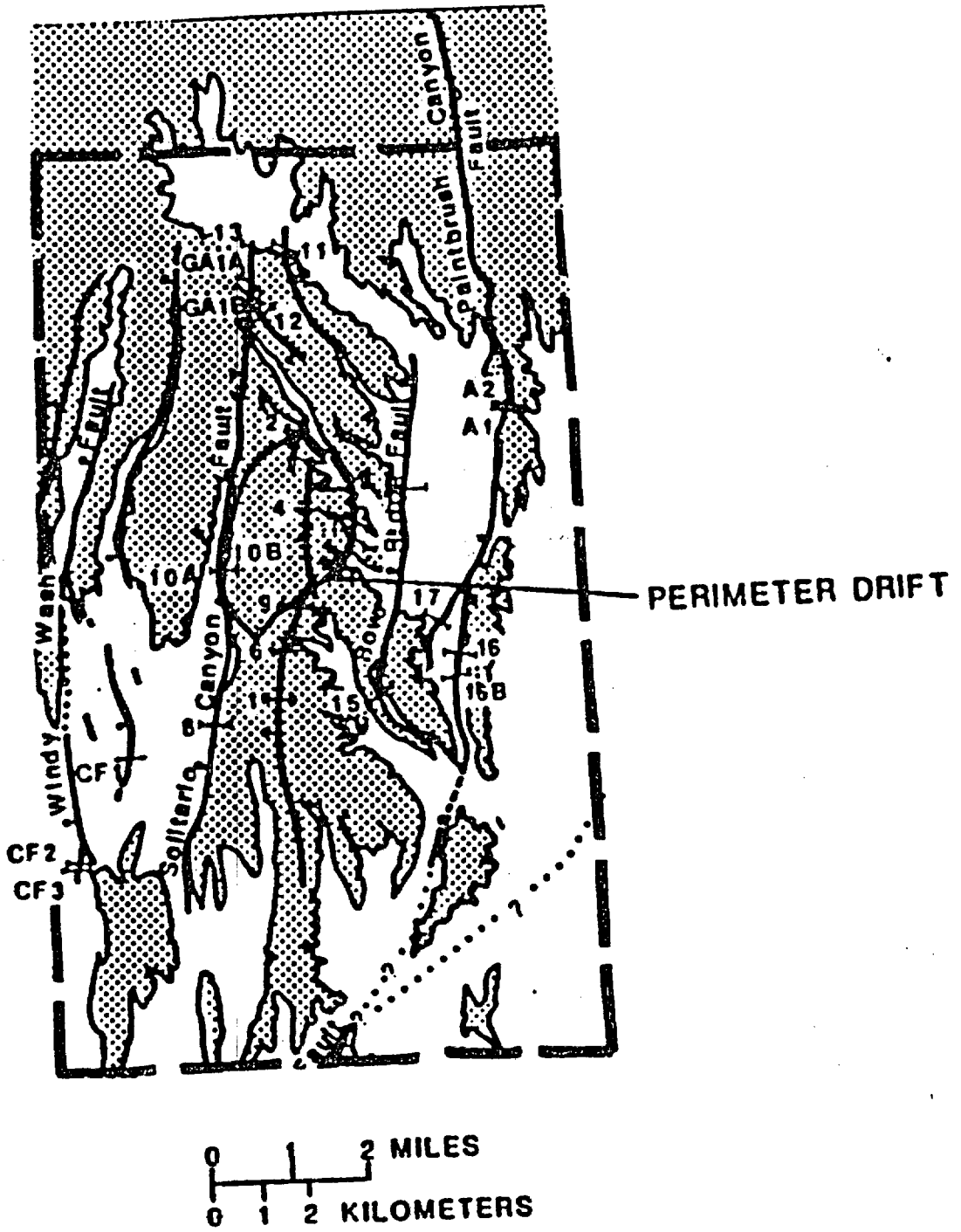


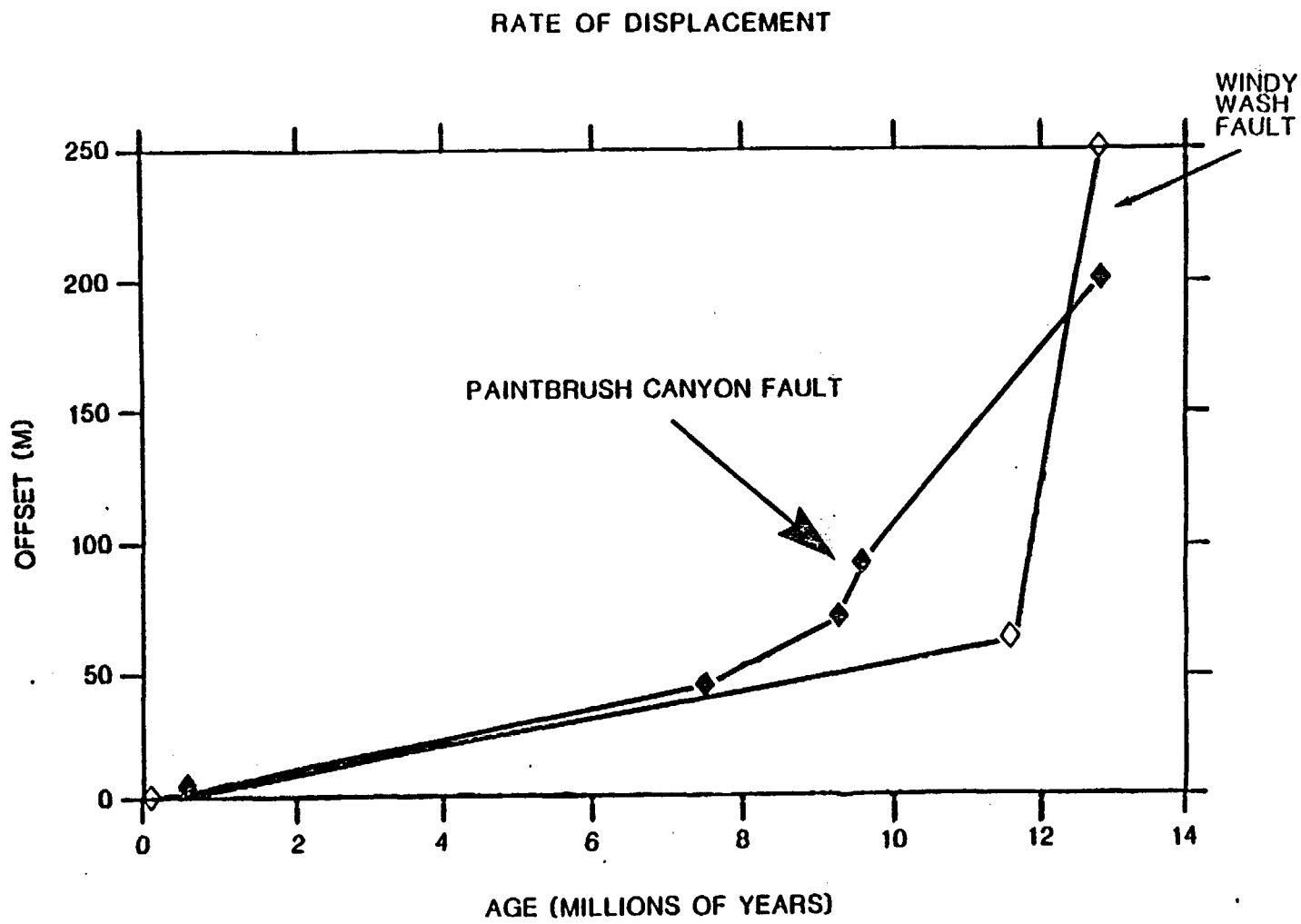
TECTONICS

T. GRANT

J. FRAZIER

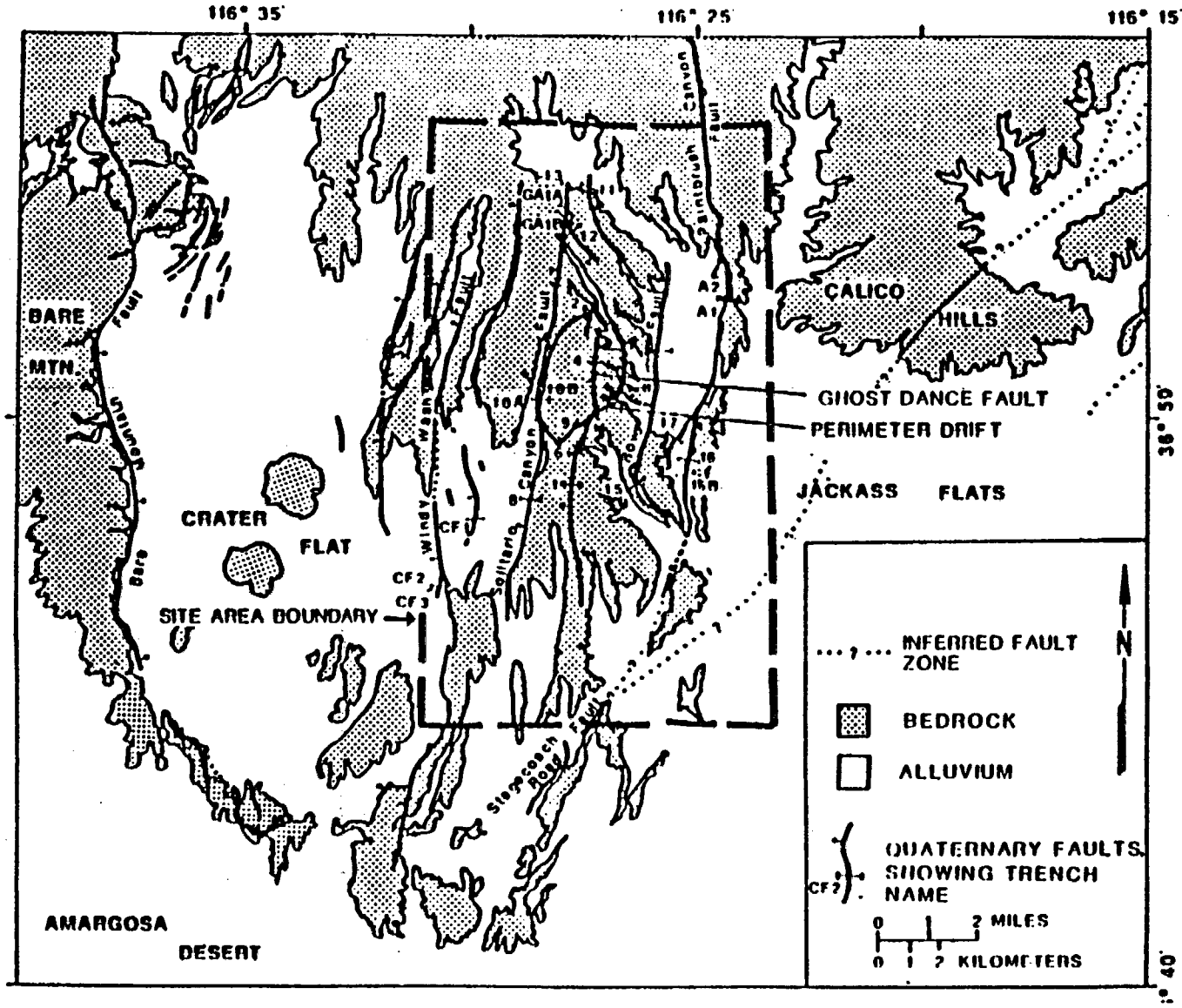

116° 35'
116° 25'
116° 15'
38° 50'
38° 40'
BARE MTN.
Bare Mtn. Fault
CRATER FLAT
SITE AREA BOUNDARY
AMARGOSA DESERT
Windy Wash Fault
Solitario Canyon Fault
Stagecoach Road Fault
Paintbrush Canyon Fault
CALICO HILLS
GHOST DANCE FAULT
PERIMETER DRIFT
JACKASS FLATS
GA1A
GA1B
A2
A1
10A
10B
16A
16B
CF
CF2
CF3
