UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 24, 1998

Mr. Samuel Rousso, Director
for Program Management and Administration
Office of Civilian Radioactive Waste Management
U. S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

SUBJECT: SUMMARY OF THE NOVEMBER 5-6, 1997, U.S. DEPARTMENT OF ENERGY/U.S. NUCLEAR REGULATORY COMMISSION TECHNICAL EXCHANGE ON THE TOTAL-SYSTEM PERFORMANCE ASSESSMENT

Dear Mr. Rousso:

The purpose of this letter is to transmit the summary of the November 5-6, 1997, Technical Exchange between the staff of the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission. Some organizations other than DOE and NRC that were represented at the meeting were the NRC's Advisory Committee on Nuclear Waste, the U.S. Nuclear Waste Technical Review Board, the State of Nevada's Nuclear Waste Project Office, and Clark and Nye Counties, Nevada.

The primary goal of the Technical Exchange was to discuss respective staff approaches to performance assessments for Yucca Mountain, Nevada. A secondary goal of the Technical Exchange was for the NRC staff to provide DOE with early feedback regarding DOE's total-system performance assessment (TSPA) to be prepared as part of its forthcoming Viability Assessment (VA). Although many items of mutual interest were identified and constructively discussed, no open items *per se* were identified.

For those areas discussed, the staff believes that DOE's science, design, and performance assessment programs are well-integrated with substantial communication between disciplines. In addition, the staff is pleased that DOE recognizes the need and has committed to provide transparency in the documentation supporting the VA. This documentation is expected to include the technical bases for the positions and design alternatives expressed in the VA as well as the identification of areas for which additional confirmation/experimentation/data collection is needed to build its licensing case.

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As a result of these discussions, the staff did identify a number of TSPA areas it will continue to carefully evaluate in the context of issue resolution. These areas, described in more detail in the attached *Meeting Summary*, concern the use or treatment of formal expert judgment, modeling of saturated zone hydrology, and the evaluation of disruptive events.

In closing, this meeting resulted in a good exchange of information and views between DOE, NRC, and other interested parties and, we believe, made substantial progress in addressing TSPA issues. No response to this letter is required. If you have any questions regarding the enclosed meeting minutes, please contact Michael P. Lee of my staff. He can be reached at (301) 415-6677.

Sincerely,

[Original signed by:]

Michael J. Bell, Acting Chief
Performance Assessment and High-Level Waste Integration Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards

Enclosure: As stated

cc: See attached list

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Letter to S. Rousso from M. Bell dated: June 24, 1998

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ENCLOSURE

MINUTES OF THE NOVEMBER 5-6, 1997 U.S. DEPARTMENT OF ENERGY/U.S. NUCLEAR REGULATORY COMMISSION TECHNICAL EXCHANGE ON TOTAL SYSTEM PERFORMANCE ASSESSMENTS FOR YUCCA MOUNTAIN

Introduction

On November 5-6, 1997, U.S. Department of Energy (DOE) and U.S. Nuclear Regulatory Commission (NRC) staff conducted a Technical Exchange to discuss the respective staff approaches to conducting performance assessments for the proposed repository at Yucca Mountain, Nevada. A secondary goal of the Technical Exchange was for the NRC staff to give DOE early feedback regarding the sufficiency of DOE's total-system performance assessment (TSPA) to be prepared as part of its forthcoming Viability Assessment (VA). This technical exchange was the second in a series that concerned the Yucca Mountain VA performance assessment; the first Technical Exchange was conducted in July 1997. In this Technical Exchange, the following major performance assessment areas were examined: flow and transport in the saturated zone; waste package degradation abstraction and analyses; and the treatment of disruptive events. The Technical Exchange also included limited discussion of the two staffs' respective approaches to biosphere modeling. The detailed agenda for this two-day meeting can be found in Attachment 1.

The Technical Exchange was held at the offices of DOE's Yucca Mountain Site Characterization Project Office in Las Vegas, Nevada. A two-way video conference connection between Rockville (Maryland) and Las Vegas permitted remote participation of additional DOE and NRC staff and other interested parties. Besides staff from DOE, NRC, the CNWRA and DOE's Management and Operating (the "M&O") contractor, representatives from the State of Nevada, the Nevada Nuclear Waste Task Force, Clark and Nye Counties, Nevada, and the U.S. Geological Survey (USGS) also attended the meeting. Members and staff from the U.S. Nuclear Waste Technical Review Board (NWTRB) and NRC's Advisory Committee on Nuclear Waste (ACNW) were also present. Attachment 2 contains the composite list of attendees who were present at one of the two video conference locations.

As was the case for the July 1997 Technical Exchange, following the question and comment period for each presentation, the Technical Exchange participants were asked whether some unanswered questions merited additional discussion (and clarification). To the extent that there was unanswered questions at the end of the presentations, they would record them as part of the Technical Exchange meeting summary.

November 5, 1997 — Background

The meeting commenced with opening remarks by DOE and NRC. The State of Nevada and affected units of local government declined the invitation to provide opening remarks. In the first series of formal presentations (Attachment 3), the NRC identified the goals and objectives of the Technical Exchange. Both DOE and NRC agreed that the overall goal of this Technical Exchange was for DOE to explain, and NRC to comment on, the completeness and technical adequacy of the forthcoming TSPA-VA. Moreover, DOE noted that it sought to provide the staff with some degree of understanding regarding the TSPA-VA itself. However, if more focused discussion was needed to foster understanding on some TSPA-VA issues, it was recommended that the meeting summary reflect this need and identify the type of interaction(s) that might be needed.

As a point of caution, the staff reminded the audience that the current NRC performance assessment capability (referred to as Version 3.1 of the TPA computer code or TPA 3.1) was still under development and thus any results attributed to it during the Technical Exchange should be regarded as **preliminary**. Also, in any discussions referring to a "reference biosphere" or "critical group" at Yucca Mountain, the views of the staff should not be regarded as a staff position or preference on these matters because these concepts are expected to be addressed in a forthcoming site-specific rule for Yucca Mountain, which is currently under consideration by the Commission.[1]

Technical Presentations

As noted above, the Technical Exchange focused on four major performance assessment subjects. The first subject was the treatment of flow and transport in the saturated zone (SZ) at Yucca Mountain. During the July 1997 Technical Exchange, it was noted that based on the current state of knowledge, both the DOE and the NRC staffs have had different views on the role of matrix diffusion in ground-water transport at Yucca Mountain. DOE intends to take credit for matrix diffusion as a mechanism for retarding the transport of radionuclides. In contrast, the NRC staff believes that the results of site characterization suggest fracture-driven transport models.

To guide the TSPA-VA SZ flow and transport work, DOE recently sponsored a formal expert elicitation to assess the reasonableness of current flow and transport models based on the present body of site characterization data. With the expert elicitation now complete,[2] DOE's first presentation was a summary of the elicitation results by the Sandia National Laboratories (SNL), including limited discussion of the implications the elicitation results may have on TSPA-VA assumptions/abstractions. This presentation is contained in Attachment 4.[3] In summary, the collective opinion of the SZ expert elicitation panel was that few mechanisms would lead to the mixing of a contaminant plume at Yucca Mountain. Accordingly, the SZ expert panel regards advective transport (in the matrix) to be the primary transport mechanism. Lateral and vertical dispersion are likely to be small, and the plume is most likely to be channelized and laminar in its geometry. Moreover, in the opinion

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[1] Subsequent to the Technical Exchange, the Commission approved the staff's proposed strategy for the development of site-specific disposal regulations at Yucca Mountain. This strategy is described in SECY-97-300 and was approved on December 24, 1997.

[2] At the time of the Technical Exchange, it was noted that the summary documentation for the SZ expert elicitation was under preparation.

[3] This and the other two DOE presentations in this series were intended to provide additional background and information regarding the basis for DOE's position on the role of matrix diffusion in flow and transport at the Yucca Mountain site.

of the panel, any change in the geometry of the plume is expected to be in response to stratigraphic/structural influences rather than to dilution and mixing. Overall, SNL noted that the SZ expert elicitation revealed no "surprises" regarding the current conceptual model for solute transport at Yucca Mountain although the NRC staff – as observers of the elicitation – did point out that the expert panel had differing views as to the cause of the large hydraulic gradient to the west of the site, and the effect this gradient might have on flow and transport. In presenting the results of the SZ elicitation, SNL identified members of the expert panel and noted which experts were responsible for which opinions. It was noted that wide differences existed in the respective opinions of some experts and for some issues, only one expert was willing to offer an opinion. This information evoked extensive questioning and discussion on how DOE would treat such information in the VA. In those areas where the results of the SZ elicitation yielded few or widely divergent opinions, DOE noted that it could supplement the elicitation with additional data, as needed.[4] In the question and comment period, there was additional discussion of the following:

- Explanations for differences in the respective experts' opinions on certain parameter values;
- The extent to which dilution at the well head was considered during the elicitation; and
- The expert's views on the importance of vertical and lateral dispersion.

The second DOE flow and transport presentation was a summary of hydraulic testing activities by the USGS, including tracer tests, at the C-Well Complex. In summary, the USGS presentation: (1) covered testing activities and results for the 1995-97 time frame; (2) reviewed how testing activities were integrated with the site-scale SZ modeling efforts (conducted principally by Lawrence Berkeley National Laboratory); and (3) discussed future testing plans.[5] The USGS made this presentation and it can be found in Attachment 5. Overall, they reported that the results of the tracer tests conducted thus far appear to show that matrix diffusion does occur at least within the Bullfrog unit of the welded tuff aquifer. A brief question and comment period followed the presentation during which the principal investigators were asked to interpret the meaning of some test results.

The third and final DOE flow and transport presentation was a summary by the Los Alamos National Laboratory (LANL) of evidence supporting matrix diffusion in the SZ. In its presentation, contained in Attachment 6, LANL cited and reviewed four lines of evidence in supporting the DOE position on the role of matrix diffusion at the site. In LANL's view, this evidence includes: (1) SZ water ages; (2) theoretical/empirical calculations; (3) literature studies; and (4) experiments from the C-Well Complex. During the presentation, DOE noted that it intends to elaborate further on the significance of this evidence in the forthcoming

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[4] As a general point, DOE noted that for this and some of the other formal expert elicitations recently completed, it may need to perform some degree of post-elicitation processing of the elicitation results in order to derive the parameter values or other information needed for the TSPA-VA and/or the other-related VA products. DOE indicated that it was developing a procedure to describe when and how such post-elicitation processing would take place.

[5] Future DOE plans for testing at the C-Well Complex are described in the *Final Report on the Enhanced Characterization of the Repository Block Planning Effort*, dated November 1997.

TSPA-VA. Following this presentation, there was a question and comment period which included some discussion between staff from LANL, NRC, and the CNWRA on the feasibility of conducting laboratory experiments to test DOE's hypothesis regarding the significance and extent of matrix diffusion at the site.

The first suite of SZ presentations (Attachments 4 through 6) focussed on DOE's defense of the use of matrix diffusion in its models. Despite these presentations, the NRC staff repeated its position that it was not convinced that matrix flow and diffusion were the predominant transport mechanisms at the site. The staff noted that it believes that there are alternative interpretations of the data that show more conclusively that fracture flow dominates at the site. For example, in the briefing materials found in Attachment 7, the CNWRA presented geochemical analyses that suggest that fracture waters in the tuff aquifer are not in chemical equilibrium with either matrix minerals or matrix waters - thereby suggesting that under ambient conditions, any fracture-matrix interactions are expected to be limited. In the view of the CNWRA, although matrix diffusion may occur, the specific pore volume of rock matrix into which the radionuclides may diffuse or advect is likely to be much less than the bulk matrix porosity. Following this presentation, there was a brief question and comment period which resulted in a suggestion that an Appendix 7 meeting on this topic be scheduled to allow the opportunity for further discussion and exchange of information.

Next, the second major subject of the Technical Exchange was discussed - scenario selection and the treatment of disruptive events. This agenda item was a continuation of earlier limited discussions that took place during the July 1997 Technical Exchange. For the VA, DOE has elected to consider the effects of only four disruptive events on the performance of a proposed geologic repository - these being seismic and igneous activity, nuclear criticality, and human intrusion. However, at the time of a possible License Application submittal, it is expected that DOE's assessment will need to reflect consideration of all (reasonably) credible scenarios and disruptive events. Moreover, the staff expects DOE to demonstrate that it has employed some type of rigorous scenario screening methodology that, among other things, treats scenarios as mutually exclusive events. Thus, with this background in mind, and in the spirit of no "surprises" (at the time of the VA publication),[6] the staff thought that discussing this issue in the context of DOE's overall VA plans would be useful.

The first DOE scenario presentation is contained in Attachment 8 and was made by SNL. This presentation described the philosophy and approach to the scenario selection methodology being currently employed for the TSPA-VA. As a matter of background, SNL

[6] In its review of the four VA elements, DOE is aware that the staff will consider existing open items, to the extent that they still apply. For example, it is the NRC staff's position that *Site Characterization Analysis* (SCA) Open Items 95 and 105, concerning the need for DOE to describe its plans to implement a defensible scenario screening methodology as part of site characterization, have not been adequately addressed by DOE and therefore still apply. Accordingly, the staff intends to review TSPA-VA and VA License Application Plan to determine what progress the Department has made in addressing these (and other) staff concerns.

noted that there is presently no NRC guidance[7] on this subject nor international consensus on an acceptable approach to the selection of scenarios for consideration in a total-system performance assessment. Moreover, it is SNL's view that developing a comprehensive list of features, events, and processes (FEPs) unique to the Yucca Mountain site is not necessary because the results of site characterization thus far have led to the identification of those FEPs thought to be most important to repository performance. Overall, the current scenario selection approach being used by DOE for the VA relies upon its principal investigators to identify those FEPs present at the site[8] and believed to be potentially important to design or performance, and then analyzing their significance using a modified event tree-type of an approach. In the question and comment period that followed, the staff noted that in DOE's analyses, probabilities are not being assigned to all branches of an event tree and consequently, DOE may not be analyzing a suite of scenarios that are mutually exclusive - that is to say that the sum of the probabilities for those FEPs being evaluated in the TSPA-VA may exceed one because not all of the events being considered may not be mutually exclusive. DOE's plans for the treatment of this issue will continue to be discussed and evaluated.

The subsequent scenario-related presentations concerned some specific discussion of how the four aforementioned disruptive events are being modeled and abstracted by DOE in the TSPA-VA. These presentations, found in Attachments 9 through 11, were made principally by SNL with the assistance of the respective subject matter experts from LANL, DOE's M&O, and the USGS. Each presentation was followed by a brief question and comments period in which the audience asked specific questions on DOE's modeling efforts. In the question and comment period that followed, the NRC staff noted that DOE may be undertaking the correct types of technical investigations and analyses necessary to understand the disruptive phenomena of interest. DOE will need to demonstrate that the results of this work are integrated into its total-system performance assessment.

The NRC staff made the final set of scenarios-related presentations. The first (Attachment 12) was an expanded discussion of the treatment of disruptive events in Version 3.1 of the TPA computer code. The second concerned the staff's views on an acceptable approach to the selection and screening of scenarios. In its presentation, found in Attachment 13, the NRC noted that there has been substantial progress in addressing the staff's earlier SCA concerns in this area. However, despite this progress, there remain some important differences in the respective staff philosophies, which were identified during the presentation. In an attempt to provide a path to resolution in this area, the staff identified what it believed to be the attributes of an acceptable scenario selection methodology. In the question and comment period that followed, the staff noted that these attributes were expected to form the basis for *Acceptance Criteria* in an *Issue Resolution Status Report* (IRSR) to be prepared on this subject later in Fiscal Year 1998.

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[7] It was noted that the NRC staff have been studying this issue and two contractor reports have been published as NUREG/CRs — i.e., NUREG/CR-1667 and 6351.

[8] Those scenarios and disruptive events thought to be important by DOE were: (1) identified in previous TSPAs; (2) judged to have an effect on overall repository performance; (3) believed to occur over the repository lifetime; (4) determined to be high-probability events; or (5) are of high public concern.

November 6, 1997 — Technical Presentations (continued)

On Day 2, the third major agenda item of the Technical Exchange was introduced - waste package degradation. This agenda item was a continuation of earlier discussions that took place during the July 1997 Technical Exchange. In summary, the DOE and the staff have different views regarding how much credit (performance) can be attributed (allocated) to partially failed waste packages. DOE wants to take credit for the residual protection offered by a partially failed waste package container that has not lost its structural integrity. The staff agrees that partially-failed waste packages do afford some protection. However, it is difficult to quantify and defend any particular value. Therefore, it is the staff's approach that no performance credit has been given to waste packages canisters once the container walls have been breached.

DOE's M&O made the first presentation in this area by introducing the results and conclusions from the recently completed expert elicitation on waste package degradation (see Attachment 14).[9] In this presentation, an overview of the elicitation process was provided, including the identification of the elicitation panel members and the key assessments they were requested to make. Following a summary of the elicitation results, DOE's M&O discussed how it intended to modify its waste package materials testing programs to reflect key elicitation recommendations, which included adjusting its testing programs to address:

- Corrosion-resistant material selection;
- Pitting of carbon steel and the viability of galvanic protection; and
- Viability of ceramic coatings.

Following the presentation, there was an extensive question and comment period in which most of the discussion concerned the following areas:

- Material properties (including thermal stability) of titanium and carbon steels in waste package applications;
- Amount of credit attributed to spent fuel cladding;
- Treatment of dry oxidation; and
- Types of support materials being considered for the waste package canisters.

The second waste package degradation presentation was DOE's views on how radioactive waste could be released from a failed waste package canister. This presentation, found in Attachment 15, was made by Lawrence Livermore National Laboratory (LLNL) and focussed on the use of pitting and corrosion models to evaluate waste package performance. During the question and comment period, the audience asked LLNL to describe the physio-chemical mechanisms responsible for the occurrence of crevice corrosion and the applicability of process-level modeling to various waste package candidate materials. LLNL noted that it has two reports which address many questions raised during the discussions and they will make these reports available to the NRC staff and other interested parties.

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[9] At the time of the Technical Exchange, it was noted that the summary documentation for the waste package expert elicitation was under preparation.

The final DOE presentation was a discussion of DOE's approach to the abstraction and modeling of waste package degradation and how this work would be rolled-up into the TSPA-VA. This presentation was made by DOE's M&O and can be found in Attachment 16. During the presentation, DOE's M&O (with the support of other DOE contractors) provided additional information on the scope of the various waste package experiments being conducted (i.e., the types of parameters being modeled, configurations for the tests, etc.), preliminary interpretations regarding the results of waste package testing thus far, and clarification describing how the results of the recently completed expert elicitation were being integrated into its programs.

Following the DOE suite of presentations, the CNWRA and NRC made three presentations which provided an overview of the status of NRC modeling activities in the EBS area. The first presentation, found in Attachment 17, concerned the staff efforts to develop an improved waste package degradation model as part of Version 3.1 of the TPA computer code. The second presentation, which concerned source term modeling activities, can be found in Attachment 18. The third presentation examined the NRC staff's views regarding the effect of waste package failure on the rate of radionuclide release. This presentation can be found in Attachment 19. One important aspect in this series of presentations was the delineation of the differences in the respective staff approaches to modeling waste package degradation. As an example, the deterministic (mechanistic) approach to waste package failure used by the NRC staff[10] was compared and contrasted with the DOE's approach which used a probabilistic method to evaluate penetration of the waste package overpacks by general and pitting corrosion. During the presentation, the staff learned about the DOE's effort to gradually migrate toward a mechanistic model with more emphasis on the near-field chemistry and the chemistry of the local environment inside the pit that is mostly responsible for pit penetration. DOE asked the staff to present all assumptions made in the NRC's source term modeling approach. In response, it was noted that an exhaustive listing and discussion on the staff's waste package modeling assumptions were beyond the scope of the meeting, although such information could be provided to the State off-line. In the radionuclide release calculations, the NRC's bathtub model was contrasted with DOE's flow-through model. Also, dependency of source term calculations on water infiltration and evolution of the near-field environment were presented in TPA 3.1. The strong dependence of radionuclide release on the mode of waste package failure was highlighted.

The second agenda item in Day 2 of the Technical Exchange concerned the fourth and last major discussion topic - analyses related to the evaluation of the biosphere in the Yucca Mountain area. DOE had three presentations in this area and NRC had four. As a matter of background, it was noted by the NRC staff that revisions to 10 CFR Part 60 are being contemplated by the Commission, consistent with the 1995 findings and recommendations of the National Academy of Sciences (NAS) on revised disposal standards for Yucca

[10] See Mohanty, S., *et al.*, "Engineered Barrier System Performance Assessment Code: EBSPAC Version 1.0 b - Technical Description and User's Manual," San Antonio, Texas, Center for Nuclear Waste Regulatory Analyses, CNWRA 96-011, 1996.

Mountain.[11] One of the NAS' recommendations was that health- or dose-based performance measures (that are risk-based) be adopted for certain target populations, in the Yucca Mountain vicinity, using the "critical group approach" described by the *International Commission on Radiological Protection.* The staff noted that although the ongoing biosphere work of the two staffs, as described in the following presentations, would be valuable in gaining an improved understanding regarding the technical considerations associated with this type of analysis, the approaches, assumptions, and conclusions of this work should be regarded as preliminary until the Commission's views on this subject are known.

The first presentation concerned a recently completed biosphere survey of the dietary and lifestyle characteristics of residents in the Amargosa Valley area. The goal of the survey was to collect quantitative information on the level of locally-produced food consumption to calculate annual consumption estimates, the results of which are to be factored into dose assessments as part of the forthcoming TSPA-VA. In summary, the survey covered the existing population in Nye County within 80 kilometers of the site, and provided specific statistics on local water and food consumption. Highlights and results of the food consumption survey for the NTS/Yucca Mountain area can be found in the briefing materials contained in Attachment 20. Overall, the results of the survey suggest that 80 percent of the adults in Amargosa Valley area consume locally-produced food and near 90 percent consume local ground water. The survey also shows that no resident in the NTS/Yucca Mountain area lived a subsistence lifestyle in which all of the food and water consumed was locally produced. This presentation was followed by a brief question and comment period. In response to questions, DOE stated that the goal of the survey was not to identify which residents in the NTS/Yucca Mountain area could be considered members of the so-called "Yucca Mountain critical group," because that determination falls within the authority of the NRC. Rather, the intent of the survey was to exercise cautious but reasonable assumptions about lifestyles and habits of the current population to estimate the potential dose to residents down-gradient from the site.

The second biosphere presentation was an overview of the initial efforts by SNL to model dilution at a pumping well. The proposed approach discussed considers a hypothetical pumping well 5 kilometers down-gradient from the proposed repository at Yucca Mountain. In this presentation, it was noted that material was preliminary and subject to additional refinement which is expected to be described in the TSPA-VA. The briefing slides are contained in Attachment 21. Again, the presentation was followed by a brief series of questions and comments in which most of the questions asked concerned specific details regarding the construct of this modeling exercise.

The final DOE biosphere presentation was an overview by DOE's M&O of the dose assessment activities supporting the TSPA-VA. The *GENII-S* computer code has been selected to perform the necessary calculations for the TSPA-VA. In summary, dose

[11] See National Research Council, "Technical Bases for Yucca Mountain Standards," Washington, D.C., National Academy Press, Commission on Geosciences, Environment, and Resources, July 1995. Also see footnote No. 1.

conversion factors (DCFs) for 39 radionuclides will be calculated, at three receptor sites and under three different climate conditions - e.g., pluvial vs. non-pluvial. Some preliminary calculations of doses, using DOE- and NRC-derived biosphere DCFs, were shared with the audience. Sensitivity and uncertainty analyses are also contemplated as part of the TSPA-VA to identify sensitive parameters and pathways. The presentation ended with a brief series of questions and comments in which most of the questions asked concerned specific details regarding the constructs and assumptions to be used in this modeling exercise. During the question and comment session, it was noted that for DOE's analyses, the average member of the critical group was assumed to reside down-gradient from the site, in Amargosa Valley. Following questioning, they also noted that the soil transfer factors were from the literature, including reports of the *International Atomic Energy Agency* (IAEA).

The next series of biosphere-related presentations focused on three CNWRA analyses addressing the implementability of the 1995 NAS recommendations. The results of these analyses were first introduced in NRC's 1996 *Annual KTI Status Report,*[12] and discussed in general terms, later, during the July 1997 total-system performance technical exchange. The purpose of repeating the presentations was to provide additional detail on the analytical approaches/assumptions used to conduct these analyses. However, as a point of clarification regarding this work (see Attachment 23), the NRC reminded the audience that approaches, assumptions, or conclusions being described should in no way be construed to express the views or the preferences of the NRC staff on what the nature of a future NRC implementing rule for Yucca Mountain should be. The three CNWRA presentations were on the following topics:

- Scoping study of dispersion in the saturated zone;
- Use of ground water in the arid and semi-arid United States; and
- DCFs for Version 3.1 of the TPA computer code.

The briefing slides for each of these presentations can be found in Attachments 24 to 26, respectively. A brief series of questions and comments followed the end of each presentation. Most of the questions asked concerned specific details regarding the constructs and assumptions to be used in the respective analyses. During the question and comment period, the following points were noteworthy:

Dispersion Study (Attachment 24): A computer modeling study of flow and transport was performed to examine possible flow patterns and plume spread in the complex hydrostratigraphic setting of the tuff aquifer below the proposed geologic repository. Using hydrogeologic data for Boreholes H-5 and H-4, two-dimensional simulations were performed and visualizations produced for ground-water flow paths, particle travel times, and plume distributions. For the cross-section considered and boundary conditions assumed in this study, the flow paths may be strongly influenced by factors such as dip of the stratigraphic units, the presence of faults, and contrasts in hydraulic conductivities between adjacent units. Particle travel times were influenced by the assumed effective porosity for the

[12] Sagar, B. (ed.), "NRC High-Level Radioactive Waste Program Annual Progress Report: Fiscal Year 1996,"U.S. Nuclear Regulatory Commission, NUREG/CR-6513, No. 1, January 1997. [Prepared by the Center for Nuclear Waste Regulatory Analyses.]

fractured tuff units. The transverse dispersivity influenced the vertical plume spread. If the vertical dispersivity of the tuffs is similar to low values in the literature (i.e., millimeters to a few hundred centimeters), the simulations suggest that contaminant plumes below the repository may remain near the surface of the water table and exhibit only relatively moderate vertical spreading, except in regions of flow redirection induced by structural features. Overall, the modeling study suggests that the degree of plume mixing is likely to be relatively small, which is consistent with the views of the DOE expert panel on saturated flow and transport. However, vertical mixing of the plume with distance could be enhanced by flow through or around faults (i.e., the Bow Ridge Fault).

Ground Water Use Study (Attachment 25): The purpose of this study[13] was to examine water well drilling practices in arid portions of the US, to draw inferences regarding the types of water wells that might have been drilled at NTS had the land not been withdrawn by the Federal Government. One of the study's findings was information that suggested that in some portions of the southwest U.S., it is common practice to construct deep wells (depths-to-water greater than 240 meters) for domestic and stock water. Thus, it was argued that wells with comparable depths-to-water could be relied upon to provide water in the NTS/Yucca Mountain region for a small community or a cluster of homes. Also, although stock water supplies could be obtained in the Jackass Flats basin, the CNWRA suggested that natural forage was insufficient to graze cattle.

As a matter of record, the representative for the State of Nevada expressed the view that few inferences could be obtained from this study because the circumstances (and economics) associated with the development of each well identified in the study varied from well-to-well. As an example, it was noted that prior to the establishment of NTS, there was a working cattle ranch at Jackass Flats that relied upon a shallow (alluvial) well for its water. Accordingly, in the State's opinion, there was no scientific basis for specifying where members of a hypothetical critical group may be found, based on previous well drilling information, because the factors that contribute to water-use and drilling decisions in any particular location were too difficult to quantify.

TPA 3.1 DCFs (Attachment 26): Consistent with the NAS recommendations, the staff has been working to incorporate a dose-assessment capability into its total-system performance assessment computer code. As part of the development of this capability, TPA 3.1 will rely on site-specific DCFs to make the necessary radionuclide concentration-to-dose conversions. This presentation discussed the staff efforts thus far to derive and apply site-specific DCFs. Overall, the staff believes that the respective DOE and NRC approaches to deriving DCFs are consistent and produce similar results. During the question and comment period it was noted that the IAEA was the source of the food transfer factors used by the CNWRA.

The last NRC biosphere-related presentation was an overview of NRC's involvement in the IAEA's biosphere modeling and assessment methods (BIOMASS) program. The NRC has been previously involved in BIOMASS and, because of the recent NAS recommendations to

[13] See Wittmeyer, G.W., *et al.*, "Use of Groundwater in the Arid and Semi-Arid Western United States: Implications for [the] Yucca Mountain Area," San Antonio, Texas, Center for Nuclear Waste Regulatory Analyses, letter report, August 1996.

implement a risk-based standard for Yucca Mountain, the staff has a keen interest on the outcome of this program, which was described in the briefing materials provided in Attachment 27. It was noted during the discussion that DOE has recently applied to the IAEA to become an active supporter of the program,[14] when previously they have not been involved in BIOMASS. Both NRC and DOE indicated during comments that the activities in BIOMASS are highly supportive of the resolution and identification of implementation issues related to reference biosphere and critical group concepts.

Summary/Wrap-Up

The DOE and NRC staff prepared their respective closing comments. Because one objective of the Technical Exchange was to give DOE early feedback regarding the sufficiency of its TSPA to be submitted as part of its forthcoming VA, DOE requested that the staff consider that issue.

NRC Staff Comments/Observations
It is the staff's view that although they identified and constructively discussed many items of mutual interest, no open items *per se* were identified.

Also, as noted during the July 1997 Technical Exchange, the staff believes that DOE recognizes the need to provide transparency in the documentation supporting the VA. This documentation is expected to include the technical bases for the positions and design alternatives expressed in the VA and the identification of areas for which additional confirmation/experimentation/data collection is needed to build its licensing case.

Preliminary NRC Pre-VA Observations
Besides its wrap-up (or summary comments), the staff identified a number of TSPA areas it expected to evaluate in detail in future DOE/NRC interactions and when the VA is produced. These points are not rank-ordered:

Expert Elicitation: DOE has noted that conducting some type of post-processing (including augmentation) of the results of the expert elicitations it has sponsored may be necessary to obtain specific data/information needed to support the TSPA-VA. Because of the need for this post-processing, it is not clear whether DOE's performance assessment program has been properly integrated into the initial elicitation scoping process. Moreover, it is not clear to the staff what value expert judgment would have when, as in some cases, only one or two experts offer an opinion. As part of the TSPA-VA documentation, the staff expects DOE to addresses these issues.

Matrix Diffusion: Although DOE has moderated its position somewhat, attributing more credit for fracture flow in its ground-water transport models, both staffs continue to have different views on regarding matrix diffusion. For its part, the NRC staff still recognizes the need to evaluate DOE's data and analyses of the C-Well Complex to better understand this

---

[14] The main focus of BIOMASS is the continuing development of international consensus and attendant guidance on practical approaches to the implementation of the reference biosphere and critical group concepts.

phenomenon. Accordingly, the staff believes that it would be beneficial to conduct an Appendix 7 meeting on this subject to better understand the basis for the differences in the respective staff views.

Treatment of Disruptive Events: At the process level, DOE and its contractors may be conducting (or planning to conduct) the right types of investigations and analyses necessary to understand the four disruptive phenomena of interest. How this information will be treated, in a total-system performance assessment, though, is still not clear to the staff. That is to say, the staff is interested in gaining visibility of DOE's abstracted models and data that will be used to support the TSPA-VA. Moreover, DOE's overall plans for addressing SCA Comments 95 and 105 are still not apparent. As a result, the staff believes that it would be beneficial to conduct an Appendix 7 meeting to get some insight into these two issues.

Waste Package Testing Programs: The experimental and testing programs of DOE's contractors for the waste package seem comprehensive. As a general observation, it was noted that because of the complexity of waste package corrosion behavior, one major challenge facing both staffs will be their ability to appropriately abstract the waste package testing results so licensing decisions can be made.

Biosphere Modeling Activities: The staff believes that DOE's work in this area thus far has been well thought-out and should be sufficient for the required TSPA-VA calculations.

DOE Staff Comments/Observations
Following NRC staff comments, DOE agreed with the staff that many performance assessment issues were constructively discussed and that no open items *per se*. Based on the nature of the staff-level discussions, DOE offered the following thoughts for future NRC considerations as the staff prepares to review the VA:

Treatment of Disruptive Events: DOE believes that it can adequately address the staff's concerns regarding how it will integrate the results of its disruptive event work into TSPA-VA. The Department agrees that a smaller, Appendix 7-type of a meeting on this subject would be worthwhile prior to the staff's review of the VA.

Saturated Zone Hydrology (Including the Treatment of Matrix Diffusion): DOE observed that understanding the nature of flow and transport phenomena in the Basin and Range is not a simple task and for the Yucca Mountain site, this understanding is not as mature as the Department would like it to be. It was acknowledged that additional work in this area is needed to better understand the fracture-matrix interactions. After completion of the VA, it is likely that DOE may sponsor additional expert elicitations to help interpret the data used in any potential License Application. However, for the purposes of the VA, DOE expects to prepare the best technical arguments it can based on what it believes to be scientifically-defendable interpretations of the available data. Accordingly, DOE continues to recognize the need to ensure that its position regarding matrix diffusion is technically defensible and supported by adequate documentation.

Conservatism of NRC's Modeling Approaches: The Department is aware of the impact recent budget reductions on NRC's HLW program and is sympathetic of the staff's desire to maintain a credible program and review capability. However, the Department is concerned that the net effect of these reductions may be the introduction of excessive conservatism into its modeling efforts as a way of compensating for a less comprehensive and sophisticated performance assessment computer code. Moreover, because of the integrated nature of the *Key Technical Issues* to NRC's performance assessment program, the Department is also concerned that the *Acceptance Criteria* being prepared for the *IRSRs* may reflect some degree of over conservatism as well. Accordingly, the Department requested that, as the staff develop its *Acceptance Criteria*, the criteria be written is such a way affords DOE some flexibility in its demonstrations.

Expert Elicitation: DOE appreciates the staff's concerns related to the post-elicitation application of the results of expert opinion. However, because of the evolving nature of the repository program and because of the lead-time needed to prepare and conduct a formal elicitation, there will always be the potential that some issues will not be addressed by an expert panel in "real time." Although such occurrences are undesirable, in the first instance, they may be unavoidable given the fiscal and temporal constraints beyond the Department's control. In the unavoidable event that DOE must perform some type of post-elicitation processing or augmentation, it will do so under certain controls. DOE is developing an administrative procedure to control how such an activity would take place and how they would treat new and relevant data following the completion of an elicitation. Once this procedure has been developed and approved, a copy will be provided to the NRC staff.

At the close of these discussions, the staff representing the State of Nevada and Clark County, Nevada, were invited to make some closing comments. Both participants declined to make comments.

Michael P. Lee
Division of Waste Management
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission

Abraham van Luik
Yucca Mountain Site Characterization
Office
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy

AGENDA
DOE/NRC Technical Exchange on
Total System Performance Assessments (TSPA) for Yucca Mountain

Wednesday, November 5, 1997

- **Opening Remarks**

- **Saturated Zone Hydrology**
  - Results/conclusions from the DOE expert elicitation — Insights related to matrix diffusion and/or vertical mixing
  - C-Well Complex test results: Alternative interpretations and process model incorporation
  - Matrix diffusion/modeling assumptions for the TSPA-VA
  - NRC views on evidence of fracture flow at the site

- **Treatment of Disruptive Events**
  - Overview of DOE 's Features-Events-Processes approach to consequence analyses for non-mutually exclusive events
  - Updates on DOE approach to the treatment of disruptive events for the TSPA-VA, including treatment of criticality
  - NRC approach to the treatment of disruptive events in IPA Phase 3 consequence modeling: Assumptions for volcanism, faulting, and seismicity
  - NRC pre-VA views

Thursday, November 6, 1997

- **Waste Package Degradation**
  - Results/conclusions from the DOE expert elicitation
  - DOE views on how waste is being released from the waste package canister
  - DOE approach for the TSPA-VA
  - Key assumptions and approach NRC's waste package modeling in IPA Phase 3

- **Biosphere Evaluations**
  - Results of recent DOE Biosphere Survey
  - DOE preliminary views on modeling dilution at pumping well
  - DOE approach for the TSPA-VA — Utilization of Biosphere Survey Results
  - NRC treatment of biosphere issues in IPA Phase 3
    - Dilution assumptions
    - Regional drilling practice survey, including pumping assumptions
    - Dose Conversion Factors

- **Closing Remarks**

ATTACHMENT 1

LIST OF ATTENDEES
AT THE DOE/NRC TECHNICAL EXCHANGE
ON TOTAL-SYSTEM PERFORMANCE ASSESSMENTS
FOR YUCCA MOUNTAIN, NEVADA

November 5-6, 1997

Advisory Committee on Nuclear Waste
A. Campbell L. Deering

Center for Nuclear Waste Regulatory Analyses
R. Baca G. Cragnolino R. Fedors M. Jarzemba P. LaPlante L. McKague
S. Mohanty W. Murphy B. Sagar J. Stamatakos G. Whittmeyer

Clark County, Nevada
E. von Tiesenhausen

ICF Kaiser
C. Whipple

FRA, Inc
R. Budnitz

Los Alamos National Laboratory
B. Robinson

Lawrence Livermore National Laboratory
B. Halsey

Nevada Nuclear Waste Task Force
J. Treichel

Nye County, Nevada
M. Murphy P. Montazer N. Stellavato

State of Nevada
S. Frishman L. Lehman

Pacific Northwest National Laboratory
P. Eslinger

U.S. Department of Energy (DOE)
L. Desell C. Einberg A. Gil A. Van Luik

DOE Management and Operating Contractors
B. Andrews K. Ashe T. Bruno S. Echols D. Geiger P. Gottlieb
A. Haghi P. Hammond K. Iyengar J. Lee J. Linhart C. Lum
N. Lui K. Mon M. Nutt A. Smith J. Tappen J. Tung
D. Sevougian D. Swanson M. Wasipiek T. Williams D. Wu J. Yonker
J. York

Sandia National Laboratories
S. Altman B. Arnold R. Barnard H. Dockery N. Francis J. Gauthier
M. Itamura C. Ito M. Wilson

U.S. Geological Survey
M. Fahy A. Geldon G. Rosenbloom J. Stuckless P. Tucci M. Umari
R. Wallace

ATTACHMENT 2

LIST OF ATTENDEES
AT THE DOE/NRC TECHNICAL EXCHANGE
(continued)

November 5-6, 1997

S,C and A, Inc
S. Colwell

U.S. Nuclear Regulatory Commission

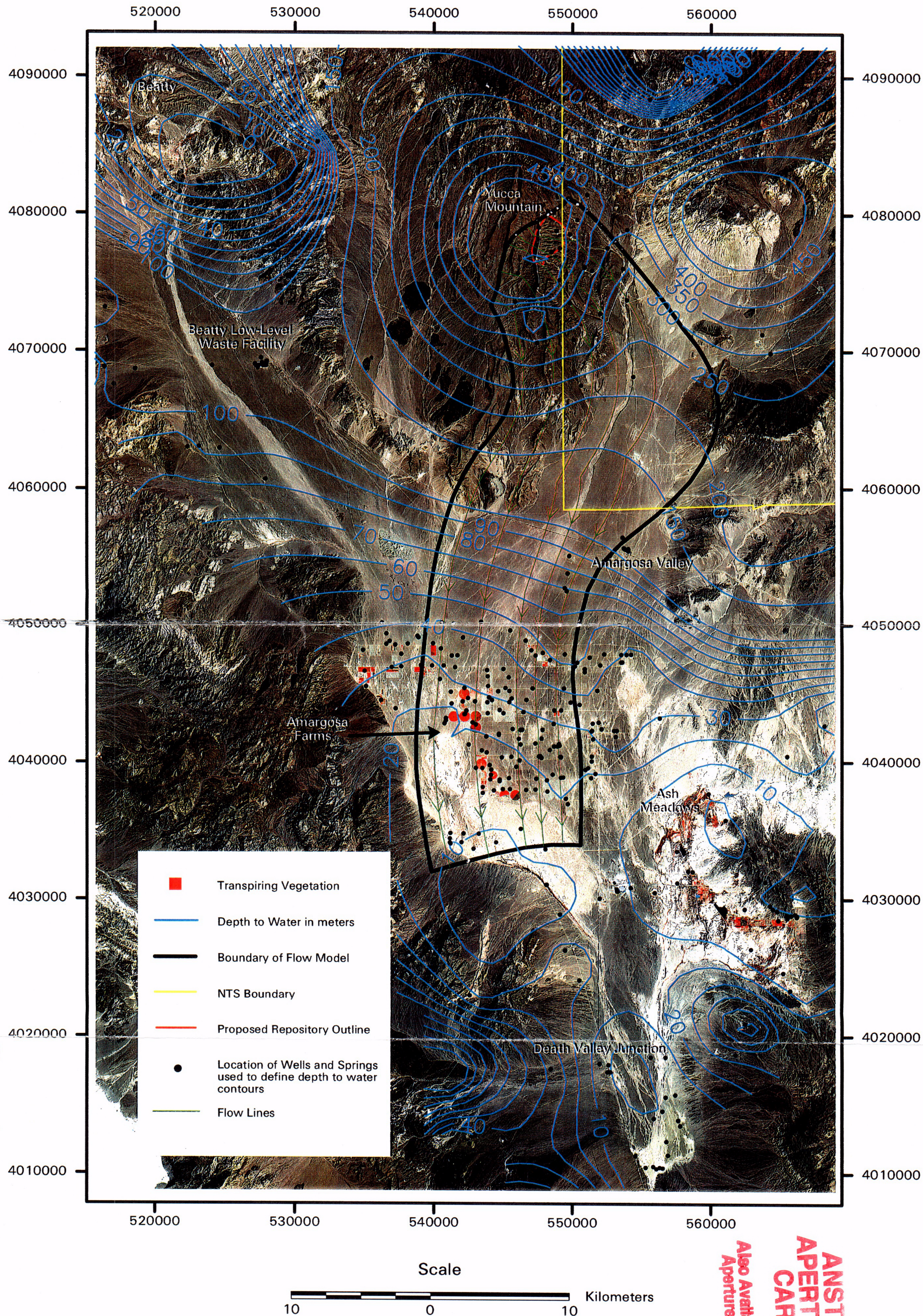
T. Ahn	B. Belke	M. Bell	J. Bradbury	D. Brooks	M. Byrne
K. Chang	D. Codell	N. Coleman	B. Eid	N. Eisenberg	J. Davis
L. Hamdan	B. Ibrahim	P. Justus	M. Lee	C. Lui	T. McCartin
K.McConnell	C. McKenny	M. Nataraja	K. Stablein	J. Trapp	S. Wastler

U.S. Nuclear Waste Technical Review Board

D. Bullen	L. Reiter	J. Wong

ATTACHMENT 3

Vegetation Map and Depth to Water: Yucca Mountain Region



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LIMITATIONS:

- NRC Recognizes the Developing Nature of DOE's TSPA-VA

- NRC's Presentations on its TPA 3.1 Code and Reference Case are Preliminary and Verification Testing is Continuing

- NRC's Presentations on Reference Biosphere and Critical Group Represent Preliminary Staff Views and Should Not Be Considered as Staff Positions in the Context of NRC's Development of a HLW Implementing Rule

- Another TSPA Technical Exchange is Planned for 03/98 to Continue TSPA-VA/TPA Discussions. Specifically Focusing on:

    - Reference Case Assumptions, Models, Data and Results for TSPA-VA
    - TPA 3.1 Sensitivity Studies Results

OBJECTIVES AND LIMITATIONS OF TECHNICAL EXCHANGE

November 5-6, 1997
DOE/NRC Technical Exchange on
Total System Performance Assessments
for Yucca Mountain

Keith I. McConnell
301/415-7289 - KIM@nrc.gov
Division of Waste Management
Performance Assessment and HLW Integration Branch

OBJECTIVES AND LIMITATIONS OF TECHNICAL EXCHANGE

OBJECTIVES:

- Continue Discussions Initiated in July 1997 Technical Exchange
  - Focused Meeting with a Limited Number of Topics (Facilitate In-Depth Discussion)
    - * Address Topics Not Considered in July (i.e., Disruptive Events and Biosphere)
    - * Follow up on Discussion Points Identified in July Technical Exchange

- Compare and Contrast Respective NRC TPA and DOE TSPA-VA Approaches (Assumptions, Abstractions, Process Models, Data, etc.) to Identify Areas of Agreement and Difference

  - Identify and maintain focus on key performance issues
  - Identify areas of agreement and difference in respective approaches and determine the significance of differences
  - Identify measures necessary to reach closure

- Continue Progress Towards Issue Resolution (i.e., No More Questions at this Time at the Staff Level)

ATTACHMENT 4

YUCCA
MOUNTAIN
PROJECT

Studies

Summary of the Results of the Saturated Zone Expert Elicitation

Presented to
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:
Bill W. Arnold, Senior Member Technical Staff
Sandia National Laboratories
Albuquerque, New Mexico

November 5, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Role of Expert Elicitation in Quantifying Uncertainty

- Assist in generating parameter uncertainty ranges and, if possible, their distributions.
- Assist in defining the "reasonable" likelihood of alternative conceptual models that should be evaluated for TSPA.
- Assess the "reasonableness" of the current SZ flow and transport models given the available information.
- Provide useful information exchange with SZ modelers and TSPA staff to assist in the development of defensible SZ flow and transport analyses.
- Focus on assessment of uncertainty.