INFERRED FAULT ZONE
BEDROCK
ALLUVIUM
QUATERNARY FAULTS, SHOWING TRENCH NAME
0 1 2 MILES
0 1 2 KILOMETERS
N

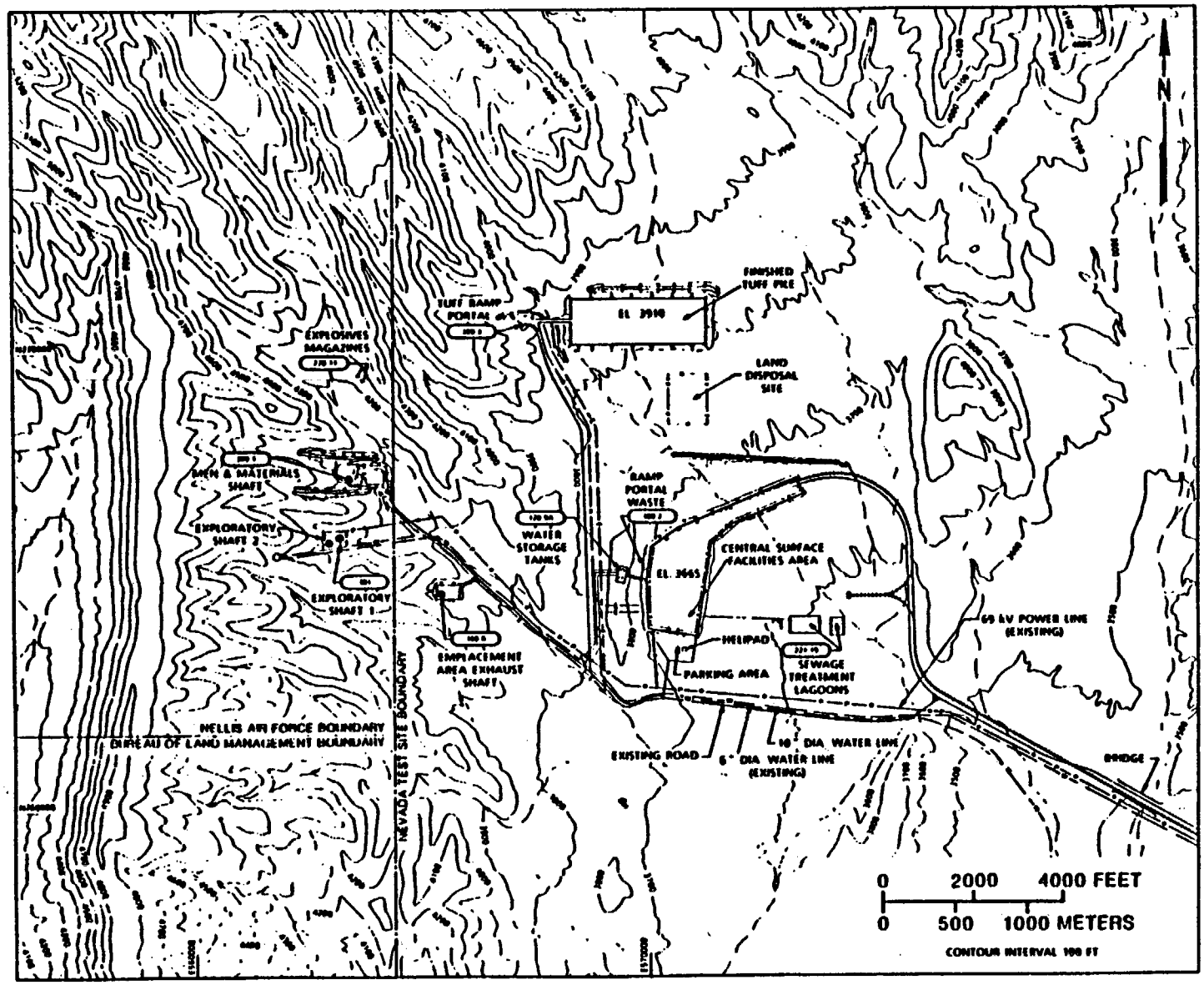

PERIMETER DRIFT
Windy Wash Fault
Solitario Canyon Fault
Bow Ridge Fault
Paintbrush Canyon Fault
GA1A
GA1B
10A
10B
A2
A1
16B
CF1
CF2
CF3
0 1 2 MILES
0 1 2 KILOMETERS


RATE OF DISPLACEMENT
WINDY WASH FAULT
PAINTBRUSH CANYON FAULT
OFFSET (M)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
AGE (MILLIONS OF YEARS)