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Expert Elicitation Panel Members

• Allan Freeze (AF)	(R. Allan Freeze Engineering)
• Lynn Gelhar (LG)	(Massachusetts Institute of Technology)
• Don Langmuir (DL)	(Colorado School of Mines)
• Shlomo Neuman (SN)	(University of Arizona)
• Chin-Fu Tsang (CT)	(Lawrence Berkeley National Laboratory)

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Expert Elicitation Implementation

- Project organized by Geomatrix Consultants, Inc. under the direction of Kevin Coppersmith.

- Project components and schedule:
  - Workshop #1 — June 4-6, 1997
    (focused on site characterization data)
  - Workshop #2 — July 22-23, 1997
    (focused on interpretations and modeling)
  - Workshop #3 — Aug. 11-12, 1997
    (focused on interpretations by panel members)
  - Individual elicitation interviews — Aug. 13 - Sept. 3
  - Draft report to DOE — Oct. 31, 1997

SZ Expert Elicitation Topics

- General conceptual model of groundwater flow.
- General conceptual model of solute transport.
- Large hydraulic gradient.
- Hydraulic conductivity (site scale).
- Specific discharge (site scale).
- Dispersivity / dilution factor.
- Climate change / disruptive events.
- Effective porosity / matrix diffusion.
- Mixing depth.
- Sorption / colloid facilitated transport.
- Thermal effects.

Disclaimer

- Final documentation of the SZ expert elicitation was not available at the time this presentation was prepared.
- Quantification of uncertainty distributions for parameters presented here has not been completely reviewed. In addition, composite uncertainty distributions are not presented.
- Summary points for each topic are meant to address issues of greatest significance to performance assessment analyses, but are not necessarily a complete listing of opinions expressed by expert panel members. Please refer to the final expert elicitation report when it becomes available for more complete documentation.

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General Conceptual Model of Groundwater Flow

- No fundamental uncertainties in nature of flow system. (AF)
- Flow channelization is expected both at the scale of major geologic structures and at the scale of formational heterogeneities. (CT, AF)
- Significant flow occurs in only 10 to 20% of fractures. (CT)
- Zones of flow do not consistently occur at the same stratigraphic horizons (as indicated by borehole flowmeter surveys). (LG)
- Faults may have significantly altered permeability, lower in the perpendicular direction and higher along strike and dip. (AF)
- Flow is to the southeast from the site and south at Fortymile Wash. (DL, AF)
- Flow probably does not occur from the volcanic units into the underlying carbonate aquifer; transport from the site to 20 km distance occurs primarily in the volcanic units and the alluvium. (CT, DL, LG)

General Conceptual Model of Groundwater Flow (cont.)

- Flow beneath Yucca Mountain is a combination of snowmelt recharge from Pahute Mesa and/or Timber Mountain and from local snowmelt recharge. (DL)
- Recharge appears to be occurring along Fortymile Wash. (DL)
- No significant short-term transients in flow system; steady-state analysis is appropriate. (AF)
- Concept of isolated "compartments" in the SZ is not supported. (SN)
- Volcanic aquifer downgradient of the site is highly transmissive. (LG)
- There probably is good interconnection of permeable fractures at the scale of hundreds of meters to kilometers. (LG)

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General Conceptual Model of Solute Transport

- General skepticism regarding large-scale mixing and dilution.
- Primary transport mechanism is advective transport. (AF)
- No scientific basis for "stirred tank" model. (SN)
- Few mechanisms lead to substantial mixing of the plume, perhaps from climatic transients. (AF)
- Larger-scale features (confining units, faults) will change geometry of plume rather than cause dilution. (LG)
- Lateral and vertical dispersion are likely to be small. (AF)
- Channelized flow in the UZ will lead to localized, higher concentration "point sources". (CT)

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General Conceptual Model of Solute Transport (cont.)

- Three general groundwater types in the Yucca Mountain area: volcanic rock groundwaters, alluvial groundwaters, and regional carbonate aquifer groundwaters. (DL)
- Dispersion cannot be interpreted solely as dilution; dispersion coefficient is expression of resolution and is scale-dependent. (SN)

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Large Hydraulic Gradient

- Large hydraulic gradient (LHG) is not a unique feature in the region.
- Apparent LHG is unique in that it does not correspond to any obvious geologic or topographic features.
- Two credible interpretations: saturated flow system or perched flow system. (AF)
- Probability of saturated vs. perched models:

(AF)	0.70 saturated	0.30 perched	
(CT)	0.40 saturated	0.60 perched	
(SN)	0.04 saturated	0.95 perched	0.01 other

- Given the saturated model, probability of controlling feature:

(AF)	0.65 horizontal	0.35 vertical

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Large Hydraulic Gradient (cont.)

- Probability of sudden or transient changes in the LHG is very low to zero. (CT, AF)
- LHG is not a crucial issue. (AF, LG)
- LHG is an important issue from the perspective of demonstrating understanding of site hydrology and in terms of defining inflow boundaries for site groundwater flow model. (SN)

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Hydraulic Conductivity (Site Scale)

- Greater confidence placed on large-scale multiwell hydraulic testing (as at C-wells) than on single-borehole tests. (CT, LG)

- Hydraulic conductivity of volcanic aquifer (cm/s):

(CT)	1×10^{-6} (1 % percentile)	1×10^{-1} (99% percentile)
(AF)	3×10^{-5} (lower bound)	3×10^{-3} (upper bound)
(SN)	1.1×10^{-3}	7.4×10^{-2}
(LG)	9.4×10^{-5} (-2σ)	9.4×10^{-3} ($+2\sigma$)

- Hydraulic conductivity of alluvium (cm/s):

(AF)	1×10^{-4} (lower bound)	1×10^{-2} (upper bound)
(LG)	1×10^{-2} (-2σ)	1×10^{-0} ($+2\sigma$)
(CT)	1×10^{-6} (1 % percentile)	1×10^{-1} (99% percentile)

- Hydraulic conductivity of aquitards (factor less than volcanic aquifer):

(AF)	180x (lower bound)	20x (upper bound)
(LG)	100x (lower bound)	10x (upper bound)
(CT)	100x (lower bound)	10x (upper bound)

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Hydraulic Conductivity (Site Scale) (cont.)

- **Hydraulic conductivity of carbonate aquifer (cm/s):**

(AF)	3×10^{-5} (lower bound)	3×10^{-3} (upper bound)
(LG)	1.2×10^{-3} (-2σ)	1.2×10^{-1} ($+2\sigma$)
(CT)	1×10^{-6} (1 % percentile)	1×10^{-1} (99% percentile)

- **Hydraulic conductivity of faults in volcanic aquifer (factor greater than volcanic aquifer):**

(AF)	2x (lower bound)	18x (upper bound)

- **Hydraulic conductivity of upper volcanic aquifer (cm/s):**

(SN)	2×10^{-5}	3×10^{-2}

*** Note that estimates are made for effective properties at the scale of the site scale SZ flow model.**

Specific Discharge (Site Scale)

- Estimates are for average groundwater flow in the volcanic aquifer beneath the site.

- Specific discharge (m/year):

(CT)	9.5×10^{-4} (1 % percentile)	9.5×10^{1} (99% percentile)
(AF)	1×10^{-2} (lower bound)	1×10^{0} (upper bound)
(SN)	3.9×10^{-1} (10% percentile)	5.0×10^{0} (90% percentile)
(LG)	6×10^{-2} (-2σ)	6×10^{0} ($+2\sigma$)

* Note that estimates are based on hydraulic gradient of 0.0003 (CT, AF, and LG) or 0.0001 to 0.0004 (SN)

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Dispersivity / Dilution Factor

- **Longitudinal dispersivity (m):**

(LG)	5 (-2σ)	500 (+2σ)	(at 5 km)
(LG)	3.2 (-2σ)	3200 (+2σ)	(at 30 km)
(SN)	1/10 grid cell length		(crude rule of thumb)

- **Horizontal transverse dispersivity (m):**

(LG)	0.016 (-2σ)	16 (+2σ)	
(SN)	1/10 to 1/3 long. disp.		(crude rule of thumb)

- **Vertical transverse dispersivity (m):**

(LG)	0.00016 (-2σ)	0.16 (+2σ)	

- **Dilution factor:**

(CT)	2	10	(within channels at few km)
(CT)	100	1000	(including pumping well)
(DL)	10	50	(at ~30 km)
(AF)	1	100	(median=10) (at 25 km)

Climate Change / Disruptive Events

- Water table rise under pluvial conditions (m):

(DL)		120 (upper bound)
(AF)	25 (lower bound)	150 (upper bound)
(LG)		200 (upper bound)

- Water table rise and alterations to flow system from disruptive events:

(CT)	Expect changes to be transitory.
(DL)	Very low probability of significant change in water table.
(AF)	Short-lived increases in fluid pressure.
(AF)	No significant transfer of groundwater.
(SN)	Short-lived fluctuation in water table of cm to meters.
(SN)	Probably won't cause long-lasting changes to flow regime.

- Specific discharge under pluvial conditions (ratio to ambient):

(AF)	1 (lower bound)	10 (upper bound)	(median=3.2)
(LG)	(perhaps 2 to 3)		
(LG)	(greater transience and about 2 - 3 x increase in transverse dispersivity)		

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Effective Porosity / Matrix Diffusion

- Evidence for possible matrix diffusion on the field scale from separation of PFBA and bromide tracers in the C-wells tracer test is ambiguous. (SN)
- Effective porosity:
  (SN) 0.001 (lower bnd.) 0.10 (upper bnd.) (kinematic)

Mixing Depth

- Vertical plume width (m):
  - (LG) (expect about 23 m) (not the same as "mixing depth")
  - (LG) (mixing due to vertical dispersivity about 4.4 m across width of repository)
- General comments:
  - (CT) "Mixing depth" not a realistic concept.
  - (AF) Flow tubes from infiltration will remain discrete.
  - (SN) No scientific basis for "mixing depth".

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Sorption / Colloid Facilitated Transport

- General comments on sorption:
  - (CT) Laboratory K_d values should apply at field scale.
  - (DL) Effective K_d values are generally higher than lab values.
  - (SN) Sorption may occur, but field data are scarce and relationship to permeability is unclear.
  - (LG) Laboratory K_d values cannot be used without knowing how representative they are to field conditions.

- Effective K_d (ml/g):

(DL)	0 (lower bnd.)	10 (upper bnd.)	(Np, volcanic, fractures)
(DL)	(10 to 100 x higher)		(Np, volcanic, matrix)
(DL)	10 (10% perc.)	100 (95% perc.)	(Np, alluvium)
(DL)	100 (20% perc.)	1000 (80% perc.)	(Np, carbonate aquifer)

- General comments on colloids:
  - (DL) Influence of colloids will be attenuated by filtration, degradation of colloids and desorption of actinides.
  - (DL) Key actinide of concern is Pu.

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Thermal Effects

- General comments:
  - (CT) No convection is expected to occur.
  - (CT) Heat pulse will likely have passed by time contaminants reach water table.
  - (DL) Silica and calcite precipitation may clog matrix and fine fractures.
  - (AF) Impact of repository heating could be significant to SZ flow and transport.
  - (AF) Transient UZ flow could result in increased recharge below the repository.
  - (AF) Convection cells and mineralogic alteration are possible.
  - (LG) Expect thermal effects on SZ to be modest.
  - (LG) Buoyancy may reduce vertical plume width.

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Implications for TSPA

- Some parameter distributions will be used to semi-quantitatively evaluate the reasonableness of current flow and transport models. Examples:
  - Specific discharge in the volcanic aquifer.
  - Water table rise from climate change.
  - Change in specific discharge from climate change.
- Some parameter distributions will be used to inform development of parameter uncertainty distributions. Examples:
  - Permeability of hydrostratigraphic units.
  - Dispersivity.
  - Sorption coefficients.
- Low estimates of vertical transverse dispersivity may require re-examination of the conceptual model and alternative analytical methods in numerical simulations for accurate solution.

ATTACHMENT 5

Hydraulic & Conservative Tracer Tests

- Open-hole Hydraulic Test in 5/95.
- Observation Wells Packed off in 6/95 Hydraulic Test. (Plus Flow Survey).
- Long-term Hydraulic Test from 5/8/96 to 11/12/97. Distant Observation Wells Monitored.
- 2/96 Iodide Tracer Test in Lower Bullfrog-Upper Tram.
- 1/9/97 Pyridone Tracer Test in Lower Bullfrog (c1-c3).
- 1/10/97 2,6 DFBA Tracer Test (c2-c3).

Hydraulic and Conservative Tracer Testing

at the C-Holes Complex

1995-1997

By

Arthur Geldon and Mike Fahy

U.S. Geological Survey

M.J. Umari: P.I.

Integration with Modeling

- Next Version (Grid) of Site-Scale SZ Model Will Accommodate Data From the C-holes and Feature-Dependent Properties.

- C-holes Personnel are Involved Now, with Modeling and Structural Geology Groups in Identifying Faults to Define Discretely in Model.

- Longitudinal Dispersivity at 29-m and 86-m Scales are Available from C-Holes Conservative Tracer Testing. Also, Flow Porosity and Storage Porosity Values Available.

- Reactive Tracer Field and Laboratory Results are Discussed by LANL.

Future Testing Plans at the C-holes

- Prow Pass Hydraulic and Conservative Tracer Testing

  - Prow Pass is Low-Flow Zone: With Bullfrog Gives Range in Hydraulic & Transport Parameters

  - One of First Horizons to be Reached by Radionuclides from Breached Repository.

  - Special Equipment Designed for Test.

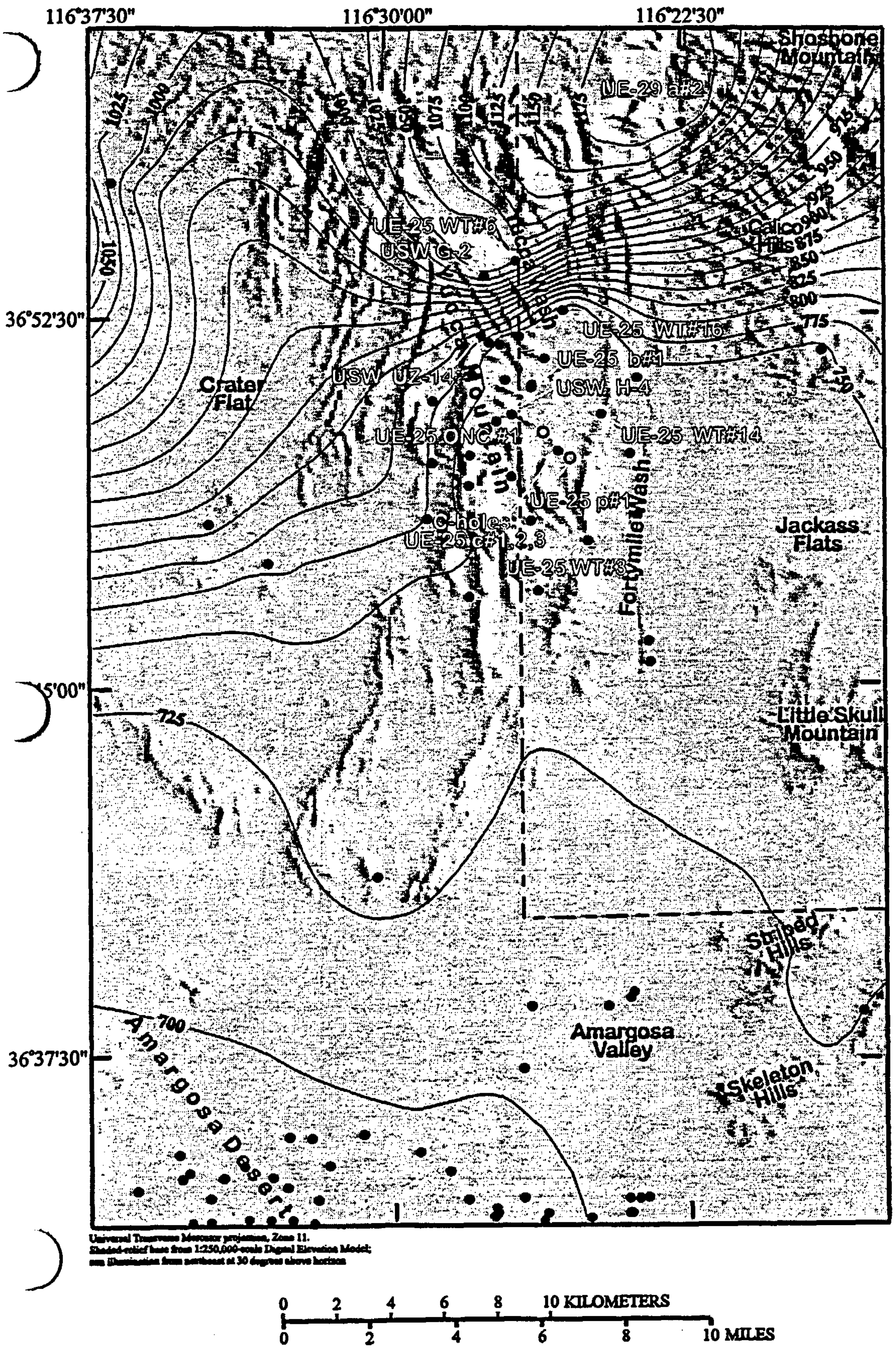
  - Reinstrumentation Complete by 1/98; Start Testing in 1/98.

- Hydraulic and Tracer Testing in Paintbrush Canyon Fault at C-holes,

  - Deferred to FY99 Because of Budget.

  - Important Test; Should not be Canceled.

HYDRAULIC TEST RESULTS, C-HOLE COMPLEX, 1995-97

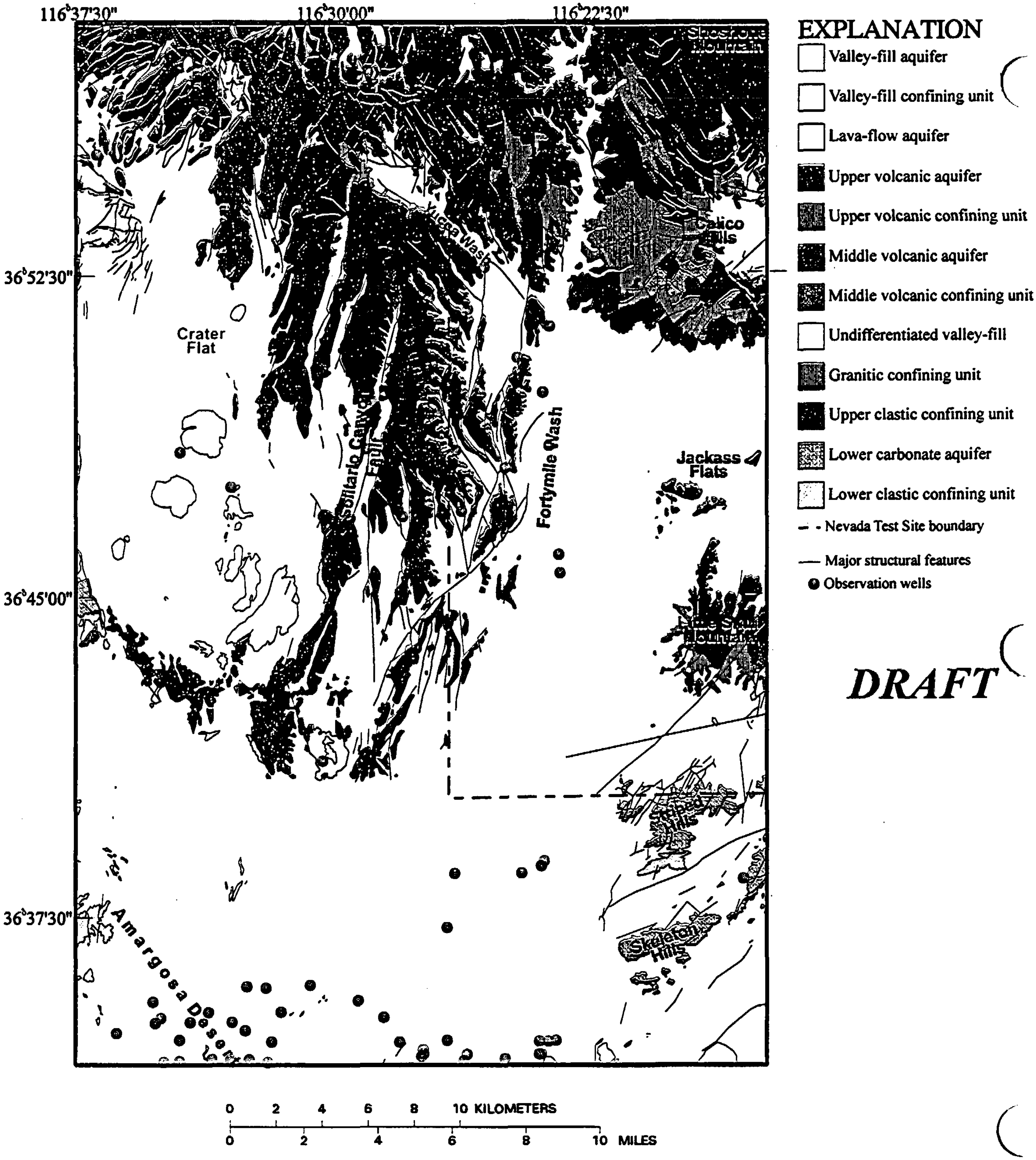


EXPLANATION

- ● Observation Well used in contouring
- ○ Observation Well not used in contouring
- – – Nevada Test Site Boundary
- —1000— Potentiometric contour - Shows altitude of potentiometric surface. Contour interval 25 meters. Datum is sea level.

DRAFT

Potentiometric surface that includes the large hydraulic gradient. Water-level altitude data outside the model domain, which were used for control, were obtained from tables 1 and 2 in Ciesnik (1995).



DRAFT

Generalized hydrogeologic units with major structural features (limestone aquifer, lower volcanic aquifer, and lower volcanic confining unit do not appear at the land surface).

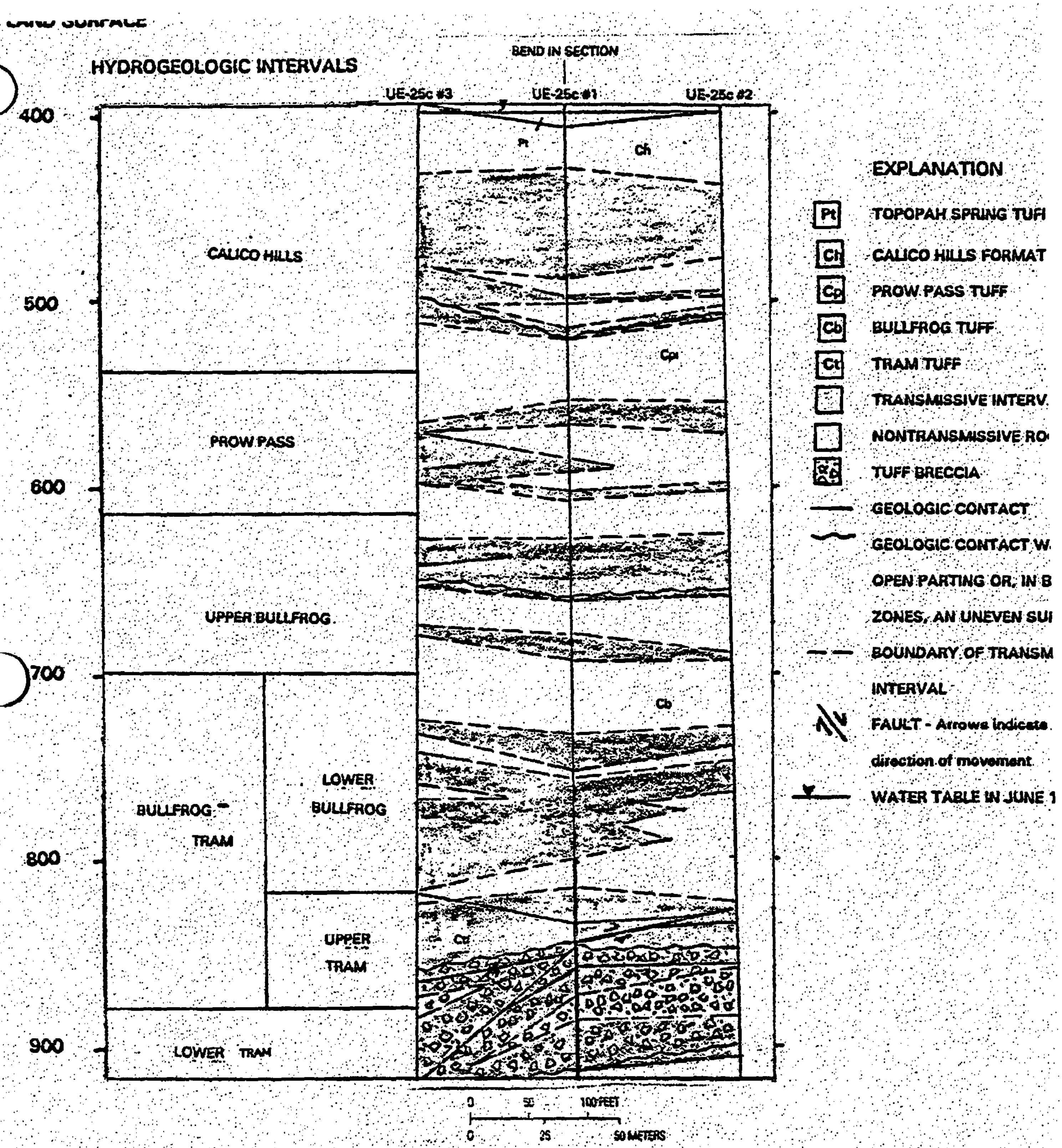


Figure 5 - Hydrogeologic intervals in the C-holes during hydraulic and tracer tests, 1995 to 1997 (Modified from Geldon, 1996)

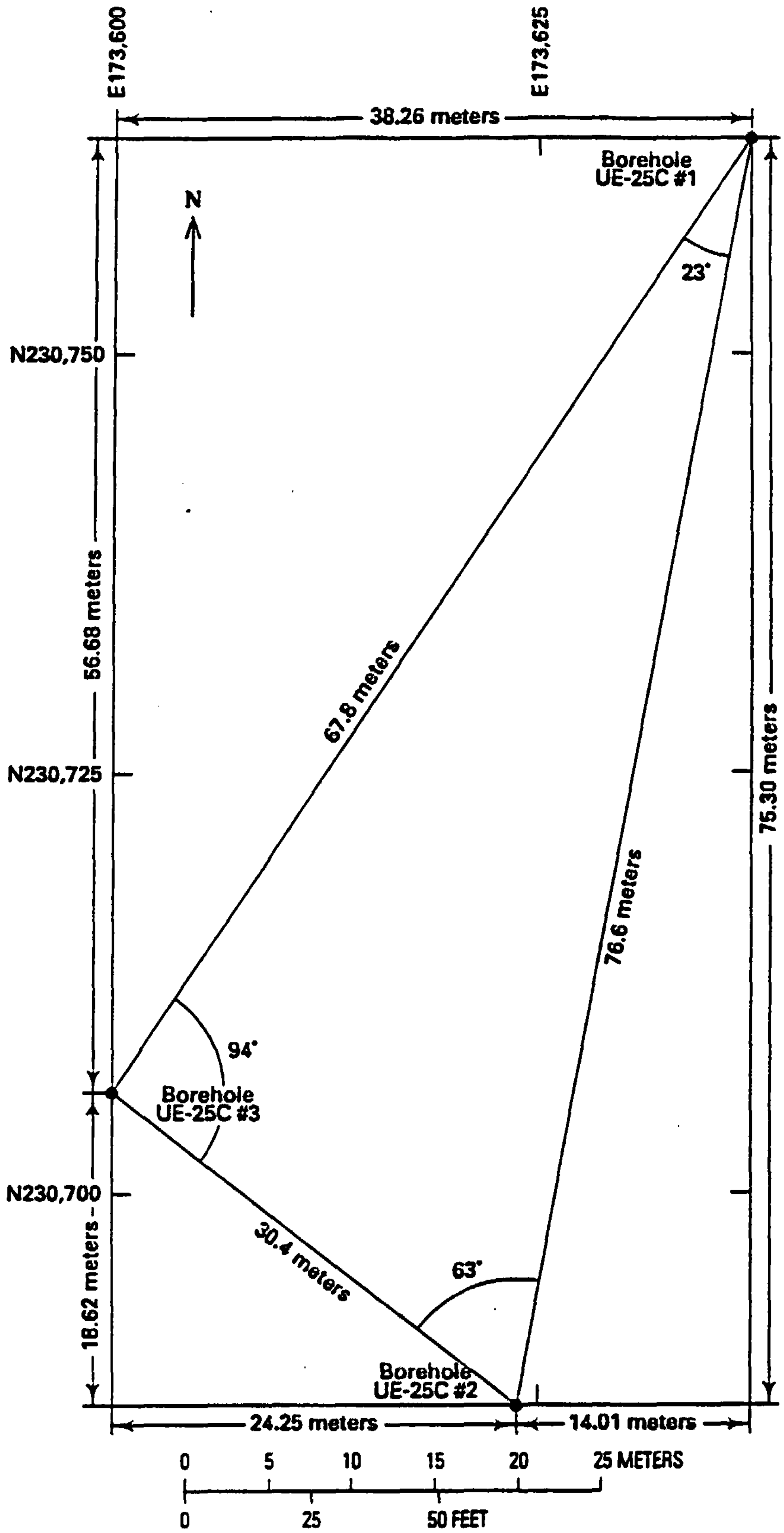
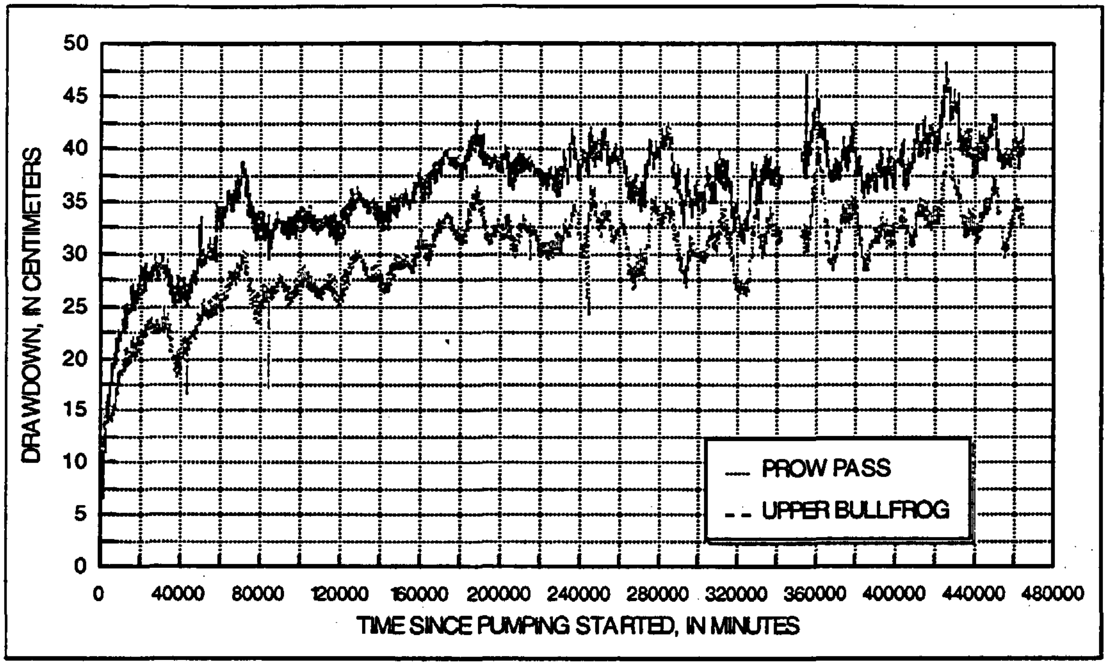


Figure 2.--Surface locations of boreholes UE-25c #1, UE-25c #2, and UE-25c #3. [Map is referenced to Nevada State Central Zone Coordinates.]



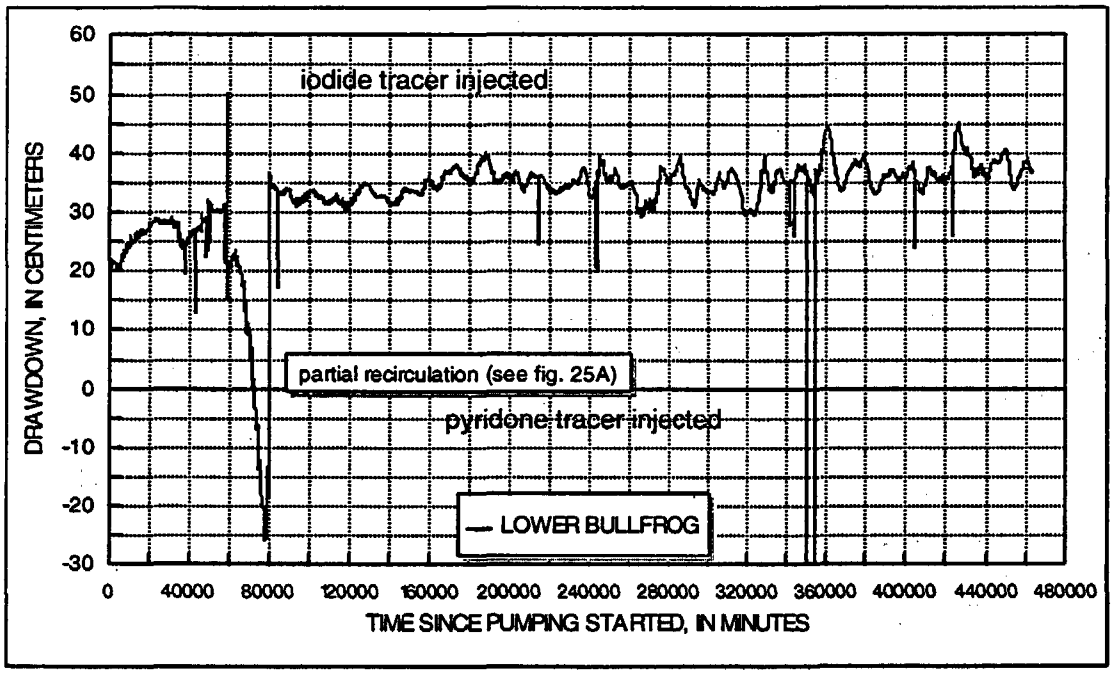


Figure 23 - UE-25 c#1 drawdown, May 8, 1996 to March 26, 1997

HYDRAULIC TESTS IN UE-25 C#3, 1995 TO 1997

	TEST 1	TEST 2	TEST 3	TEST 4
START PUMPING	5/22/95	6/12/95	2/08/96	5/08/96
STOP PUMPING	6/01/95	6/16/95	2/13/96	3/26/97
LENGTH (DAYS)	10.0	4.0	4.9	322.3
INTERVAL PUMPED	CALICO HILLS TO TRAM	CALICO HILLS TO TRAM	BULLFROG-TRAM	LOWER BULLFROG
DISCHARGE (L/S)	17.9	22.5	8.49	9.53
PUMPING WELL DRAWDOWN (M)	7.76	10.9	2.86	5.98
OBSERVATION WELLS	C#1,C#2, WT#14, WT#3,H-4, ONC-1	C#1,C#2	C#1,C#2	C#1,C#2, WT#14, WT#3,H-4, ONC-1
DISTANCE TO OBSERVATION WELLS (M)	29-3,526	29-86	29-86	29-3,526
GEOLOGIC UNITS IN OBSERVATION WELLS	TOPOPAH SPRING TO LITHIC RIDGE	CALICO HILLS TO LOWER BULLFROG	CALICO HILLS TO BULLFROG-TRAM	TOPOPAH SPRING TO LITHIC RIDGE
OBSERVATION WELL DRAWDOWN (CM)	0-43	43-352	14-25	15-51

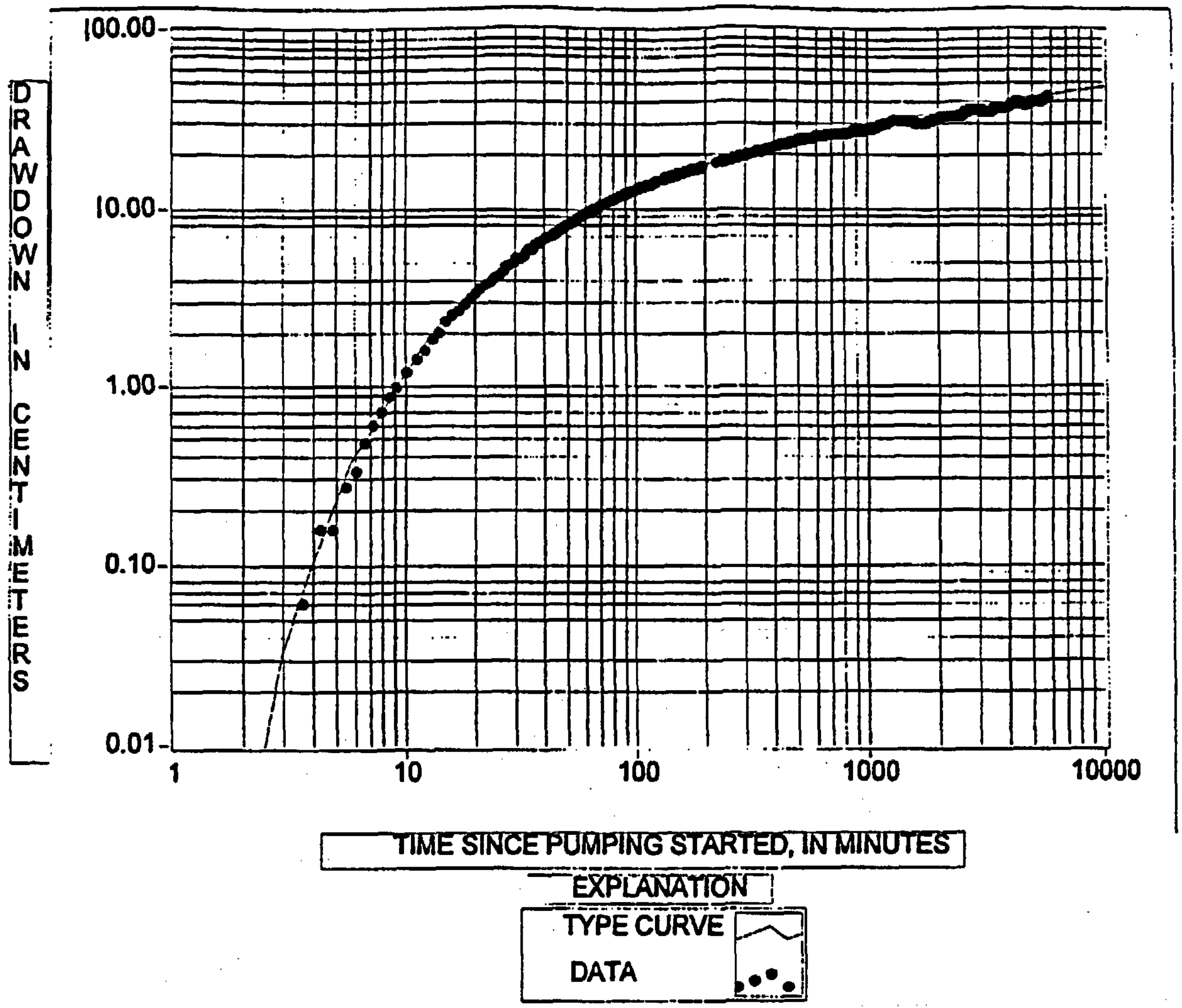


Figure 28 - Analysis of drawdown in the Prow Pass interval of UE-25 c#1, June 12-16, 1995 by the method of Theis (1935)

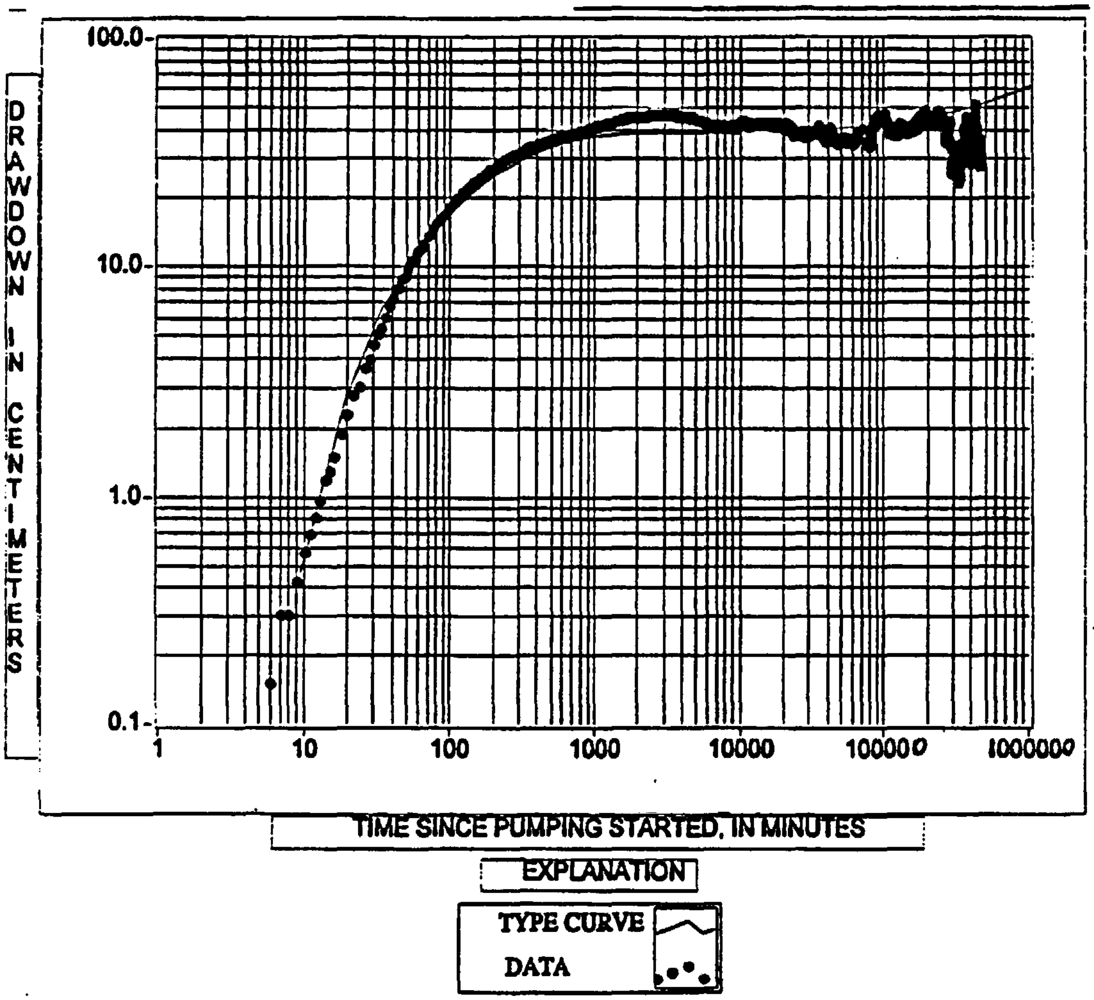


Figure 27 - Analysis of drawdown in the Calico Hills interval of UE-25 c#2, May 8, 1996 to March 26, 1997 by the method of Neuman (1975)

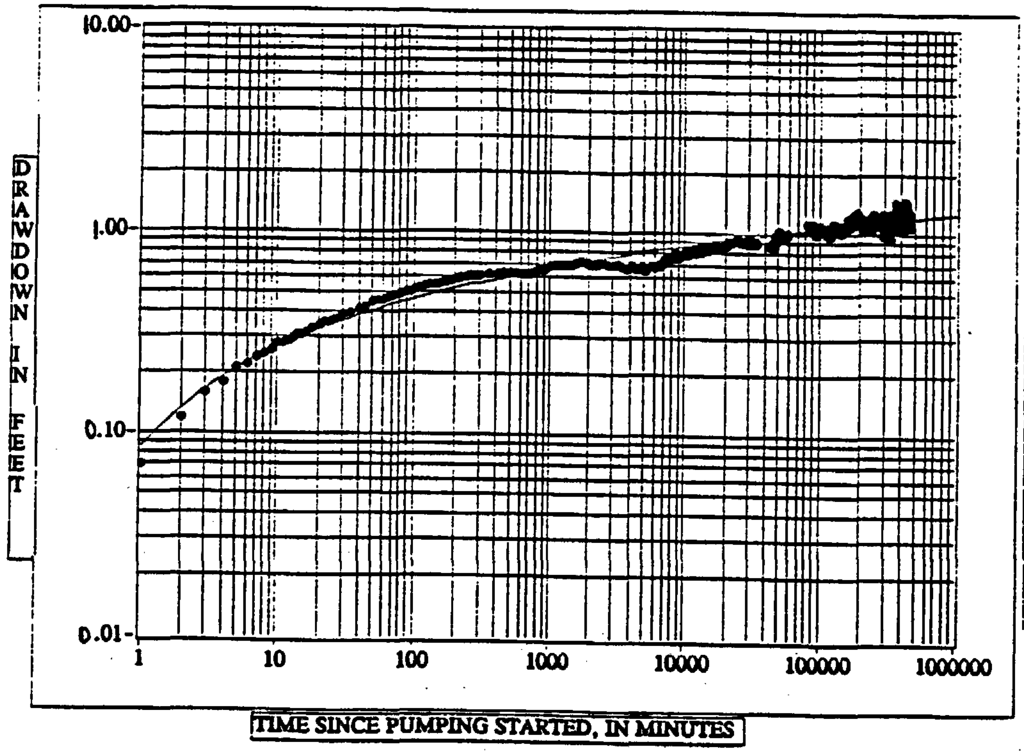


Figure 30 - Analysis of drawdown May 8, 1996 to March 26, 1997 in the Lower Bullfrog interval of UE-25 c#1 by the method of Theis (1935)

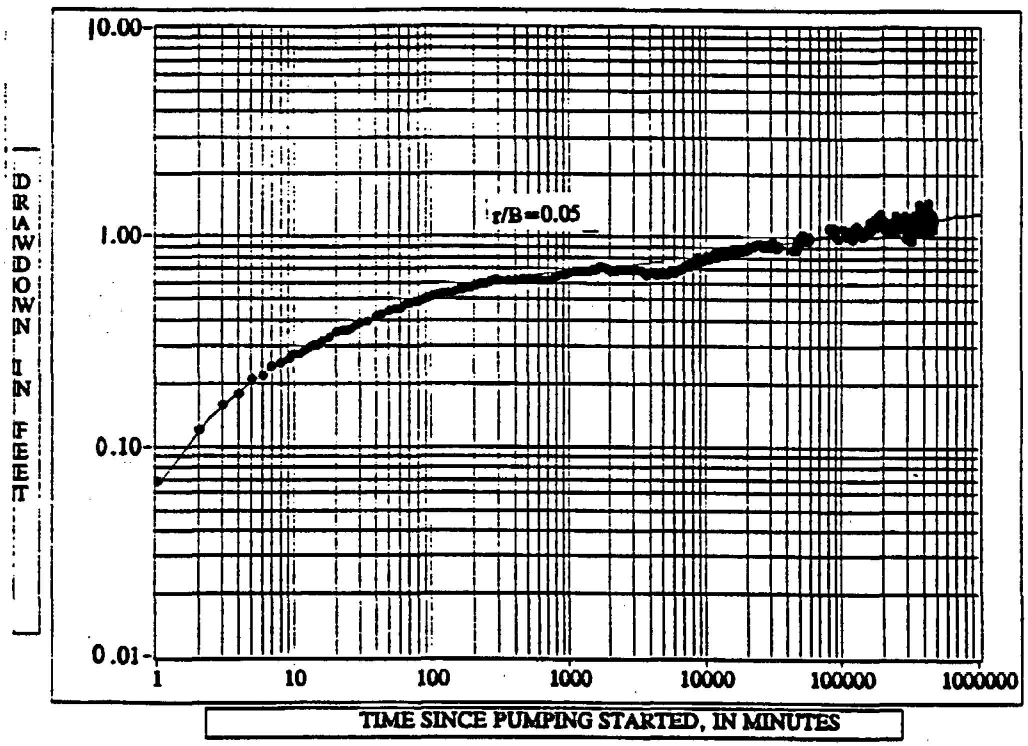


Figure 31 - Analysis of drawdown May 8, 1996 to March 26, 1997 in the Lower Bullfrog interval of UE-25 c#1 by the method of Streltsova-Adams (1978)

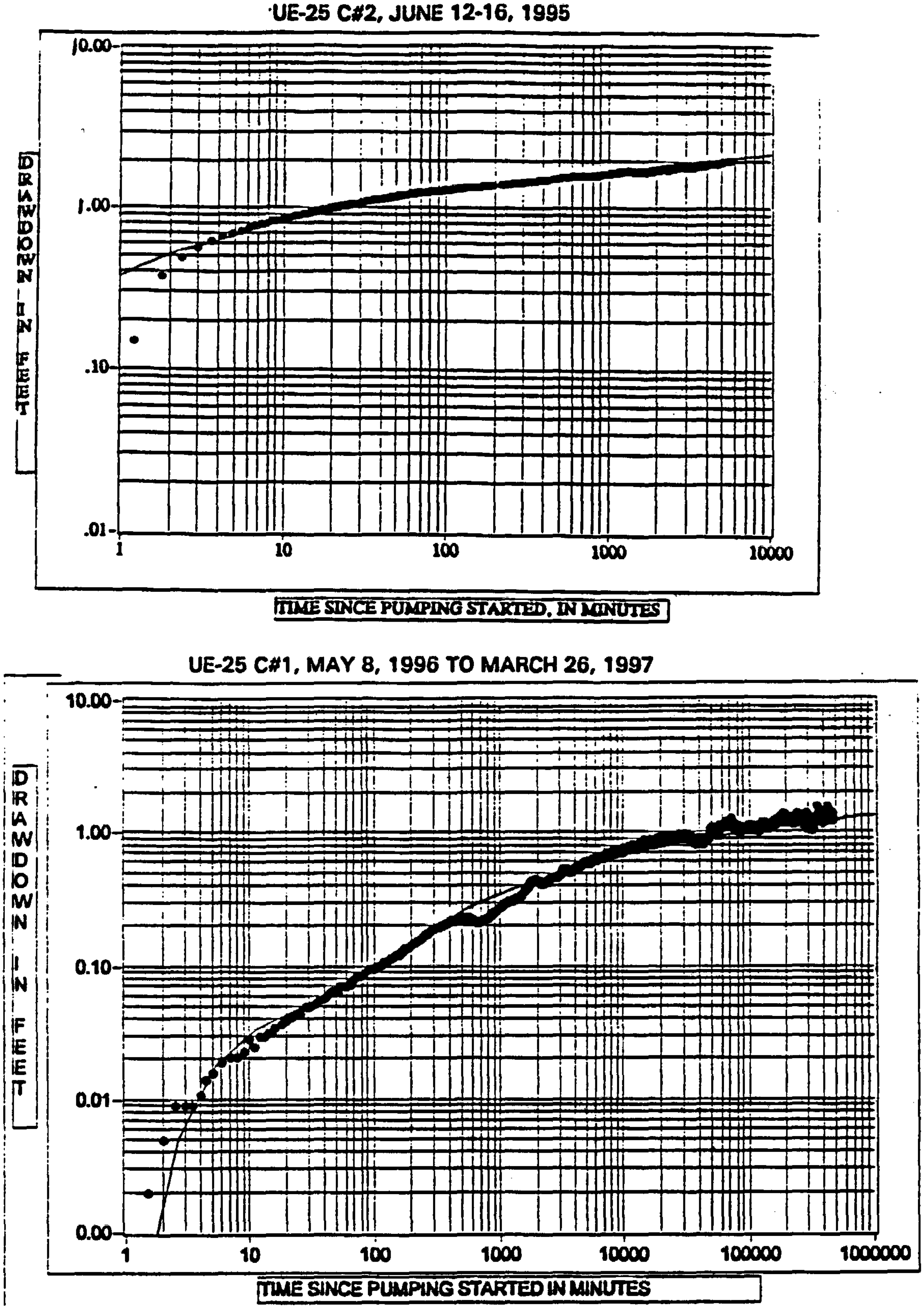


Figure 29 - Analysis of drawdown in the Upper Bullfrog interval: (A), UE-25 c#2, June 12-16, 1995 by the method of Theis (1935); (B), UE-25 c#1, May 8, 1996 to March 26, 1997 by the method of Streltsova-Adams (1978)

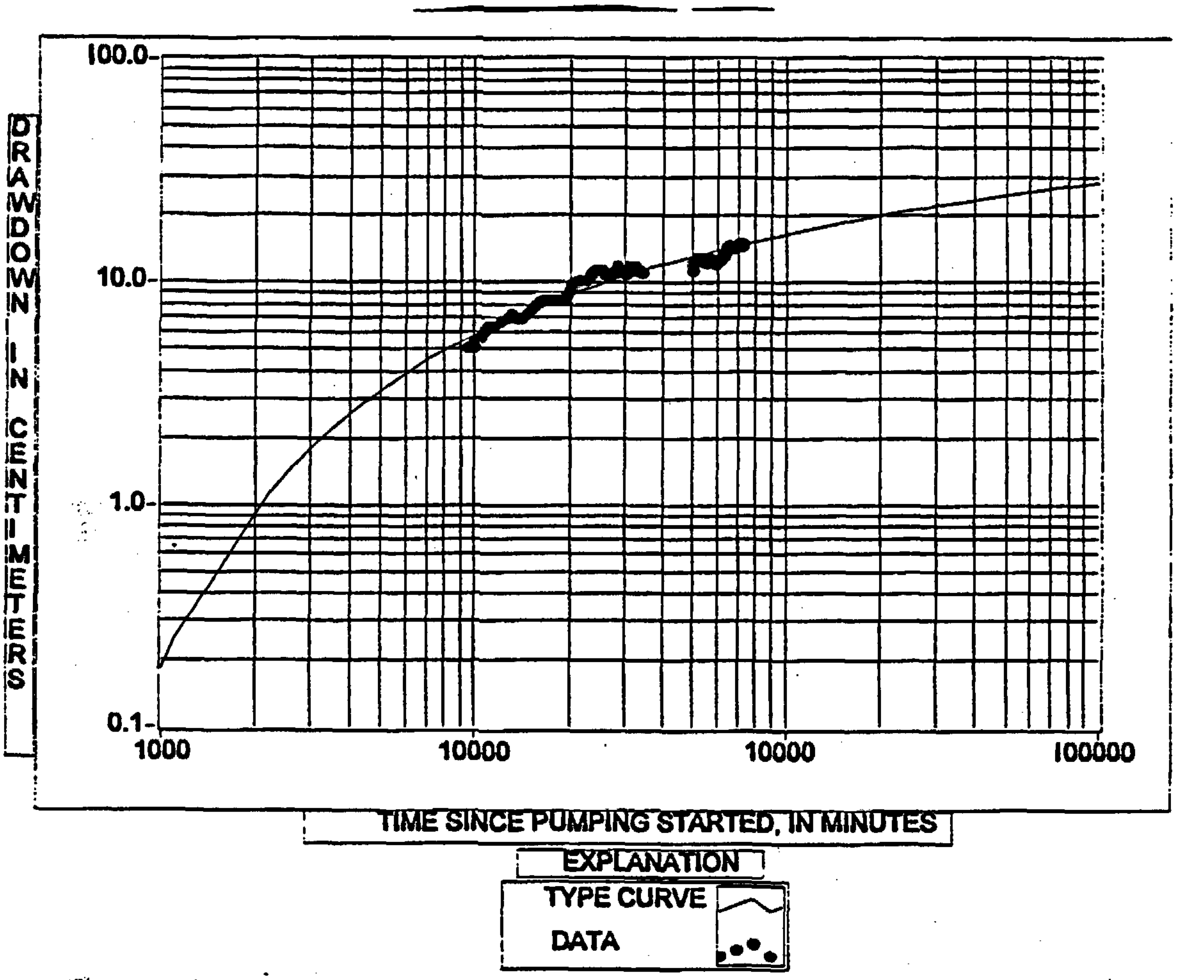


Figure 34 - Analysis of drawdown in UE-25 WT#14, May 8 to June 27, 1996 by the method of Theis (1935)

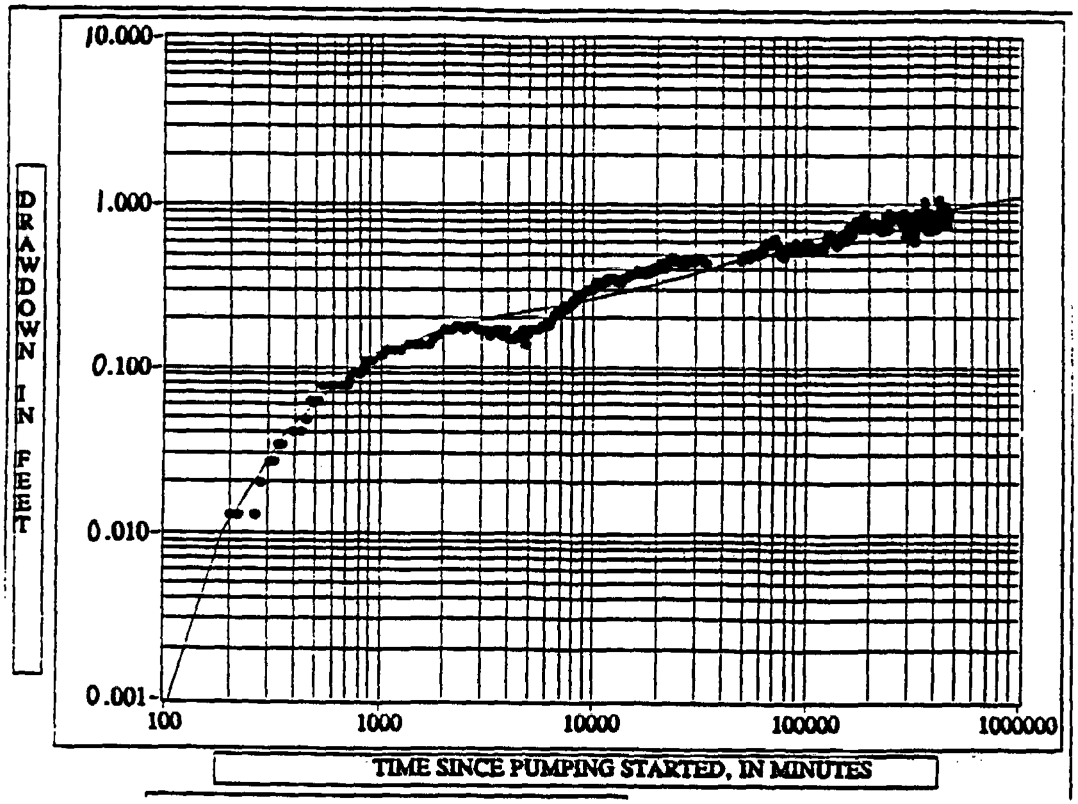


Figure 32 - Analysis of drawdown in UE-25 ONC-1, May 8, 1996 to March 26, 1997 by the method of Streltsova-Adams (1978)

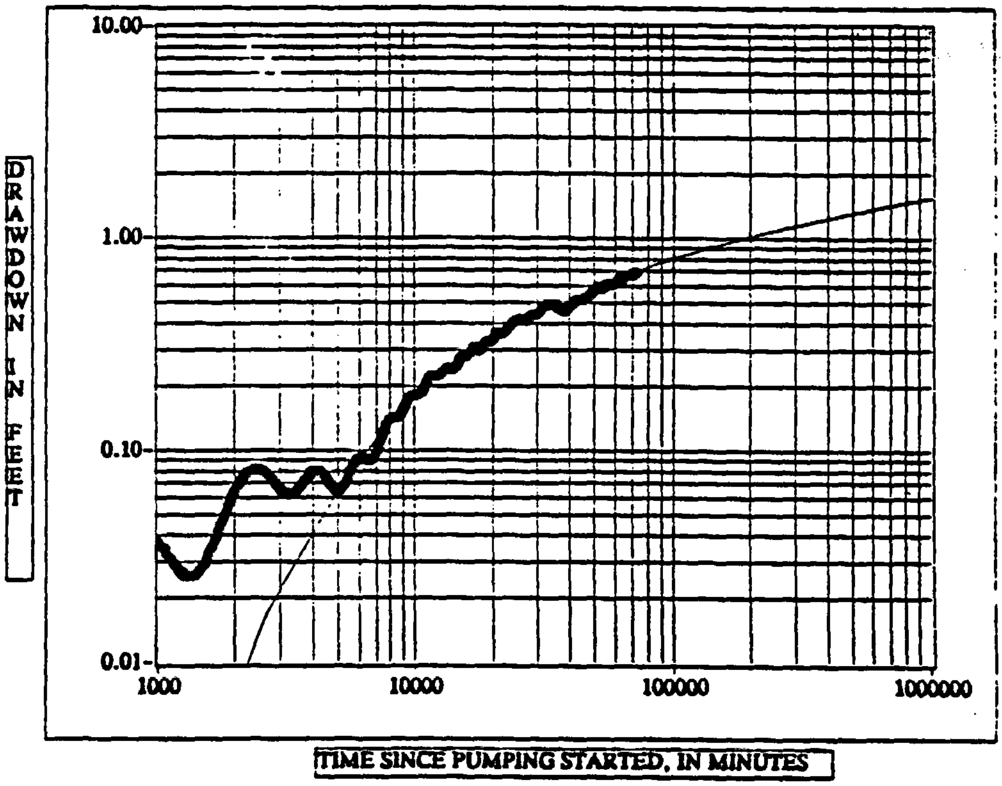
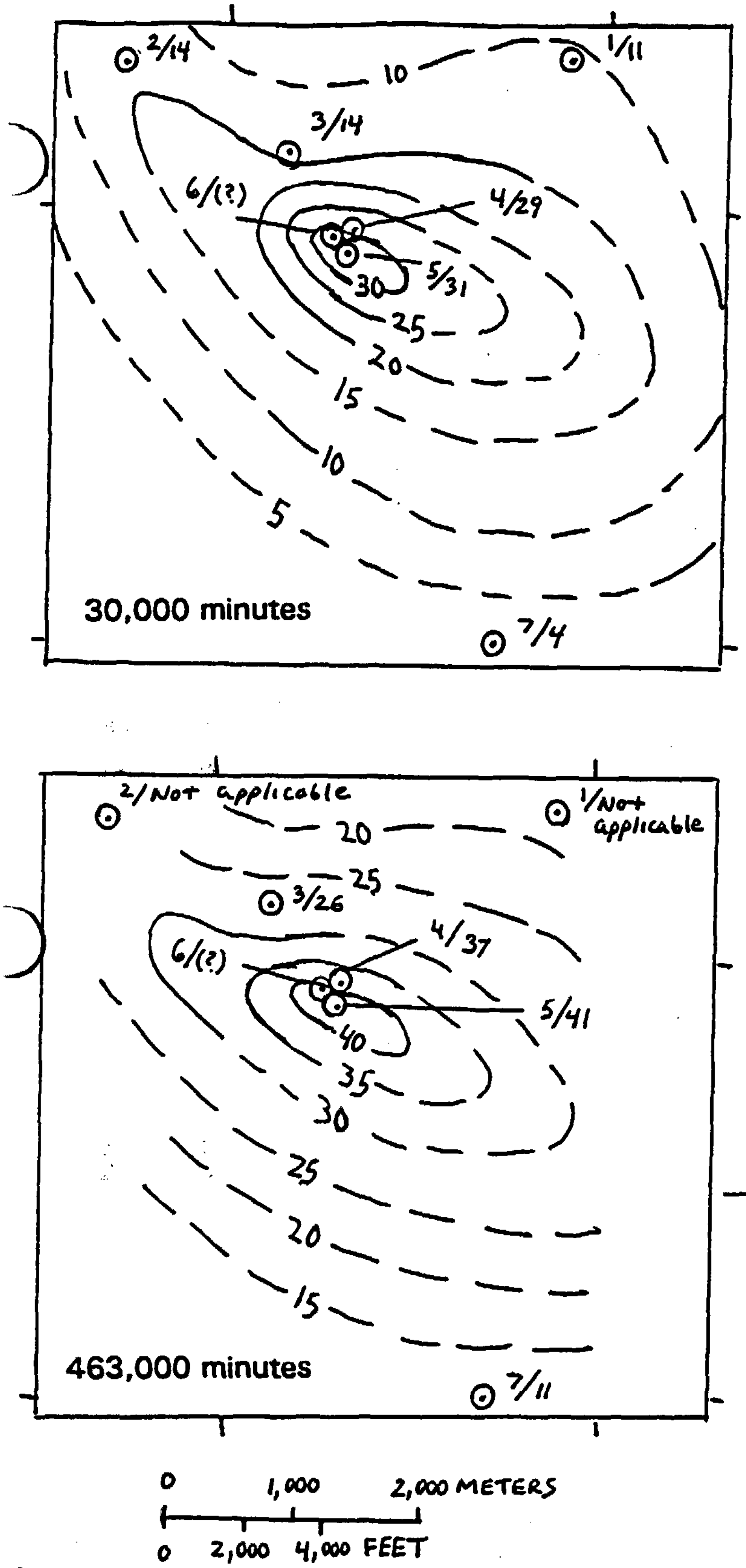


Figure 33- Analysis of drawdown in USW H-4, May 8 to June 27, 1996 by the method of Theis (1935)



EXPLANATION

1/0.36 OBSERVATION WELL - Well number to left of slash; drawdown, in centimeters, to right of slash; not applicable if drawdown affected by a recharge boundary

—— 0.4 - - - LINE OF EQUAL DRAWDOWN - Interval, 5 centimeters;

OBSERVATION WELL NUMBERS

1. UE-25 WT#14
2. USW H-4
3. UE-25 ONC-1
4. UE-25 c#1
5. UE-25 c#2
6. UE-25 c#3
7. UE-25 WT#3

Figure 38 - Distribution of drawdown in observation wells 30,000 minutes (20.8 days) and 463,000 minutes (321.5 days) after pumping started in UE-25 c#3 on May 8, 1996

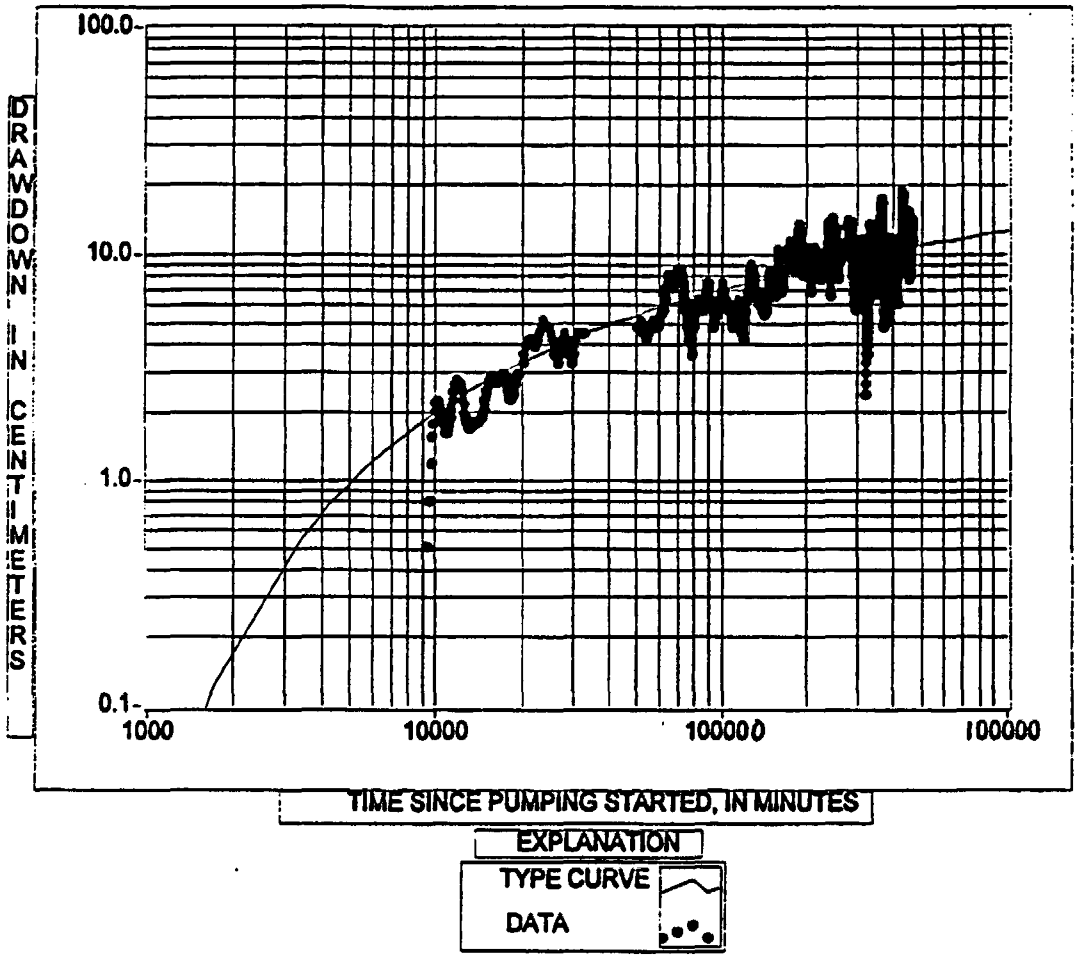


Figure 35 - Analysis of drawdown in UE-25 WT#3, May 8, 1996 to March 26, 1997 by the method of Theis (1935)

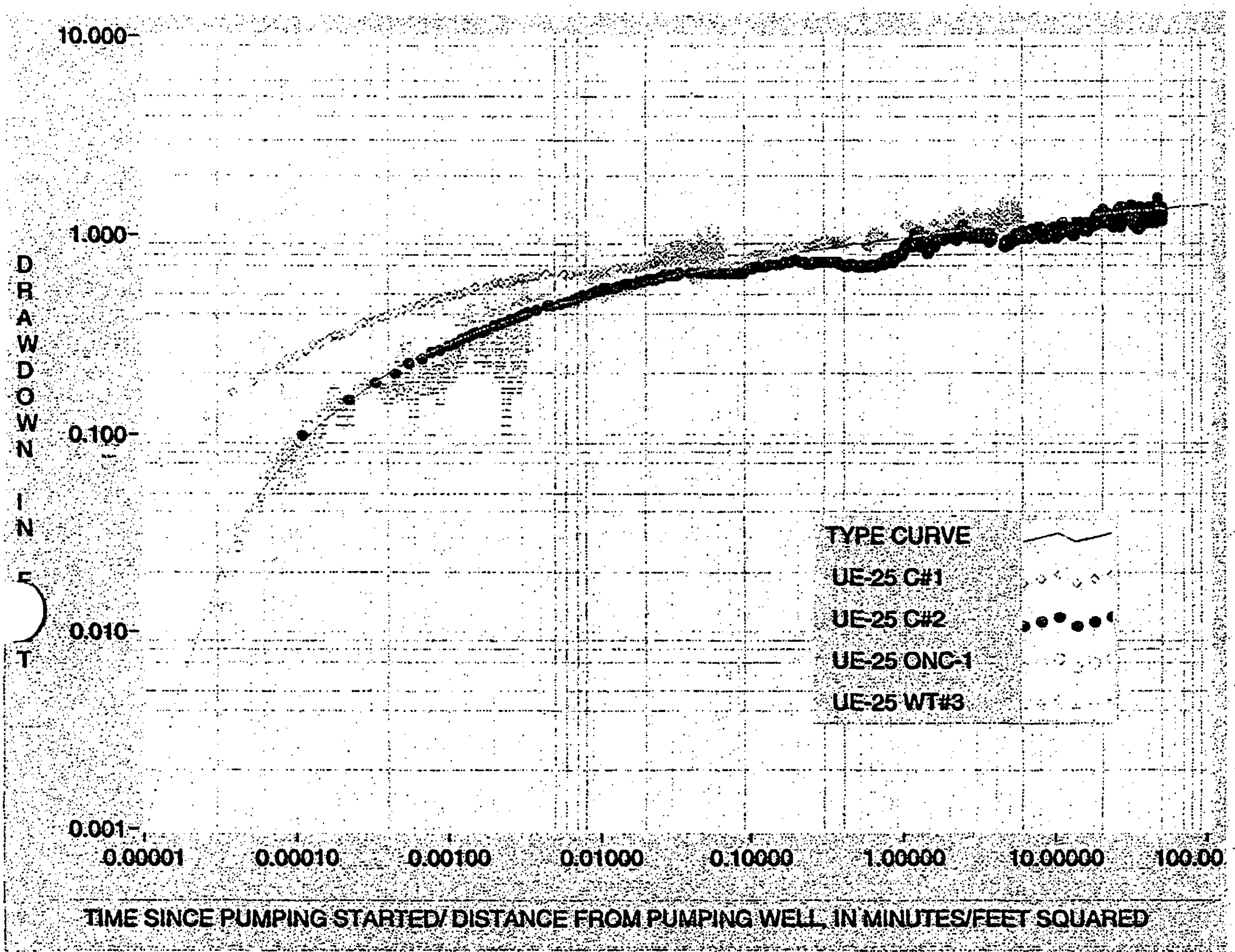
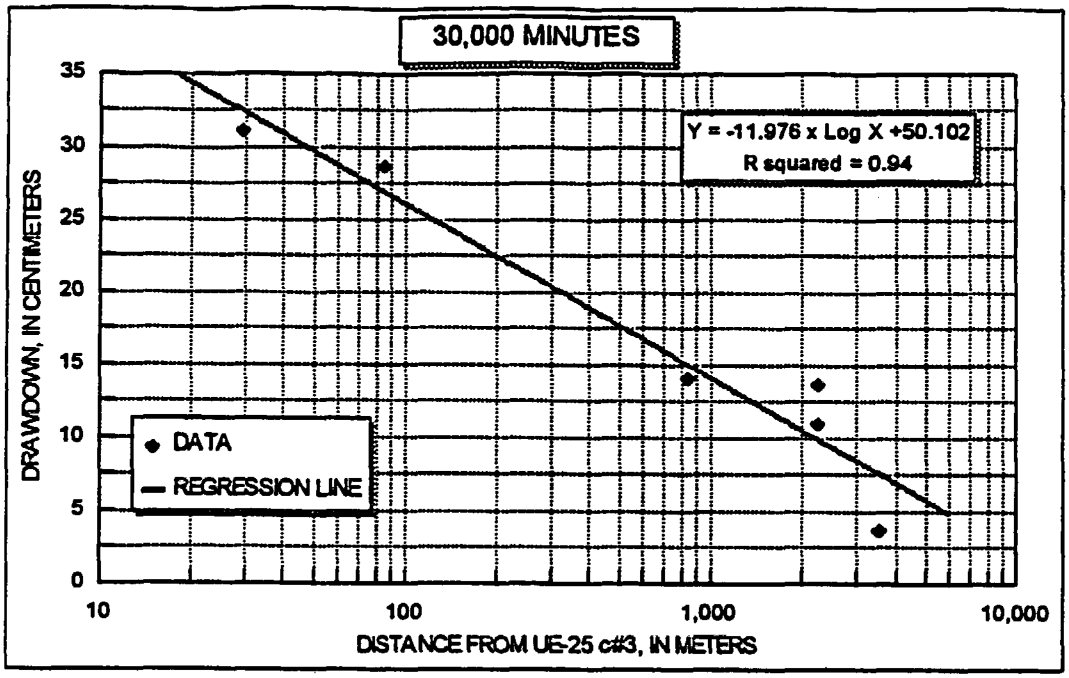


Figure 37 - Analysis of drawdown in observation wells as a function of time divided by the square of the distance from the pumping well, hydraulic test in UE-25 c#3, May 8, 1996 to March 26, 1997



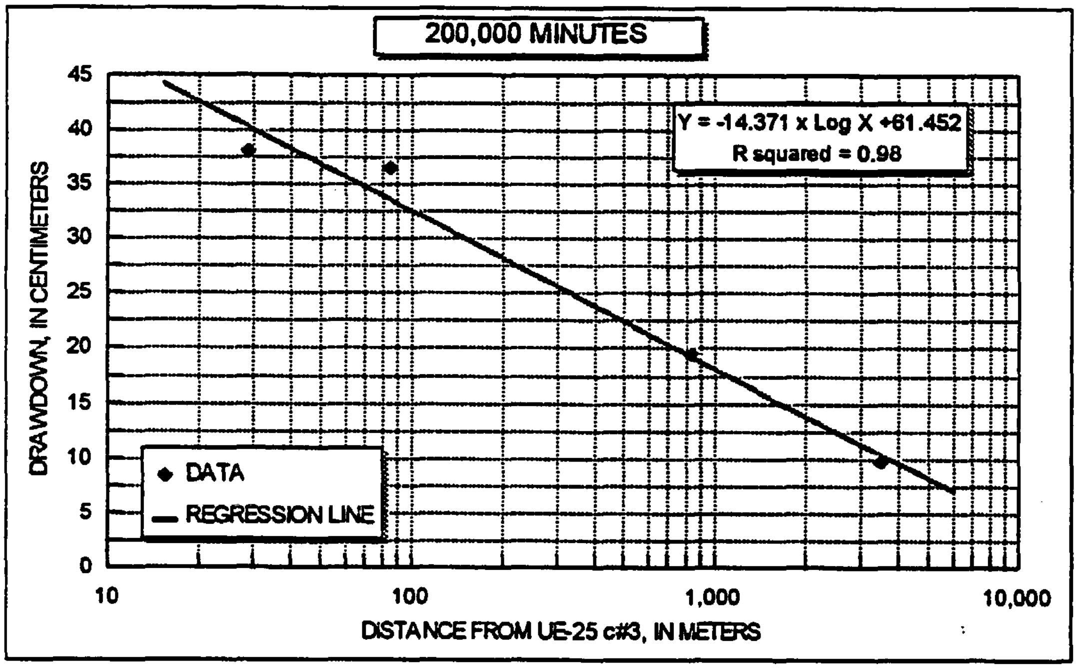


Figure 39 - Analyses of drawdown in observation wells as a function of distance from the pumping well 30,000, 200,000, 305,000, and 463,000 minutes after pumping started in UE-25 c#3 on May 8, 1996

CONCLUSIONS

- THE MIOCENE TUFFACEOUS ROCKS FROM THE TOPOPAH SPRING TUFF DOWN TO THE LITHIC RIDGE TUFF ARE A SINGLE AQUIFER IN A 21-KM^2 AREA SURROUNDING THE C-HOLES.

- HYDRAULIC CONNECTION ACROSS GEOLOGIC CONTACTS IN THE TUFFACEOUS ROCKS IS MAINTAINED BY A NETWORK OF FRACTURES, FAULTS, AND INTERVALS WITH LARGE MATRIX PERMEABILITY.

- TRANSMISSIVITY OF THE CALICO HILLS FORMATION AND CRATER FLAT GROUP IN THE C-HOLES DECREASES FROM 1,300-1,600 M^2/D IN THE LOWER BULLFROG TO 4-10 M^2/D IN THE CALICO HILLS.

- TRANSMISSIVITY OF THE TUFFACEOUS ROCKS DECREASES NORTHWESTERLY FROM 2,600 M^2/D IN WT#3 TO 700 M^2/D IN H-4 AND AVERAGES ABOUT 2,200 M^2/D.

- STORATIVITY OF THE TUFFACEOUS ROCKS AVERAGES ABOUT 0.002 IN THE VICINITY OF THE C-HOLES.

- DISTRIBUTIONS OF HYDRAULIC PROPERTIES IN THE VICINITY OF THE C-HOLES AND THEIR EFFECT ON DRAWDOWN DURING HYDRAULIC TESTS ARE INFLUENCED BY NORTHERLY AND NORTHWESTERLY TRENDING FAULTS.

- RECHARGE BOUNDARIES INTERPRETED TO BE FAULTS AFFECTED DRAWDOWN IN OBSERVATION WELLS ABOUT 2,250 METERS NORTH OF C#3 AFTER ABOUT 50 DAYS OF PUMPING.

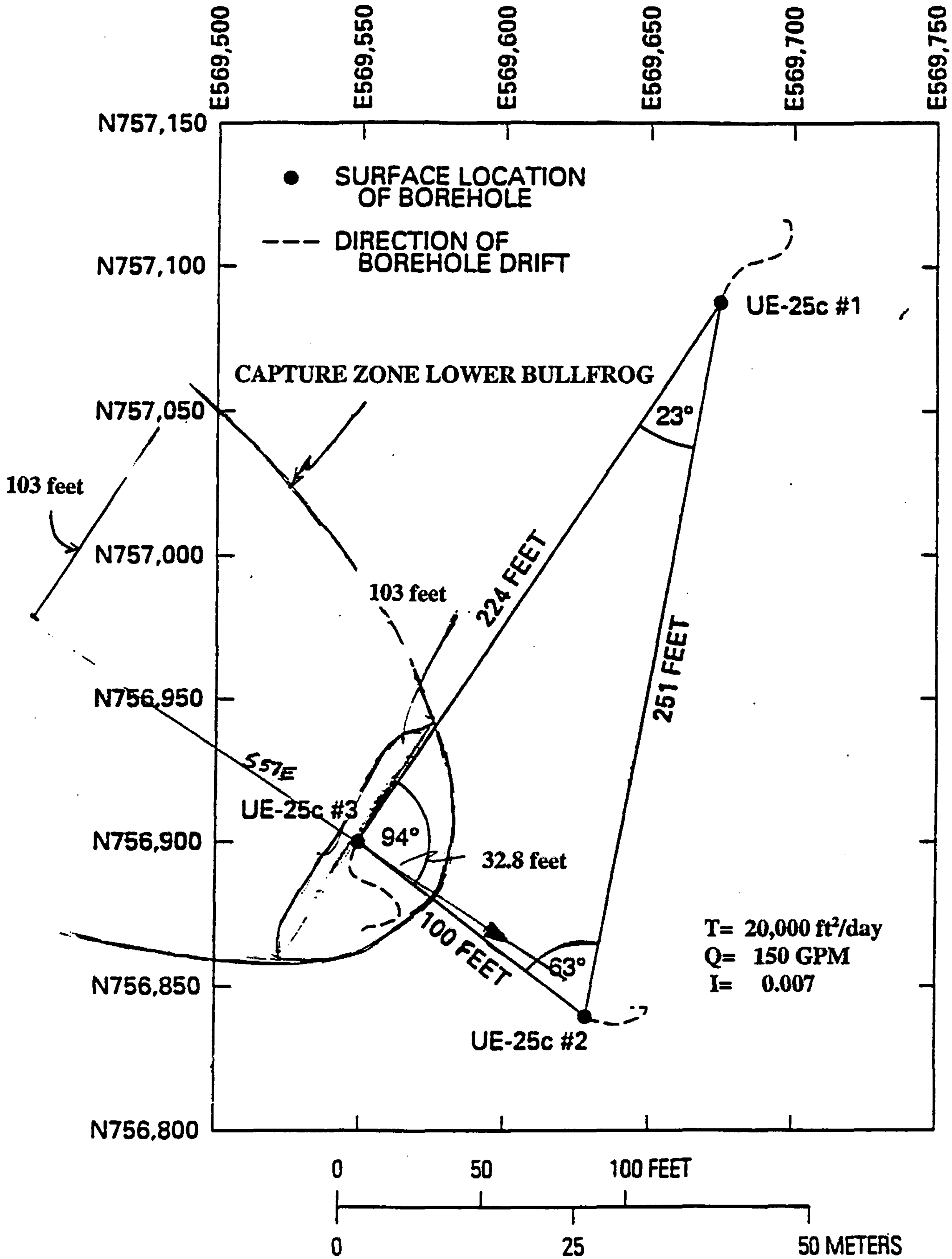
- SPATIAL RELATIONS BETWEEN FAULTS AND HYDRAULIC PROPERTIES DETERMINED IN C-HOLE HYDRAULIC TESTS CAN BE USED TO EXTRAPOLATE POSSIBLE PERMEABILITY DISTRIBUTIONS IN AREAS FOR WHICH TEST DATA ARE UNAVAILABLE FOR THE TUFFACEOUS ROCKS.