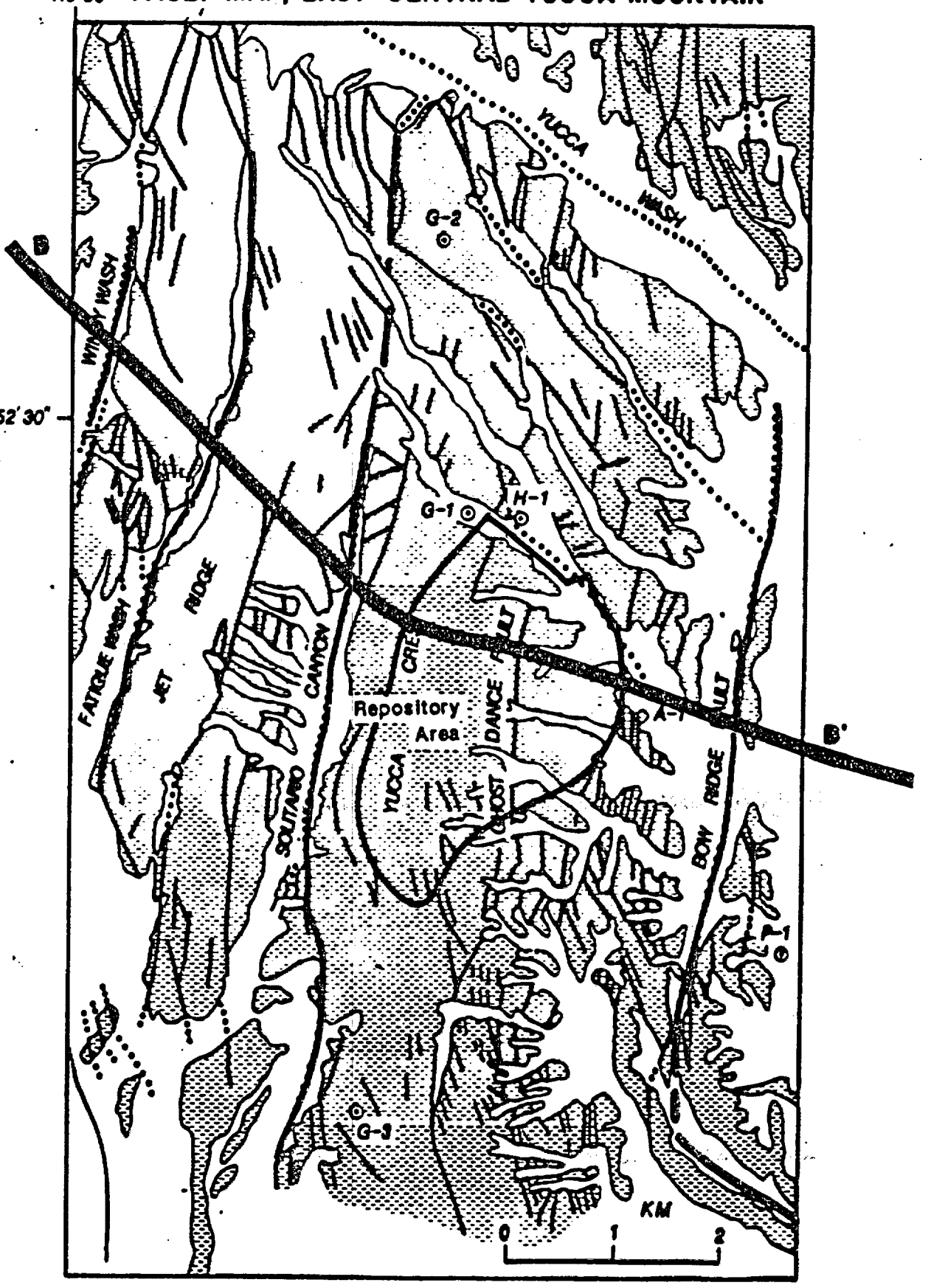
FAULT CHARACTERISTICS

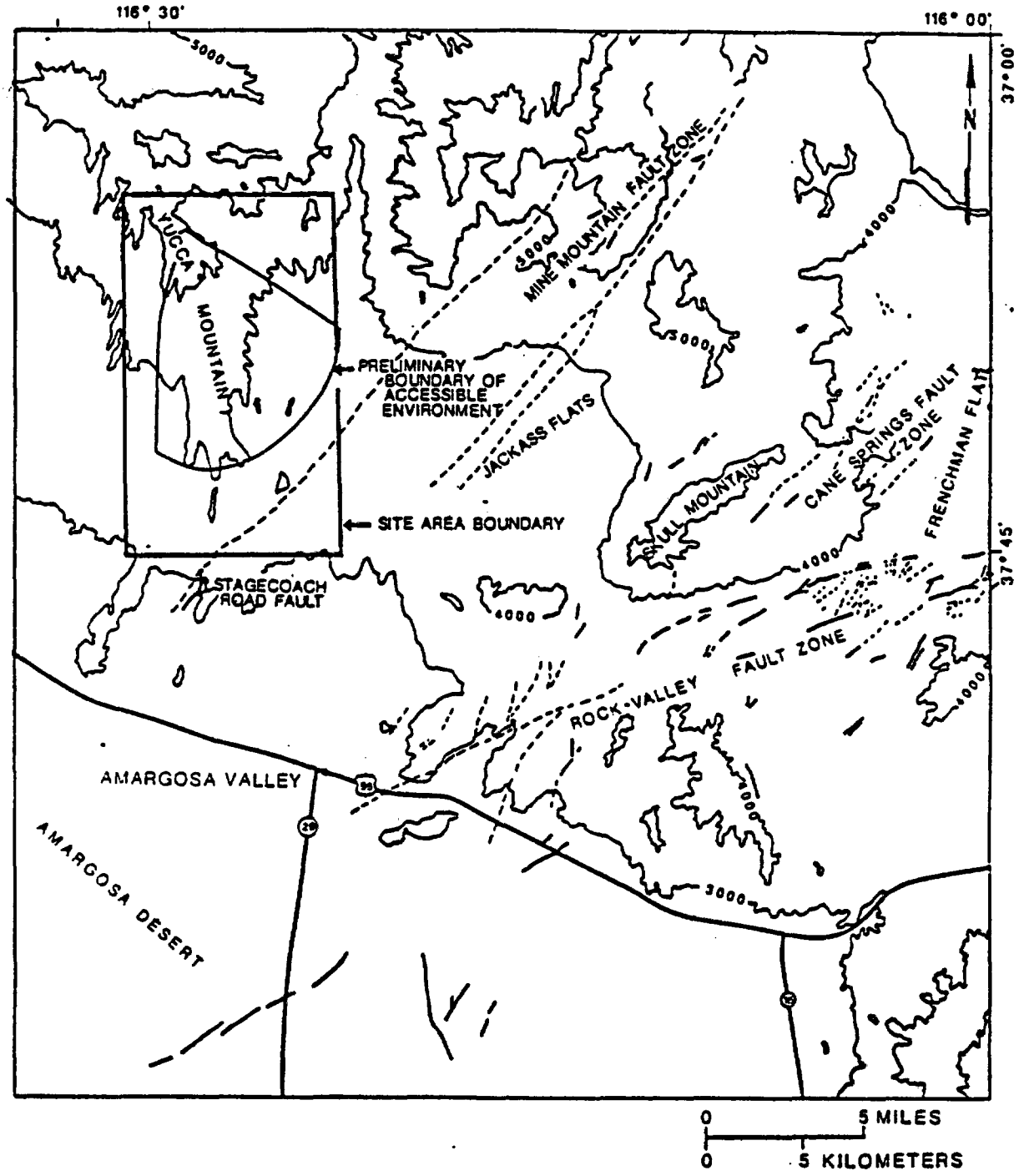
FAULT	LENGTH (KM)	OFFSET (M)	AGE OF OFFSET (MY)	AVERAGE SLIP RATE (MM/YR)
WINDY WASH	6-19	200-450	12.9	0.10-0.30
		60	11.6	0.005
		0.4-0.6	0.19-0.27	0.001-0.003
		0.2	0.005-0.040	-
		<0.1	0.003-0.0065	-
PAINTBRUSH CANYON	17-31	200	12.9	0.03
		90	9.6	0.06
		70	9.3	0.01
		45	7.5	0.006
		4.1	<0.7	~0.008
		2.1	-	-


116° 35'
116° 25'
116° 15'
36° 50'
36° 40'
BARE
MTN.
Bare Mtn. Fault
CRATER
FLAT
SITE AREA BOUNDARY
AMARGOSA
DESERT
Windy Wash Fault
Solitario Canyon Fault
Stagecoach Road Fault
Paintbrush Canyon Fault
GAIA
CF1
CF2
CF3
A2
A1
CALICO
HILLS
GHOST DANCE FAULT
PERIMETER DRIFT
JACKASS
FLATS
INFERRED FAULT ZONE
BEDROCK
ALLUVIUM
QUATERNARY FAULTS SHOWING TRENCH NAME
CF2
N
0 1 2 MILES
0 1 2 KILOMETERS


N
FINISHED TUFF PILE
TUFF RAMP PORTAL
EL 3910
EXPLOSIVES MAGAZINES
LAND DISPOSAL SITE
SHEN & MATERIALS SHAFT
RAMP PORTAL WASTE
EXPLORATORY SHAFT 2
WATER STORAGE TANKS
CENTRAL SURFACE FACILITIES AREA
EL. 3665
EXPLORATORY SHAFT 1
69 kV POWER LINE (EXISTING)
HELIPAD
EMPLACEMENT AREA EXHAUST SHAFT
PARKING AREA
SEWAGE TREATMENT LAGOONS
NELLIS AIR FORCE BOUNDARY
BUREAU OF LAND MANAGEMENT BOUNDARY
NEVADA TEST SITE BOUNDARY
EXISTING ROAD
10" DIA WATER LINE
6" DIA WATER LINE (EXISTING)
BRIDGE
0 2000 4000 FEET
0 500 1000 METERS
CONTOUR INTERVAL 100 FT

116°30′ FAULT MAP, EAST-CENTRAL YUCCA MOUNTAIN





Map showing relation of proposed repository area to Mine Mountain, Cane Spring, Rock Valley, and Stagecoach Road fault zones.

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PROJECT INTERACTIONS WITH TECTONICS

PROJECT COMPONENTS

PRECLOSURE OPERATIONS
- SURFACE WASTE HANDLING FACILITIES
- UNDERGROUND FACILITIES
- AREA OF WASTE STORAGE

POSTCLOSURE PERIOD
- AREA OF WASTE STORAGE
- CONTROLLED AREA +0.5 KM

TECTONIC ACTIVITY

VOLCANIC ACTIVITY
- ASHFALL
- INTRUSION/ERUPTION

FAULT DISPLACEMENT

STRAIN DEFORMATIONS

VIBRATORY GROUND MOTIONS

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SELECTED TECHNICAL CONCERNS FOR TECTONICS

TECHNICAL CONCERNS	PROPOSED GOALS
VOLCANIC ERUPTION THROUGH AREA OF WASTE STORAGE	PROB. < 10^{-6}/YR
FAULT DISPLACEMENT AT:	
- SURFACE WASTE HANDLING FACILITIES	PROB. OF 5 CM < 10^{-4}/YR
- AREA OF WASTE STORAGE	PROB. OF 5 CM < 10^{-4}/YR
GROUND MOTIONS AT SURFACE WASTE HANDLING FACILITIES	PROB. OF EXCEEDING DESIGN BASIS < 10^{-3}/YR
CHANGES TO HYDROLOGIC CONDITIONS	PROB. OF moving within of repository 100 M RISE IN WATER TABLE < 10^{-5}/YR
	CHANGES IN ROCK CONDUCTIVITY OR FRACTURE PERMEABILITY < FACTOR OF 2

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FAULT DISPLACEMENT AT WASTE HANDLING FACILITIES

CHARACTERIZATION PROCEDURES	CURRENT STATUS
1. ID SIGNIFICANT FAULTS WITHIN 100 M - NO MOVEMENT WITHIN 100,000 YRS - QUATERNARY SLIP RATE < 0.001 MM/YR	NONE KNOWN
2. ID POTENTIALLY SIFNIFICANT QUATERNARY WITHIN 5 KM	3 KNOWN
3. ESTIMATE ANNUAL PROBABILITY FOR EXCEEDING 5 CM	$< 10^{-4}$/YR

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VIBRATORY GROUND MOTIONS AT WASTE HANDLING FACILITIES

CHARACTERIZATION PROCEDURES	CURRENT STATUS
1. IDENTIFY SEISMOGENIC SOURCES	LOCAL FAULTS CONTROL
2. DETERMINE EXCEPTIONAL EARTHQUAKES	MODERATE EARTHQUAKE
3. DETERMINE ATTENUATION RELATIONS	PUBLISHED USING CALIFORNIA DATA
4. ADD EFFECTS OF LOCAL GEOLOGY	LIMITED UNE RECORDINGS
5. DEVELOP TIME HISTORIES/SPECTRA	DESIGN BASIS 0.4 - 0.6 G
6. DETERMINE MOTIONS FOR UNEs	< NATURAL EARTHQUAKES
7. ESTIMATE PROB. FOR EXCEEDING DESIGN	0.4 G < 10^{-3}/YR

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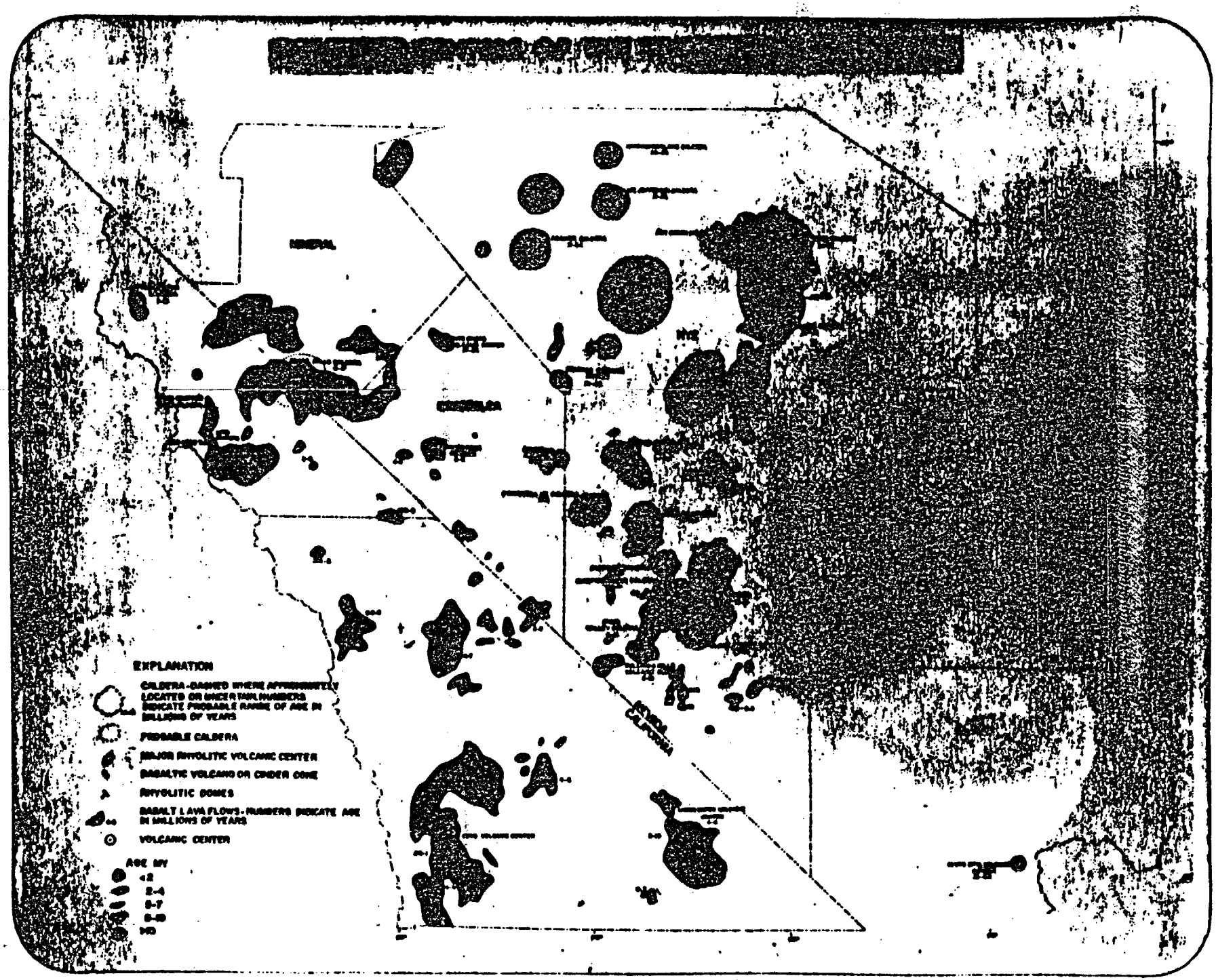
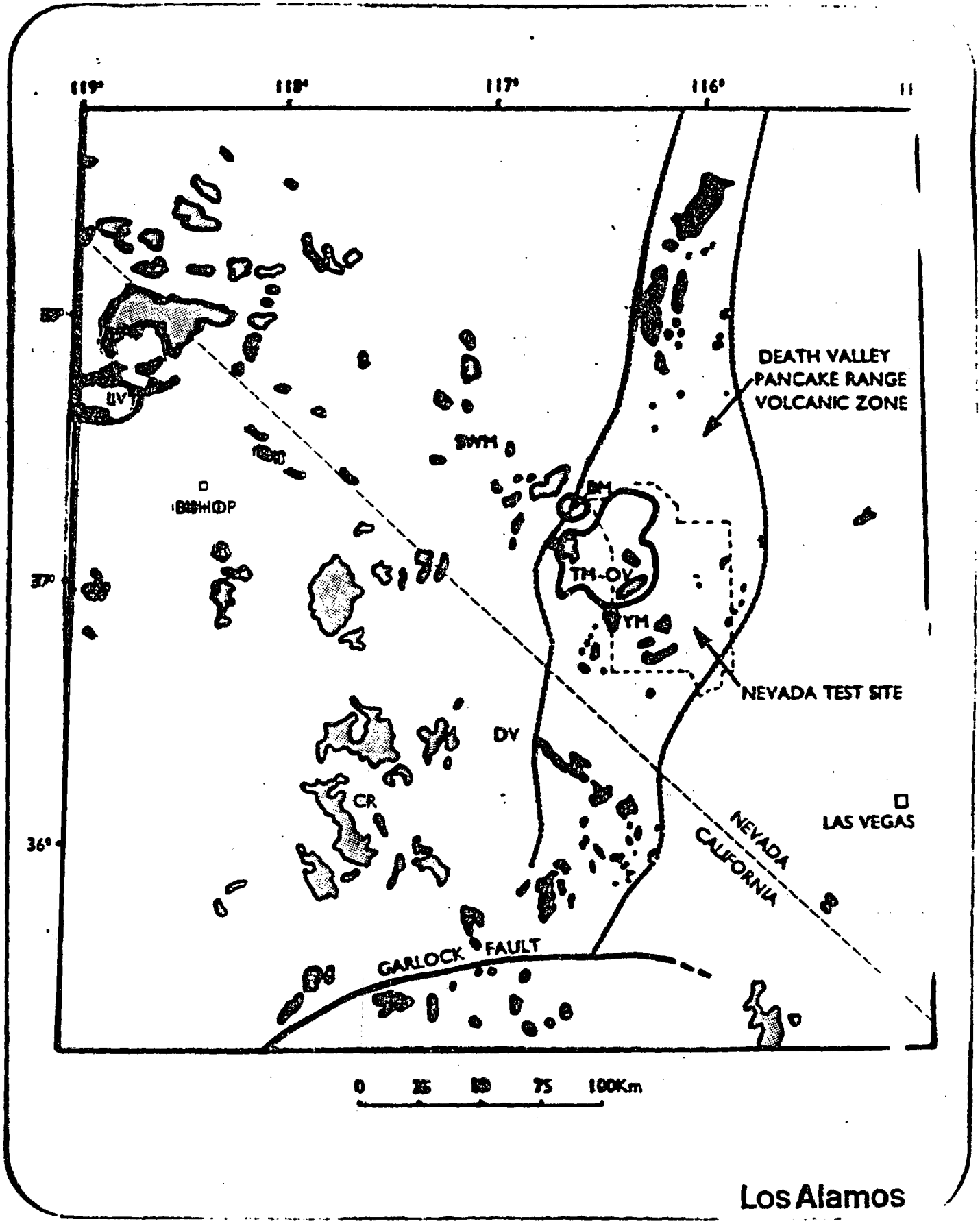
KEY TECHNICAL NEEDS FOR TECTONICS

- LOCAL QUATERNARY FAULTS (< 10 KM)
  - EXTENT, GEOMETRY, DATED OFFSETS, COMPLETENESS
- SEISMOGENIC CAPABILITIES
  - EARTHQUAKE RECURRENCE, MAX. MAGNITUDE
- FAULTING POTENTIAL
  - SYMPATHETIC SLIP, GEOLOGIC STABILITY, PROBABILITIES
- VIBRATORY GROUND MOTIONS
  - REPRESENTATIVE TIME HISTORIES, MAGNITUDE - DISTANCE ATTENUATION, PROBABILITIES
- TECTONIC-HYDROLOGIC INTERACTIONS

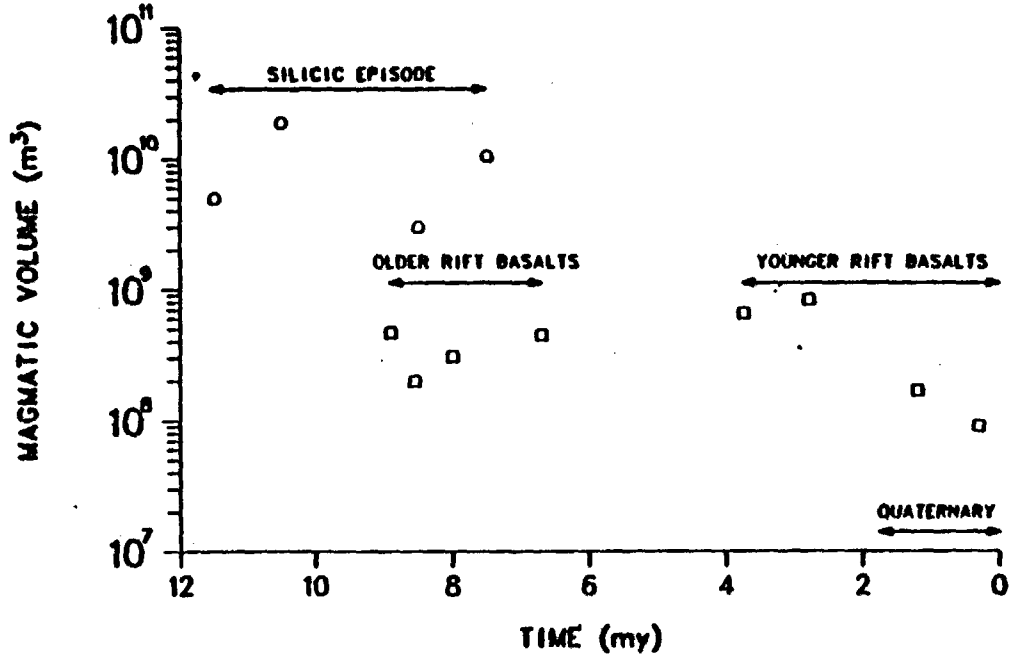
VOLCANISM

B. CROWE


EXPLANATION
CALDERA-DASHED WHERE APPROXIMATELY LOCATED OR UNCERTAIN. NUMBERS INDICATE PROBABLE RANGE OF AGE IN BILLIONS OF YEARS
PROBABLE CALDERA
MAJOR RHYOLITIC VOLCANIC CENTER
BASALTIC VOLCANO OR CINDER CONE
RHYOLITIC DOMES
BASALT LAVA FLOWS-NUMBERS INDICATE AGE IN MILLIONS OF YEARS
VOLCANIC CENTER
AGE MY
<2
2-4
5-7
8-10
>10