HYDRAULIC PROPERTIES

BOREHOLE/INTERVAL	R (M)	T (M^2/D)	K (M/D)	S
C-HOLES				
CALICO HILLS	29-78	6-9	0.1-0.2	0.0002
PROW PASS	29-81	40-60	2-3	0.0003-0.0004
UPPER BULLFROG	29-83	40-100	0.8-4	0.00002-0.0009
LOWER BULLFROG	29-86	1,300-1,600	20-50	0.0002-0.002
UPPER TRAM	30-87	800-900	20-40	0.0001-0.001
COMPOSITE	29-83	1,800-2,600	7-18	0.001-0.003
ONC-1 (PROW PASS)	843	1,000	5	0.001
H-4 (PROW PASS TO LITHIC RIDGE)	2,245	700	2	0.002
WT#14 (TOPOPAH SPRING AND CALICO HILLS)	2,249	1,300	≈10	0.002
WT#3 (BULLFROG)	3,526	2,600	≤60	0.002
TUFFACEOUS ROCKS	≤3,526	2,100-2,600	UNKNOWN	0.0005-0.003

TRACER TEST RESULTS, C-HOLE COMPLEX, 1996-97

HOMOGENEOUS MODEL



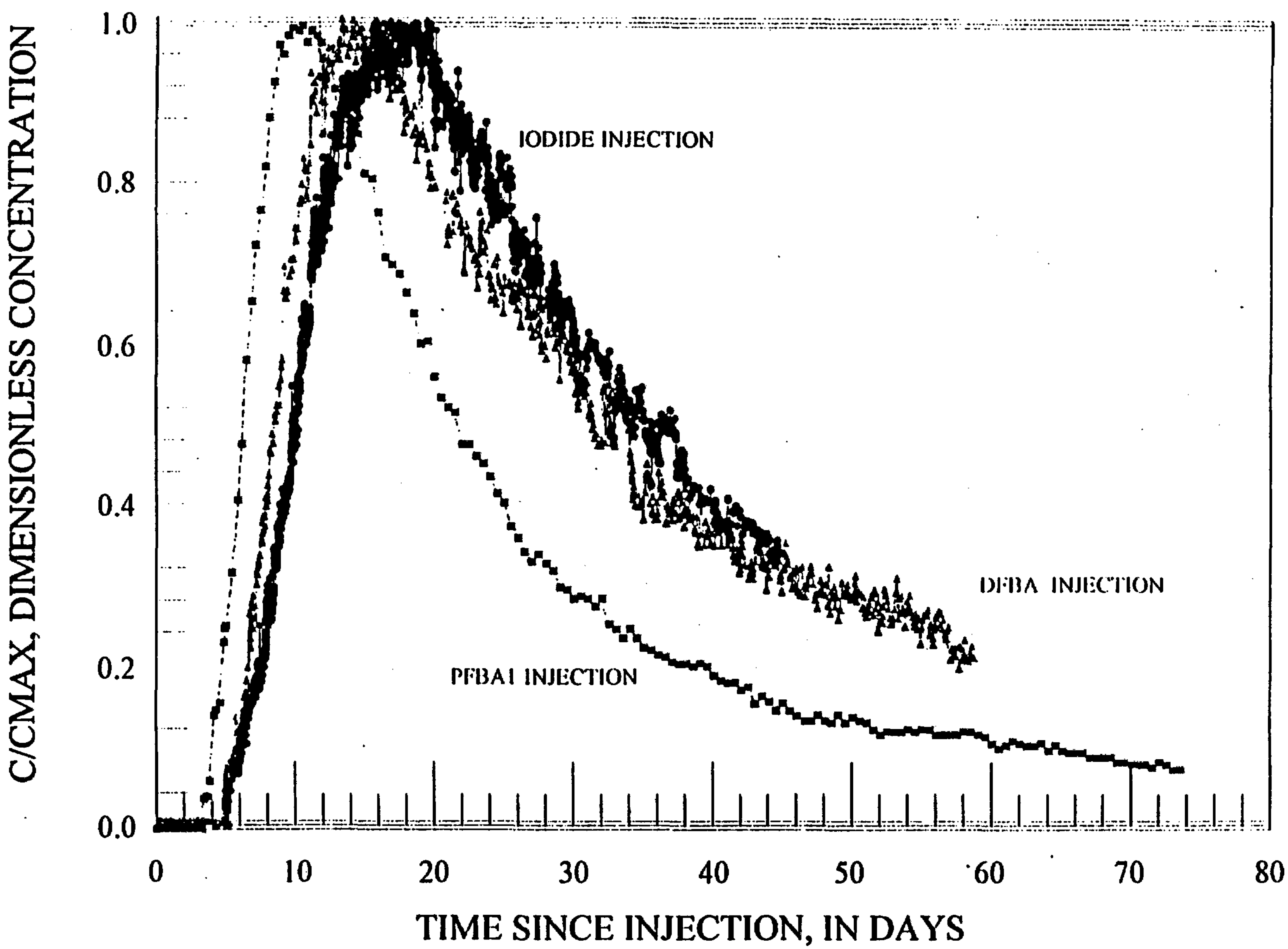
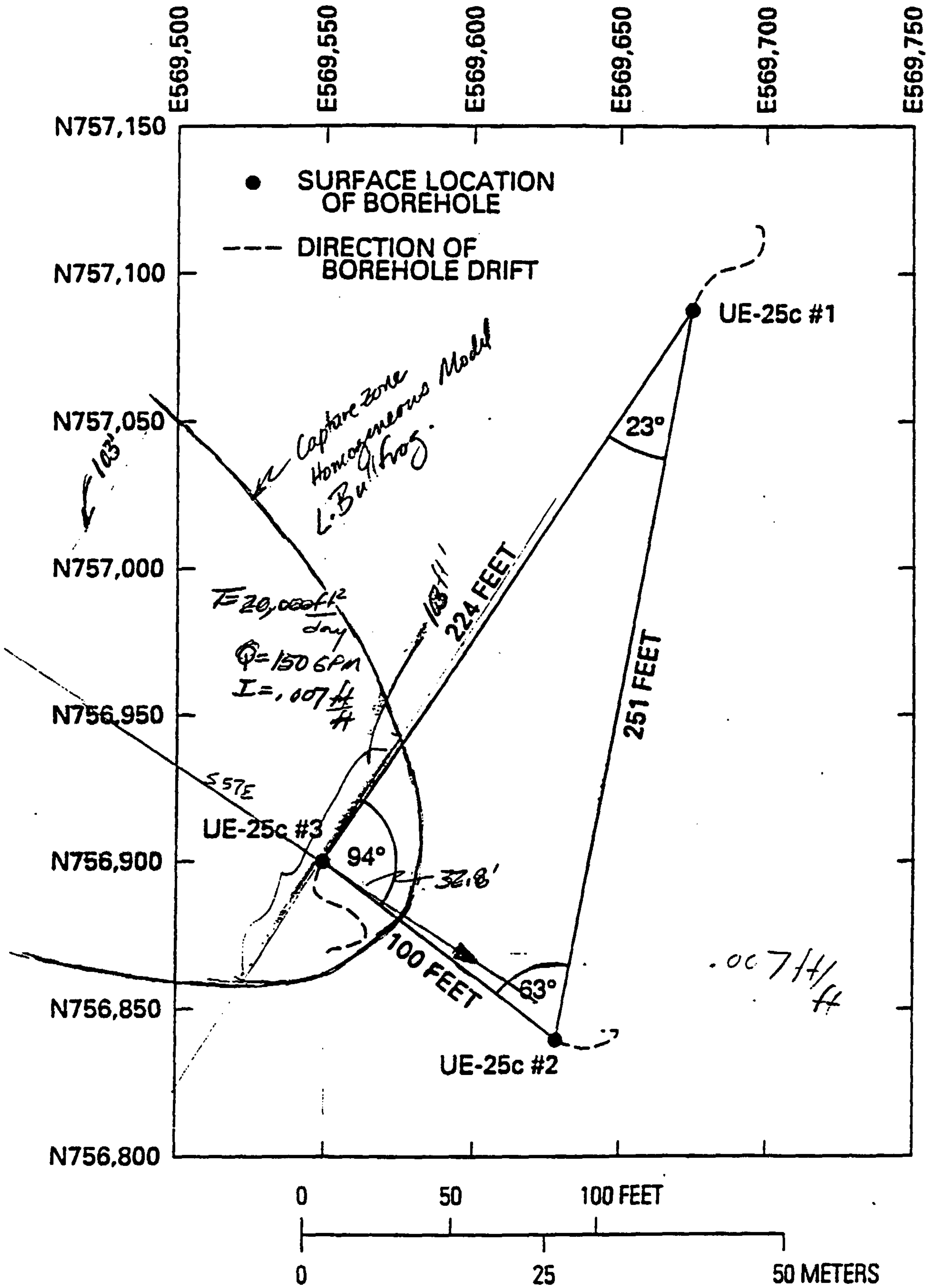


Figure 16-- IODIDE, PFBA1, AND DFBA INJECTIONS IN UE-25 C#2

HOMOGENEOUS MODEL



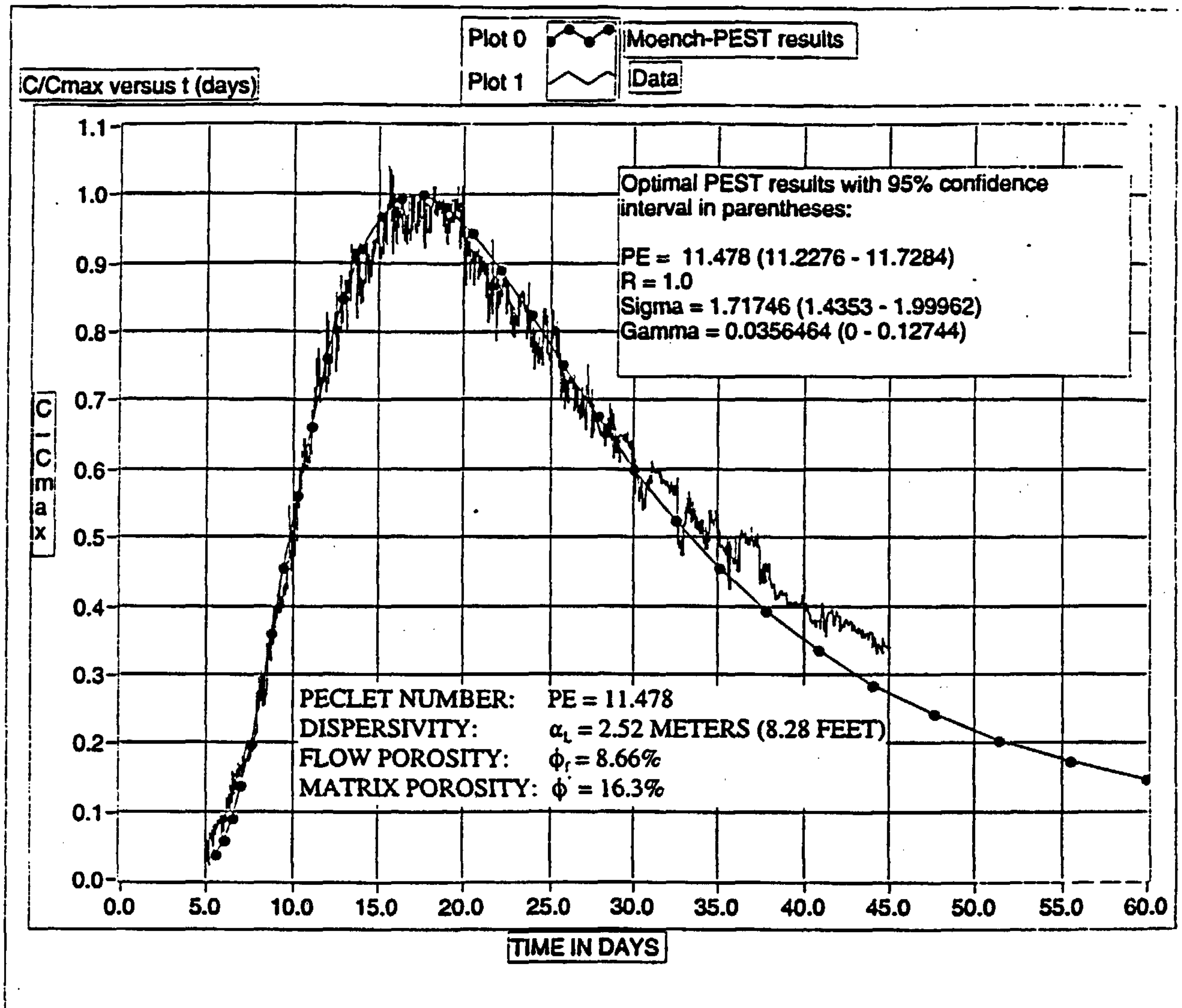


FIGURE 50. BREAKTHROUGH CURVE FOR 2/13/96 IODIDE TRACER TEST, MATCHED BY PEST PROGRAM, WITH INITIAL ESTIMATES FROM MANUAL MATCH

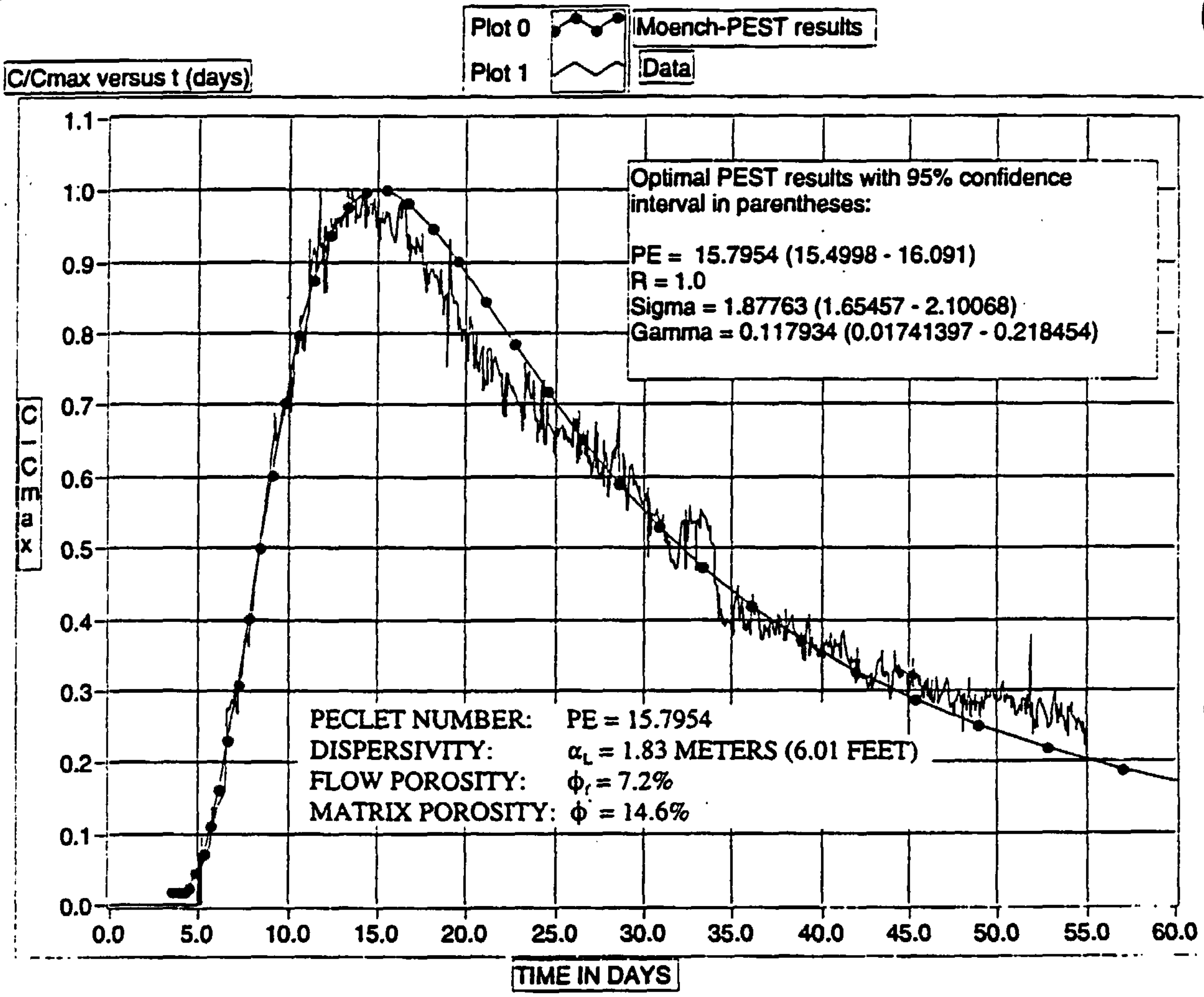
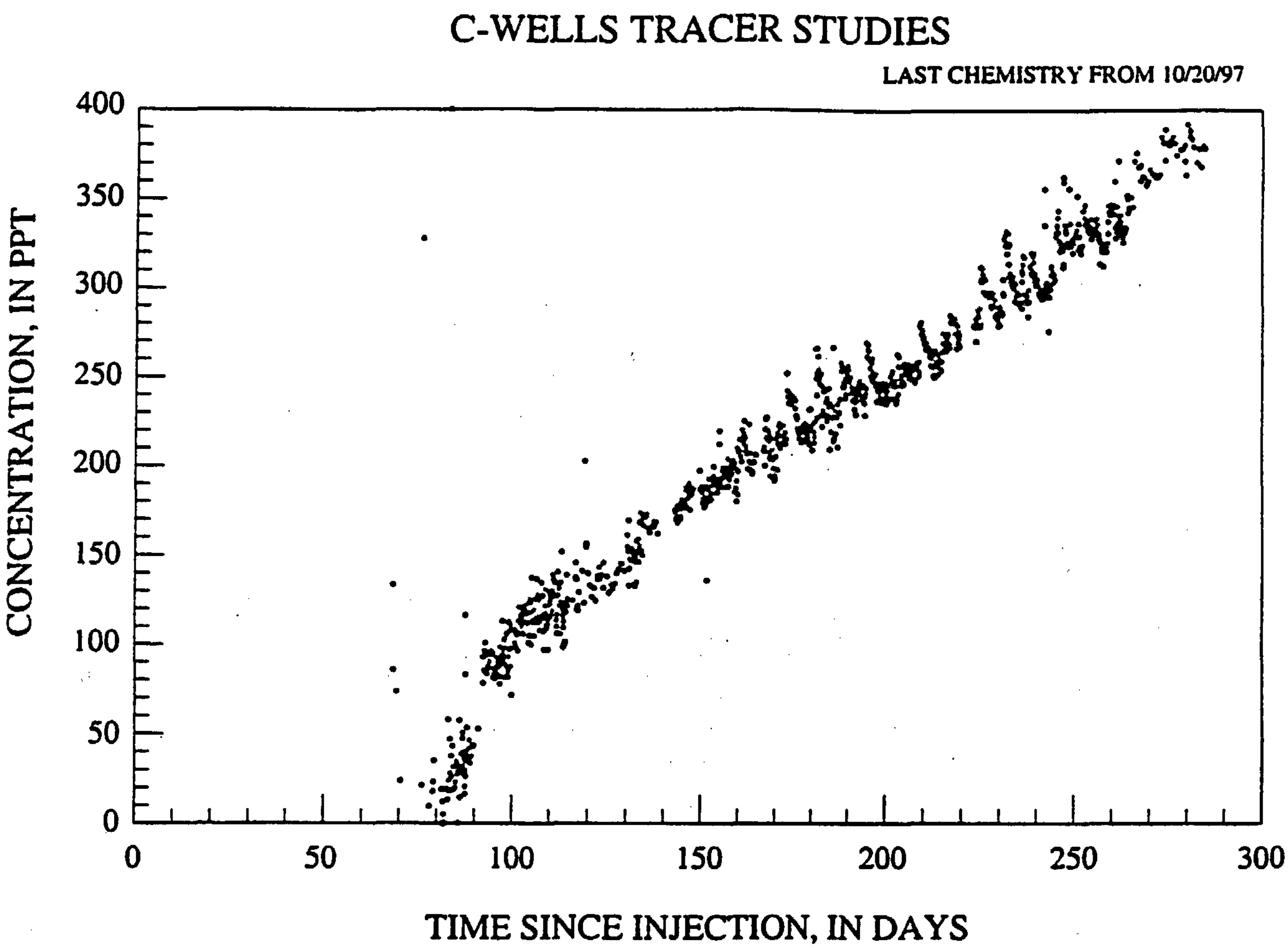


FIGURE 54. BREAKTHROUGH CURVE FOR 1/10/97 DFBA TRACER TEST, MATCHED BY PEST PROGRAM, WITH INITIAL ESTIMATES FROM MANUAL MATCH


C-WELLS TRACER STUDIES
LAST CHEMISTRY FROM 10/20/97
CONCENTRATION, IN PPT
0
50
100
150
200
250
300
350
400
0
50
100
150
200
250
300
TIME SINCE INJECTION, IN DAYS

110597.vi
Last modified on 10/29/97 at 4:47 PM

input file path: c:\labview\rcv2_inp.000

Output file path: c:\labview\rcv2_out.000

Run by: M.J. Umari

Top hat C_o calc.

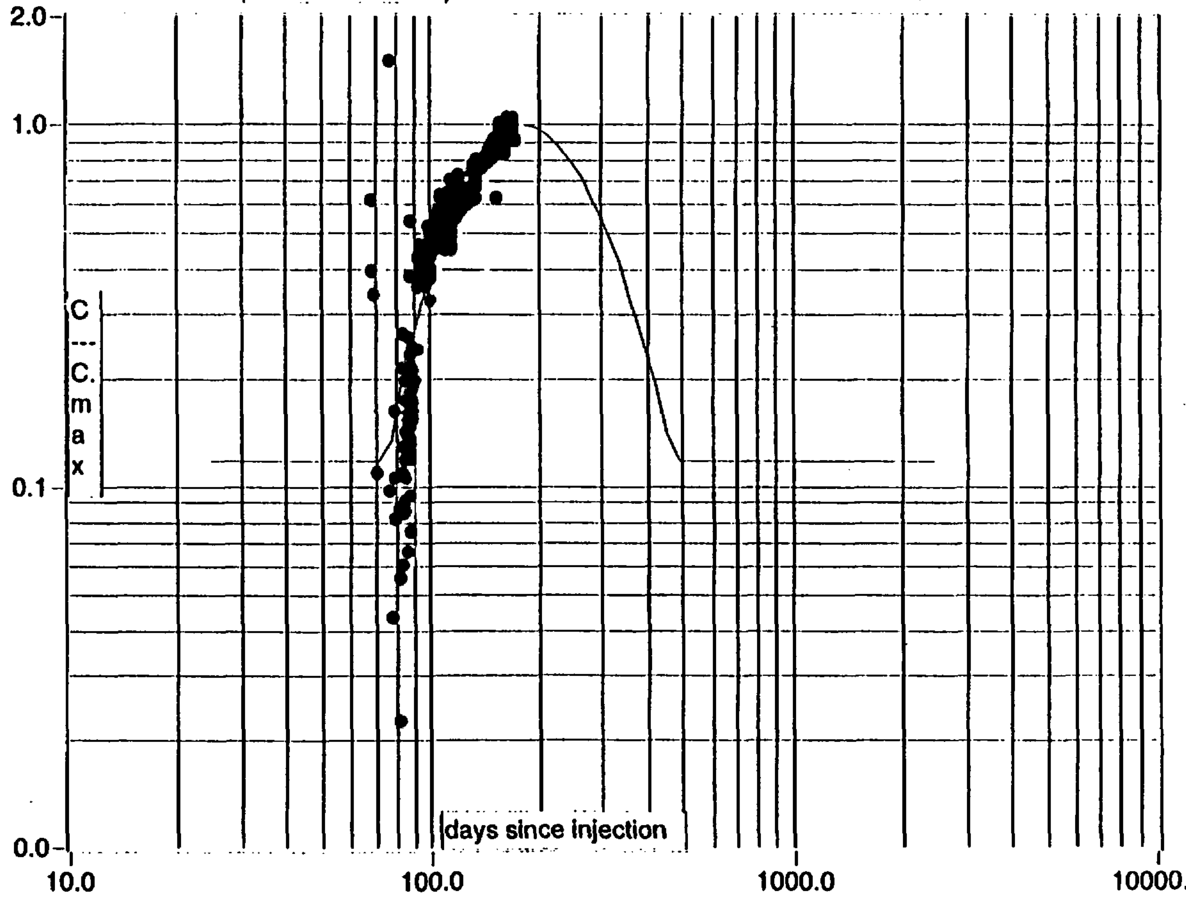
C (ppb) versus t (days)

Plot 0

Plot 1 — Results from Moench program

Plot 2 — Results from 1/9/97 to 11/12/97 Pyridone tracer test

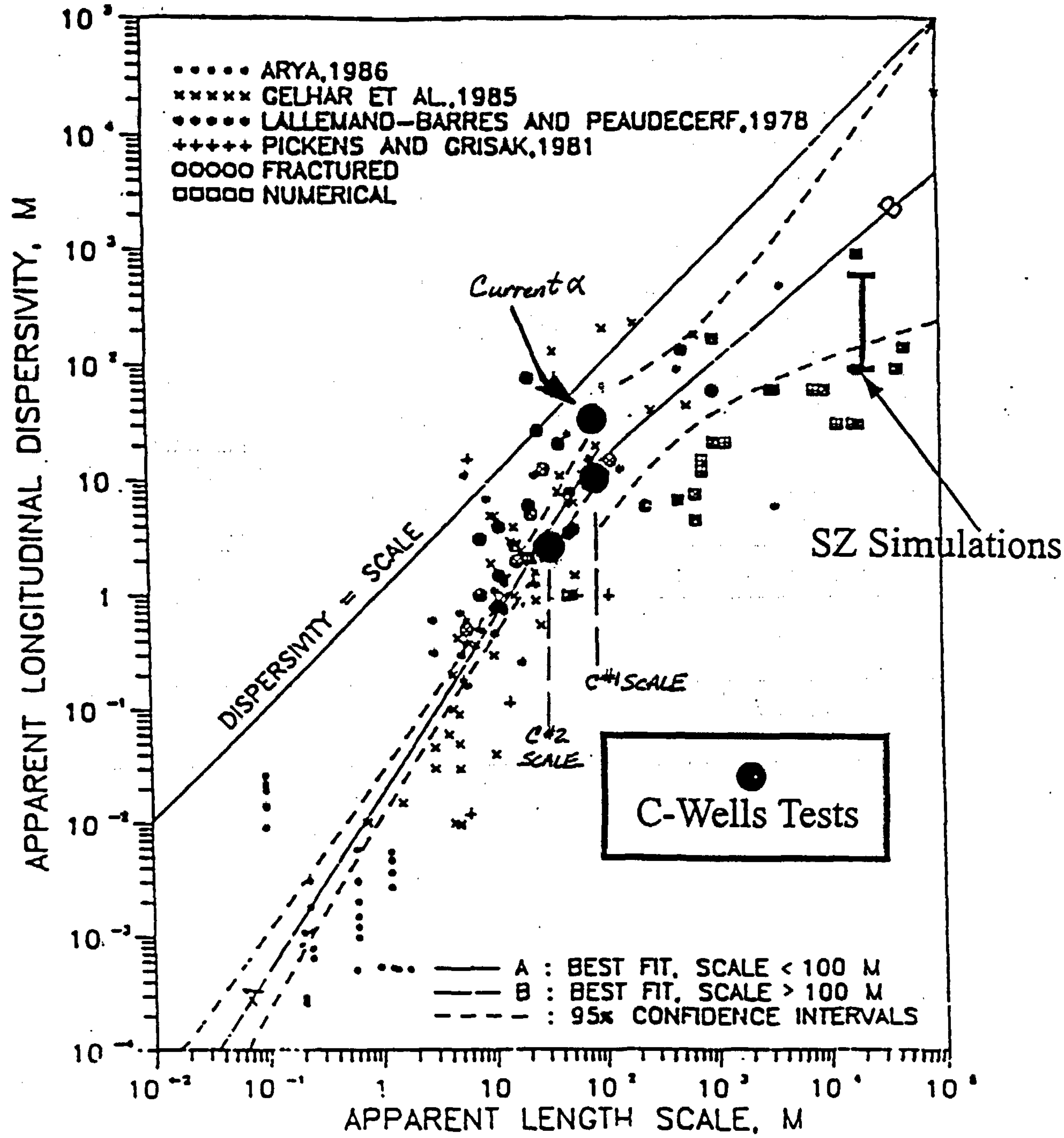
Tophat t_inj (minutes)	28.00
Mass (kg)	3.00
Pumping rate (gpm)	145.00
Inj.Vol.(gal)	4100.00
Ci(mg/l)	0.0155
Co(mg/l)	193.3177
r_L(ft)	281.00
h (ft)	212.00
r_i(in)	5.50
h_i (ft)	212.00
r_w(in)	5.50
h_w(ft)	212.00
t_a(days)	245.47
ROW 8 — Sigma(I)	0.0005
mu	0.1498
ROW 9 — SK(I)	0.0060
epsilon	0.0010
fracture porosity	0.1303
Matrix porosity	0.0001
longitudinal dispersivity (ft)	28.10
ROW 4 — BIGT	30.00
METH	3
NN	40
ROW 6 — FB(I)	1.00
ROW 7 — Gamma(i)	4.21681



ROW 5	N	1.00
ROW 5	IQD	0.00
ROW 0	LOGT	1.000
ROW 0	NLC	2.000
ROW 0	NOX	30.000
ROW 1	TDFIRST	0.100
ROW 1	DELTD	0.000
ROW 1	TDP	0.000079
ROW 1	XMUI	0.0197
ROW 1	XMUW	0.0000
ROW 2	INPTRA	2
ROW 2	NTS	10
ROW 2	KT	2
ROW 2	IFLUX	1
ROW 3	PE	10.00
ROW 3	RWD	0.0016
ROW 3	RTARD	0.97
ROW 3	XMULT	0.000

1: Dirac
2: Tophat

Scale Dependence of Dispersivity



from Neuman, 1990, *Water Resour. Res.*, 26, 8, 1749-1758.

	UE-25 c#2 IODIDE	UE-25 c#2 PFBA1	UE-25 c#2 DFBA	UE-25 c#1 PYRIDONE
Mass injected (kg)	5.0 (Iodide)	10.08 kg	11.35 kg	3.02 kg
Mass recovered [kg/ (%)]	2.347 (47%)	7.0 (69%)	7.598 (67%)	0.036 no peak (10/20/97) (1.2%)
Breakthrough (days)	5.07	2.51	5.07	56.3
Peak Conc. (ug/L)	99.5	350	251	0.392 maximum (10/20/97)
Peclet Number	11	11	12-15	10/3
Dispersivity (m)	2.6	2.6	2.4-1.9	8.56/28.5
Flow porosity (%)	8.6	6.0	9.9-7.2	13/30
Matrix porosity (%)	19	6.38	8.8-13.2	.01/.02

ATTACHMENT 6

YUCCA MOUNTAIN PROJECT

Studies

Matrix Diffusion in the Saturated Zone: Field Evidence and Implications for PA

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:
Bruce Robinson, Technical Staff Member
Los Alamos National Laboratory
Los Alamos, New Mexico

November 5, 1997

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Objectives

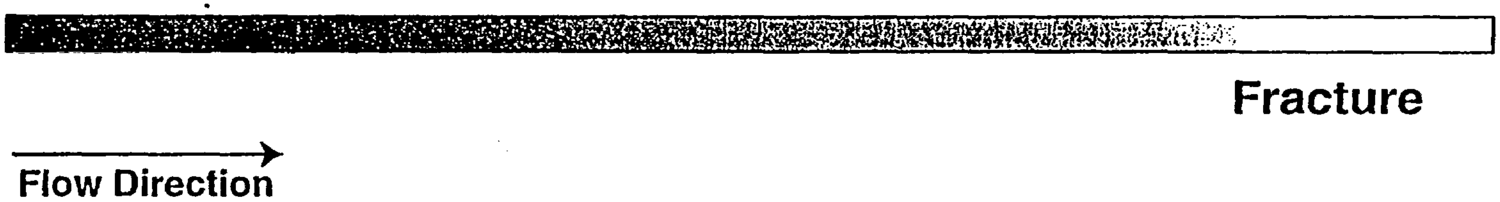
- Validate SZ Transport Conceptual Model
  - Dual-Porosity System
  - Matrix Diffusion
  - Sorption in Matrix and Fractures
- Demonstrate Field-Scale Applicability of Lab Sorption Data
- Obtain Field-Scale Transport Parameter Estimates

Evidence for Matrix Diffusion

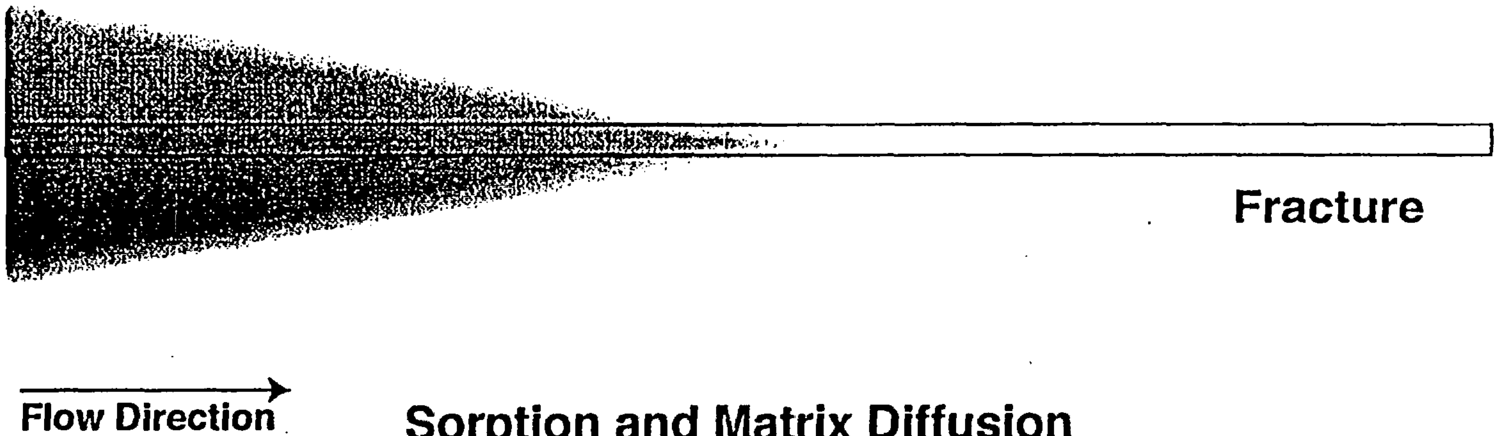
- Saturated zone water ages
- Theoretical Calculations
- Literature Studies
- C-Wells Experiments

Matrix Diffusion and Sorption

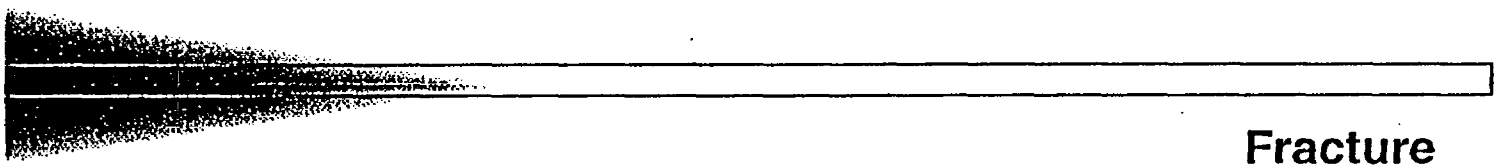
No Matrix Diffusion or Sorption



Matrix Diffusion - No Sorption



Sorption and Matrix Diffusion



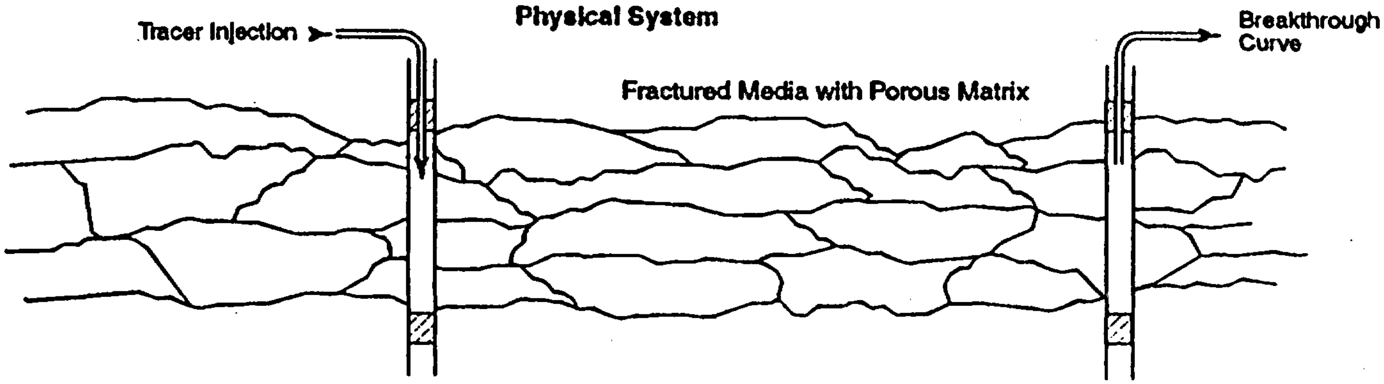
Test Strategy

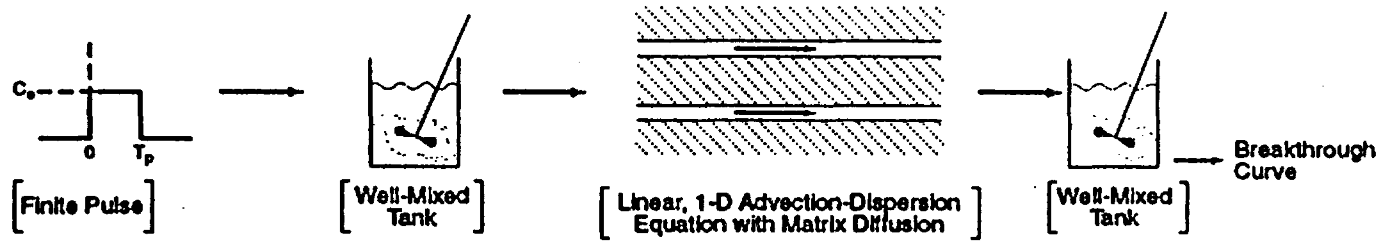
- Laboratory Sorption Studies
- Initial Conservative Pilot Test
- Multiple Tracers to Distinguish Processes:

Tracer	*Category*	*Diffusivity*	*Sorption*
PFBA	Solute	Low	None
Br^-	Solute	High	None
Li^+	Solute	Intermediate	Low
Microspheres	Colloid	Very Low	None

- Simultaneous Tracer Injection
- Interpret by Comparing Responses

Modeling Approach





Laplace Transform Transfer Functions

$$C_o\left(\frac{1-e^{-T_p s}}{s}\right) \qquad \frac{a_1}{s+a_1} \qquad \exp\left[\frac{Pe}{2}\left(1-\sqrt{1+\frac{4\tau R_f s}{Pe}\left(1+\frac{\phi}{bR_f}\sqrt{\frac{R_m D_m}{s}}\right)}\right)\right] \qquad \frac{a_2}{s+a_2}$$

C_o = injection concentration
T_p = duration of pulse, sec

a_1 = decay time^{-1}, sec^{-1}

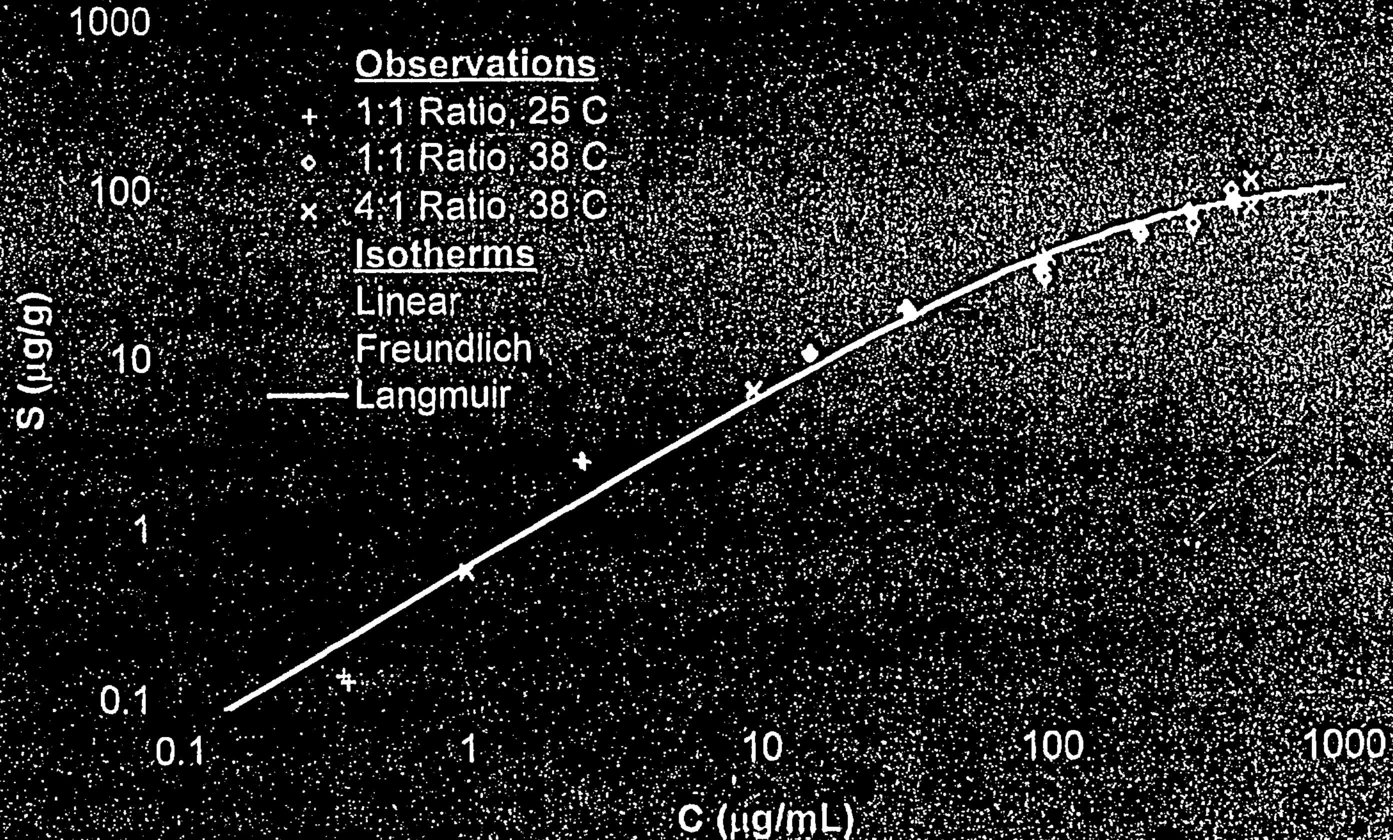
ϕ = matrix porosity
b = fracture half aperture, cm
R_f = fracture retardation factor
R_m = matrix retardation factor
D_m = diffusion coefficient in matrix, cm^2/sec
τ = mean fluid residence time, sec
Pe = Peclet number = $\frac{L}{\alpha}$ (see text)

a_2 = decay time^{-1}, sec^{-1}

s = Laplace transform variable

Lithium Sorption to Bullfrog Tuff

Batch Isotherm Results

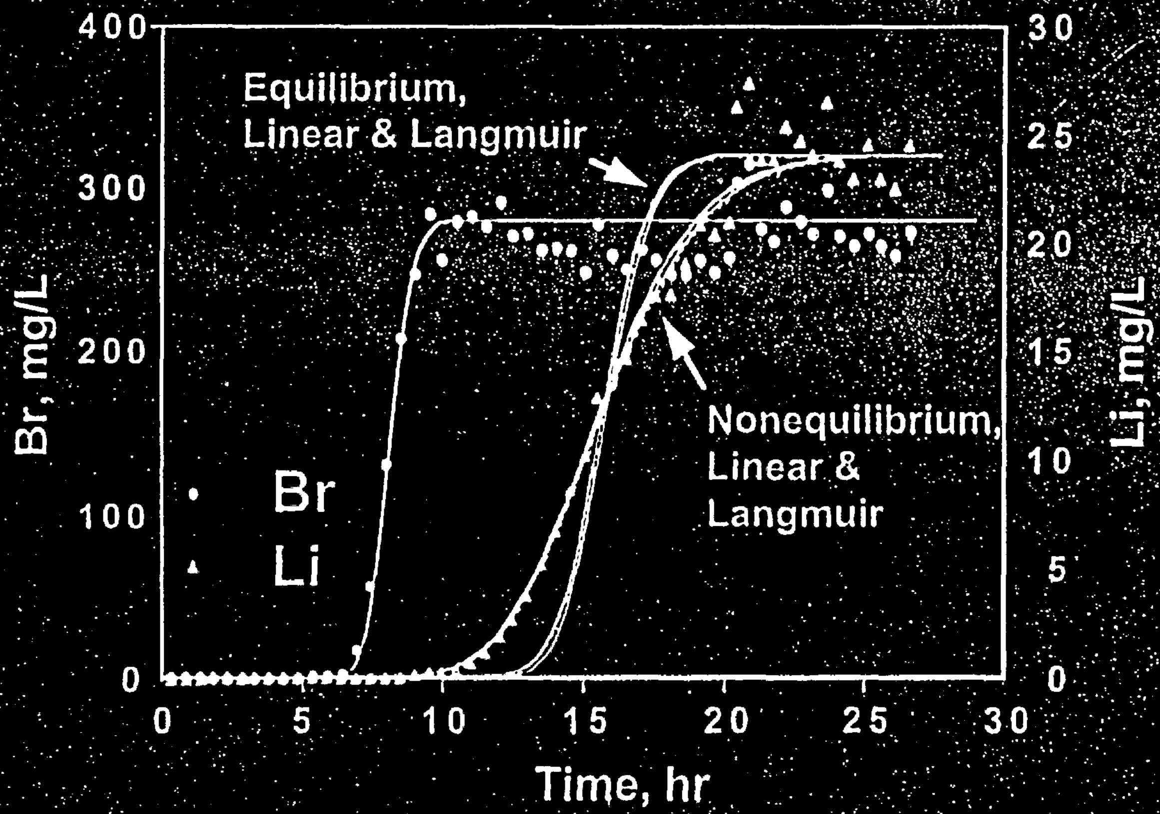


Earth and Environmental Sciences

Los Alamos

Lithium Sorption to Bullfrog Tuff

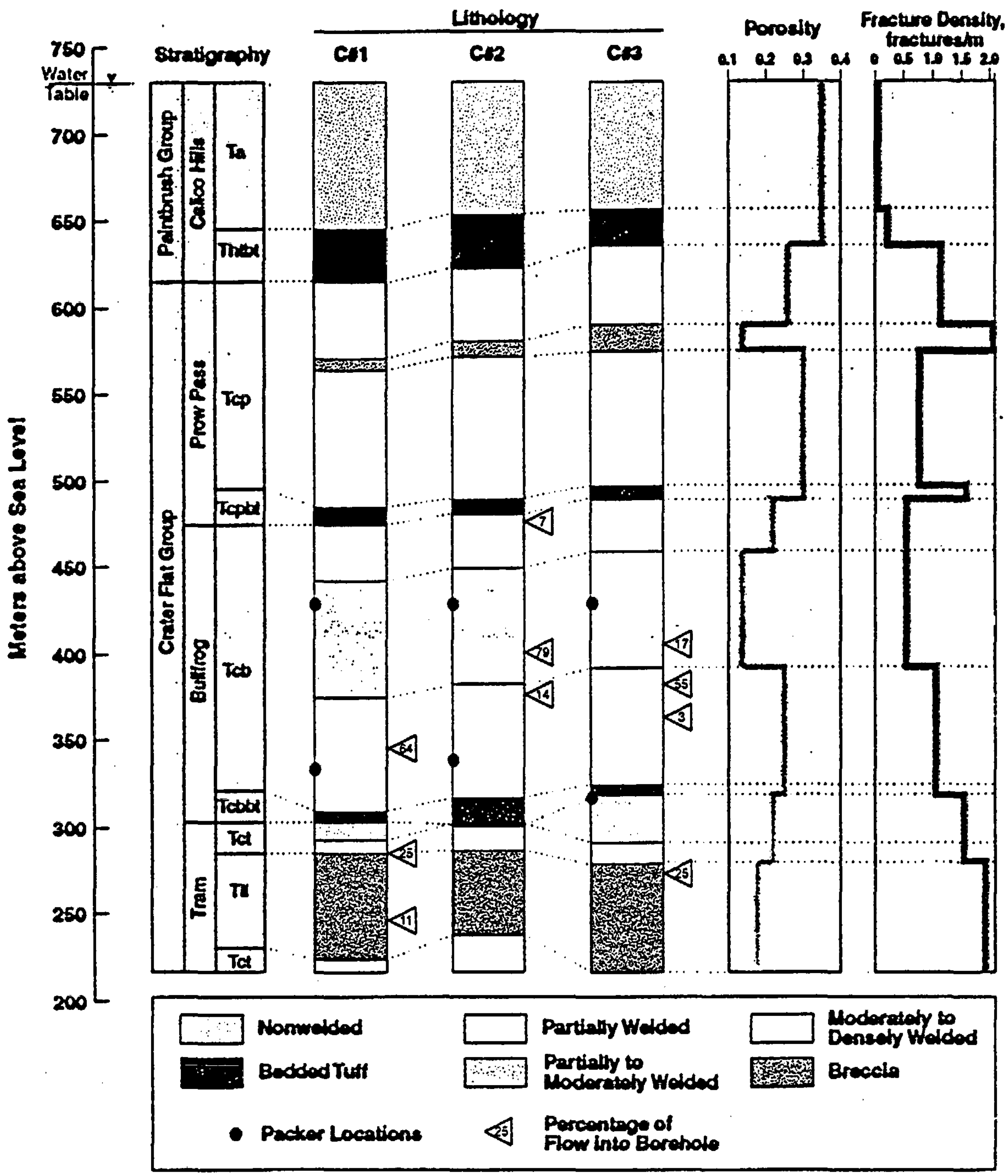
Column Study Results



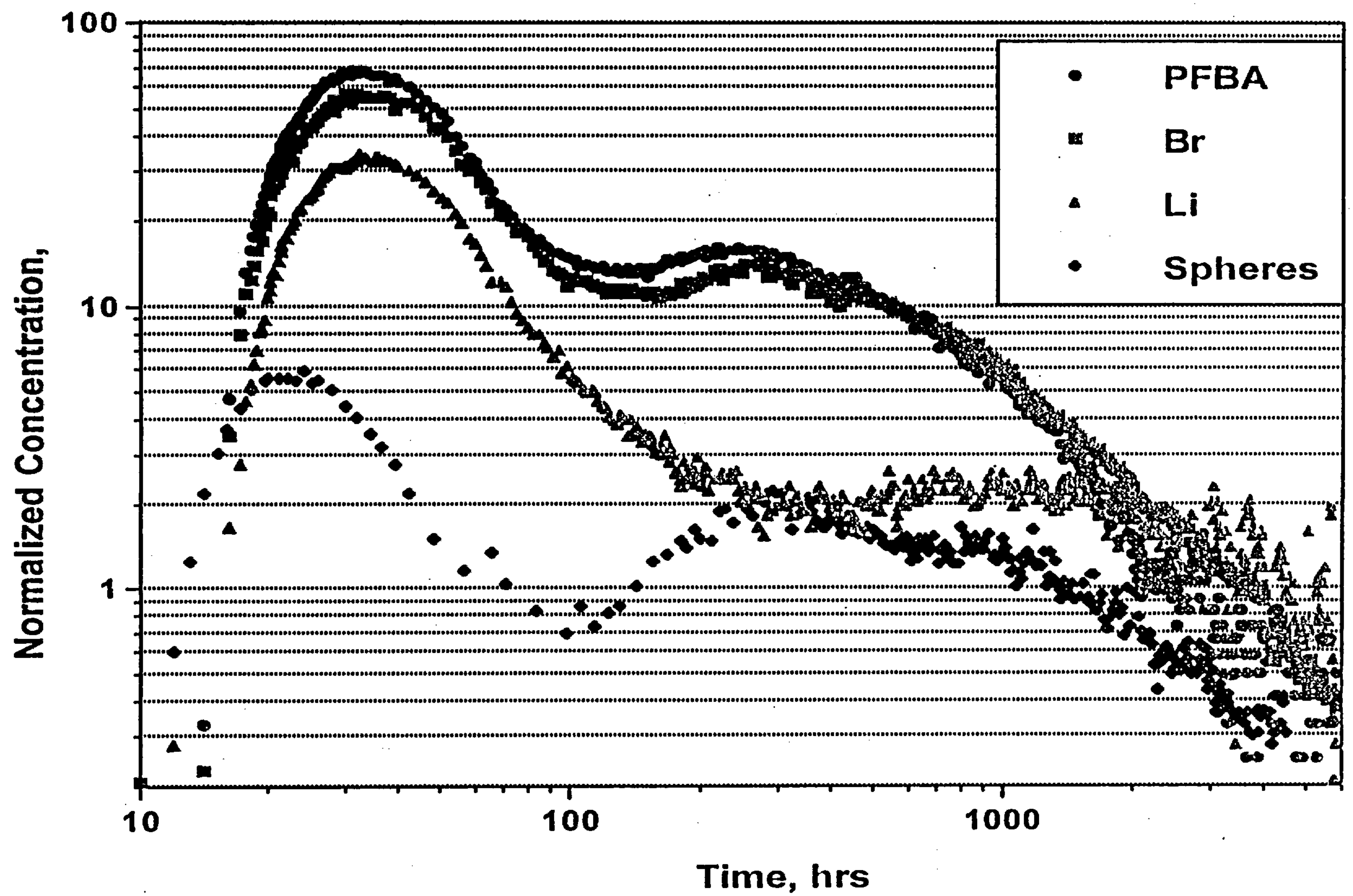
Reactive Tracer Test Details

- Cross-hole, forced-gradient test
- 30-m well separation, 90-m packed-off interval
- 350 m below water table (Lower Bullfrog Tuff)
- ~150 gpm production rate, partial recirculation (3.5%)
- Simultaneous Injection of 4 Tracers