119°
118°
117°
116°
37°
36°
DEATH VALLEY
PANCAKE RANGE
VOLCANIC ZONE
BISHOP
TH-OV
YM
NEVADA TEST SITE
DV
CR
LAS VEGAS
NEVADA
CALIFORNIA
GARLOCK FAULT
0
25
50
75
100Km

Los Alamos


MAGMATIC VOLUME (m³)
10¹¹
10¹⁰
10⁹
10⁸
10⁷
SILICIC EPISODE
OLDER RIFT BASALTS
YOUNGER RIFT BASALTS
QUATERNARY
12
10
8
6
4
2
0
TIME (my)

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PROBABILITY CALCULATIONS

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CONDITIONAL PROBABILITY

$$Pr = (E2 \text{ GIVEN } E1)$$

WHERE Pr IS THE PROBABILITY OF REPOSITORY DISRUPTION
E1 IS THE RATE OF OCCURRENCE OF VOLCANIC EVENTS
E2 IS THE PROBABILITY OF INTERSECTION OF A REPOSITORY GIVEN E1

PROBABILITY FORMULATION

$$Pr(\text{no disruptive event before time } t) = \exp^{(-\lambda t p)}$$

WHERE λ = THE RATE PARAMETER
AND p = THE PROBABILITY THE EVENT IS DISRUPTIVE

RATE PARAMETER (λ)

-- CONE COUNTS/TIME
-- RATE OF MAGMA GENERATION

DISRUPTION PARAMETER (p)

-- a/A
-- FOR YUCCA MOUNTAIN
AREA OF THE REPOSITORY/AREA OF RATE CALCULATION

PROBABILITY CALCULATIONS (CONT)

AREA OF RATE CALCULATION

- -- MINIMUM AREA CIRCLE AND MINIMUM AREA ELLIPSE
- -- ENCLOSES VOLCANIC CENTERS AND REPOSITORY
- -- STRUCTURAL SETTING OF VOLCANIC CENTERS

PROBABILITY CALCULATIONS ARE ASSEMBLED AS A MATRIX

- -- TWO RATE DETERMINATIONS
- -- TWO AREA RATIOS
- -- MAXIMUM AND MINIMUM VALUES DEFINE PROBABILITY RANGE
- -- INDIVIDUAL VALUES NOT EMPHASIZED

→ YUCCA MOUNTAIN CALCULATIONS: 10^{-8} TO 10^{-10} $YEAR^{-1}$

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CONSEQUENCE ANALYSIS (LOGAN ET AL., 1982)

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1. INTRUSION OF BASALT MAGMA THROUGH A REPOSITORY
   - -- SURFACE ERUPTION (STROMBOLIAN)
   - -- FED BY LINEAR DIKES
   - -- BASALT PARAMETERS FROM FIELD STUDIES
2. WASTE DISPERSAL ASSUMED TO FOLLOW PATTERNS OF LITHIC FRAGMENTS
   - -- 15-20 PERCENT DEPOSITED IN SCORIA CONE
   - -- 50 TO 80 PERCENT DEPOSITED IN SCORIA-FALL SHEET
   - -- 2 TO 5 PERCENT REGIONALLY DISPERSED
3. RELEASE CALCULATIONS FOR TWO HYPOTHETICAL REPOSITORIES
   - -- UNREPROCESSED SPENT FUEL
   - -- REPROCESSED WASTE
   - -- REPOSITORY AREA OF 1640 M^2, 10 YR OLD WASTE
   - -- RANDOM DIKE ORIENTATION (INVENTORY FRACTION OF 8×10^{-5})
   - -- ALL CONTACTED WASTE CARRIED TO THE SURFACE
4. DOSE CALCULATIONS
   - -- DOSE FROM WASTE IN THE ERUPTION COLUMN
   - -- DOSE FROM WASTE-BEARING SCORIA DEPOSITS
   - -- TOTAL ACTIVITY TRANSPORTED TO THE SURFACE
5. RECALULATED FOR HYDROVOLCANIC ERUPTION COMPONENT

NEW TOPICS REQUIRING REVISION OF PROBABILITY CALCULATIONS

AEROMAGNETIC ANOMALIES

-- PROBABLY BURIED BASALT CENTERS
-- REQUIRE INFORMATION FOR RATE CALCULATIONS

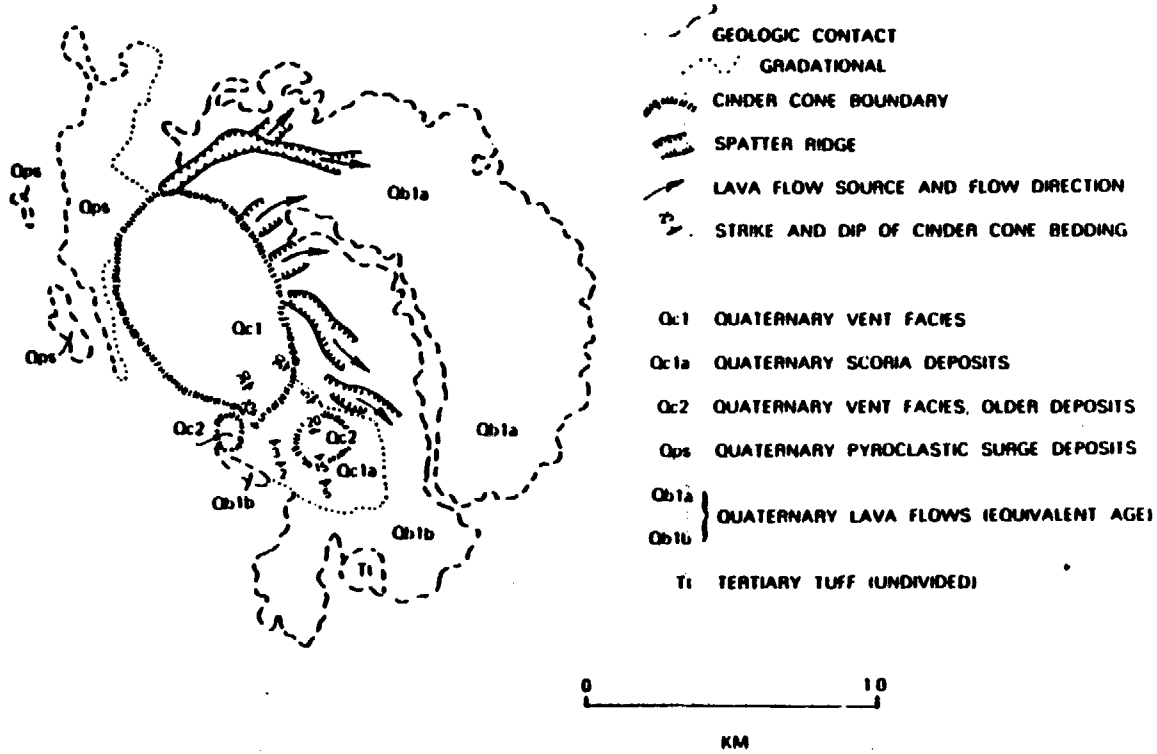
AGE OF THE LATHROP WELLS VOLCANIC CENTER

-- NEW EVIDENCE SUGGESTS CONE MAY BE 20,000 YEARS
-- EVIDENCE FOR POLYCYCLIC VOLCANISM

TIME-SPACE MODEL FOR DISTRIBUTION OF BASALTIC CENTERS

-- SUGGEST YUCCA MOUNTAIN AREA PAST PEAK OF VOLCANIC ACTIVITY

→ FOCUS ON YOUNGEST VOLCANIC ACTIVITY
→ AGE DATING TECHNIQUES


Qps
Qps
Qps
Qc1
Qc2
Qc2
Qc1a
Qb1a
Qb1a
Qb1b
Qb1b
Ti
GEOLOGIC CONTACT
GRADATIONAL
CINDER CONE BOUNDARY
SPATTER RIDGE
LAVA FLOW SOURCE AND FLOW DIRECTION
STRIKE AND DIP OF CINDER CONE BEDDING
Qc1 QUATERNARY VENT FACIES
Qc1a QUATERNARY SCORIA DEPOSITS
Qc2 QUATERNARY VENT FACIES, OLDER DEPOSITS
Qps QUATERNARY PYROCLASTIC SURGE DEPOSITS
Qb1a
Qb1b
QUATERNARY LAVA FLOWS (EQUIVALENT AGE)
Ti TERTIARY TUFF (UNDIVIDED)
0
10
KM

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AGE CONSTRAINTS AND UNCERTAINTY LATHROP WELLS SCORIA CONE

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1. CONE DEGRADATION PARAMETERS
   - -- CONSISTENT WITH AN AGE OF LESS THAN 20,000 YEARS
   - -- BEST MATCH 15,000 YEAR OLD CONE, CIMA VOLCANIC FIELD

2. SOIL DEVELOPMENT
   - -- ANALYSES NOT COMPLETED
   - -- PROFILES CONSISTENT WITH AGE OF LESS THAN 20,000 YEARS

3. DESERT VARNISH
   - -- NOT CALIBRATED FOR CONE
   - -- ANGULAR, Ti-Cr BEARING MAGNETITE CRYSTALS
   - -- SUGGESTIVE OF RECENT ERUPTION
   - -- POSITION IN VARNISH CONSISTENT WITH YOUNG AGE

4. ^{14}C AGE OF 19,900 PLUS/MINUS 300 CARBON YEARS
   - -- TECHNIQUE NOT WELL ESTABLISHED

5. CONCLUSIONS
   - -- AGE AND DETAILED CHRONOLOGY NOT RESOLVED
   - -- CURRENT DATA ARE CONSISTENT WITH AGE OF 20,000 YEARS
   - -- PROBLEM MUST BE CAREFULLY EVALUATED FOR RISK ASSESSMENT

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REQUIRED STUDIES (CONT)

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EXPERIMENTAL MEASUREMENTS
- CRYSTALLIZATION AGE OR SURFACE EXPOSURE AGE
- DUAL LABORATORY MEASUREMENTS FOR COMPARISON

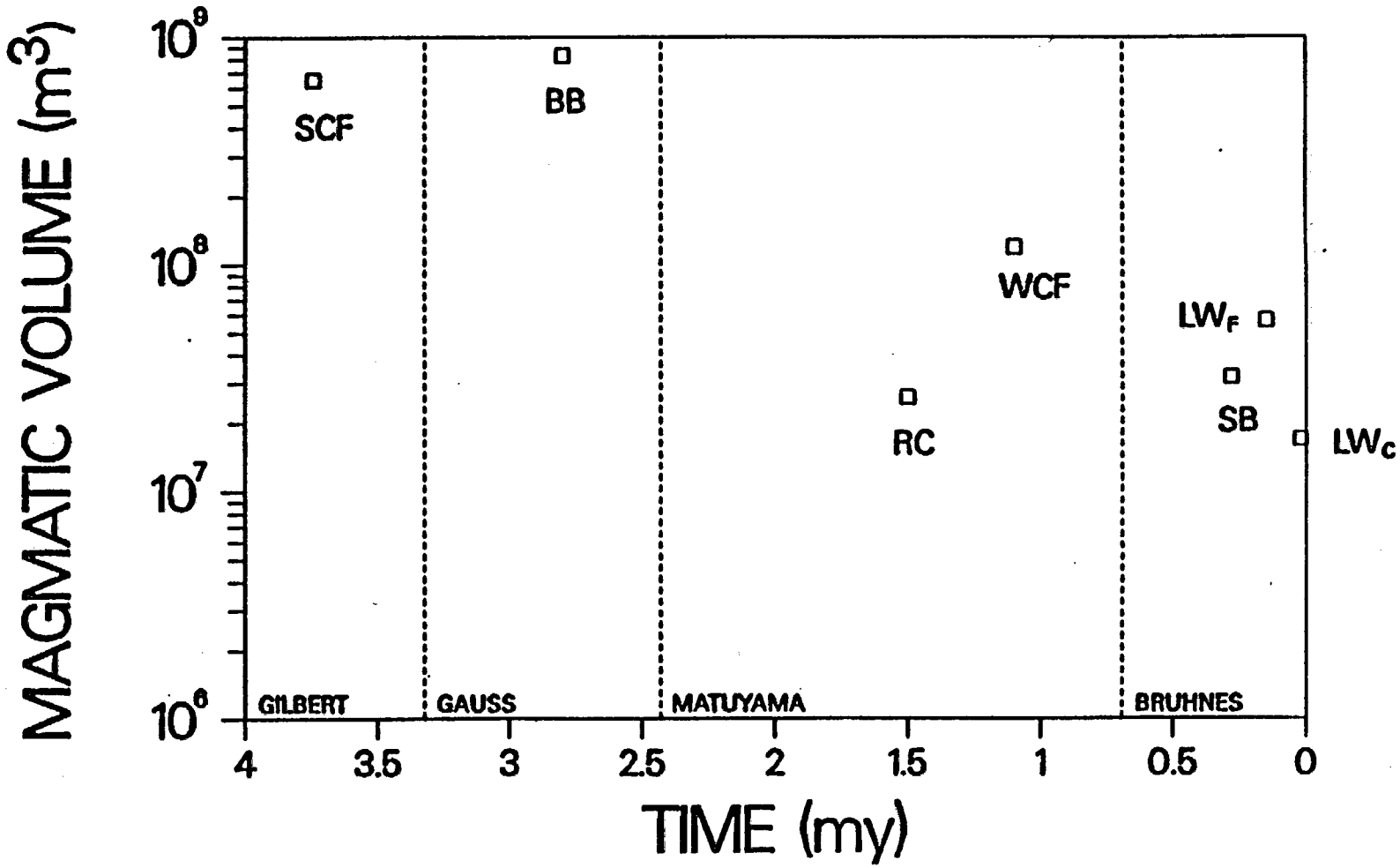
1. ^{3}He AGES (SURFACE EXPOSURE AGE)
   - -- NEAR-SURFACE COSMOGENIC PRODUCTION OF ^{3}He
   - -- REQUIRES CALIBRATION OF PRODUCTION RATES
   - -- MEASUREMENTS AT TWO LABORATORIES
     - LOS ALAMOS
     - BERKELEY

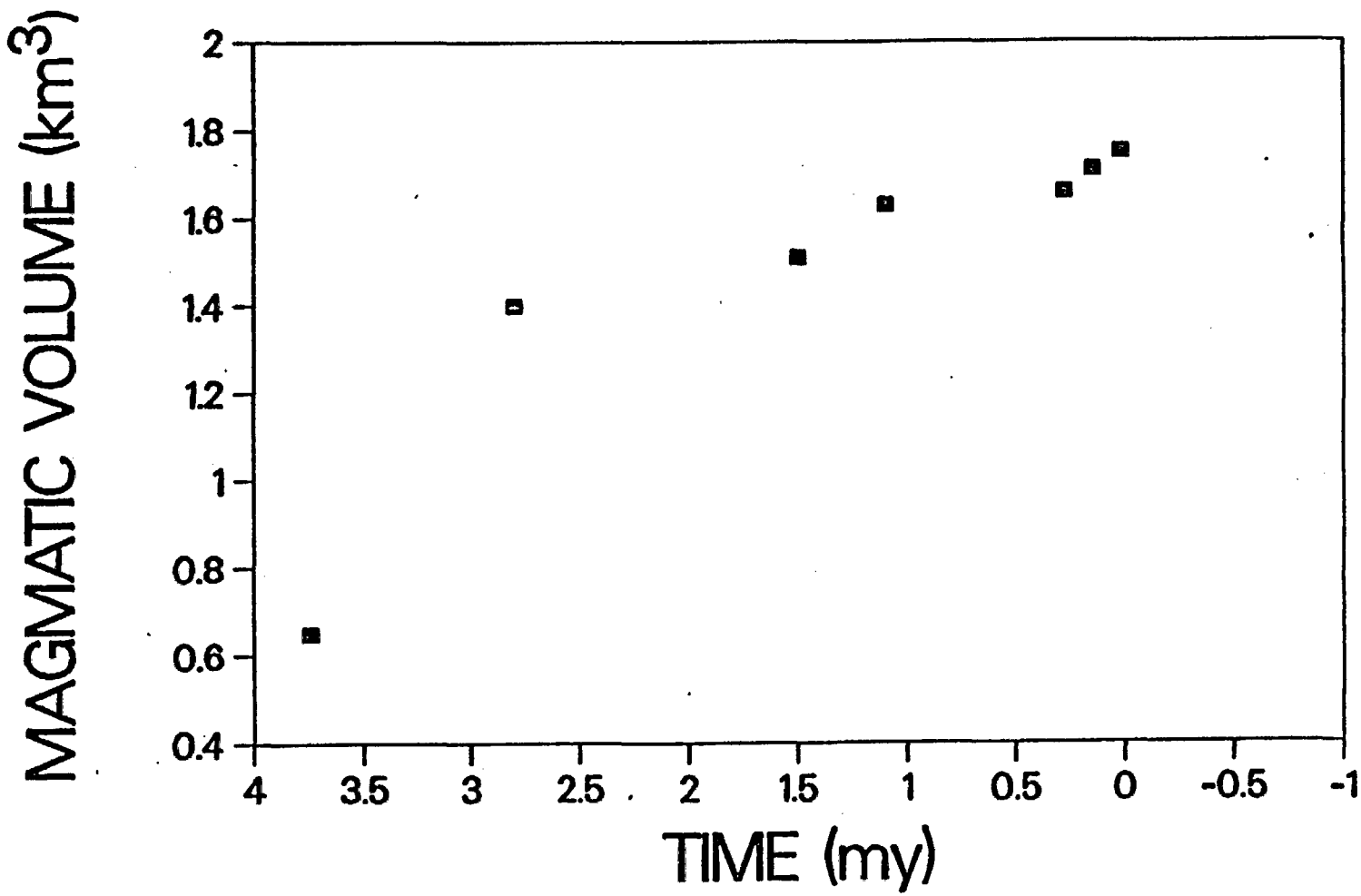
2. ^{36}Cl (SURFACE EXPOSURE AGE)
   - -- COSMOGENIC PRODUCTION OF ^{36}Cl
   - -- NM TECH PhD STUDENT (NOT NNWSI FUNDED)

3. U-Th DISEQUILIBRIUM
   - -- 75,000 HALF-LIFE
   - -- GIVES CRYSTALLIZATION AGE
   - -- MEASUREMENTS AT TWO LABORATORIES
     - LOS ALAMOS (MASS SPEC)
     - USGS (CONVENTIONAL COUNTING)

4. VARNISH DATING TECHNIQUES

5. MAGNETIC POLE POSITIONS


MAGMATIC VOLUME (m3)
10^9
10^8
10^7
10^6
SCF
BB
WCF
RC
LWF
SB
LWC
GILBERT
GAUSS
MATUYAMA
BRUHNES
4
3.5
3
2.5
2
1.5
1
0.5
0
TIME (my)


MAGMATIC VOLUME (km3)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
TIME (my)

POTENTIAL FOR HYDROTHERMAL ACTIVITY

J. STUCKLESS
S. MATTSON

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HYDROTHERMAL STUDIES INTRODUCTION

DATA ARE OBTAINED FROM:

1. **DIRECT THERMAL MEASUREMENTS**

2. **EXAMINATION OF HYDROTHERMAL DEPOSITS AND ALTERATION ASSEMBLAGES**

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HYDROTHERMAL STUDIES INTRODUCTION

- HYDROTHERMAL DEPOSITS ARE ONE TYPE OF HYDROGENIC DEPOSIT
- HYDROTHERMAL DEPOSITS ARE INVESTIGATED UNDER THIS ACTIVITY UNTIL TEMPERATURE OF DEPOSITION IS ESTABLISHED
- THIS PRESENTATION WILL CONCENTRATE ON HYDROGENIC DEPOSITS

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STATEMENT OF PROBLEM

1. DO ANY HYDROGENIC DEPOSITS OR HYDROTHERMAL DATA HAVE SIGNIFICANT IMPLICATIONS FOR REPOSITORY PERFORMANCE?

   A) STABILITY OF WASTE PACKAGE?

   B) TRAVEL TIME TO BIOSPHERE?