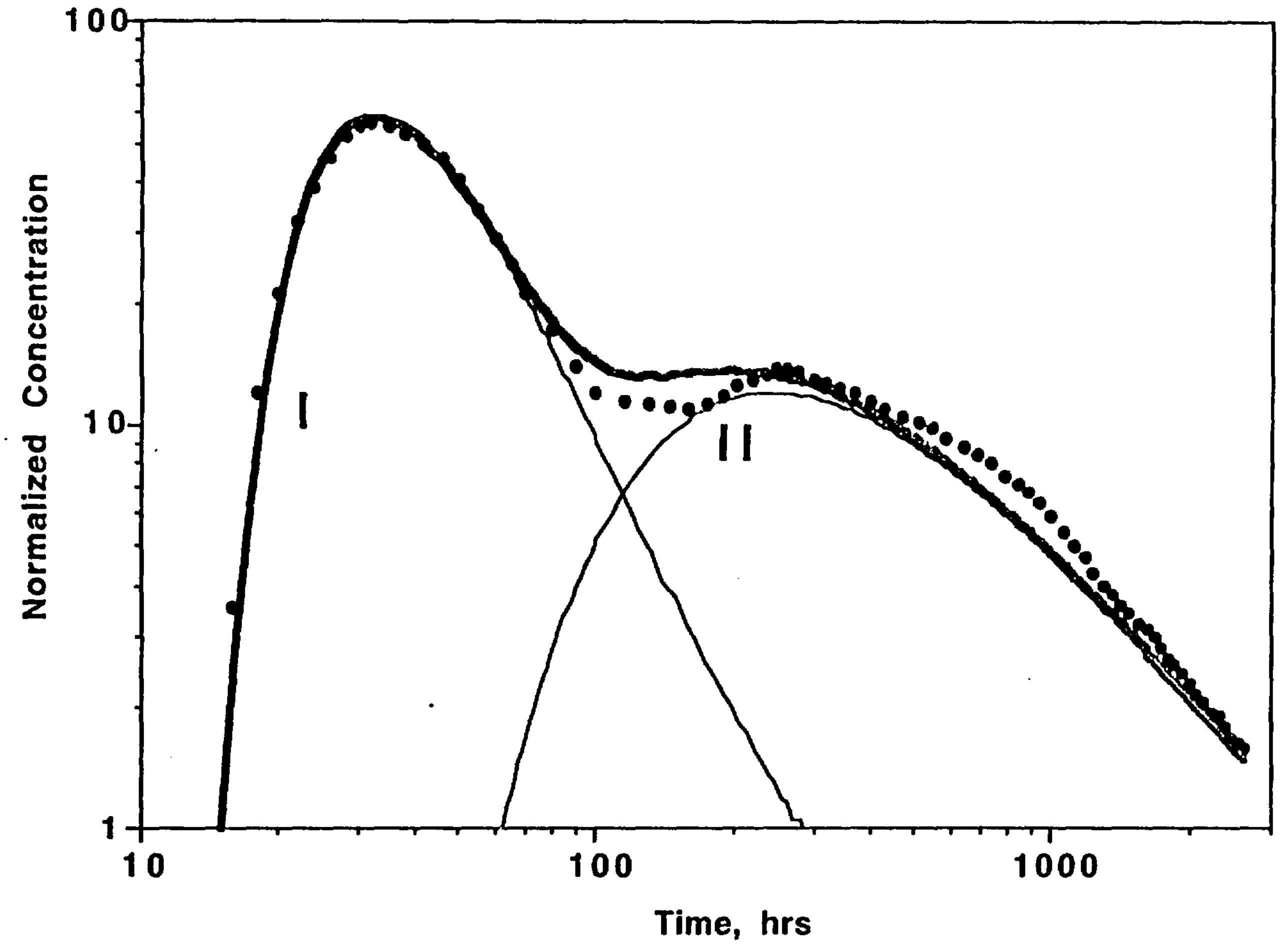
C-Wells Hydrogeology



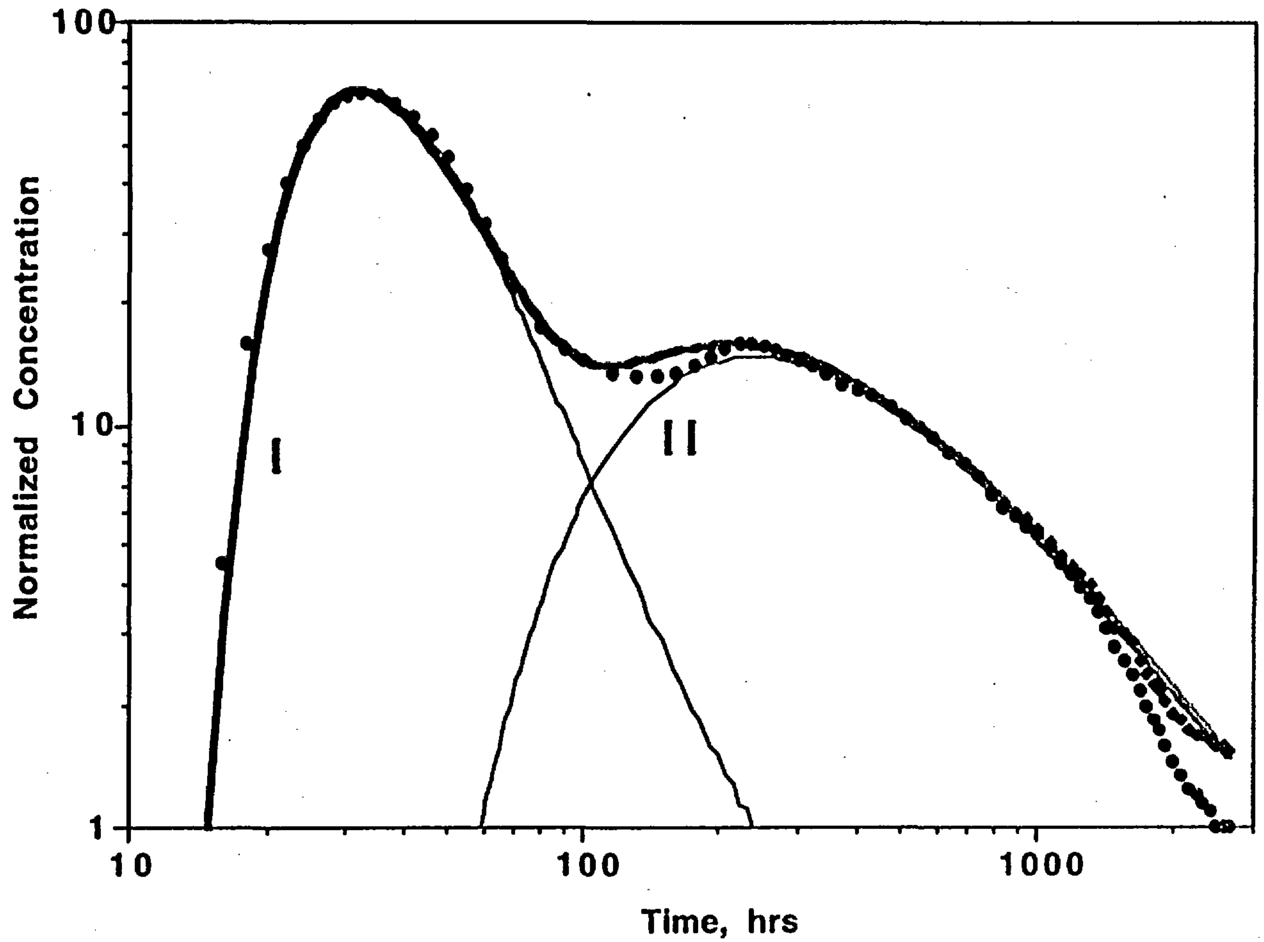
Reactive Tracer Test Results



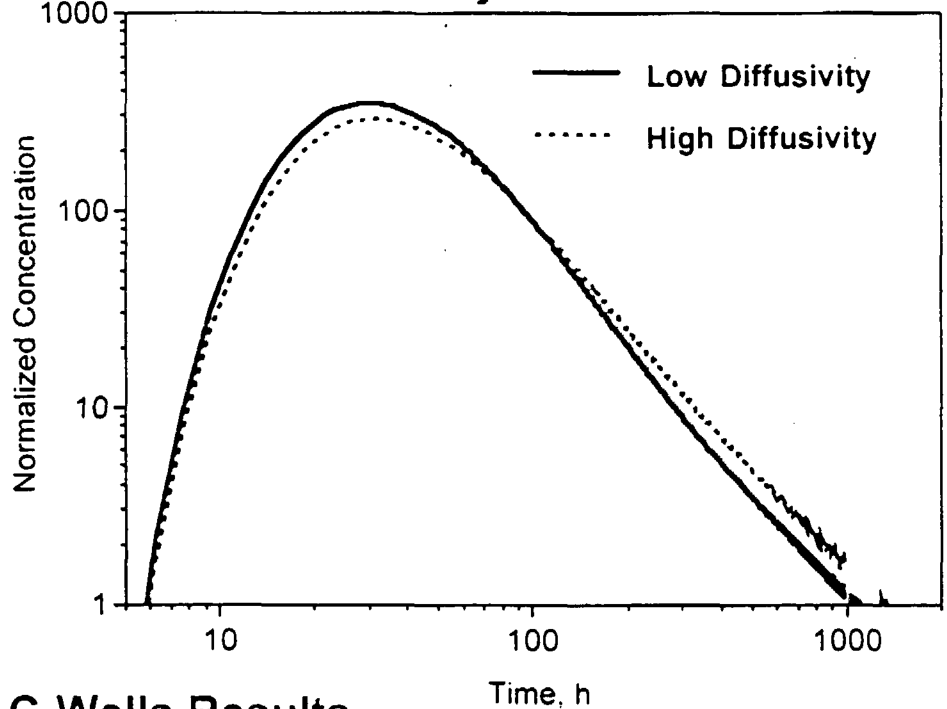
Br^- Two-Pathway Fit



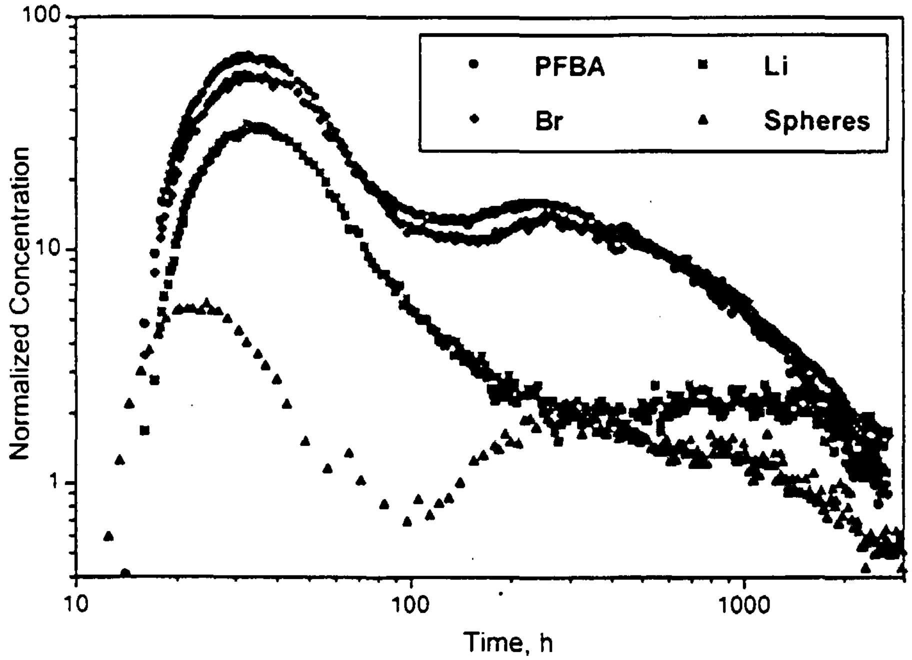
PFBA Two-Pathway Fit



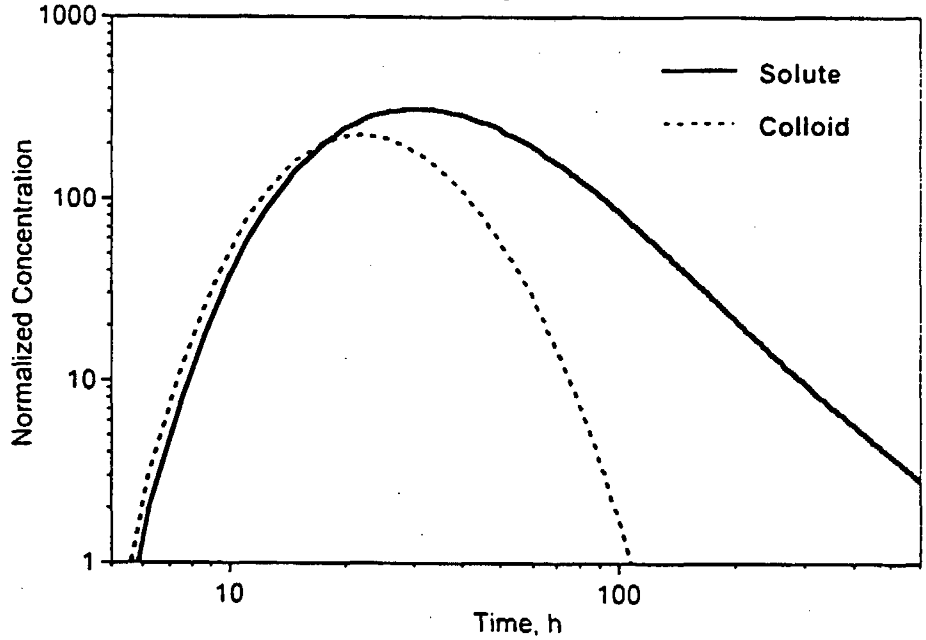
Matrix Diffusion: Theory



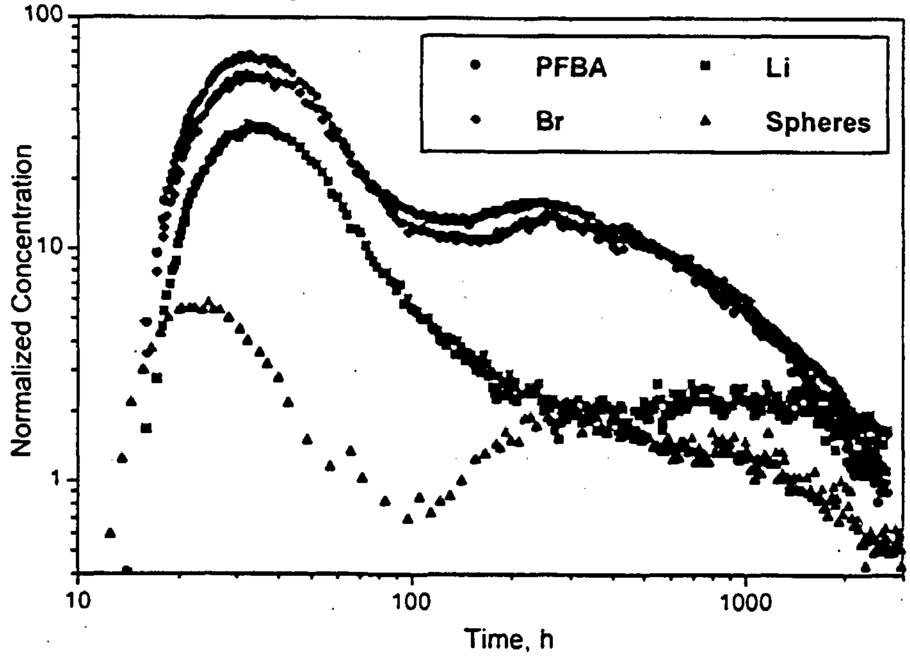
C-Wells Results



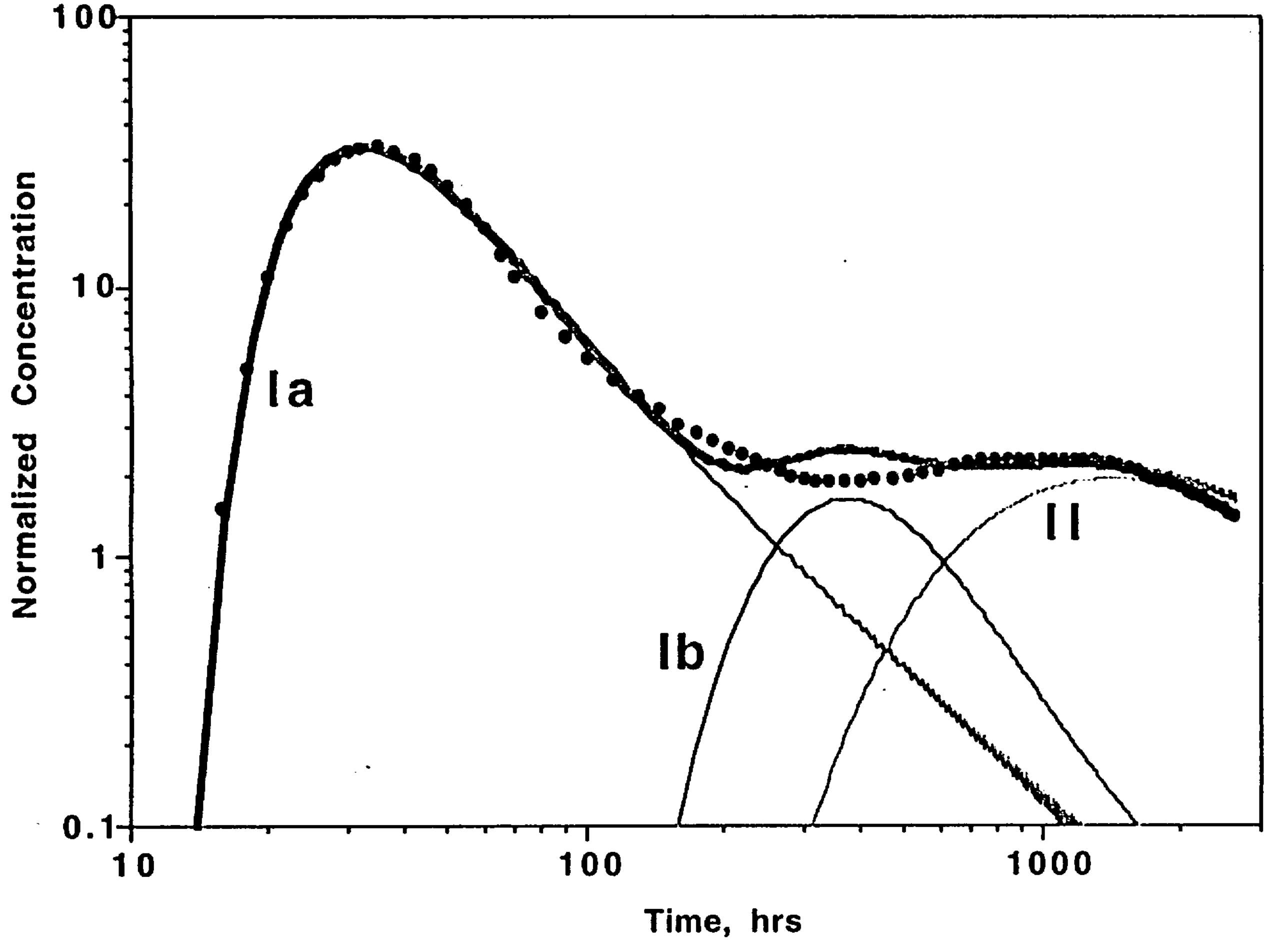
Colloid Transport: Theory



C-Wells Results



Li⁺ Three-Pathway Fit, Varying Retardation



Matrix Diffusion

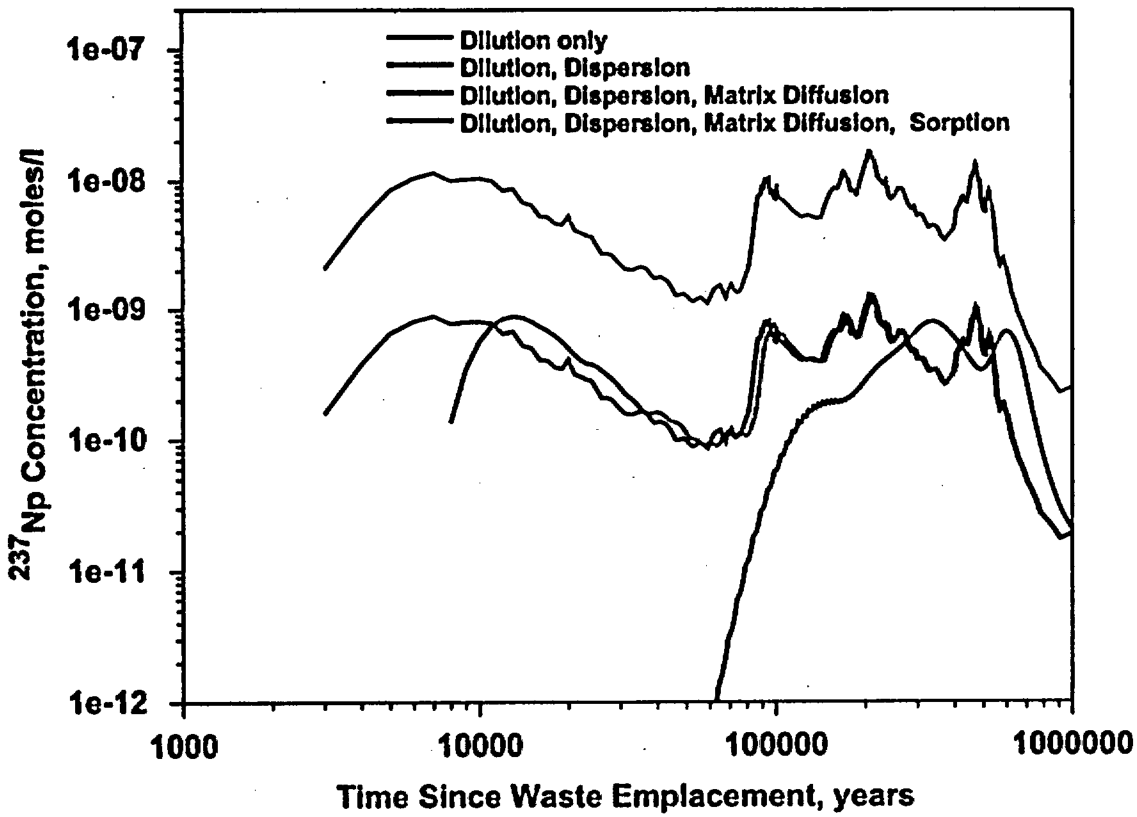
- C-Wells conservative tracer results provide clear indication of matrix diffusion in Bullfrog Tuff.
- Further analysis is necessary to establish best estimates, confidence limits, and bounds for parameters.
- Hand-off to TSPA will be documented evidence of field-scale matrix diffusion, parameter estimates, and confidence limits.
- Planned FY98 Prow Pass Tuff test will yield similar information for different unit, provide data on stratigraphic dependence of matrix diffusion parameters.

Best-Fit Parameters

Parameter	3-Pathway Equilibrium Fit 1a	3-Pathway Equilibrium Fit 1b	3-Pathway Equilibrium Fit 2	2-Pathway Kinetic Fit 1	2-Pathway Kinetic Fit 2
f, mass fraction	0.08	0.05	0.75	0.13	0.75
t, linear flow, hr	25	48	1010	35	[illegible]
Pe, linear flow	8.5	14	1.5	5.5	[illegible]
t, radial flow, hr	22	12	610	29	[illegible]
Pe, radial flow	44	19	2.7	8	[illegible]
ϕ/b, cm^{-1}	1.5	1.5	0.67	1.5	0.67
R_f	[illegible]	5	5	1.3	5
R_m	[illegible]	13	11	21	12
k_f, hr^{-1}				0.12	∞
k_m, hr^{-1}				0.18	∞

Results of Convolution Procedure

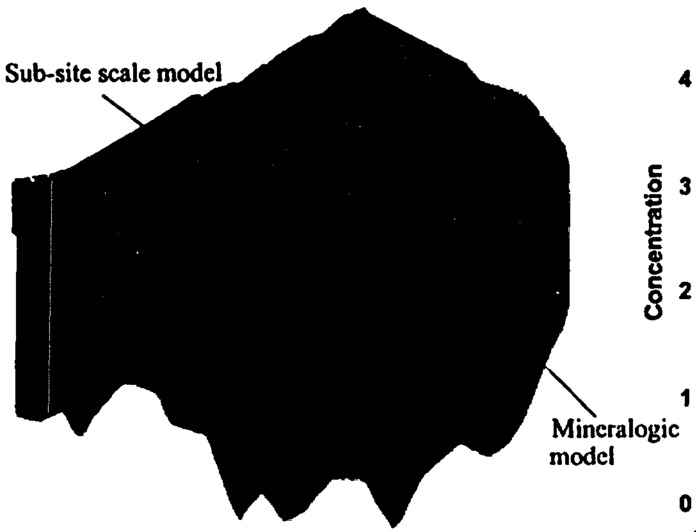
$$C_{SZ}(t) = \int_0^t C_{UZ}(t-t')f_{SZ}(t')dt'$$



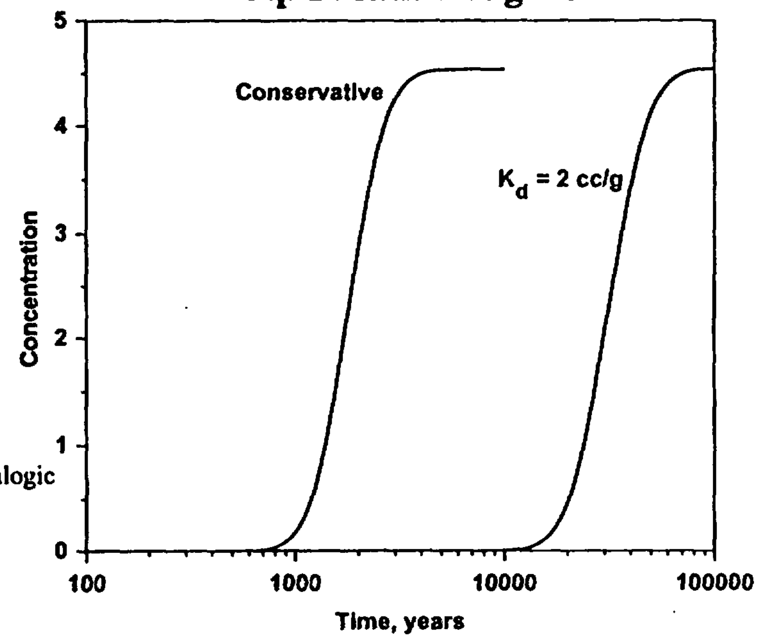
uz_vg2-2

Saturated Zone Model Sensitivity: Sorption

Zeolites in SZ Model

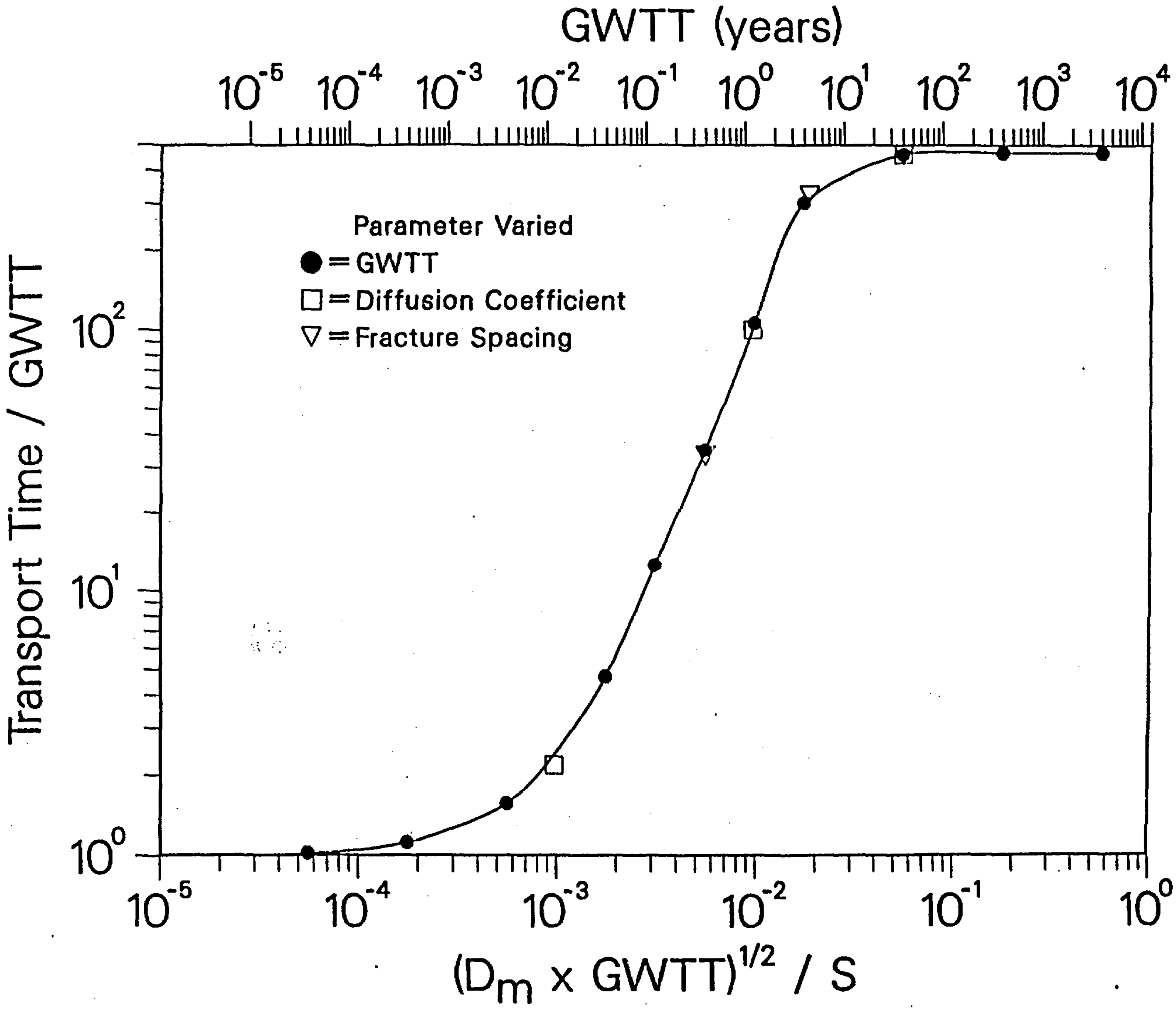


^{237}Np Breakthrough Curve



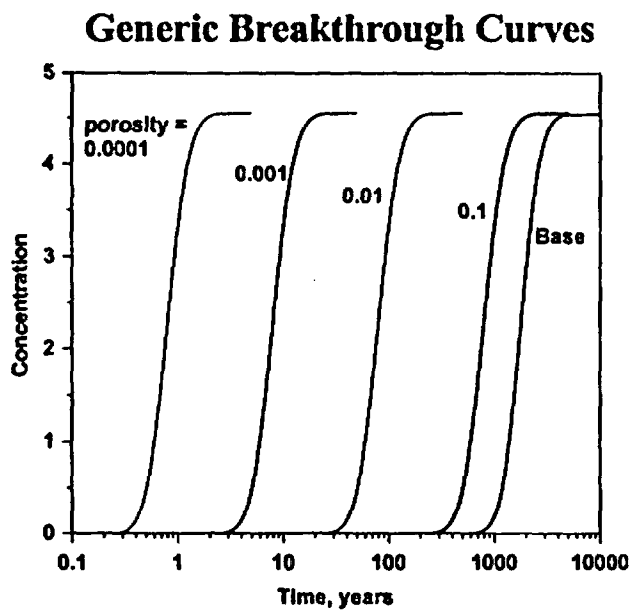
Conclusion: Sorption is a key retardation process in the saturated zone for mobile radionuclides such as ^{237}Np

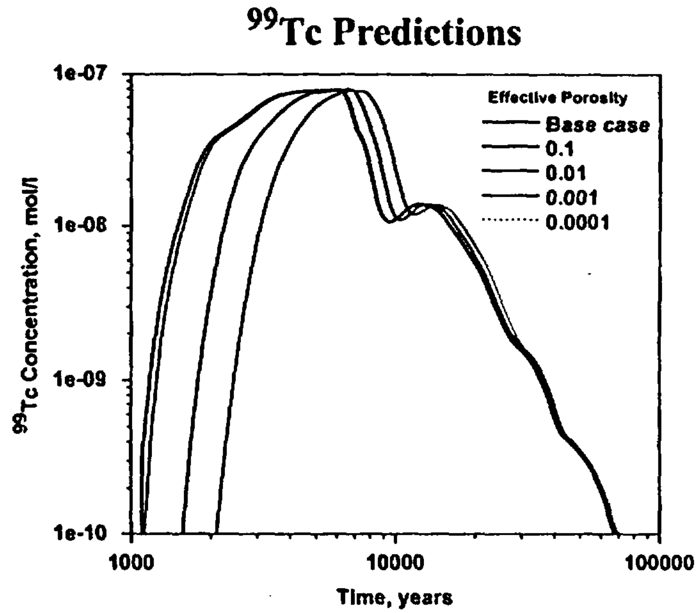
Source: SZ Transport Model Report, Section 6.7



GWTT (years)
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4}
Parameter Varied
● = GWTT
□ = Diffusion Coefficient
▽ = Fracture Spacing
Transport Time / GWTT
10^{0} 10^{1} 10^{2}
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}
$(D_m \times GWTT)^{1/2} / S$

Saturated Zone Model Sensitivity: Matrix Diffusion

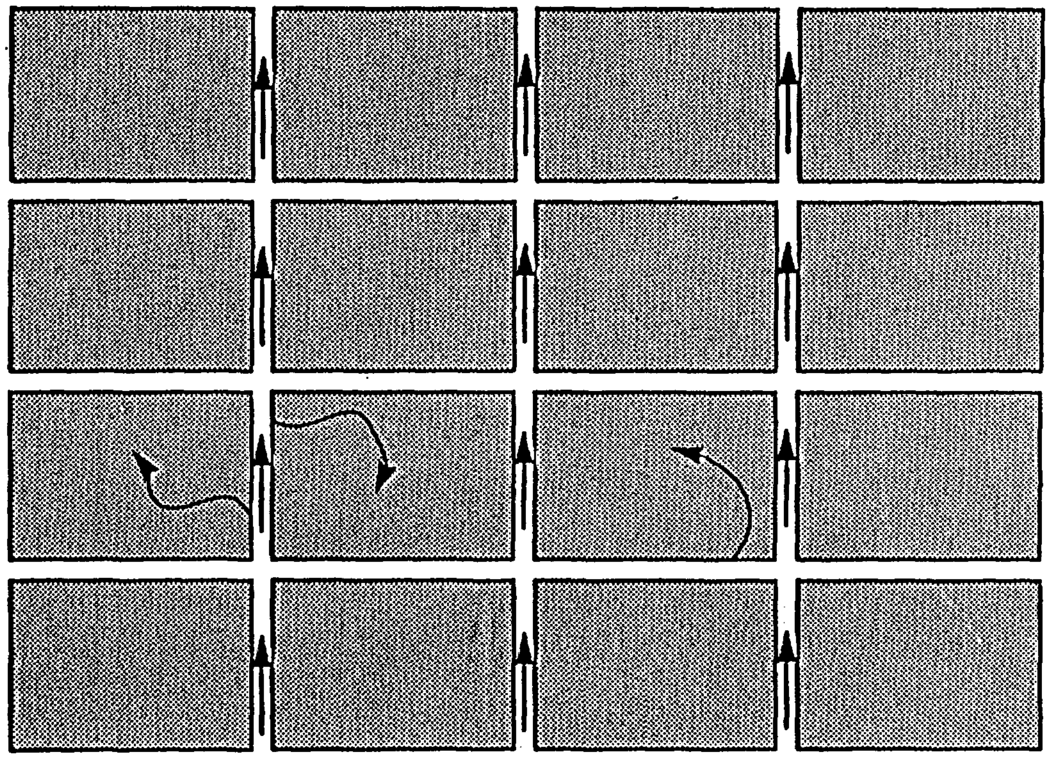


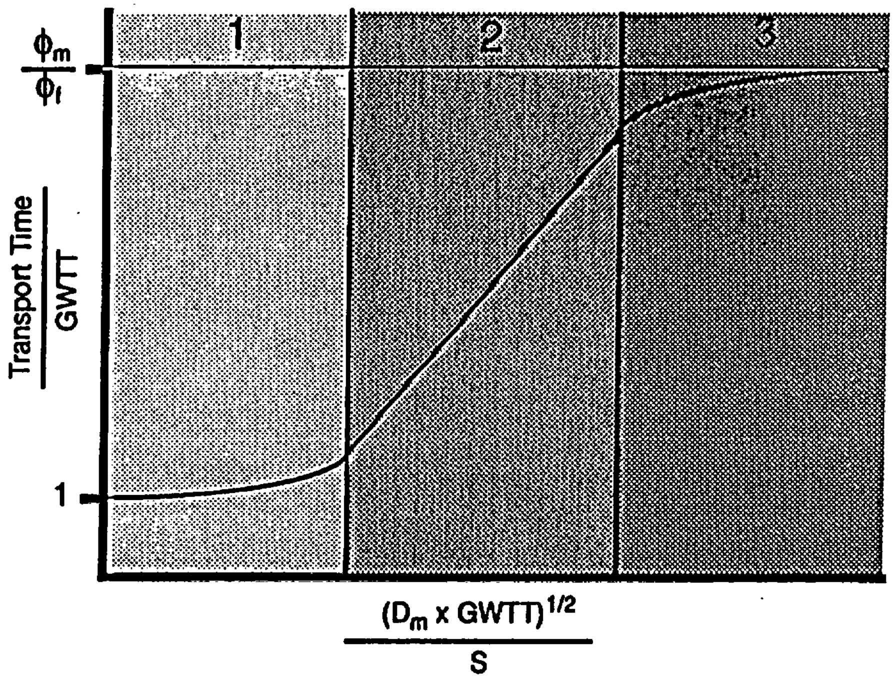


Conclusion: Degree of matrix diffusion can be captured in abstracted form through the use of an effective porosity. It affects arrival times, but not concentrations.

Source: SZ Transport Model Report, Section 6.11.2

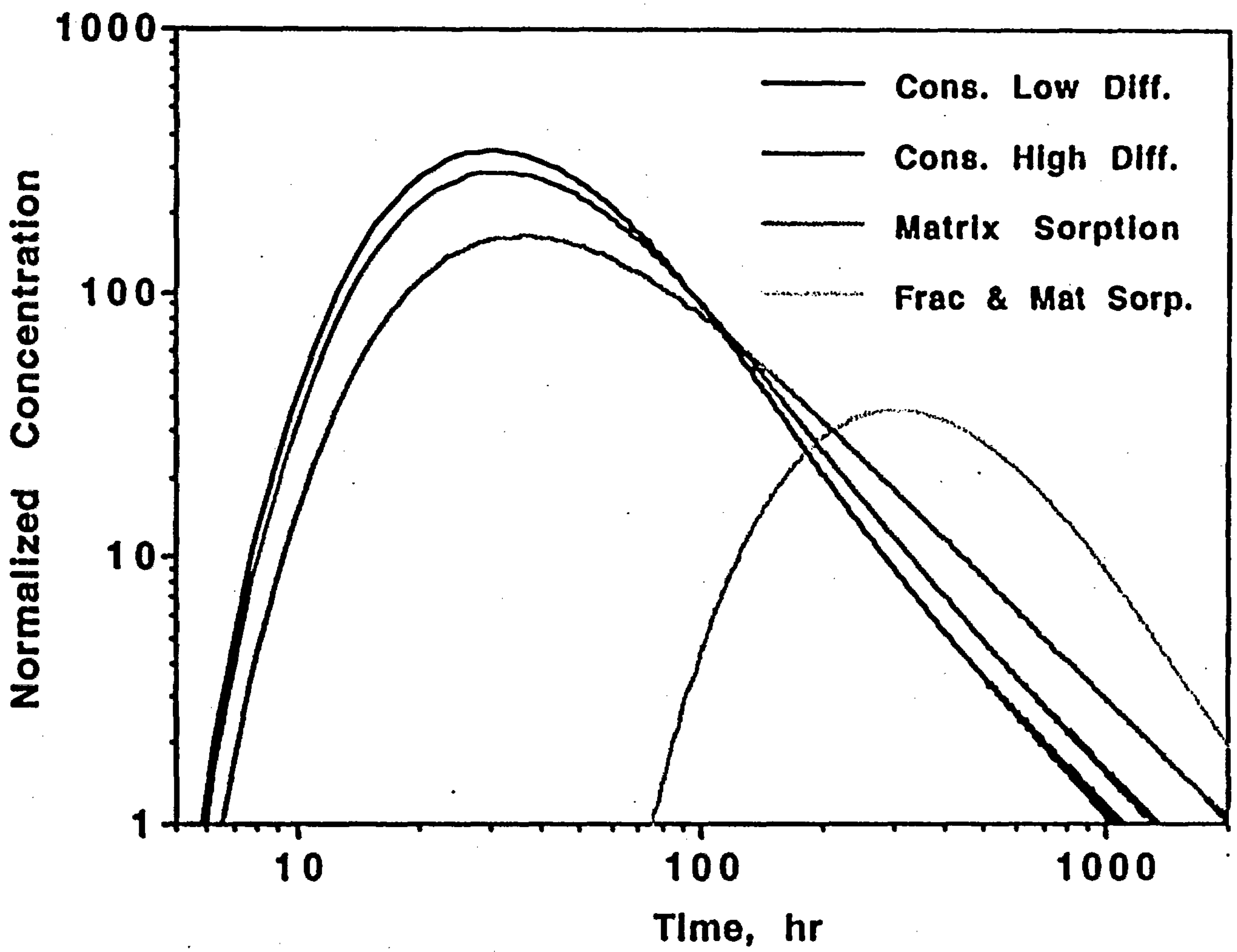
Fracture Flow With Matrix Diffusion





1
2
3
$\frac{\phi_m}{\phi_f}$
$\frac{\text{Transport Time}}{\text{GWTT}}$
1
$\frac{(D_m \times \text{GWTT})^{1/2}}{S}$

Dual-Porosity Response



Conclusions

- SZ transport conceptual model is valid (at least for Bullfrog Tuff at C-Wells)
- Field measurements of Li^+ sorption agree with lab measurements
- Matrix diffusion and sorption are effective retardation and dilution mechanisms

3. Waste and repository effects

- 3.2 Chemical
  - 3.2.2 Interactions of host materials and groundwater with repository
  - 3.2.4 Non-radioactive solute plume in geosphere

1. Natural phenomena

- 1.2 Geological
  - 1.2.3 Magmatic activity [intrusive/extrusive]

- 1.5 Hydrological
  - 1.5.5 Groundwater flow
  - 1.5.6 Groundwater conditions [saturated/unsaturated]

Examples of corresponding expansion FEPs in this project (cont'd.)

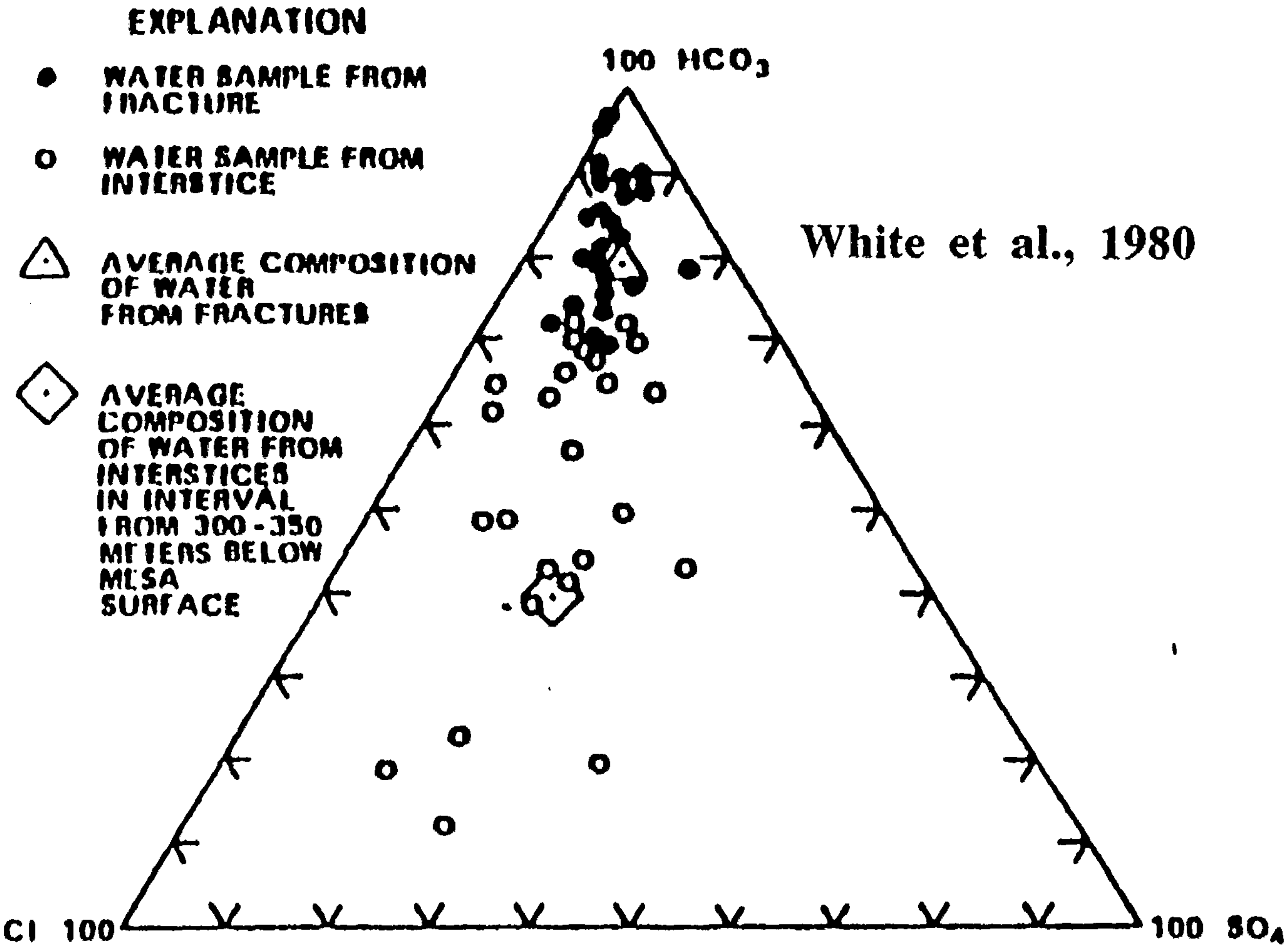
- Chemical
  - Rind formation at drift wall
  - Carrier plume - persistence and residence time in UZ
  - Carrier plume - mixing in SZ
  - Thermo-chemical alteration of SZ porosities
  - Hydrothermal alteration of TPSbv

ATTACHMENT 7

GEOCHEMICAL EVIDENCE FOR FRACTURE-MATRIX INTERACTIONS

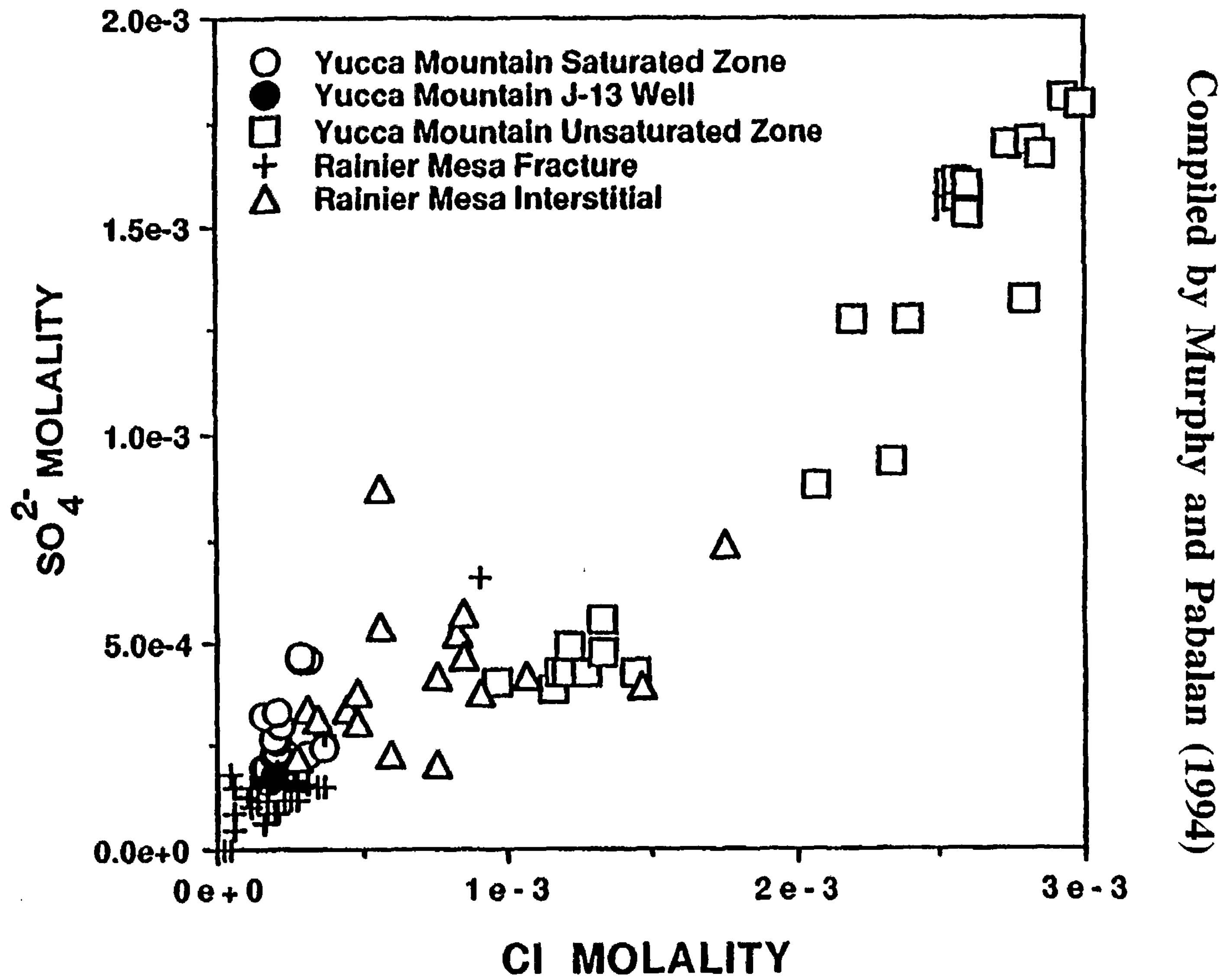
William M. Murphy
Center for Nuclear Waste Regulatory Analyses
210/522-5263 wmurphy@swri.edu

November 5–6, 1997
NRC/DOE Technical Exchange on
Total System Performance Assessment for Yucca Mountain

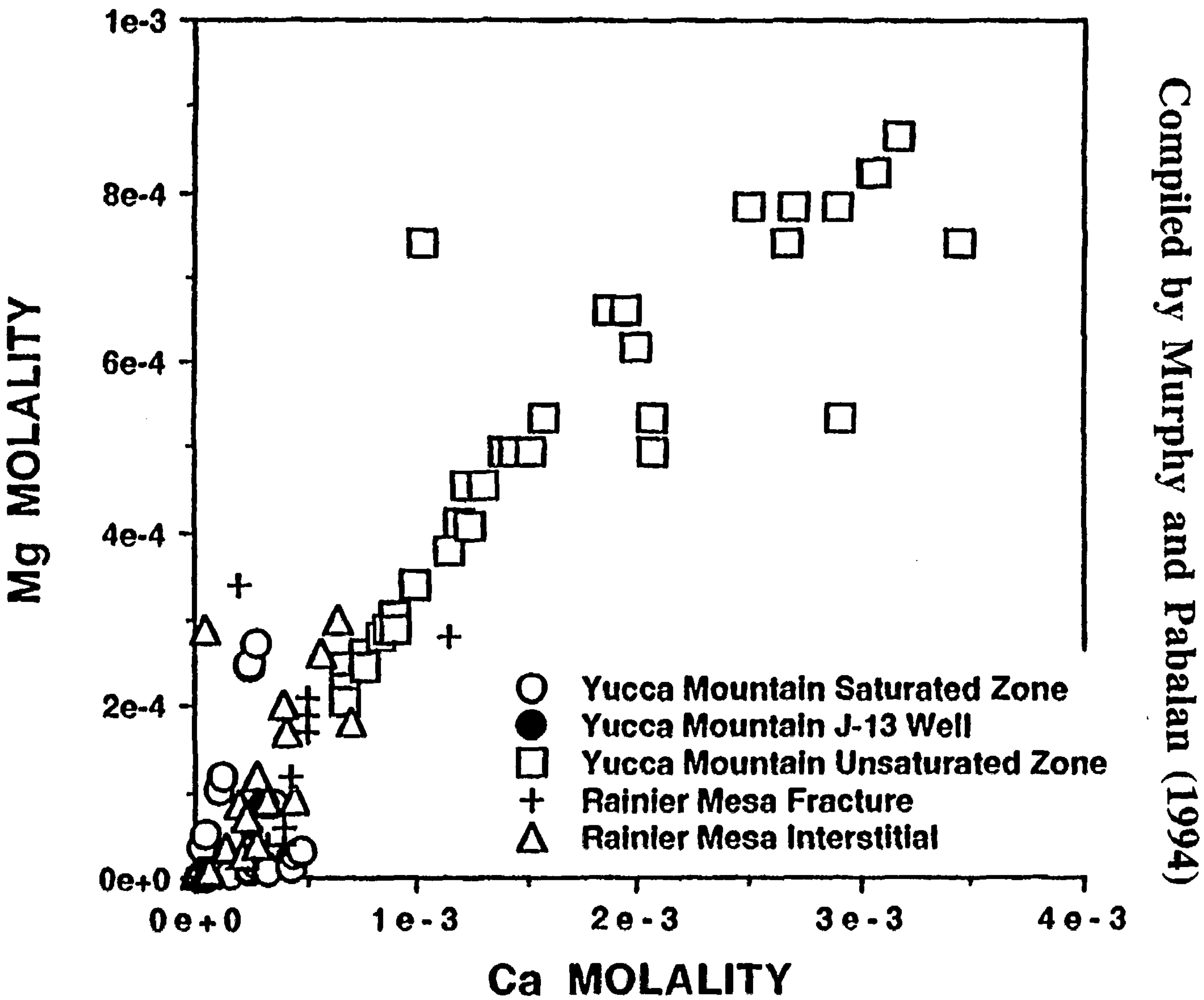


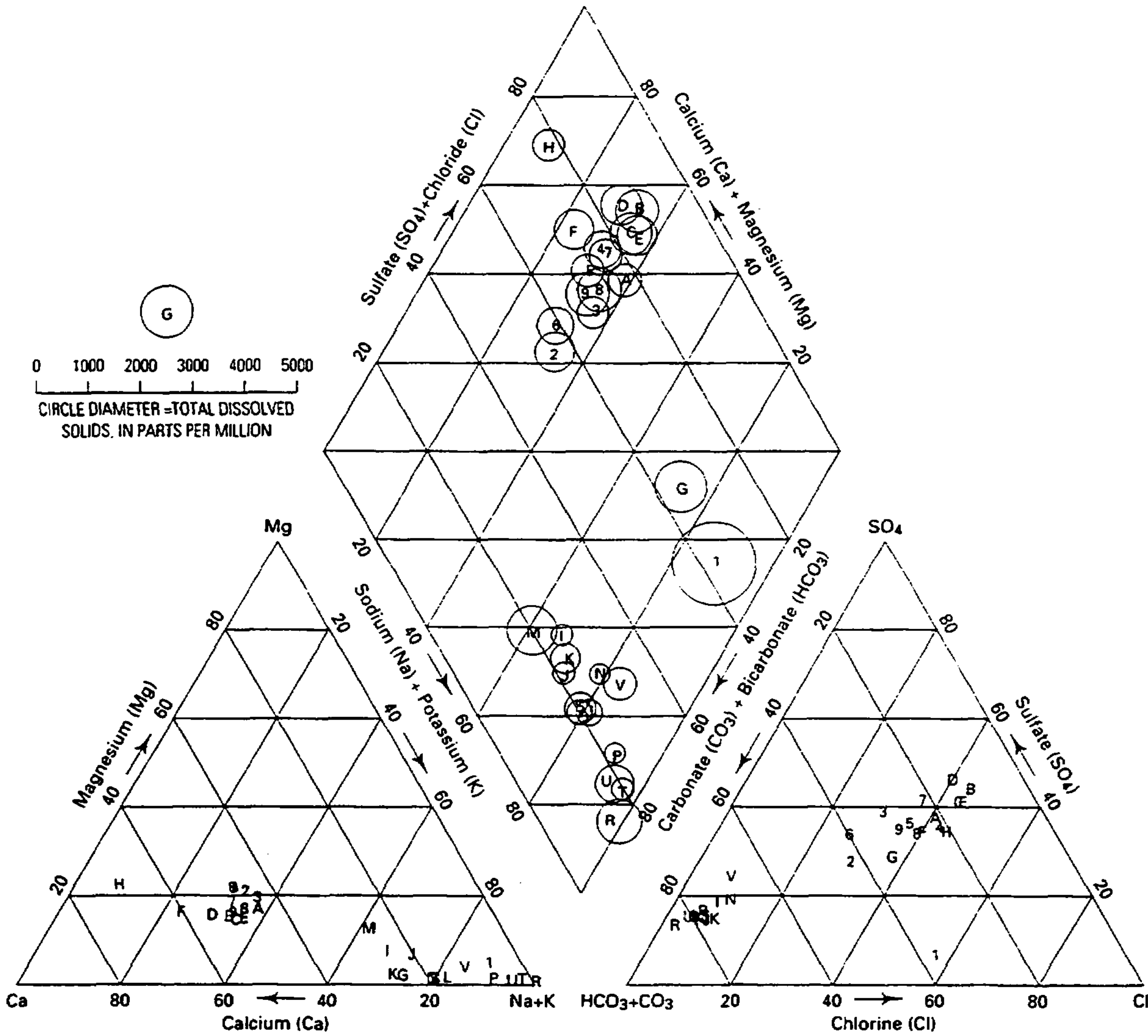
White et al., 1980

FIGURE 6.—Anion ratios of Rainier Mesa ground water.



Yucca Mountain Saturated Zone
Yucca Mountain J-13 Well
Yucca Mountain Unsaturated Zone
Rainier Mesa Fracture
Rainier Mesa Interstitial
2.0e-3
1.5e-3
1.0e-3
5.0e-4
0.0e+0
SO_4^{2-} MOLALITY
0e+0
1e-3
2e-3
3e-3
Cl MOLALITY
Compiled by Murphy and Pabalan (1994)


Mg MOLALITY
1e-3
8e-4
6e-4
4e-4
2e-4
0e+0
Ca MOLALITY
0e+0
1e-3
2e-3
3e-3
4e-3
Yucca Mountain Saturated Zone
Yucca Mountain J-13 Well
Yucca Mountain Unsaturated Zone
Rainier Mesa Fracture
Rainier Mesa Interstitial
Compiled by Murphy and Pabalan (1994)

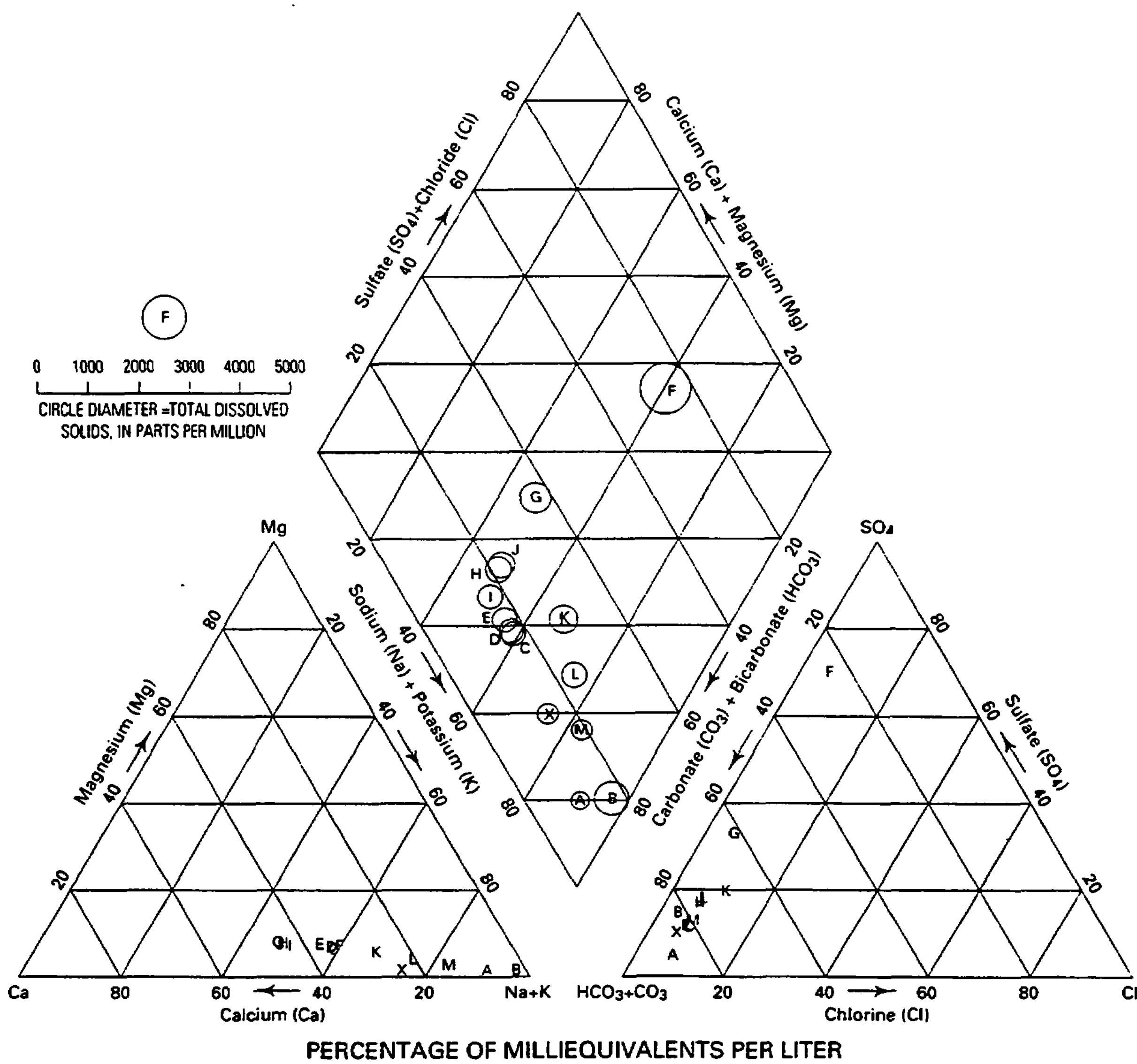


EXPLANATION

I J12	T USW-H5	8 UZ-14 (135.7 feet)
J J13	U USW-H6	9 UZ-14 (145.0 feet)
K UE-25B#1	V USW-VH-1	A UZ-14 (147.9 feet)
L UE-25C#1	1 UZ-14 (45.2 feet)	B UZ-14 (177.8 feet)
M UE-25P1	2 UZ-14 (85.4 feet)	C UZ-14 (178.3 feet)
N UE-29A2	3 UZ-14 (91.2 feet)	D UZ-14 (215.9 feet)
O USW-G-4	4 UZ-14 (95.7 feet)	E UZ-14 (226.0 feet)
P USW-H-1	5 UZ-14 (96.4 feet)	F UZ-14 (235.3 feet)
R USW-H-3	6 UZ-14 (100.6 feet)	G UZ-14 (241.0 feet)
S USW-H4	7 UZ-14 (114.9 feet)	H UZ-14 (245.7 feet)

Figure 5. Piper diagram showing top 75 meters of USW UZ–14 pore water (1–9, and A–H) and saturated-zone water compositions (I–V).

Yang et al. (199(



EXPLANATION

A NRG-7a (1510.0 feet)
B SD-9/TS (1489.0 feet)
C UZ-14A (1261.8 feet)
D UZ-14A2 (1261.8 feet)
E UZ-14B (1271.9 feet)
F UZ-14C (1282.0 feet)
G UZ-14PT-1 (1282.0 feet)
H UZ-14PT-2 (1282.0 feet)
I UZ-14PT-4 (1282.0 feet)
J UZ-14D (1282.0 feet)
L ONC#1 (SZ) (1420.5 feet)
M USW-G-2 (SZ) (2292.6 feet)
X SD-7 (3/8) (1574.0 feet)
X SD-7 (3/16) (1602.0 feet)
X SD-7 (3/17) (1602.0 feet)
X SD-7 (3/20) (1602.0 feet)
X SD-7 (3/21) (1602.0 feet)

Figure 14. Piper diagram showing perched-water composition, along with saturated-zone water compositions (ONC#1, L, and USW G–2, M).

Yang et al. (1996)

CONCLUSIONS BASED ON WATER CHEMISTRY CONTRASTS AND SIMILARITIES

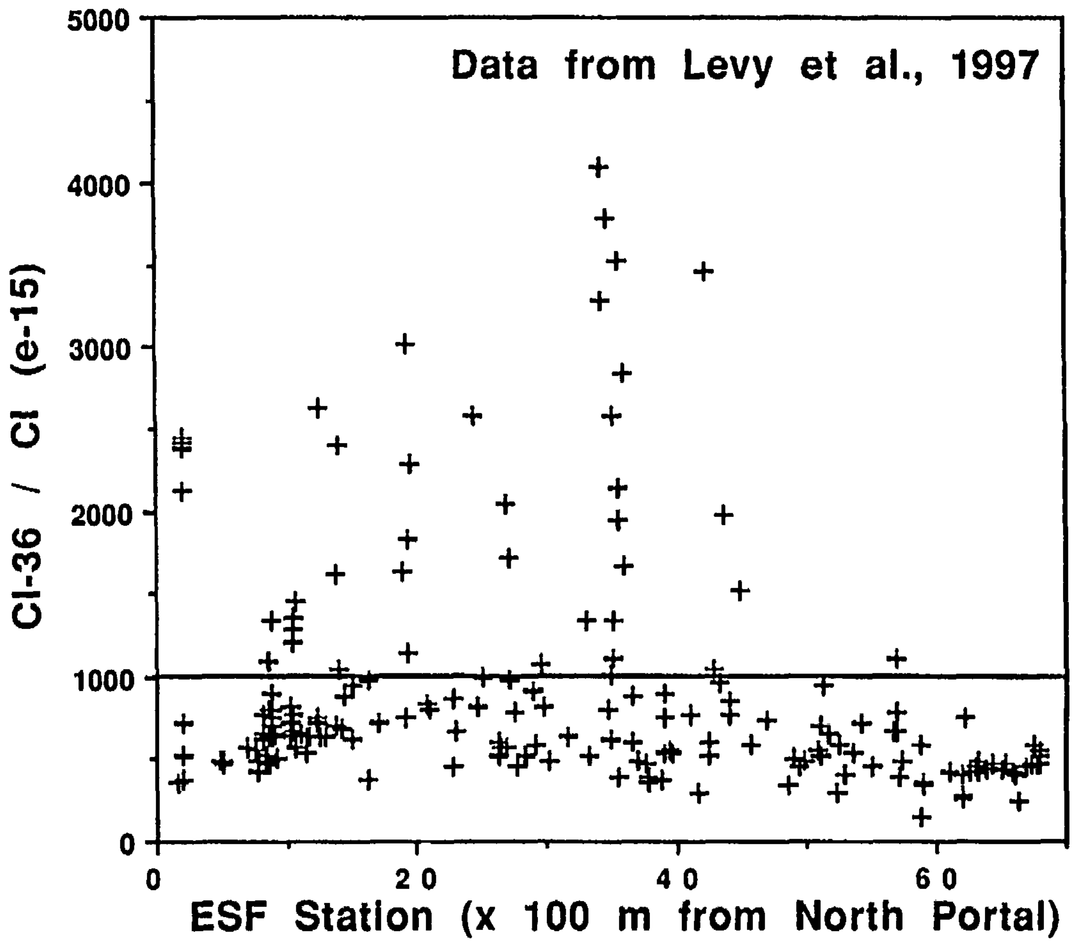
- Interactions Between Fracture Water and Matrix Water Are Limited
- Fracture and Perched Waters Are the Type of Water That Recharges the Saturated Zone Tuffaceous Aquifer
- Matrix Water Has Undergone Some Evaporation and Probably Greater Water-Rock Interaction Than Fracture Water

BOMB PULSE CHLORINE-36 IN THE ESF

- Bomb Pulse Chlorine-36 in the Exploratory Studies Facility Is Evidence for Fast Groundwater Flow, i.e., Fracture Flow

- Most Zones of the Highest Bomb Pulse Contamination in the ESF Are Associated with the Surface Manifestation of Faults

- Within These Zones Most Occurrences of Bomb Pulse Contamination in the ESF are Associated with Geologic Features Characteristic of Individual Strata (e.g., Fractures), Not Through Going Features (e.g., Faults)


Data from Levy et al., 1997
Cl-36 / Cl (e-15)
5000
4000
3000
2000
1000
0
0
20
40
60
ESF Station (x 100 m from North Portal)

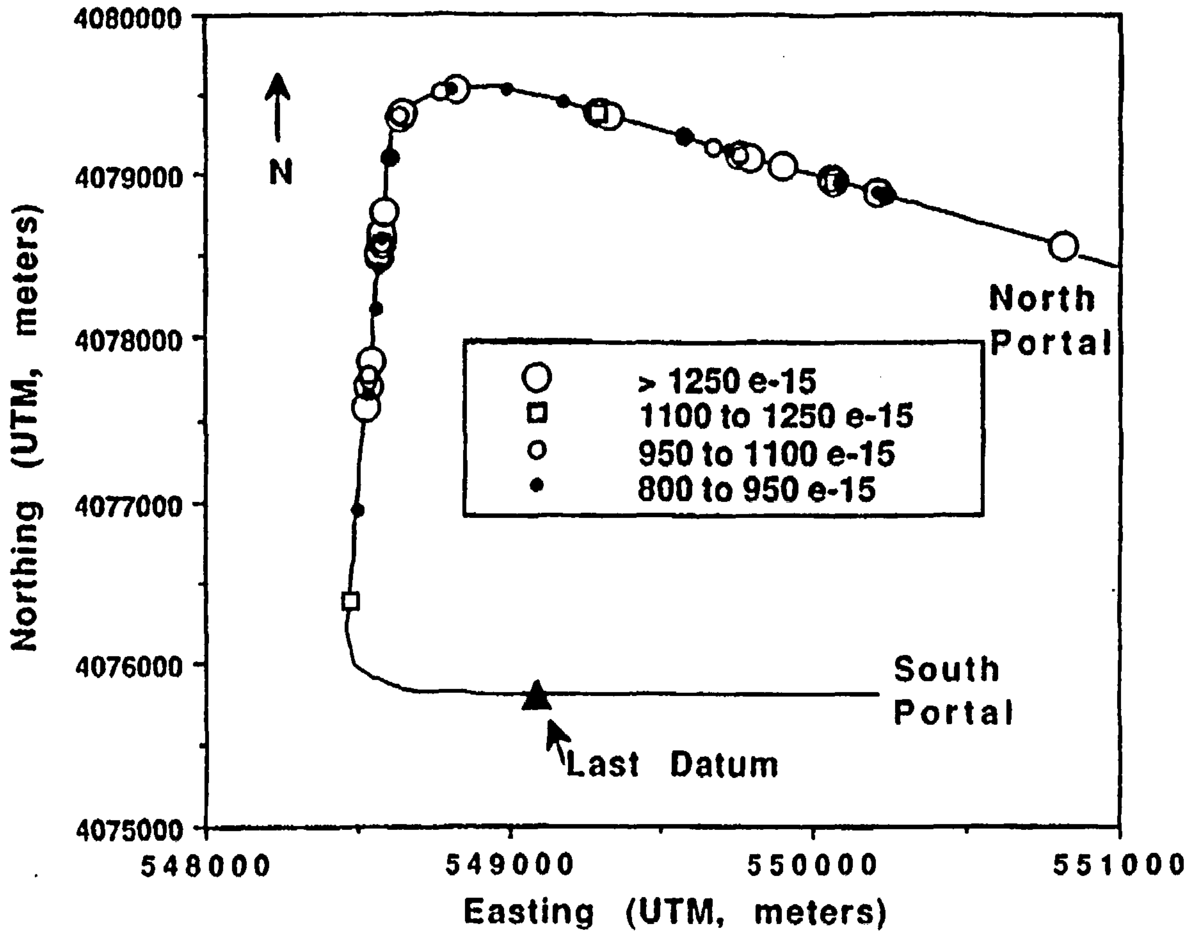


Figure 5. Map view of locations in the ESF where relatively elevated $^{36}Cl/Cl$ values have been detected. The course of the ESF extends along the solid line. Data have been reported for samples collected from the North Portal to the triangle representing the last datum. Other symbols indicate locations of samples yielding $^{36}Cl/Cl$ ratios in the ranges indicated in the legend. $^{36}Cl/Cl$ data are from reference [3].

Murphy, 1997

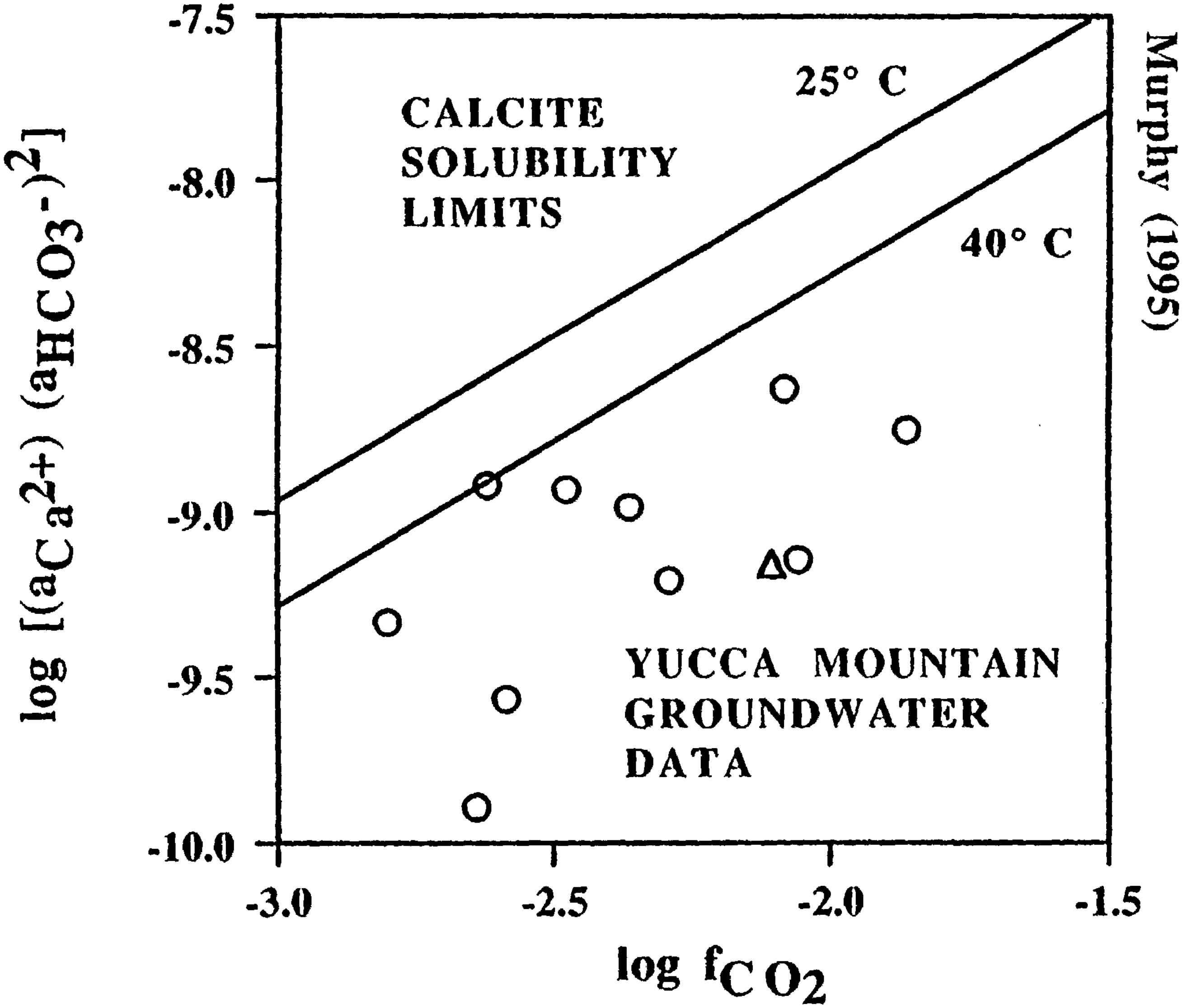
Saturated Zone Channeling

- Saturated Zone Water Sampled from the Tuffaceous Aquifer in the Vicinity of Yucca Mountain is Chemically Undersaturated with Respect to Calcite.

- Calcite Occurs in Fractures and Voids in the Rocks, But Not Everywhere.

- Water Flowing into Boreholes Does Not Interact with Rock Containing Calcite, i.e., Flow Is Channelized.

- Carbon Isotope Data and Correlation of Water Producing Zones with Calcite Free Zones Support this Interpretation.



CALCITE
SOLUBILITY
LIMITS
25° C
40° C
YUCCA MOUNTAIN
GROUNDWATER
DATA
Murphy (1995)
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-3.0
-2.5
-2.0
-1.5
log [($a_{Ca^{2+}}$) ($a_{HCO_3^-}$)^2]
log f_{CO_2}

THE NOPAL I NATURAL ANALOG AT PEÑA BLANCA

- Transport of Uranium From 3 Ma Oxidized Uranium Minerals and Deposition in Adjacent Unmineralized Rock Has Occurred But in Small Amounts and Over Small Distances
- Anomalous Uranium Occurs in Fractures Tens of Meters Away from the Zone of Uranium Mineralization

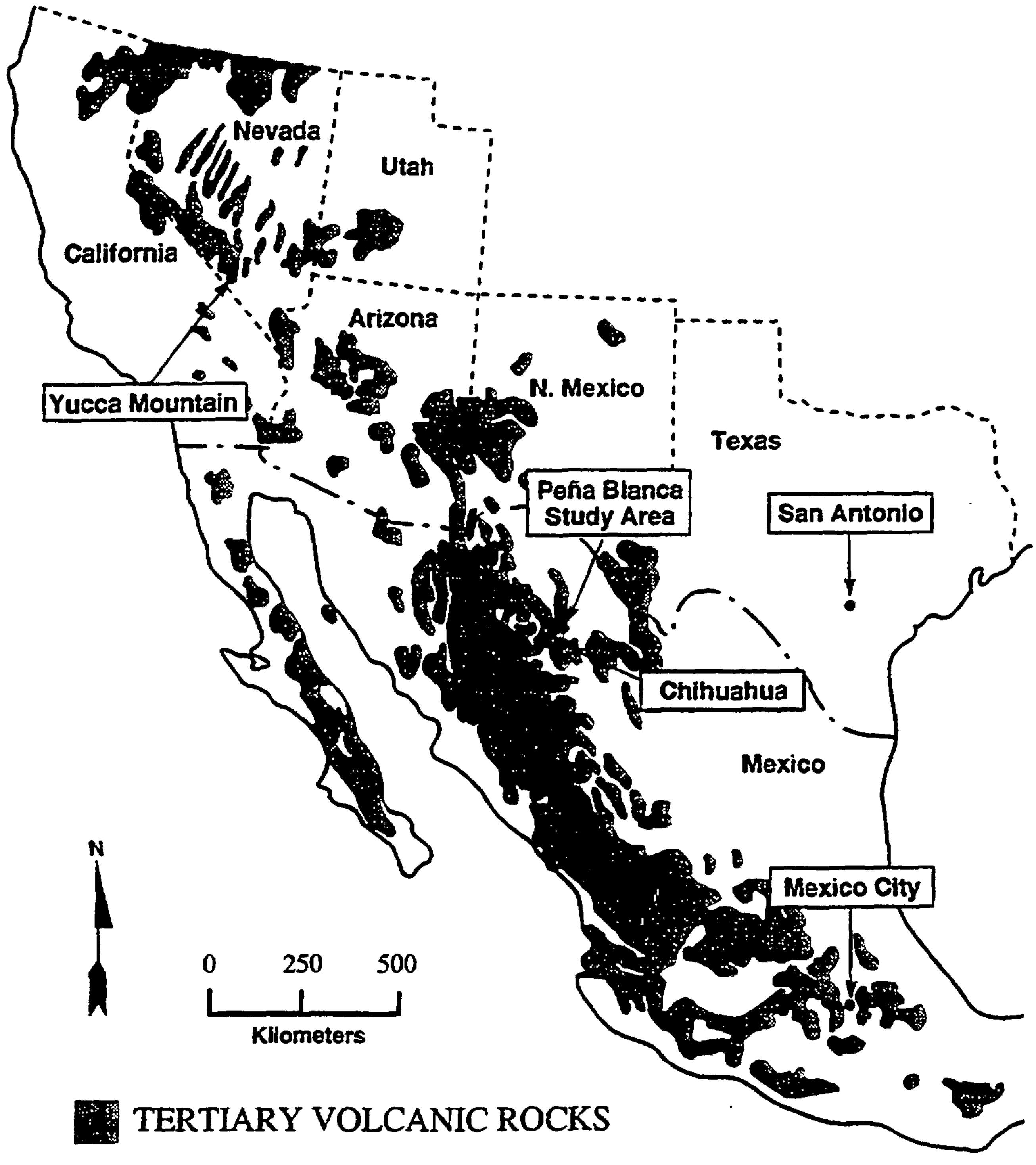
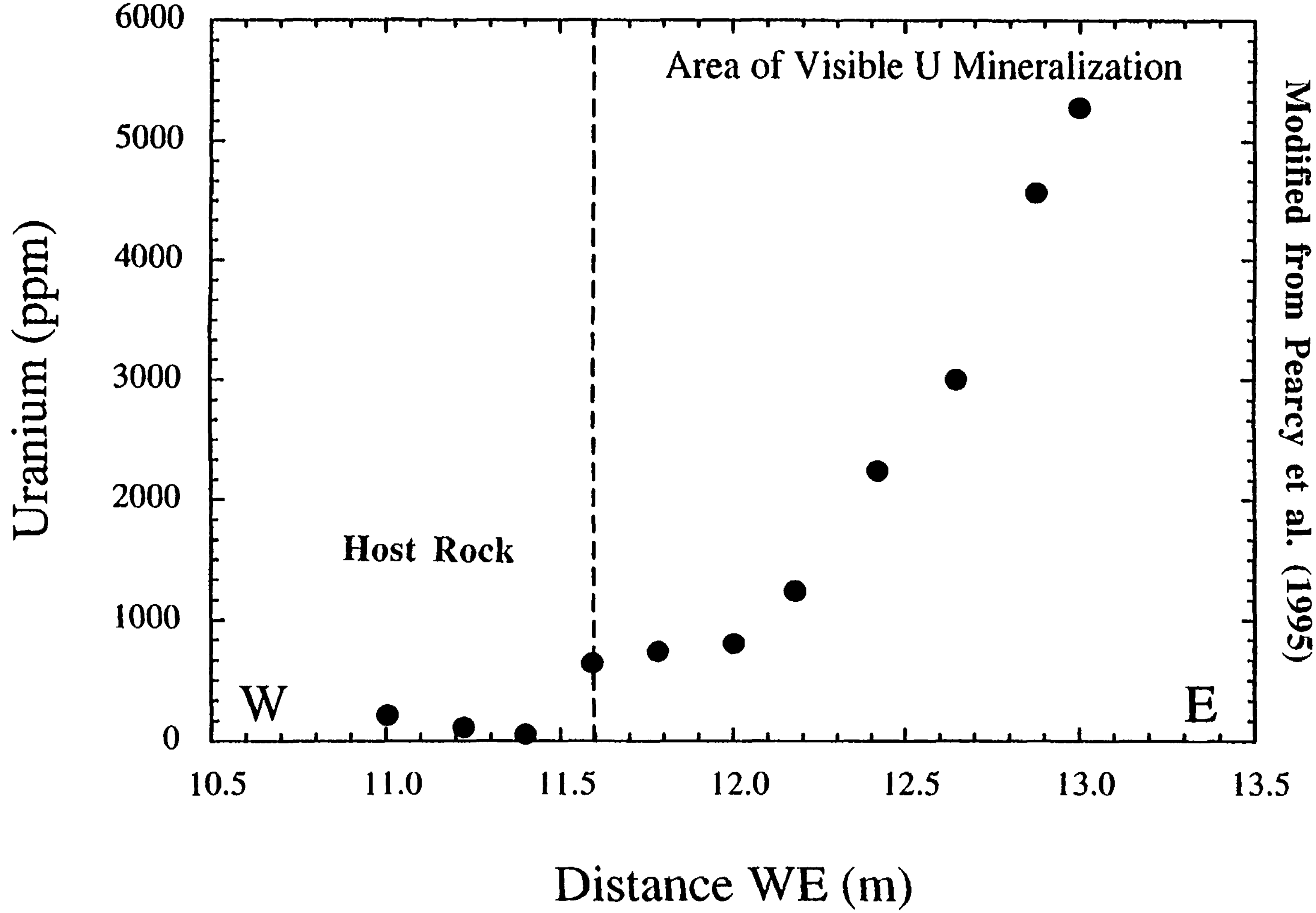
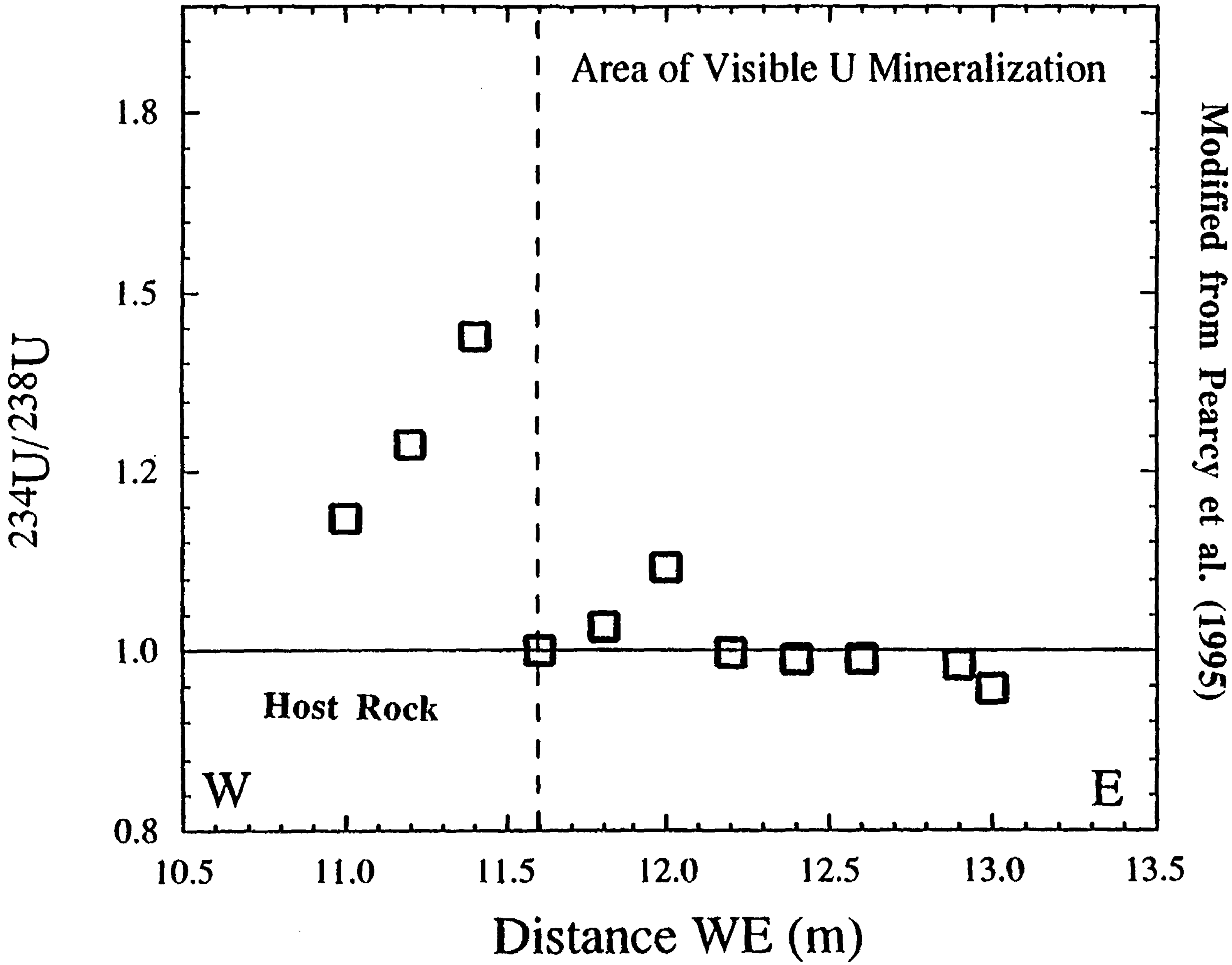


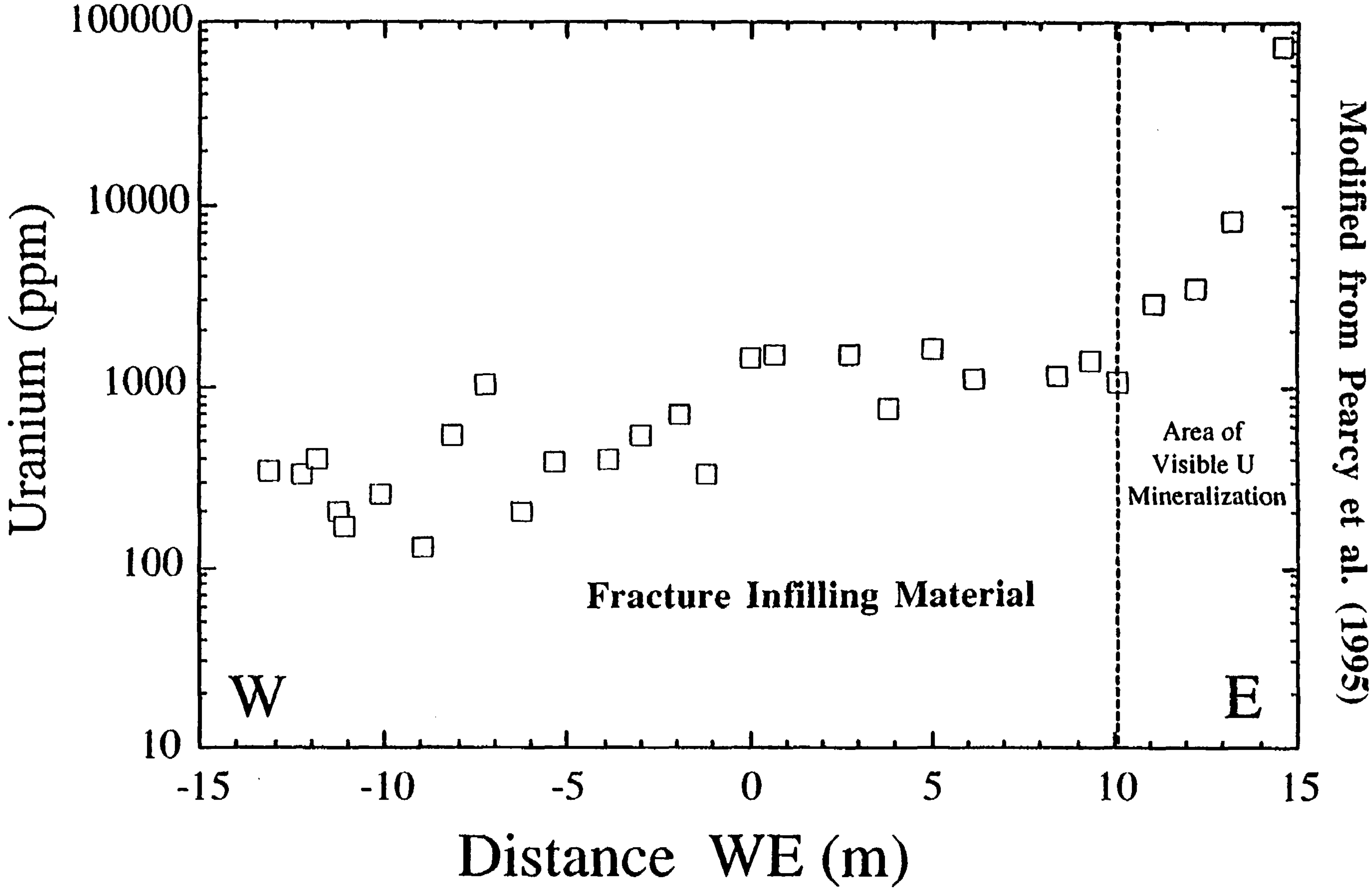
Fig. 1. The Nopal I uranium deposit is located in the Peña Blanca mining district, Chihuahua, Mexico (from Pearcy *et al.*, 1994). Yucca Mountain, Nevada, the proposed site for the U.S. HLW repository, is located northwest of the Peña Blanca district along a general trend of Tertiary volcanic rocks in the Basin and Range province.