2. DO ANY HYDROGENIC DEPOSITS HAVE POTENTIAL ECONOMIC IMPLICATIONS?

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HYDROGENIC DEPOSITS

1. MINERALS AND MINERALOIDS PRECIPITATED FROM WATER

2. TYPES IDENTIFIED AROUND YUCCA MOUNTAIN:

   A. CALCITE AND OPALINE SILICA

   B. SILICA-CEMENTED BRECCIA

   C. DRUSY QUARTZ AND OTHER RUG FILLINGS

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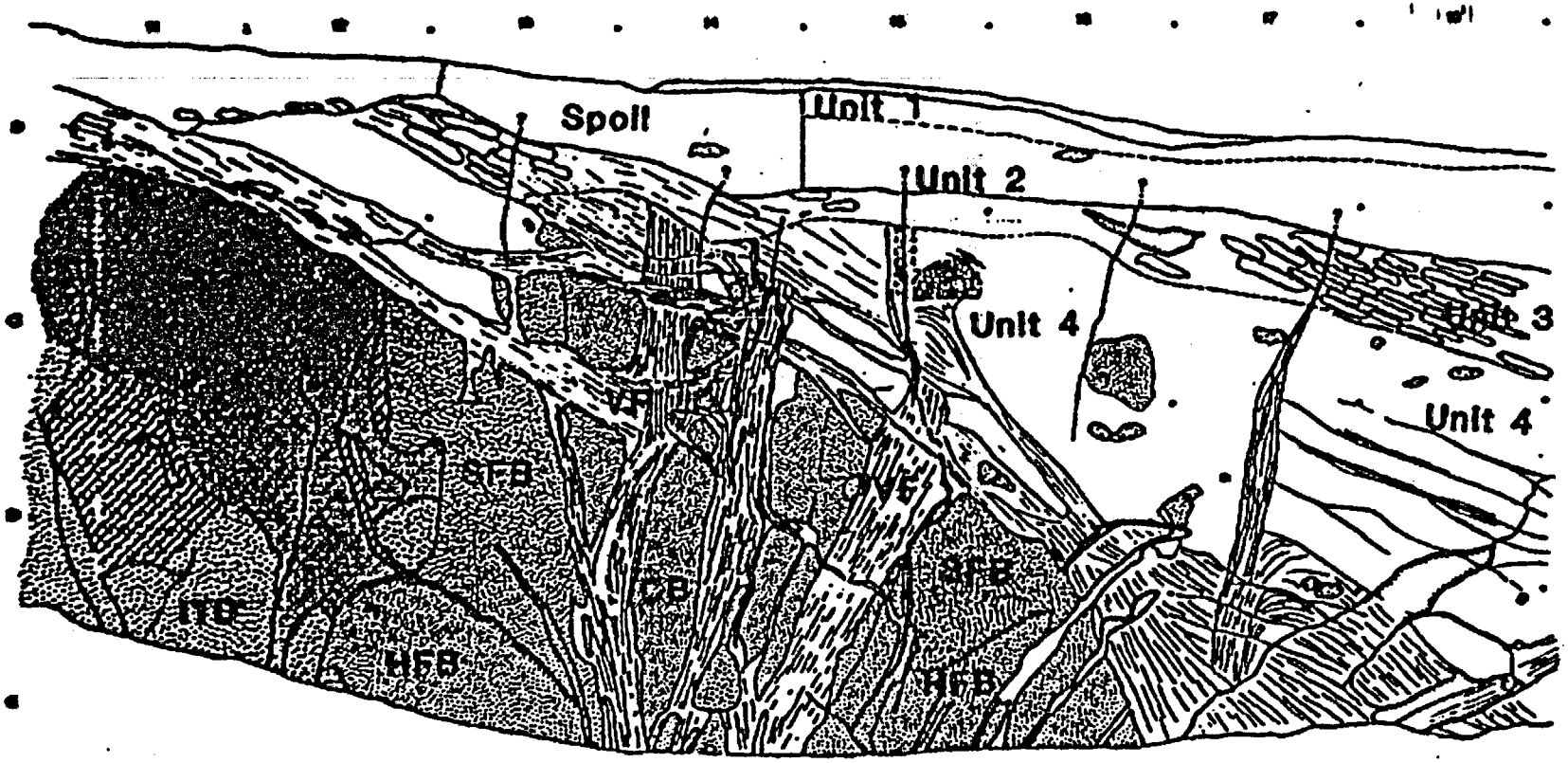
TRENCH 14

Current Status

U.S. DEPARTMENT OF THE INTERIOR · GEOLOGICAL SURVEY



MAP OF SOUTH WALL OF TRENCH 14

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MODES OF ORIGIN FOR HYDROGENIC DEPOSITS

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1. Pedogenic : Deposited by meteoric waters as part of the soil-forming process.

2. Cold springs : Ground water of deep or shallow origin moved along fractures.

3. Hydrothermal springs : Water heated by any of several mechanisms & moved up fractures.

4. Seismic springs : Hot or cold waters moved along faults as a direct result of faulting.

TRENCH 14
Current Status

(CONTINUED)

1. Available data are consistent with a pedogenic origin for the calcite and opaline silica deposit.

2. Preliminary findings argue against high temperature origin for calcite and silica.
   a) Stable isotopes suggest ~15°C.
   b) Fine-grained texture suggests low T.
   c) No obvious alteration of wall rock.
   d) Opal types and occurrences are consistent with low T origin.

TRENCH 14
Current Status

(CONTINUED)

3. Low-temperature spring seems unlikely.
   a) Biota are not abundant.
   b) Opal occurrence is not consistent with low-temperature spring analogues.

4. Four ages for calcite and opal suggest deposition more than 400,000 years ago.

TRENCH 14
Current Status

(CONTINUED)

5. Silica-cemented breccias are probably older than calcite & opaline silica (based on field relations).
   - Depositional mechanism is currently unknown.

6. Drusy quartz is oldest hydrogenic deposit and may be syn-volcanic.
   - fluid-inclusion and isotope data suggest higher temperature of formation than for calcite and opaline silica.

SCIENTIFIC APPROACH

COORDINATED INTERDISCIPLINARY STUDIES

a) Field work

b) Mineralogy

c) Geochemistry

d) Fluid inclusions

e) Geochronology

f) Tracer isotopes

g) Stable isotopes

h) Paleontology

i) Hydrology

j) Data integration

Factors which influence the evaluation of the potential for hydrothermal activity at the site in the future.

- Past occurrences and recurrence intervals of hydrothermal activity
- Present thermal regime
- The potential for recurring volcanism/plutonism, tectonic activity, etc., at and near the site that could cause hydrothermal activity

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ALTERATION MINERALOGY AND AGE PALOEHYDROTHERMAL SYSTEM AT YUCCA MOUNTAIN BELOW 3000 FT

MINERALOGY

Clay minerals -	interstratified illite/smectites with minor amounts of chlorite, kaolinite(?), and interstratified chlorite/smectite
Quartz -	Generally, in fractures and zeolitized tuff
Zeolite (Analcime) -	Greater than 500M in depth
Calcite -	Common in groundmass, fractures, and vugs

MINOR ALTERATION PHASES

Albite, fluorite, barite, hematite, manganese minerals, and disseminated pyrite

Temperature of Alteration:

Approximately 275°C ± 50°C in drillhole G-2 and 100°C ± 50°C in drillhole G-1.

- Mineralogical assemblage
- Fluid inclusions

Age: K/Ar dates on illites/smectites

10.9 ± 0.5 M yr.
11.0 ± 0.5 M yr.

Timber Mountain Tuff Age 11.3 ± 0.3

Alteration above 3000 Ft

- Sorptive zeolites (clinoptilolite and mordenite)
- Cristobalite
- Opal CT
- Plus minor phases (e.g., manganese mineral along fractures)

Processes - Authigenesis, vapor phase activity, burial diagenesis

PLANNED FUTURE WORK ON ALTERATION MINERALOGY

- Whole rock alteration and secondary mineralogy found in vugs, fractures, and veins.

- Includes X-ray diffraction, petrography, mineral chemistry, estimates of temperature (by stable isotope determinations, fluid inclusion homogeneation temperatures, and mineral and assemblage evaluation), and dating

- Dating techniques are limited

  - K-Ar dating of illites
  - U-series and U-trend techniques
  - Electron spin resonance (ESR) dating
    - quartz
    - calcite?
    - zeolite?