Area of Visible U Mineralization
Host Rock
W
E
Uranium (ppm)
0
1000
2000
3000
4000
5000
6000
10.5
11.0
11.5
12.0
12.5
13.0
13.5
Distance WE (m)
Modified from Pearcy et al. (1995)



Area of Visible U Mineralization
Host Rock
W
E
234U/238U
Distance WE (m)
1.8
1.5
1.2
1.0
0.8
10.5
11.0
11.5
12.0
12.5
13.0
13.5
Modified from Pearcy et al. (1995)



100000
10000
1000
100
10
Uranium (ppm)
-15
-10
-5
0
5
10
15
Distance WE (m)
W
E
Fracture Infilling Material
Area of
Visible U
Mineralization
Modified from Pearcy et al. (1995)

APACHE LEAP TEST SITE

- Tracer Data Indicate That Groundwater Flow Rates in Fractures Are Greater Than 60 Meters Per Day (Bassett et al., 1996)

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Yang, I.C., G.W. Rattray, and P. Yu. 1996. Interpretation of chemical and isotopic data from boreholes in theunsaturated zone at Yucca Mountain, Nevada. Water-Resources Investigations Report 96-4058. U.S. Geological Survey.

ATTACHMENT 8

YUCCA
MOUNTAIN
PROJECT

Studies

CONVERSION OF YMP SCENARIOS

Presented to
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:
G. E. Barr
Sandia National Laboratories
Albuquerque, New Mexico

November 5, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

1. NUREG/1667

- Summary discussion of NUREG/1667
- Requirements
  - Crux
    - * (Identification of classes)
    - * (SKI/SKB process system)
  - Level of understanding (mature)
- Output [=locally complete set of scenarios]

Additional FEPs proposed by PIs and included in trees

- Carrier plume with signature of repository
- Alteration of Topopah Spring basal vitrophyre
- Rockfall and drift growth
- Rind formation in/at drift wall
- Importance of two-phase flow for dryout and for redistribution
- Thermo-mechanical strain alteration of flow
- Thermally-Induced fault movement
- Fault control of SZ potentiometric surface

)　　)　　)

2. Generalized Event Trees

- Raison d'etre
  - Incompletely known system
  - Communication with PIs
  - Advice to and communication with Site Investigations
  - Advice to and communication with Design

- Requirements
  - Crux [PI inputs]
  - Level of understanding [developmental]

- Output [=exhaustive list of FEPs with appropriate context]

3. Conversion of scenarios from generalized event trees

- Alternative conceptual models
  - Resolveable
  - Irresolveable
- Identification of classes
  - Criteria to define a class
- Competing processes in a class
- Compaction or lumping

Release modes

- Corrosion R1
- Rockfall R2
- Synergistic R3

Transport modes

- UZ [from EBS to WT]
- Colloids FT1
- Solutes FT2
- Fracture Transport UT1
- Matrix Transport UT2
- Mixed Transport UT3

Transport modes

- UZ [from EBS to WT]
  - Colloids FT1
  - Solutes FT2
  - Fracture Transport UT1
  - Matrix Transport UT2
  - Mixed Transport UT3
- SZ [WT to accessible environment]
  - Matrix Transport [plume] ST1
  - Fracture Transport ST2
  - Well-mixed Transport [classical dispersion] ST3

Examples of corresponding expansion FEPs in this project

- Magmatic activity
  - formation of cinder cone(s)
  - Ash plume
  - Sill Formation
  - Corrosion of containers by magmatic gasses
  - Entrainment of contaminants
  - Interaction of dike with repository [stress-relieved region and void space]
  - Phreatomagmatic eruptions
  - Dissolution of SNF in magma
  - Fragmentation zone
  - Polycyclic eruptions

Examples of corresponding expansion FEPs in this project (cont'd)

- Groundwater flow
  - Lateral diversion
  - Perched water [as source, as condenser, as zone of accumulation, etc.]
  - Dryout
  - Hydrothermal condensation
  - Hydrothermal recirculation [e.g., heat pipe formation]
  - Buoyant plumes

ATTACHMENT 9

YUCCA
MOUNTAIN
PROJECT

Studies

TREATMENT OF DISRUPTIVE EVENTS IN TSPA-VA

Presented to
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:
Ralston W. Barnard, Ph.D.
Sandia National Laboratories
Albuquerque, New Mexico

November 5, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Outline

- Igneous-activity disruptions
- Seismic disruptions
  - seismic/volcanic coupling
- Nuclear criticality
- Human-intrusion disruptions
- Methodology for selecting scenarios

Work Done in FY-97

- Criticality scenarios were developed and documented
  - *Construction of Scenarios for Nuclear Criticality at the Potential Repository at Yucca Mountain, Nevada*; M&O Document # B00000000-01717-2200-00194, (Barnard, Barr, Gottlieb)
- Igneous-activity problems were generally identified
  - guided by February, 1997, NRC Technical Exchange
  - also taking advantage of consequence models from SWRI
  - PVHA is available
- Very little work done on seismic activity
  - some interaction with PSHA participants
- Human-intrusion analyses guided by NAS report

Timetable

(For each disturbance being included in TSPA-VA)

• Identify scenarios to be modeled:	11/15/97
• Develop models for FEPs:	1/31/98
• Do sensitivity analyses for use with base-case analyses:	3/15/98
• Document scenario selection, model development, and analyses:	6/12/98

Igneous-Activity Scenarios to be Analyzed

- Direct surface releases from volcanism resulting in doses to a critical group from airborne and soil contamination
- Increase in radionuclide source term for groundwater transport at repository resulting from close proximity of igneous intrusion
- Change in groundwater flow and transport patterns caused by igneous intrusion outside the repository block

Issues for Igneous-Activity Modeling

- Consequence Modeling
- Inputs From PVHA
- Application of Frequency-of-Occurrence PDF

Consequence Modeling

- Direct surface releases
  - constraints
    - Plumbing of Conduit
    - Entrainment
    - Dispersion
  - effects
    - Biosphere Dose Model
- Indirect Effects

Plumbing of Conduit

- Eruptions are currently thought to be monogenetic
  - (polycyclic eruptions could be treated as multiple monogenetic — as a first-order approximation)
- Fragmentation depth of magma may be above repository depth
- Repository openings may cause intrusion to form sills
  - waste packages may become encapsulated in magma

Entrainment

- *** This is the key to evaluating consequences ***
- Center's model depends on relative particle sizes for ash and waste
- Other factors that may be important include:
  - viscosity of ash/magma
  - nature of fluid magma – Newtonian? Bingham?
  - relative densities of waste and ash/magma
  - processes causing rapid waste package degradation
  - number of containers at risk

Dispersion

- Evaluate fractions of eruption types based on YM volcanic/seismic regime
  - ash plume (approximately 35 % of eruption volume)
  - cinder cone (approximately 27 vol %)
  - lava apron (approximately 38 vol %)
- Different surface expressions can have different dose consequences

Biosphere Dose Model

- Doses from igneous effects will use methodology and assumptions developed for the base case
  - critical group is a subsistence-farming family
  - dose pathway is irrigation with contaminated groundwater
- Will incorporate additional doses arising from contaminated soil from tephra dispersion

Indirect Effects

- Waste-package degradation
  - evaluate lateral and vertical extent that magmatic gases can flow from source to waste packages
  - evaluate corrosion of waste packages using liquid and gaseous constituents and temperatures
- Regional intrusions
  - evaluate locations, orientations, probabilities of dikes outside repository block with assistance from PVHA and PSHA experts

Inputs From PVHA

- Frequency-of-occurrence PDF has been provided
  - for events inside the repository block
- Need to have frequency PDF for events in larger YM region
- Connection between volcanic and seismic effects will use PSHA expertise also

Application of Frequency-of-Occurrence PDF

- Range
  - maximum frequency generally accepted as 10^{-7}/year
- Choice of mean and PDF shape may influence measure of risk
- Applicability of frequency PDF to entire YM region

Approach to Modeling Igneous Disruptions

- Estimate probabilities of new volcano forming at the repository, or in YM region
  - sources: PVHA and LANL final Synthesis report
- Estimate dike orientations, lengths, and volumes
  - sources: PVHA experts and LANL
- For direct releases
  - develop entrainment model using lithic-fragment analog data for bounding of effect
    - use magma properties, waste density, and other factors to refine model if necessary
  - use entrainment fraction in ASHPLUME (or other) dispersion model

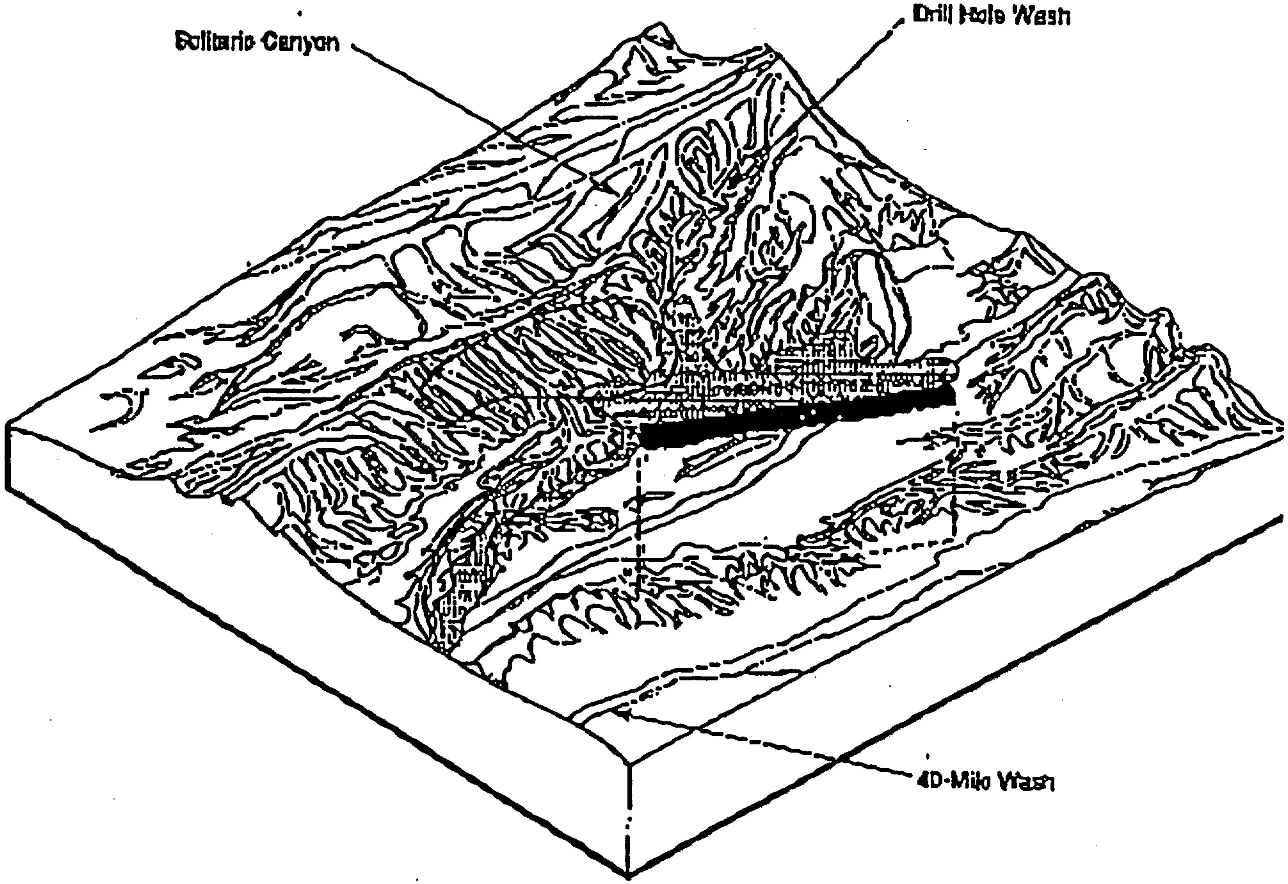
Approach to Modeling Igneous Disruptions

(continued)

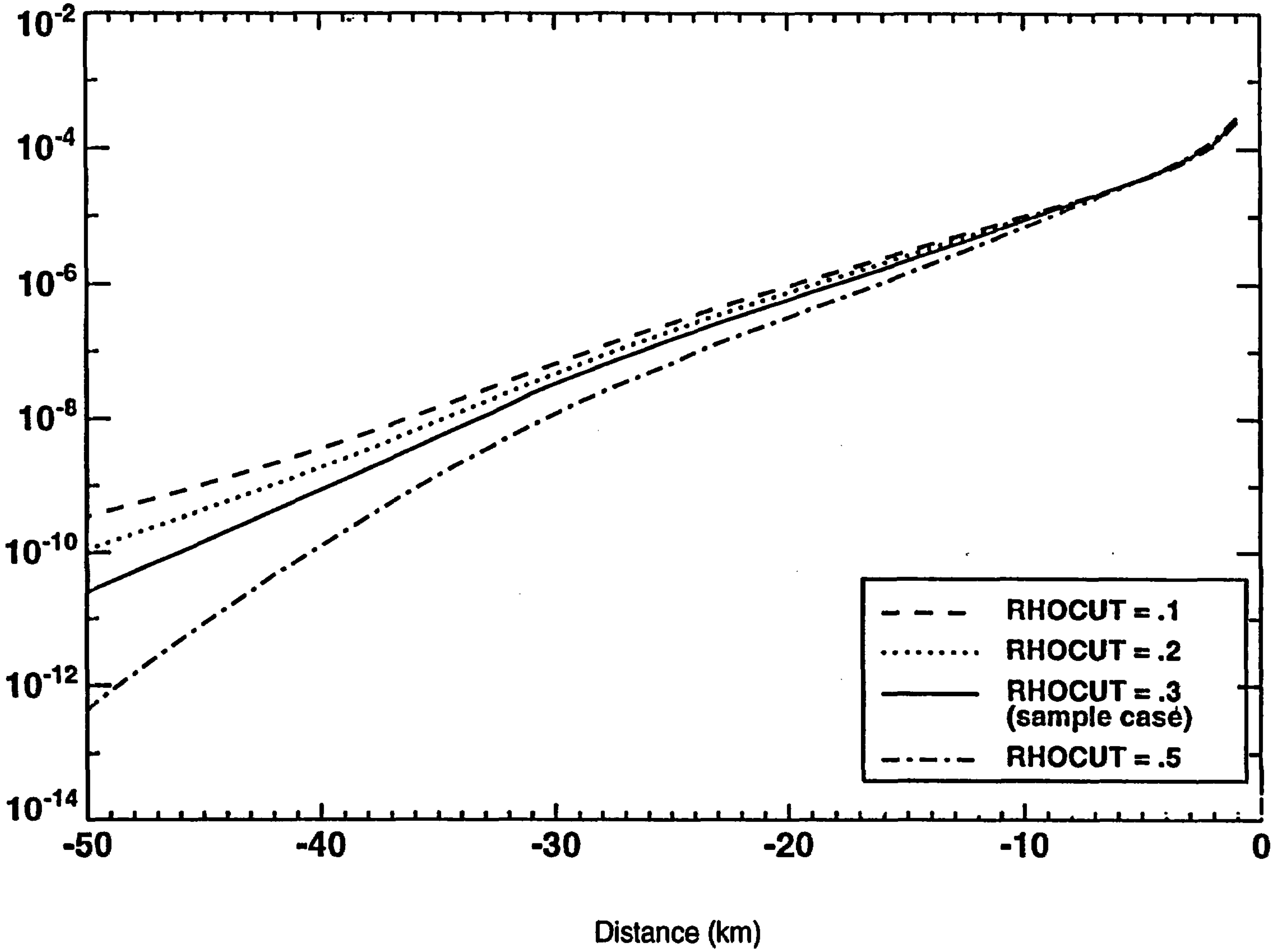
- For indirect effects
  - develop enhanced-corrosion models for waste packages, including waste mobilization
    - source: LANL volcanics experts, corrosion experts
  - incorporate dikes into sub-regional SZ flow model
    - dike as flow conduit
    - dike as flow barrier

Prior Modeling of Regional Dike Interactions

- Described in Barr *et al.*, (1993)
- Simulations did not show large changes in heads
- 2D modeling only
- Some parameters remain unconstrained
  - no data on whether dikes are barriers or conduits
  - dikes located along existing faults
    - other locations may produce greater changes



Preliminary Sensitivity Studies with ASHPLUME



Seismic-Activity Scenarios to be Analyzed

(preliminary)

- Direct effects
  - rockfall damage to waste packages permitting increased water contact on waste
    - enhanced degradation
    - enhanced mobility
- Indirect effects
  - Change in groundwater flow and transport patterns caused by faulting outside the repository block

Issues for Seismic-Activity Modeling

- Consequence Modeling
- Seismic-Volcanic Coupling
- Inputs from PSHA
  - Fault-displacement, ground-motion data primarily for repository and facility design
    - data will be adapted as possible for use by TSPA

Consequence Modeling

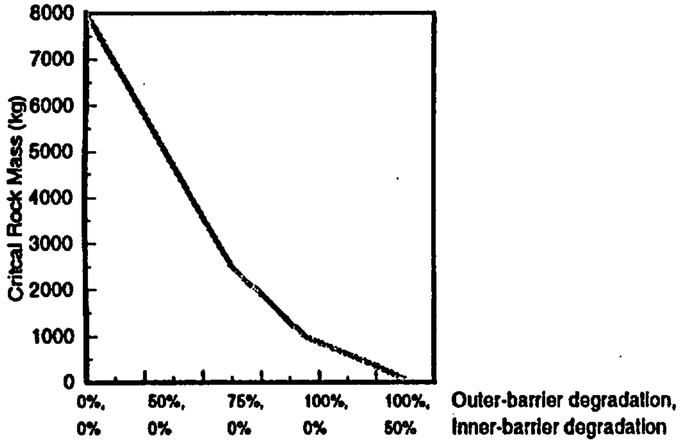
- Rockfall
  - primarily occurs from thermo-mechanical stress changes in open repository drifts
  - seismic contribution will be evaluated to see if it makes significant additional contribution
  - consequences of rockfall
    - evaluate damage to waste-package as a function of rock size and package wall thickness
    - evaluate changes to seepage patterns into drift

Seismic-Volcanic Coupling

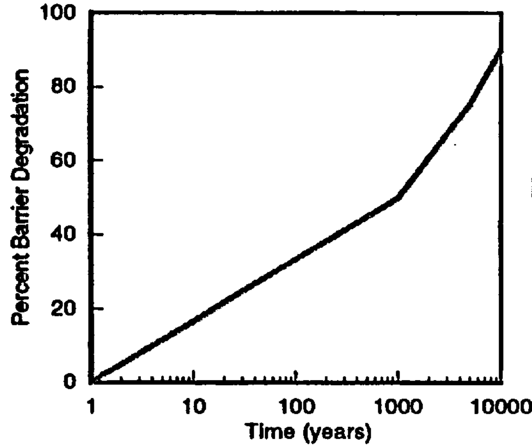
- Structural controls on frequency/magnitude of events
  - (will be discussed by Dennis O'Leary)
- Direct action on repository components
  - waste-package degradation from igneous intrusion with precursor seismic effects

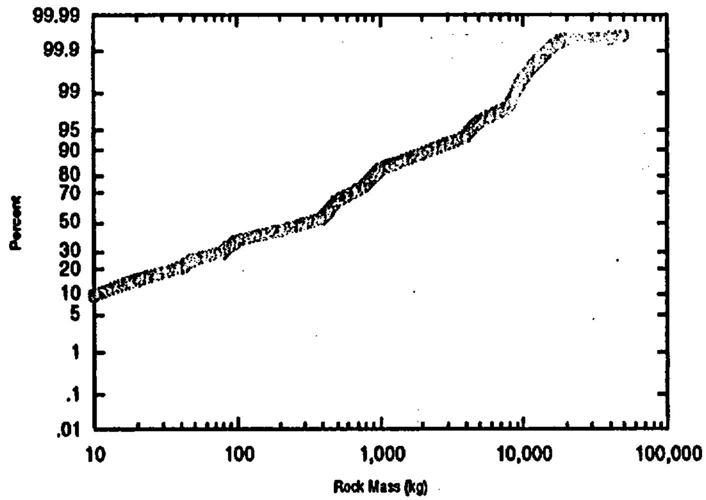
Illustration of Rockfall Model

Minimum Rock Size to Breach Package as Function of Wall Degradation

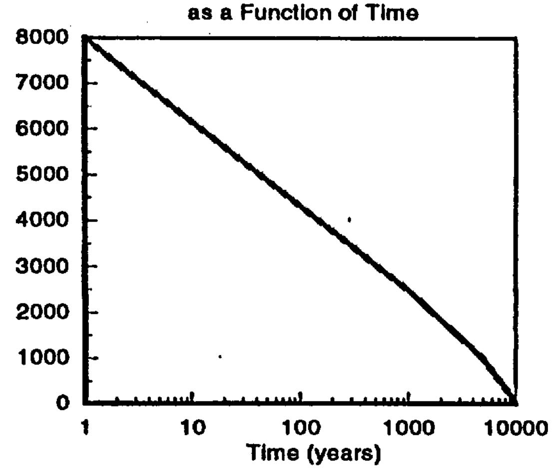


Waste-Package Wall Degradation as a Function of Time





Rock Mass to Breach Waste Package as a Function of Time



Discussions by Subject-Matter Experts

- Coupling of seismic and volcanic events
  - Dennis O'Leary - USGS
- Igneous processes
  - Greg Valentine - LANL
  - Frank Perry - LANL

Regulatory Concerns for Nuclear Criticality

- 10 CFR 60.131(h)
  - limits on value of k_{eff} to ensure that criticality is not allowed under design-basis conditions, except for unlikely, independent conditions
- Total-system performance requirements
  - (old 40 CFR 191)
  - criticality event must not prevent reasonable expectation that repository system will have doses less than standard

Summary of FY-97 Work on Criticality

- Abstraction/Testing workshop, March, 1997
- Strawman workshop summary for review, June, 1997
- Contributions by subject-matter experts, August, 1997
  - waste-package characterization
    - design
    - degradation
  - neutronics
  - geochemistry
    - reactions
    - ore-body formation
- Issuance of scenarios report, September, 1997
  - comprehensive listing of FEPs
  - selection and justification of scenarios
    - choices reflect probability more than consequence

The FEP Tree

- Based on the premise that there can be no criticality until WP is penetrated
  - water corrodes waste and WP internal structures
  - water provides moderator
- Further WP corrosion can permit fissile material to be transported to near field or far field
- Tree structure identifies FEPs that can lead to formation of critical configuration
- FEP tree leaves open question of PA consequences

The Criticality Regimes

- In-package
  - most likely location
    - sufficient fissile material is available in one waste package
    - criticality-control measures must be removed
- Near-field
  - less likely scenarios
    - most scenarios require reconcentration of fissile material
- Far-field
  - unlikely during period of performance of repository
    - reconcentration mechanisms require millions of years
  - criticality potentially could occur much nearer the accessible environment

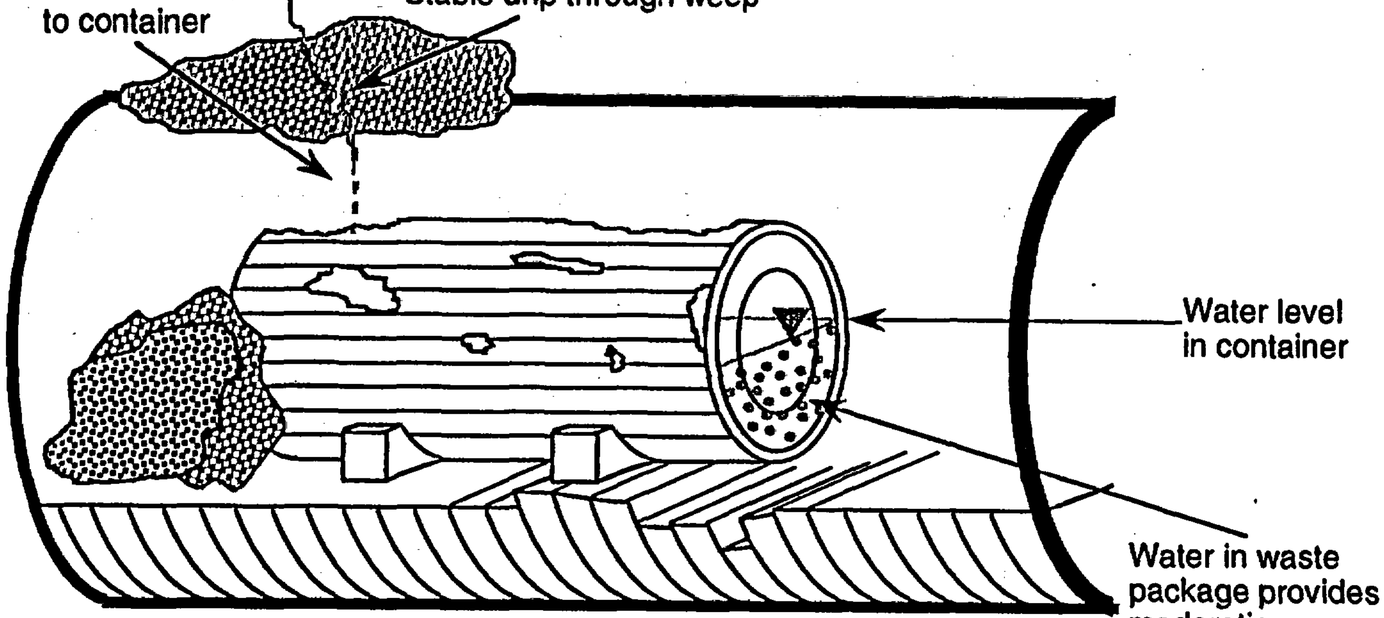
Criticality Scenarios to be Analyzed

- 8 in-package critical configurations
  - commercial spent nuclear fuel
  - DOE spent nuclear fuel
  - plutonium-glass/ceramic
- 1 each near-field and far-field critical configurations
  - contents of waste package "dumped" into drift
  - re-concentration of ^{235}U at organic reducing zone in SZ

In-Package Critical Configurations

- Depends on nature of waste-package failure
  - Bathtub
  - Flow Through
- Depends on relative degradation resistance of waste form
  - WF degrades first
  - WF and WP degrade at same time
  - WP degrades first
- Depends on processes to remove neutron absorbers
  - absorber solubility can depend on pH

Illustration of FEPs Leading to In-Package Critical Configurations



Discussion of Criticality Results

(presented by Peter Gottlieb)

- Failure mechanisms for waste form and waste-package internals
- Removal of neutron absorbers
- Formation of a critical configuration
- Power, duration of criticality
- Radionuclide inventory produced

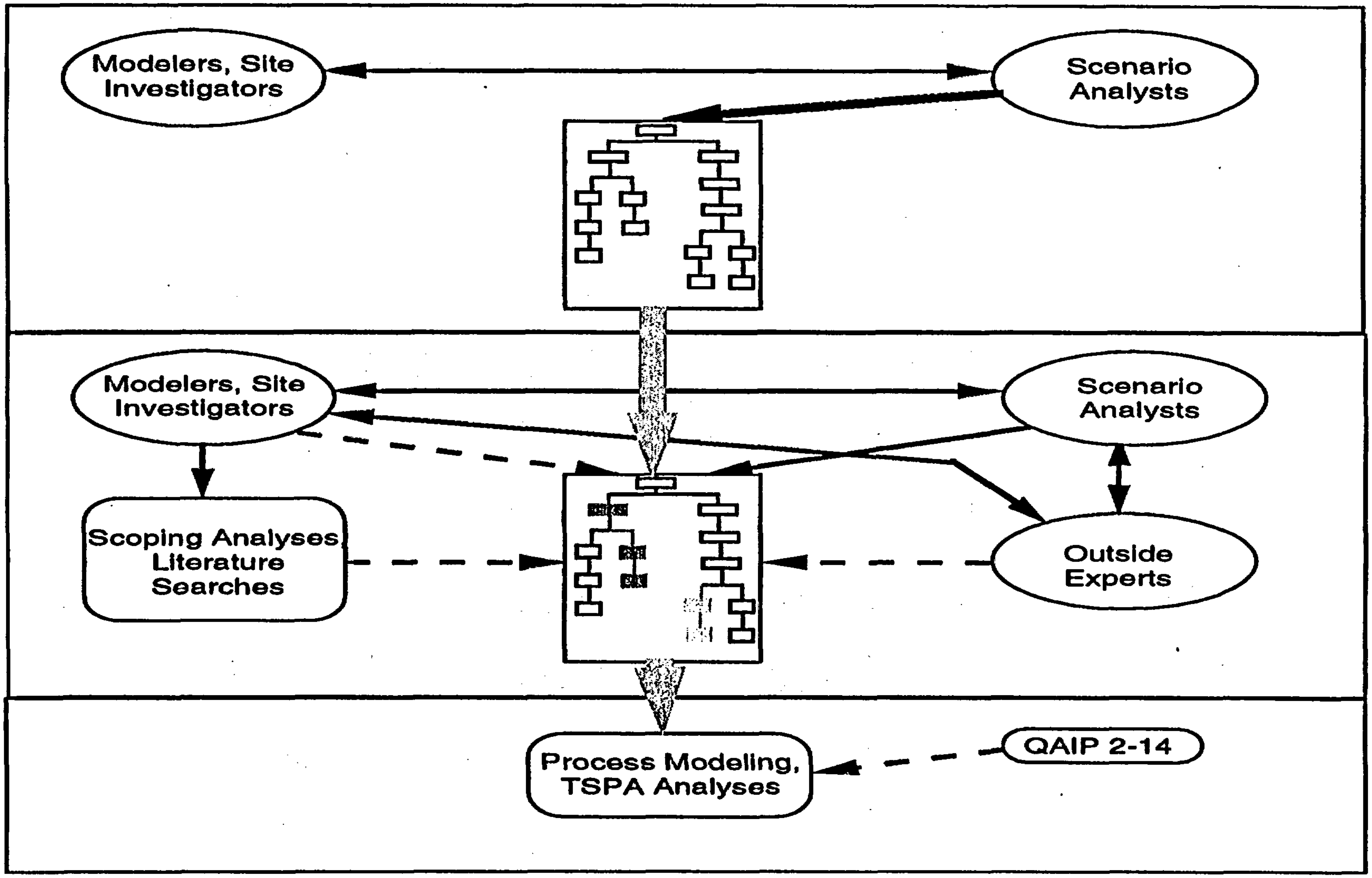
Human-Intrusion Analyses

- NAS guidance in *Technical Bases for Yucca Mountain Standards:*
  - Because of uncertainties in predicting probabilities of future human behavior, do not include human intrusion in risk-based compliance assessment
  - Estimate consequences of particular types of intrusion events
    - Consider a stylized intrusion scenario:
      - drill a single borehole into the repository
      - puncture a waste package
      - waste falls to the underlying aquifer
      - exposed waste transported to accessible environment

Interpretation of Human-Intrusion Analyses

- Provides consequence measure without invoking probability of occurrence
- Consequence from this disturbance can be compared with those for base case
  - provides a sense of resilience of repository to this type of intrusion

Paradigm for Selection of Scenarios to be Analyzed in a TSPA Analysis



Summary

- Volcanic scenarios
  - preliminary scenario selection completed
  - some models and data for direct-interaction FEPs available
    - models and data for entrainment to be developed
    - ASHPLUME code available for modeling dispersion
    - data on magmatic properties available for modeling waste-package degradation
    - PVHA results and experts available for frequency PDF
  - models for indirect-interaction FEPs available
    - SZ flow models available to be modified
    - Frequency PDFs for extended region available (?)

Summary

(continued)

- Seismic scenarios
  - preliminary FEP diagrams completed
  - scenario selection not completed
  - rockfall models under development
  - PSHA information will be incorporated as it becomes available

Summary
(continued)

- Criticality scenarios
  - scenario selection completed
  - currently collaborating with PA and WPD to develop models
    - waste-package degradation models and data from PA
    - geochemistry models and data from PA and WPD
    - neutronics analyses from WPD
- Human Intrusion
  - suggested scenario is known
  - models can be readily developed for amount of waste delivered to SZ
  - SZ flow and transport model available

ATTACHMENT 10

COUPLED PROCESSES: BASALTIC VOLCANISM AND FAULT DISPLACEMENT

Premise: Insofar as basaltic volcanism and faulting of Yucca Mountain are associated with extension of Crater Flat basin, they are coupled to some common extensional mechanism.

Coupling modes:

1. Cause and effect: basaltic intrusion generates earthquakes and local faults/fractures.

2. Joint effects of a common cause: crustal extension within Crater Flat basin generates both basaltic volcanism and faulting at Yucca Mountain.

Need to consider:

1. Evolution of Crater Flat basin through time
2. Fundamental structure and deformation mechanics
3. Three major features
   a. planar normal faulting
   b. vertical axis rotation
   c. spatial distribution and timing of basaltic volcanism

Appeal to tectonic models

PSHA expert team	preferred tectonic model
ASM	planar, independent fault block model
AAR	generic "simple shear" model
DFS	planar fault ("domino") model in a pull apart basin
RYA	planar "coalescing fault " model
SBK	half-graben (oblique rift)
SDO	half-graben/rift
	dextral shear component
ASM	"diffuse dextral shear"
AAR	within-basin fault or pull apart without fault; external fault
DFS	"diffuse" dextral deformation
RYA	none modeled
SBK	"diffuse" (regional) dextral shear (Walker Lane deformation)
SDO	"diffuse dextral shear" (sphenochasm) or partial pull apart
	basaltic volcanism
ASM	"some volcanic-tectonic connection may operate some of the time...." (200-300 Ky intervals); insignificant seismicity
AAR	background seismicity only
DFS	background seismicity only
RYA	uncoupled, independent source of background seismicity
SBK	integral component of oblique rifting; may have significance for individual faults but background seismicity
SDO	distinct seismic source but background seismicity only; coupled process

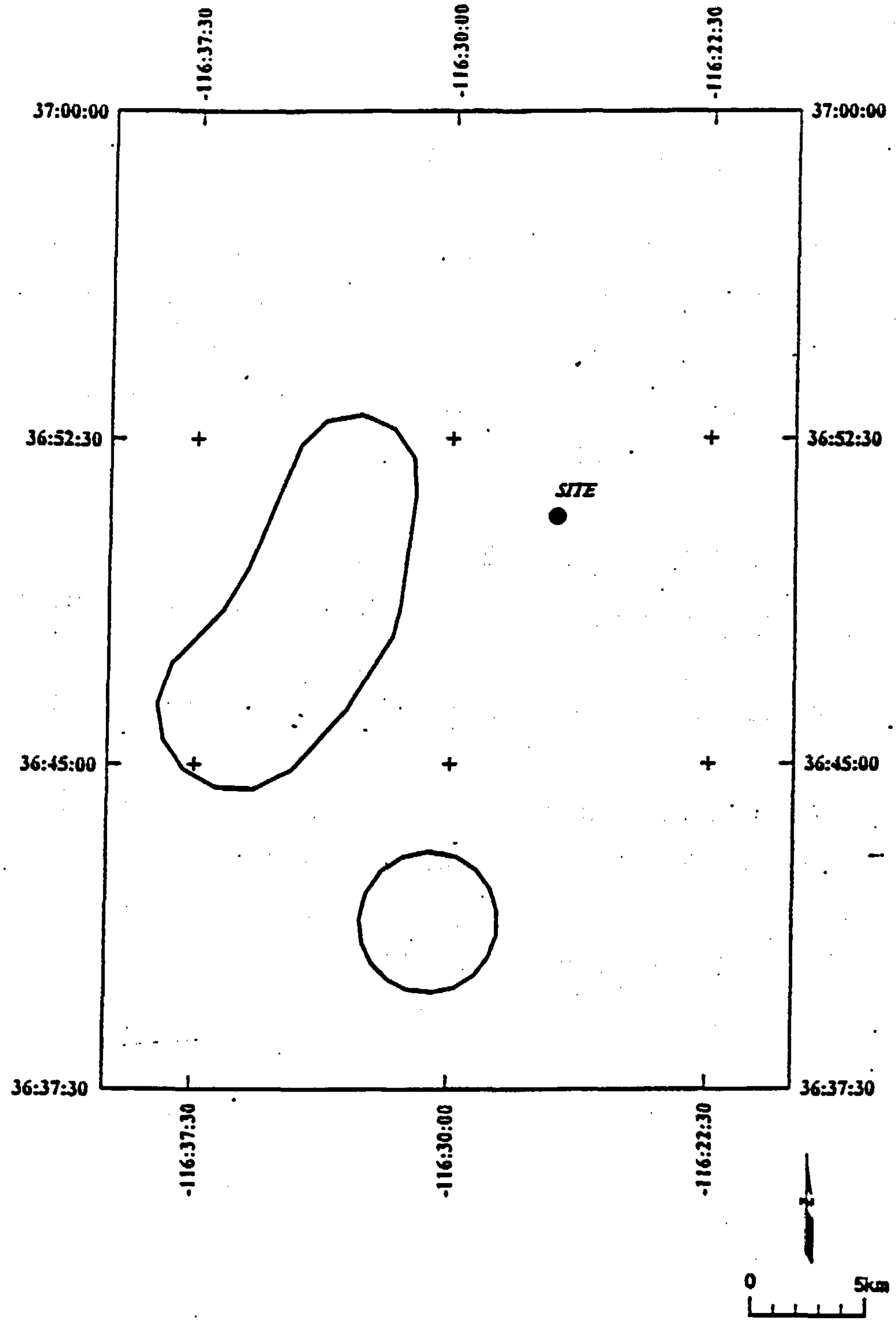


Figure SDO-10 Map of volcanic source zones included in the seismic source model.