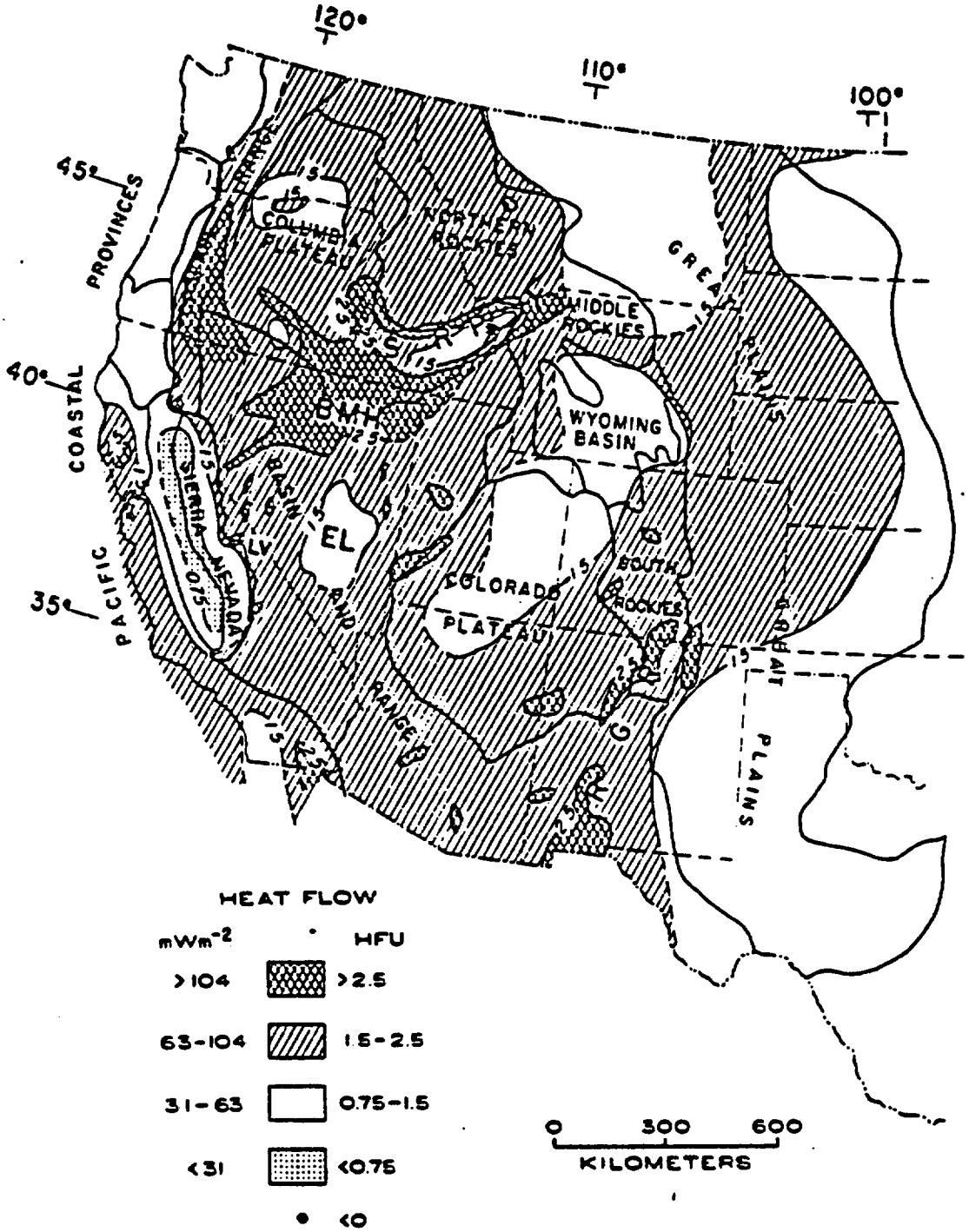

FIGURE 13.5. Map of the western United States showing heat-flow contours (in heat-flow units, HFU, 1 HFU = 41.8 mWm^{-2}), heat-flow provinces, and major physiographic divisions (SRP: Snake River Plain; BMH: Battle Mountain High; EL: Eureka Low; RGR: Rio Grande Rift Zone; Y: Yellowstone; LV: Long Valley).

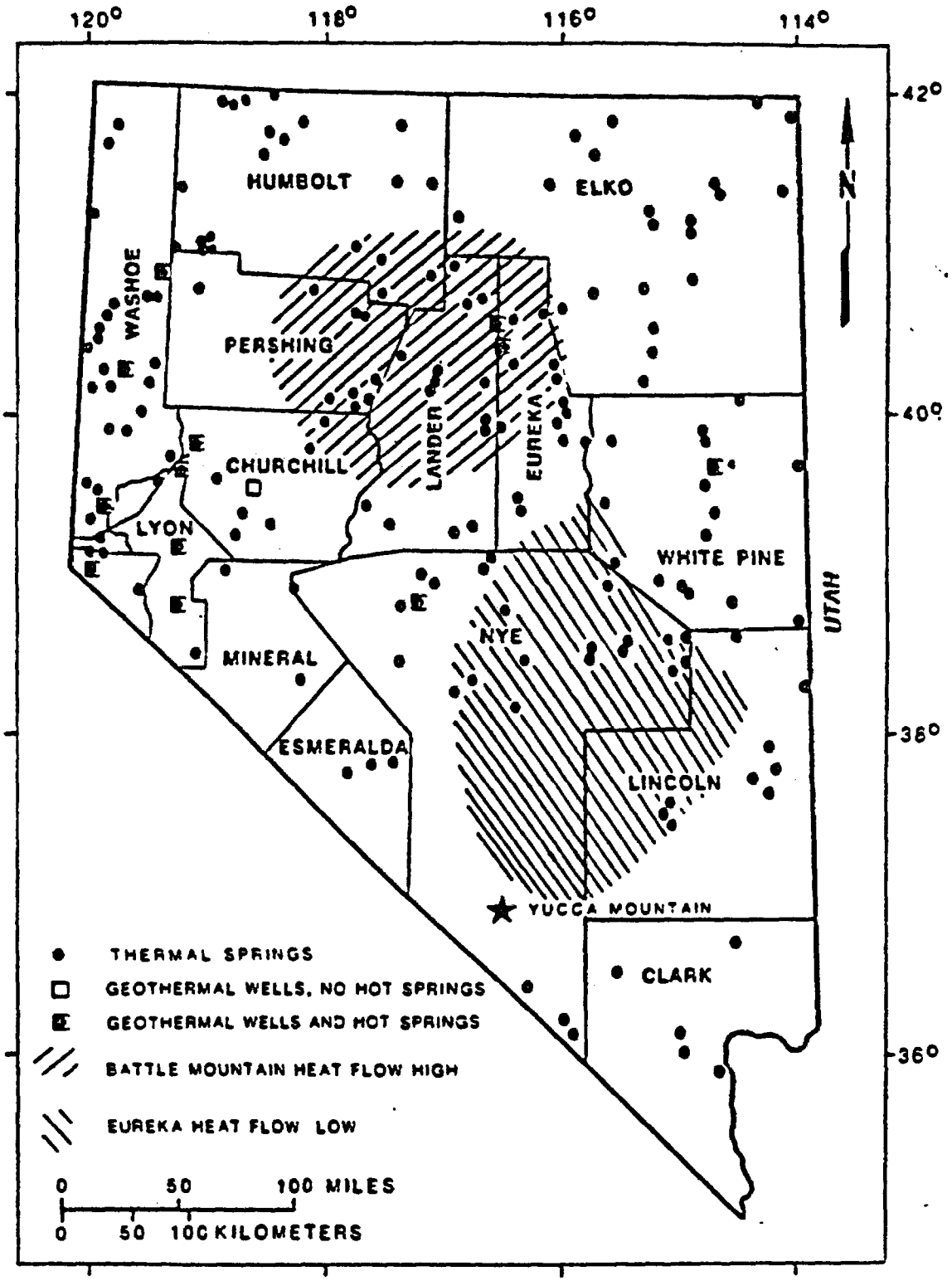

Figure 1-86. Hot springs and geothermal wells and low-temperature thermal resources in Nevada. The Battle Mountain-High and the Eureka-Low heat-flow regions are also shown. Modified from Garside (1974).

Annual Ambient Temperature ≈16-18°C

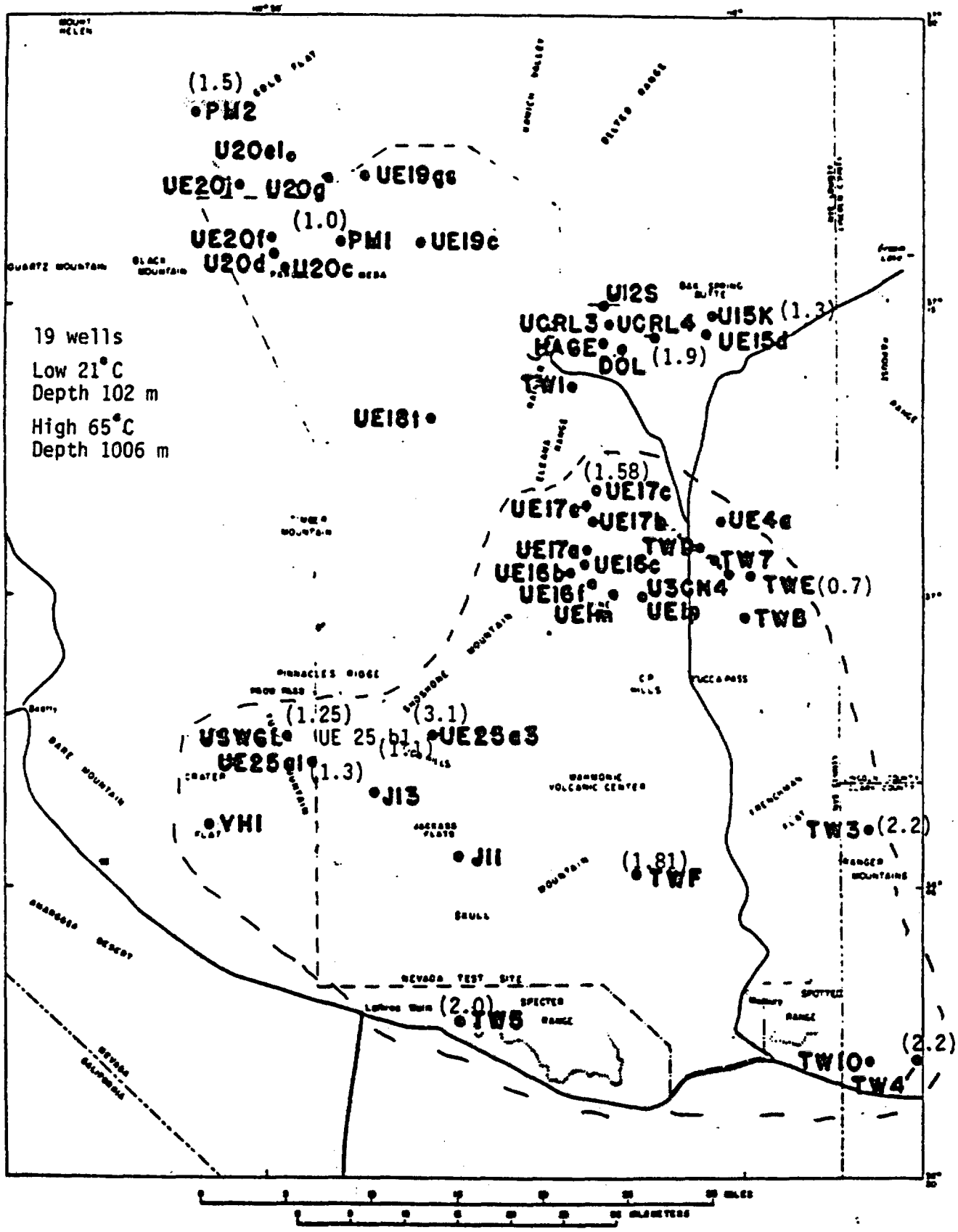

Figure 2. Map of the test-site region showing locations of wells discussed in the text. Numbers in brackets are in HFU

THERMAL REGIME AT YUCCA MOUNTAIN

New information to be obtained

- Temperature data
- Temperature gradient data
- Assessment and evaluation of present temperature, thermal conductivity, and heat flow data to allow recommendations for new Site Characterization Activities that will lead to a final assessment of the potential for hydrothermal activity