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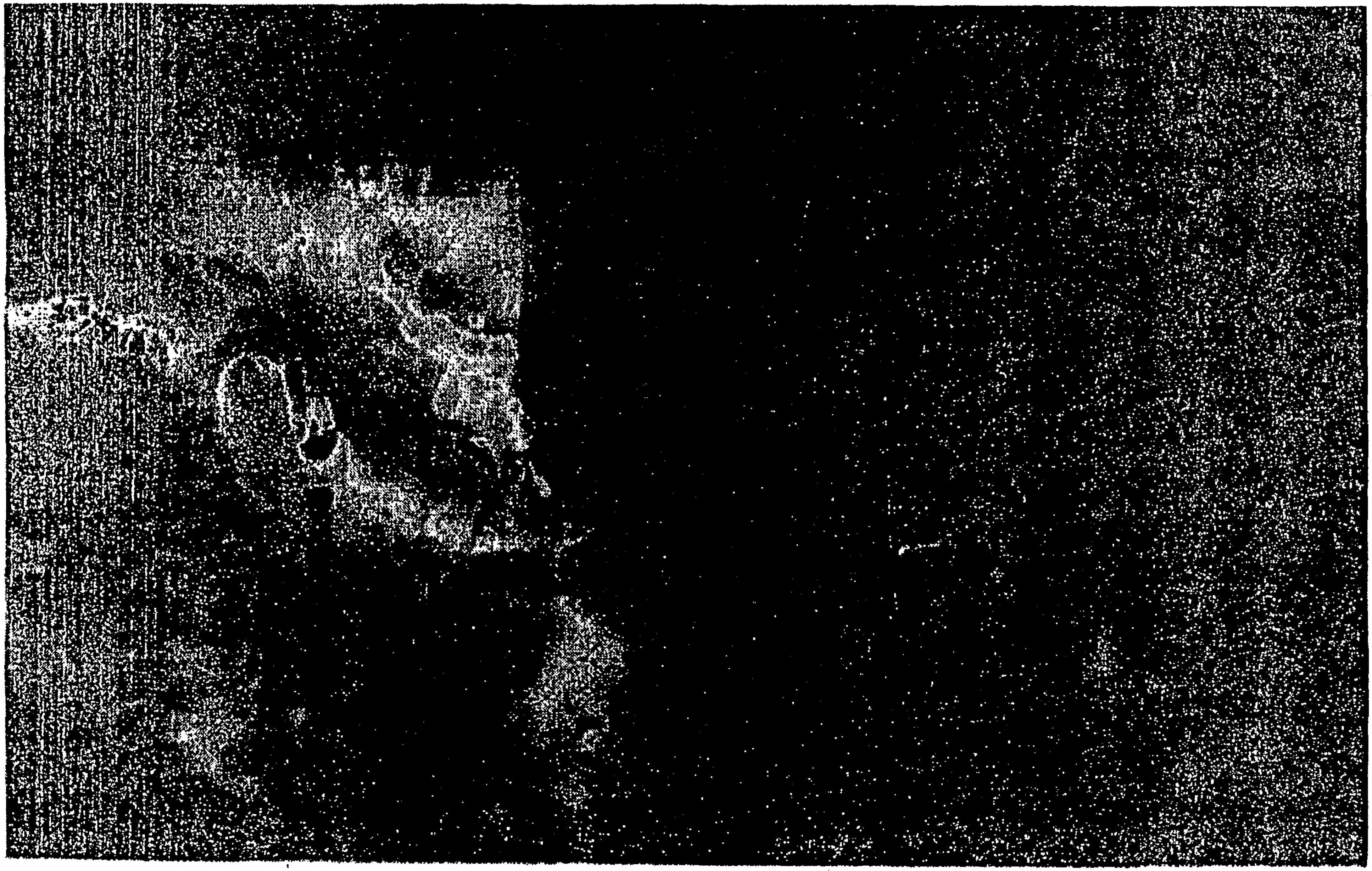
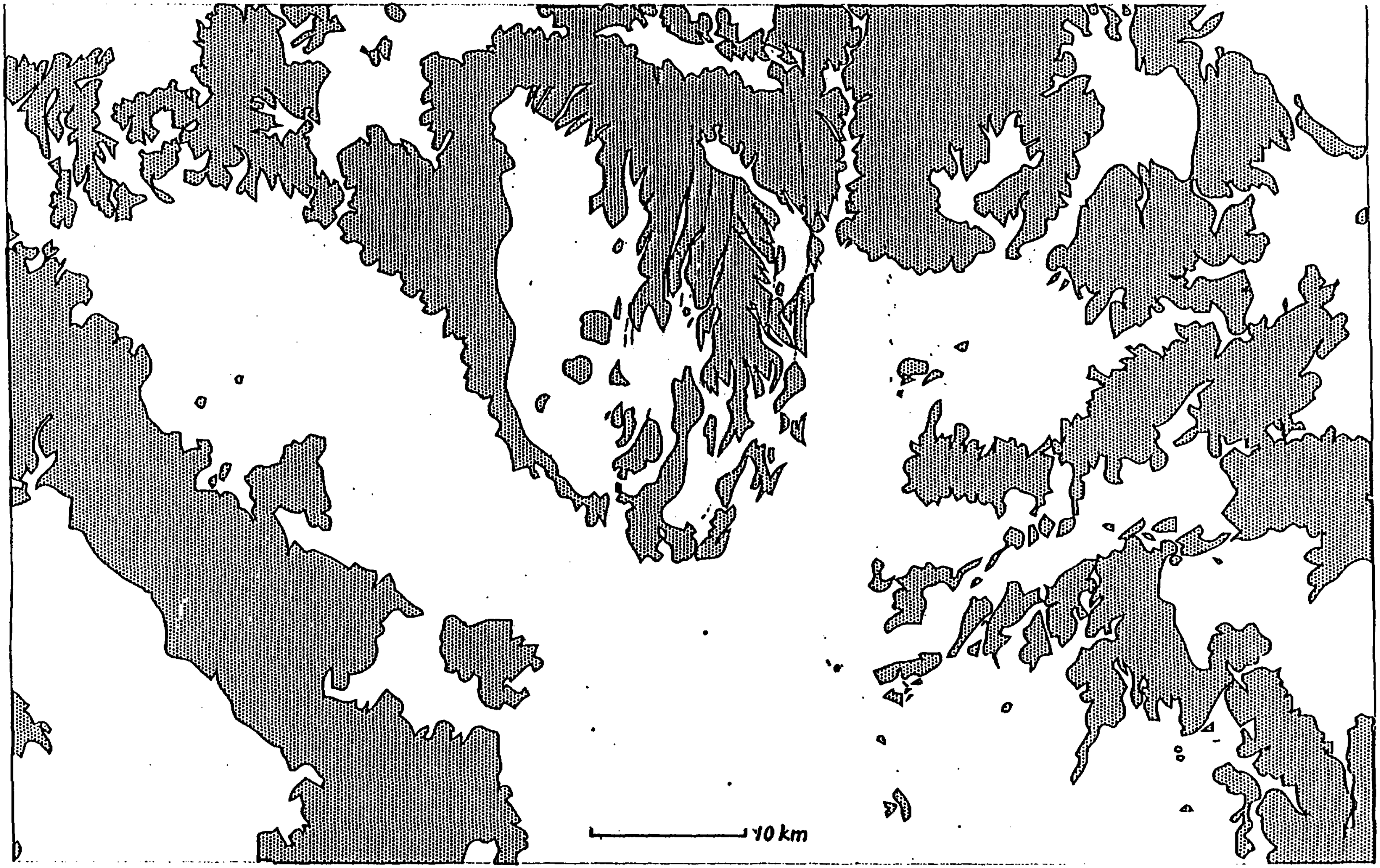
Solitario Canyon fault - Trench 8 (south wall)

- nearly pure basaltic ash and jumbled clasts fill the bottom meter of a 4-m deep, 60-70 cm wide fissure
- this fissure indicates the largest (by far) Quaternary displacement observed on Solitario Canyon fault
- relations indicate ash was deposited in fissure immediately after it opened
- purity of ash and lack of topographic trap make it unlikely that ash was locally present at time of faulting
- ash is coarse and angular, indicating minimal transport
- Age control from trench (U-series and TL) constrains event between about 40 and 120 ka
- ash is believed to correlate to Lathrop Wells Unit II, estimated to be 75 ± 10 ka




10 km

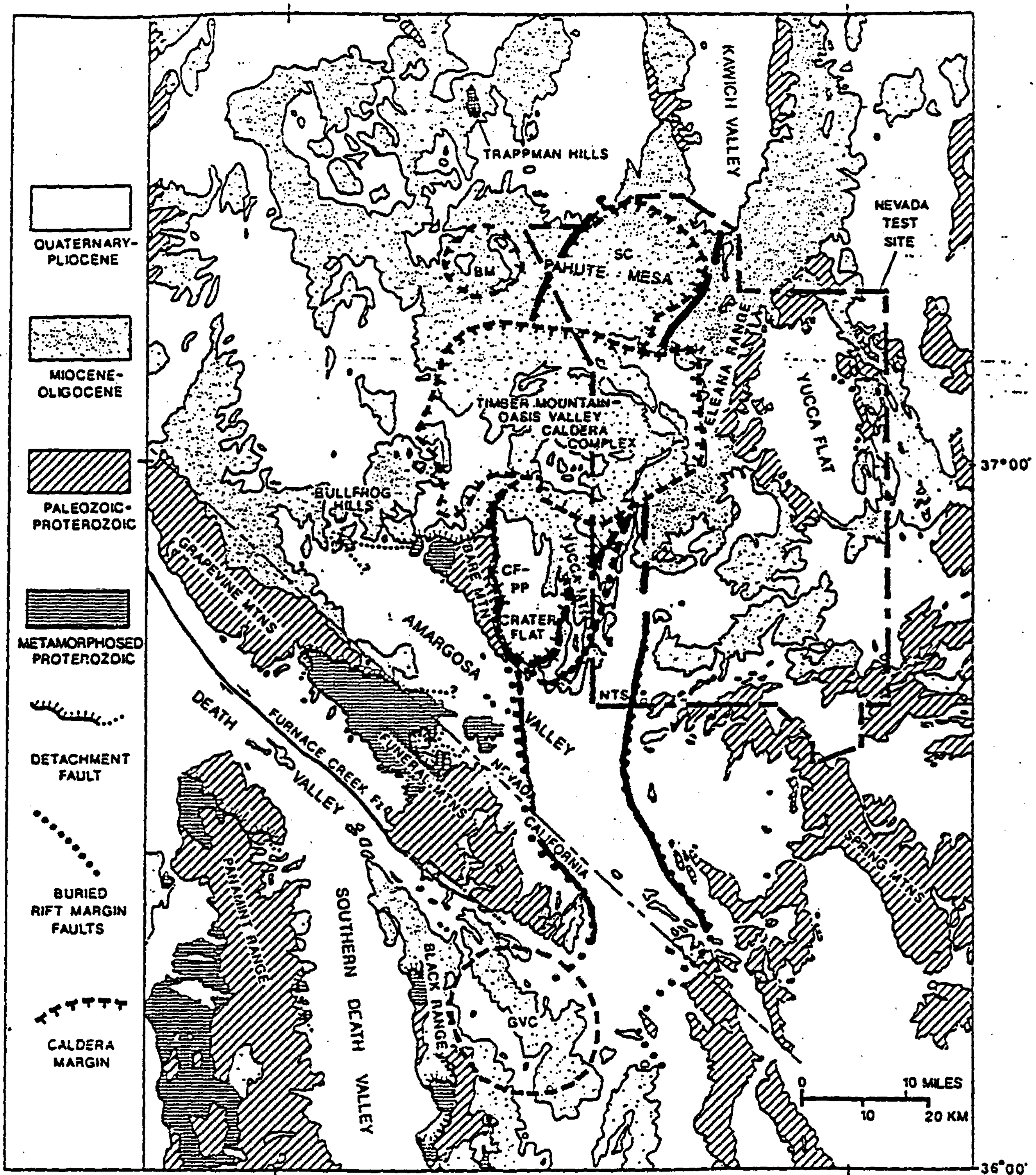


Figure 1. Generalized geologic map of the Nevada Test Site region, showing relation of caldera complexes, Greenwater volcanic center, and rift zone to metamorphic rocks and detachment structures. BM—Black Mountain caldera; SC—Silent Canyon caldera; CF-PP—Crater Flat–Prospector Pass caldera complex; GVC—Greenwater volcanic center. Buried rift margin faults shown are based on presence of steep, linear gravity gradients.

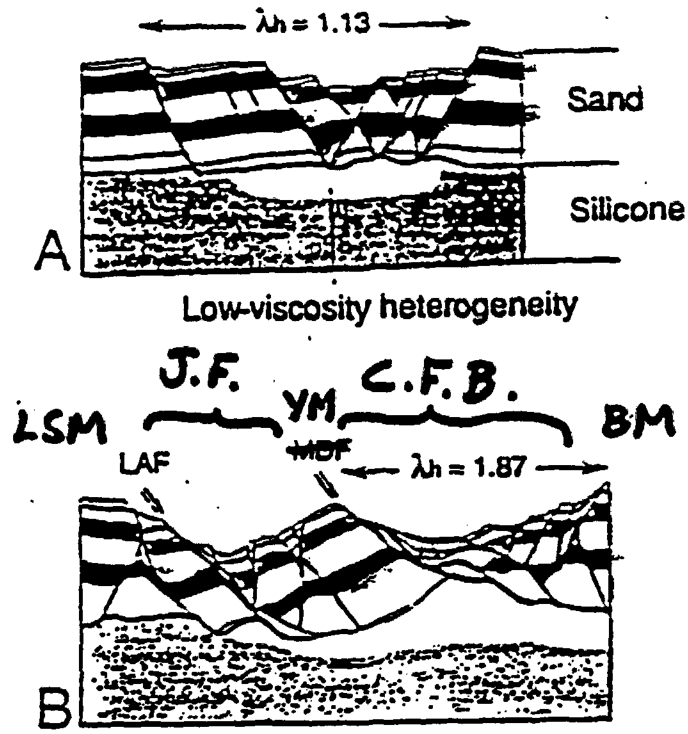


Figure 8.38. Results of sandbox model for extensional deformation by Brun and others (1994).

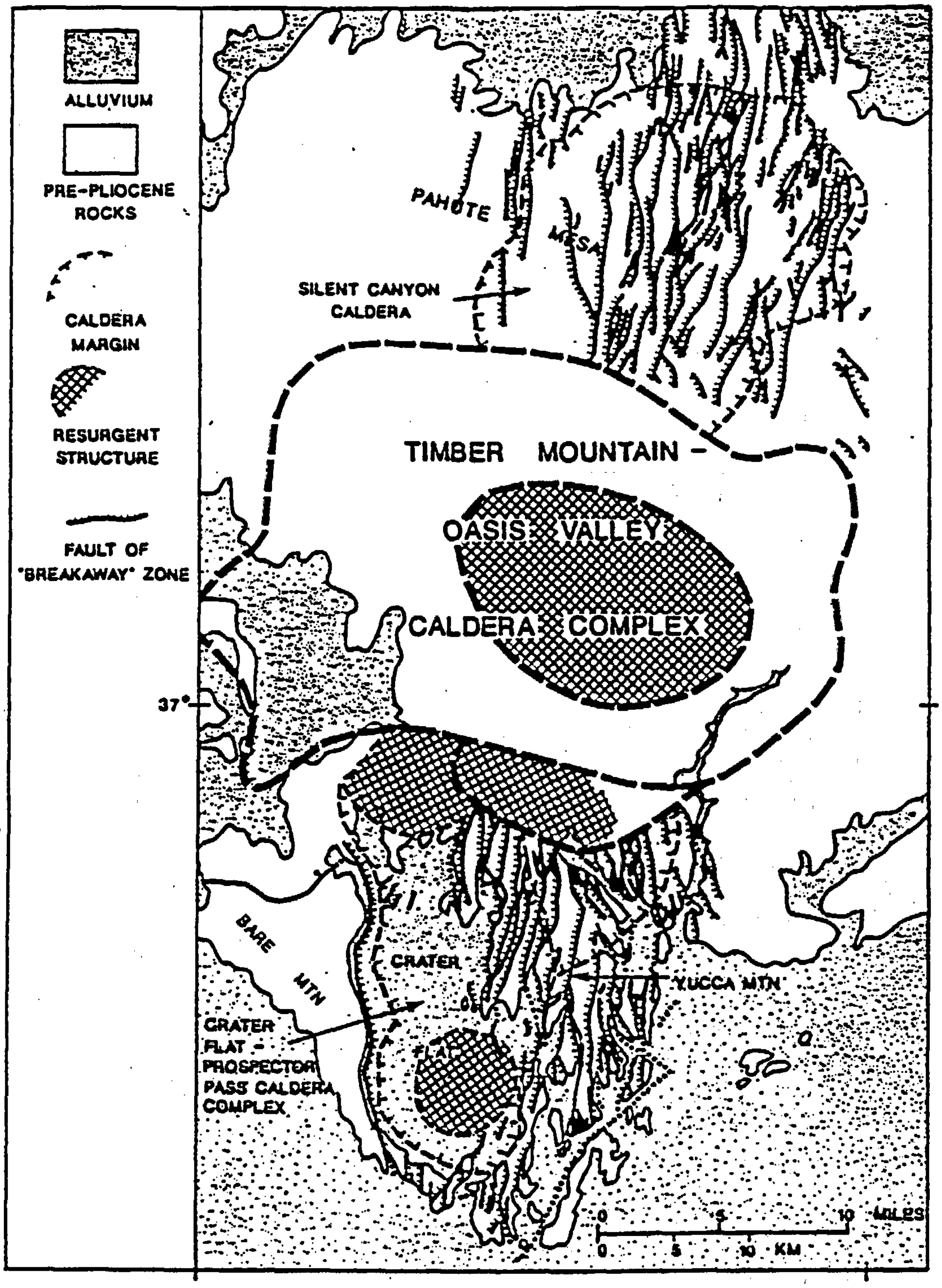
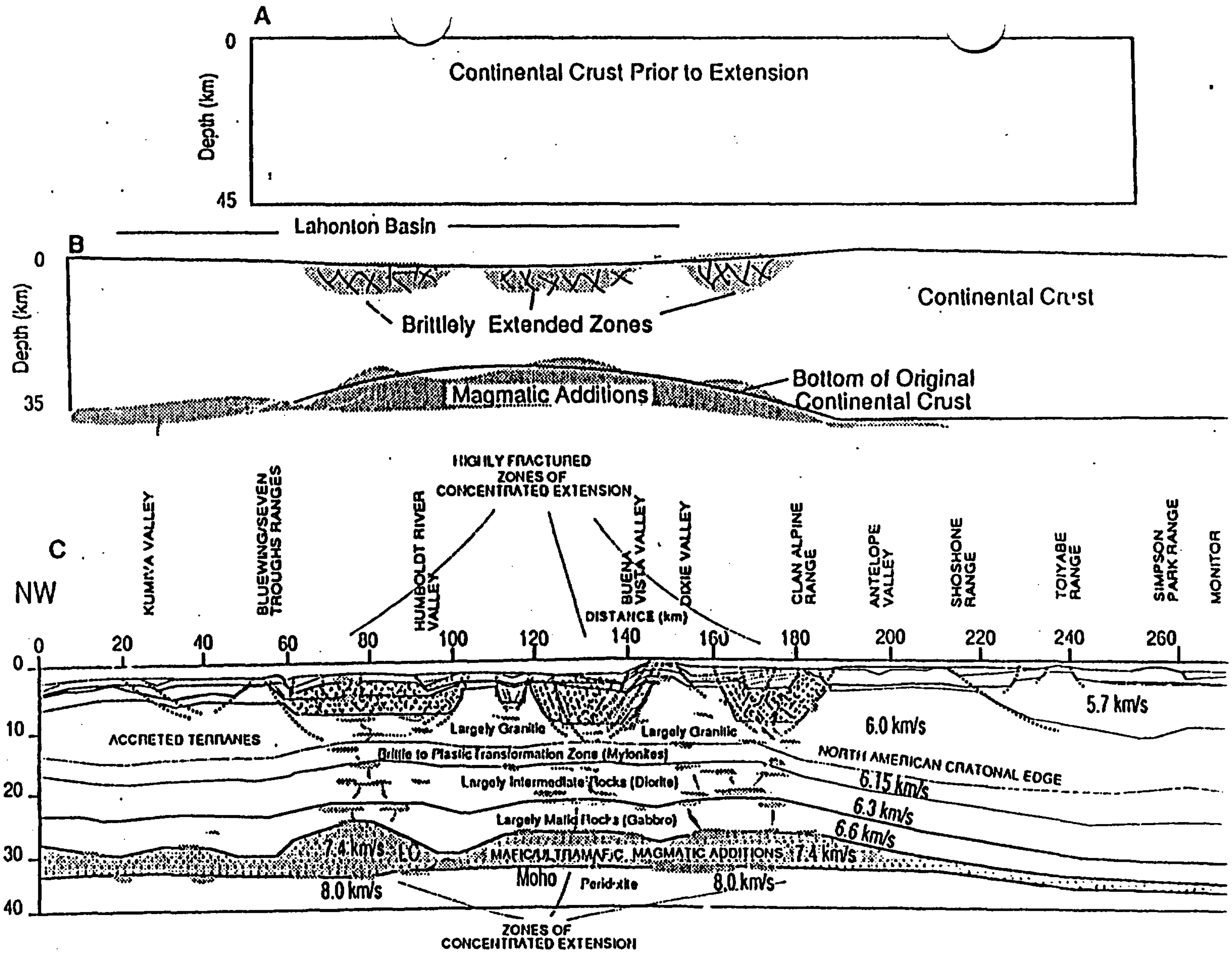
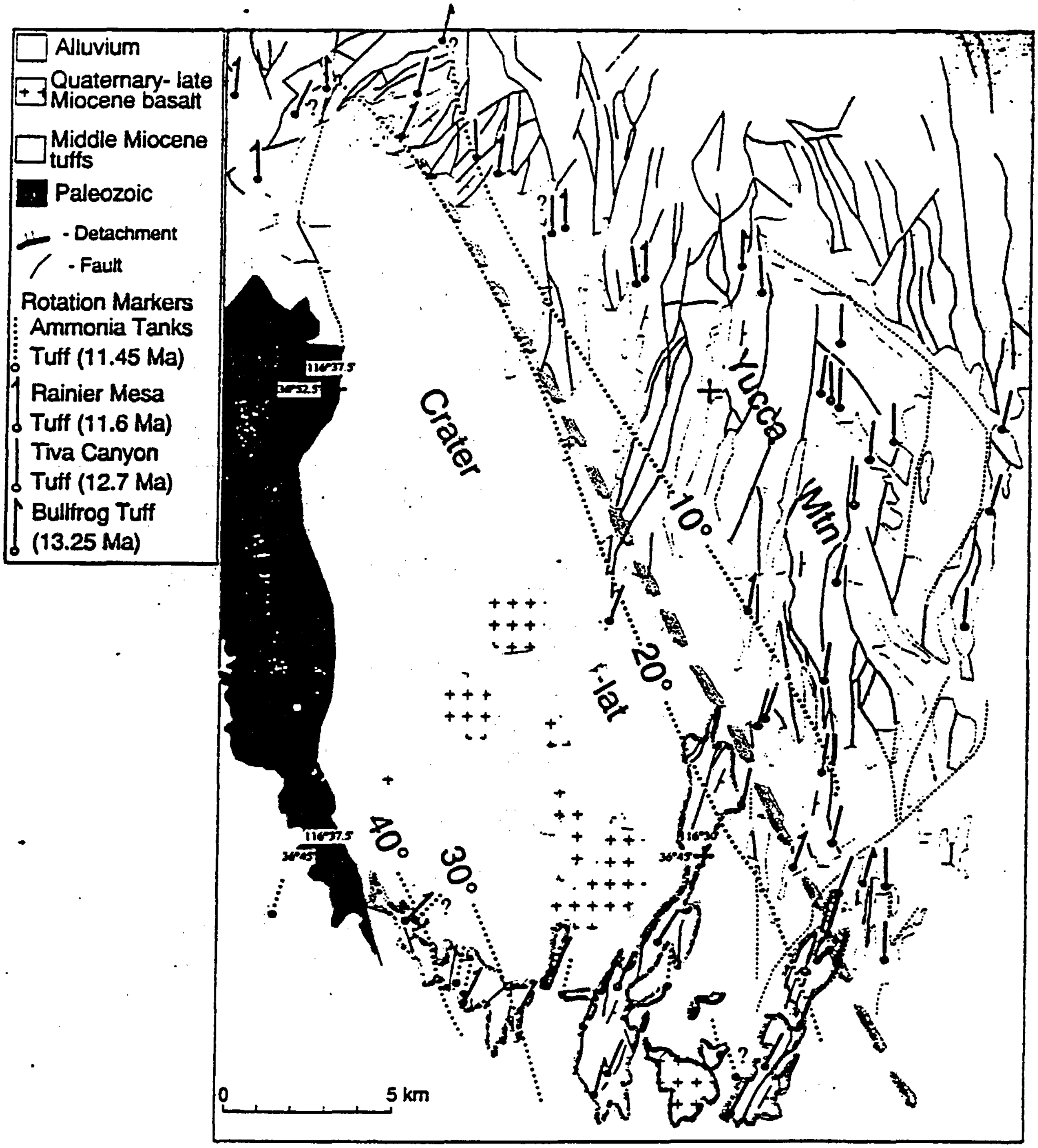
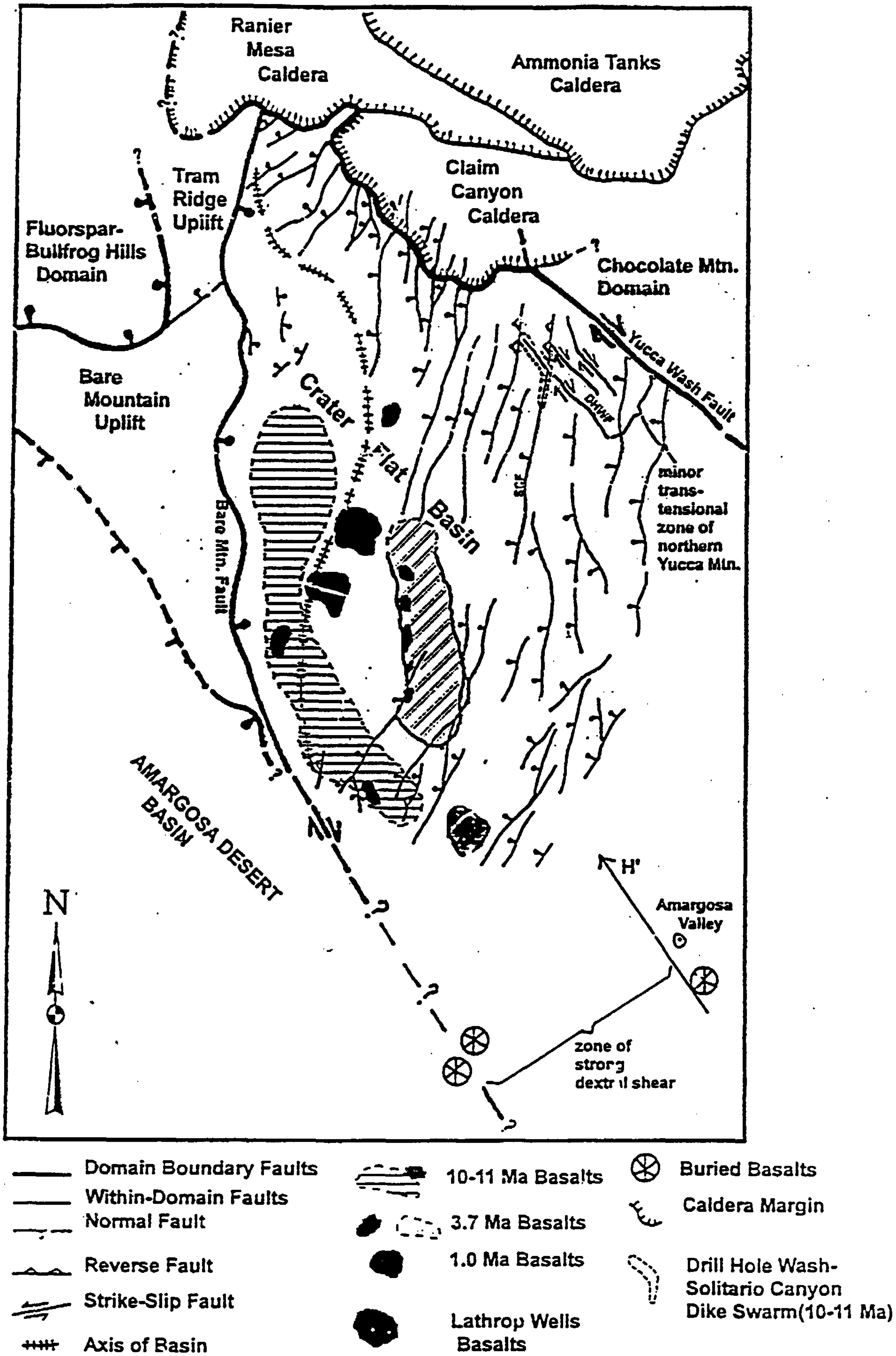


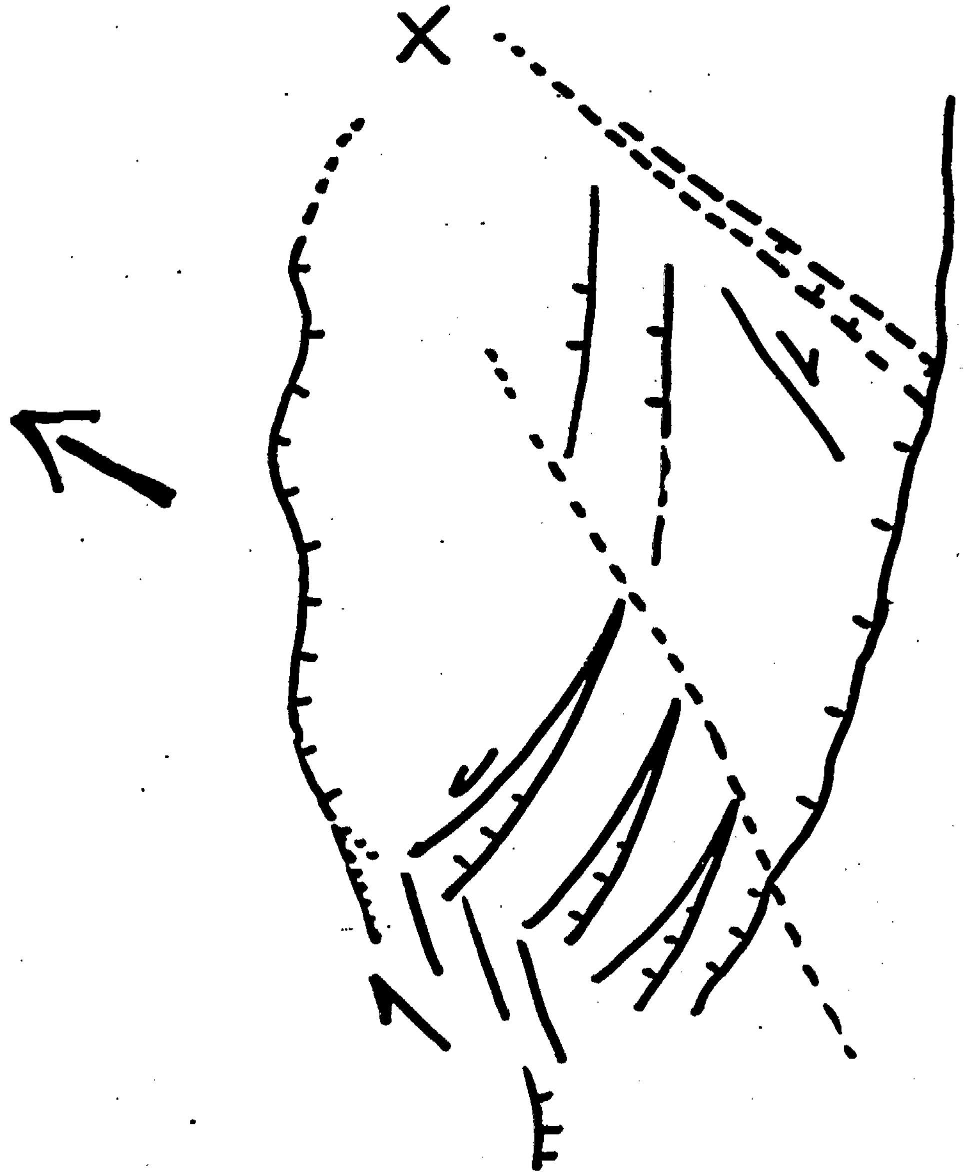
Figure 6. Fault system interpreted to be, in part, a "breakaway" zone along the eastern side of the Kawich-Greenwater Rift, showing the concentration of faults in the eastern part of the rift, within and adjacent to the Silent Canyon and Crater Flat-Prospector Pass calderas. Structure of resurgent domes is omitted, and faults outside the rift zone or within Timber Mountain caldera are not shown.

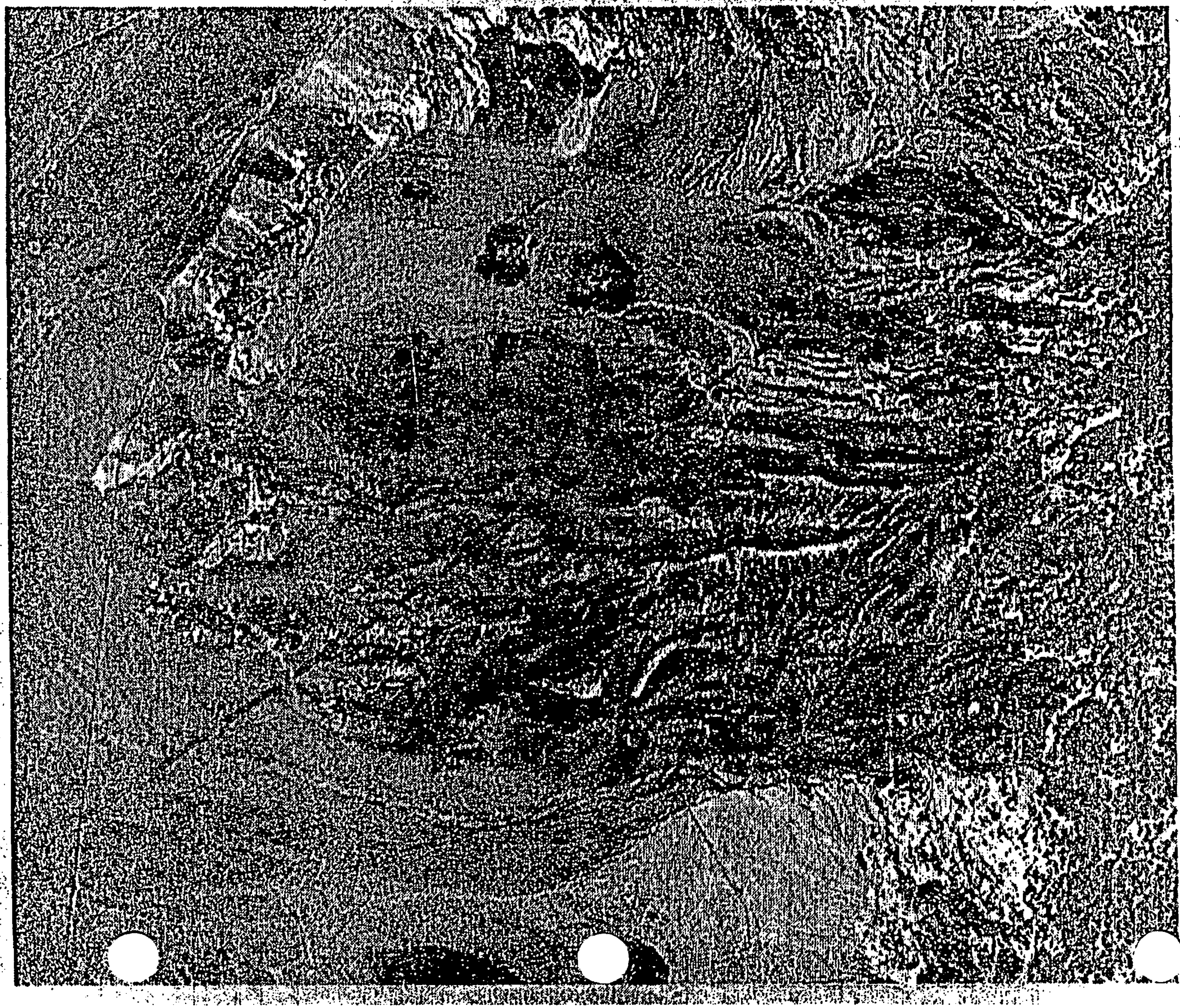

A
Continental Crust Prior to Extension
Depth (km)
0
45
Lahonton Basin
B
Continental Crust
Brittlely Extended Zones
Magmatic Additions
Bottom of Original Continental Crust
Depth (km)
0
35
C
NW
HIGHLY FRACTURED ZONES OF CONCENTRATED EXTENSION
KUMIVA VALLEY
BLUEWING/SEVEN TROUGHS RANGES
HUMBOLDT RIVER VALLEY
BUENA VISTA VALLEY
DIXIE VALLEY
CLAN ALPINE RANGE
ANTELOPE VALLEY
SHOSHONE RANGE
TOIYABE RANGE
SIMPSON PARK RANGE
MONITOR
DISTANCE (km)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
DEPTH (km)
0
10
20
30
40
5.7 km/s
6.0 km/s
ACCRETED TERRANES
Largely Granitic
Largely Granitic
Brittle to Plastic Transformation Zone (Mylonites)
NORTH AMERICAN CRATONAL EDGE
Largely Intermediate Rocks (Diorite)
6.15 km/s
6.3 km/s
Largely Mafic Rocks (Gabbro)
6.6 km/s
7.4 km/s
LC
MAFIC/ULTRAMAFIC MAGMATIC ADDITIONS
7.4 km/s
Moho
Peridotite
8.0 km/s
8.0 km/s
ZONES OF CONCENTRATED EXTENSION

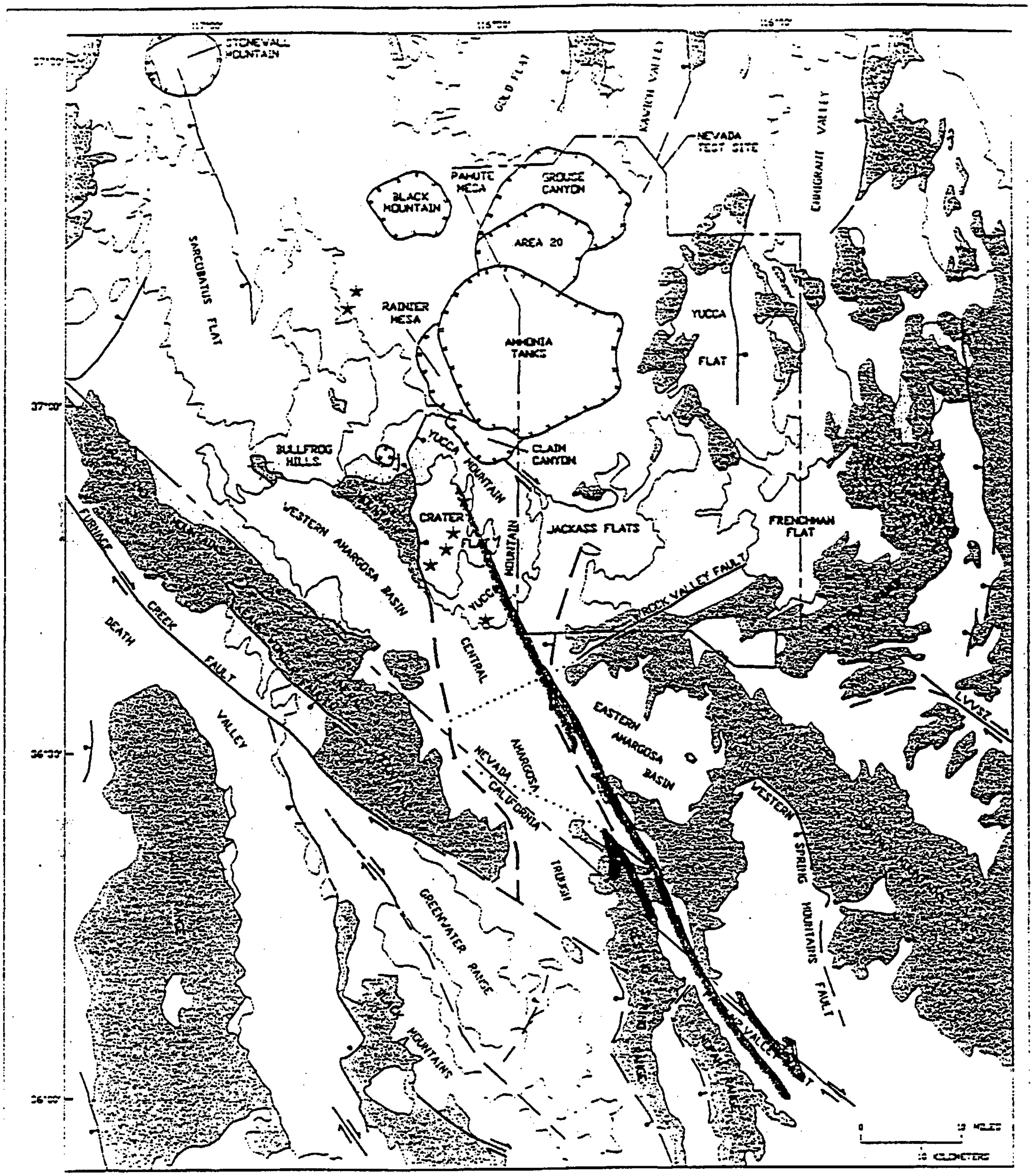

Alluvium
Quaternary- late Miocene basalt
Middle Miocene tuffs
Paleozoic
- Detachment
- Fault
Rotation Markers
Ammonia Tanks Tuff (11.45 Ma)
Rainier Mesa Tuff (11.6 Ma)
Tiva Canyon Tuff (12.7 Ma)
Bullfrog Tuff (13.25 Ma)
Crater
Yucca
Mtn
10°
20°
30°
40°
r-lat
0
5 km



Ranier Mesa Caldera
Ammonia Tanks Caldera
Claim Canyon Caldera
Tram Ridge Uplift
Fluorspar-Bullfrog Hills Domain
Chocolate Mtn. Domain
Yucca Wash Fault
Bare Mountain Uplift
Crater Flat Basin
Bare Mtn. Fault
DHW
SCF
minor trans-tensional zone of northern Yucca Mtn.
AMARGOSA DESERT BASIN
H'
Amargosa Valley
zone of strong dextral shear
N
Domain Boundary Faults
Within-Domain Faults
Normal Fault
Reverse Fault
Strike-Slip Fault
Axis of Basin
10-11 Ma Basalts
3.7 Ma Basalts
1.0 Ma Basalts
Lathrop Wells Basalts
Buried Basalts
Caldera Margin
Drill Hole Wash-Solitario Canyon Dike Swarm(10-11 Ma)



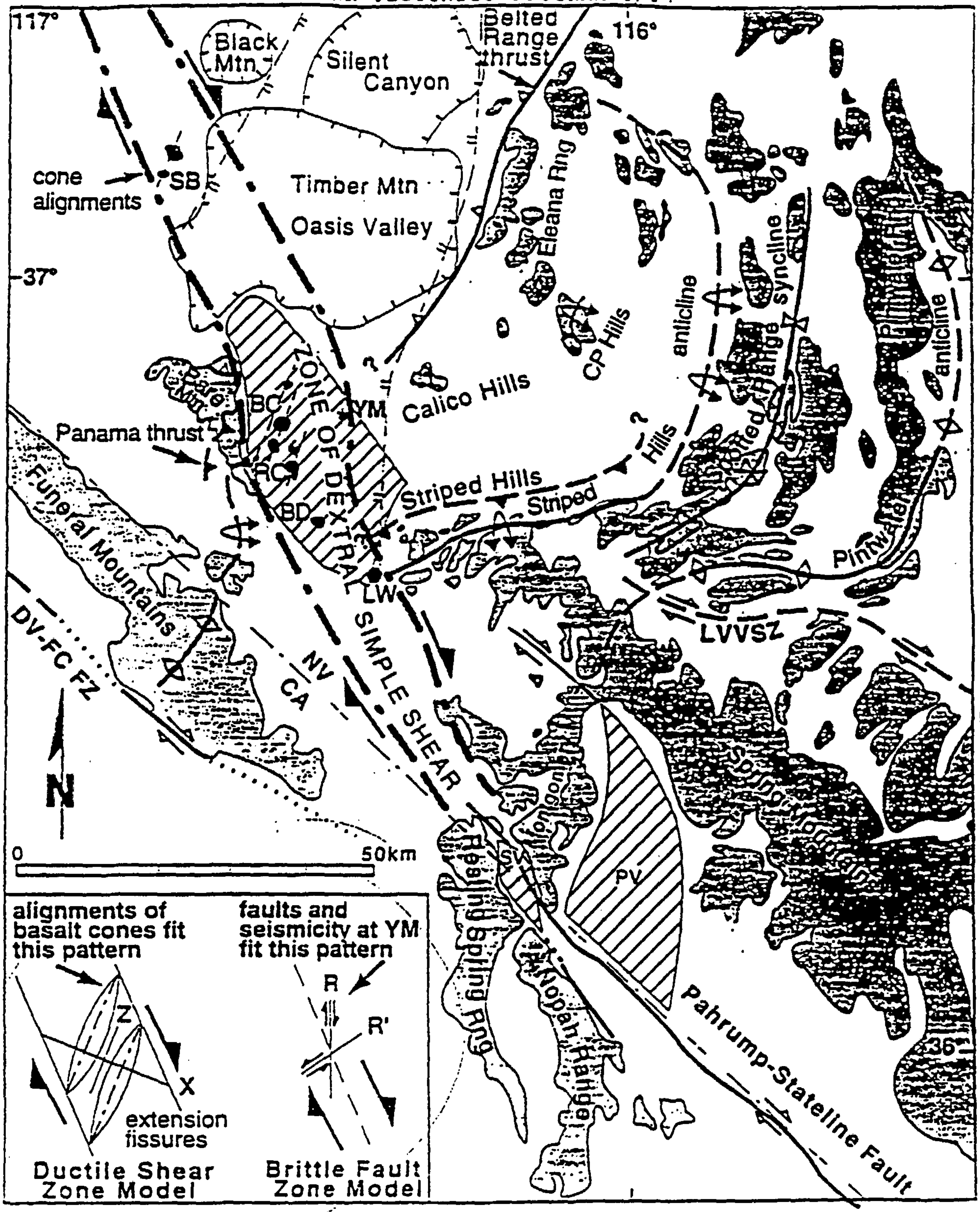




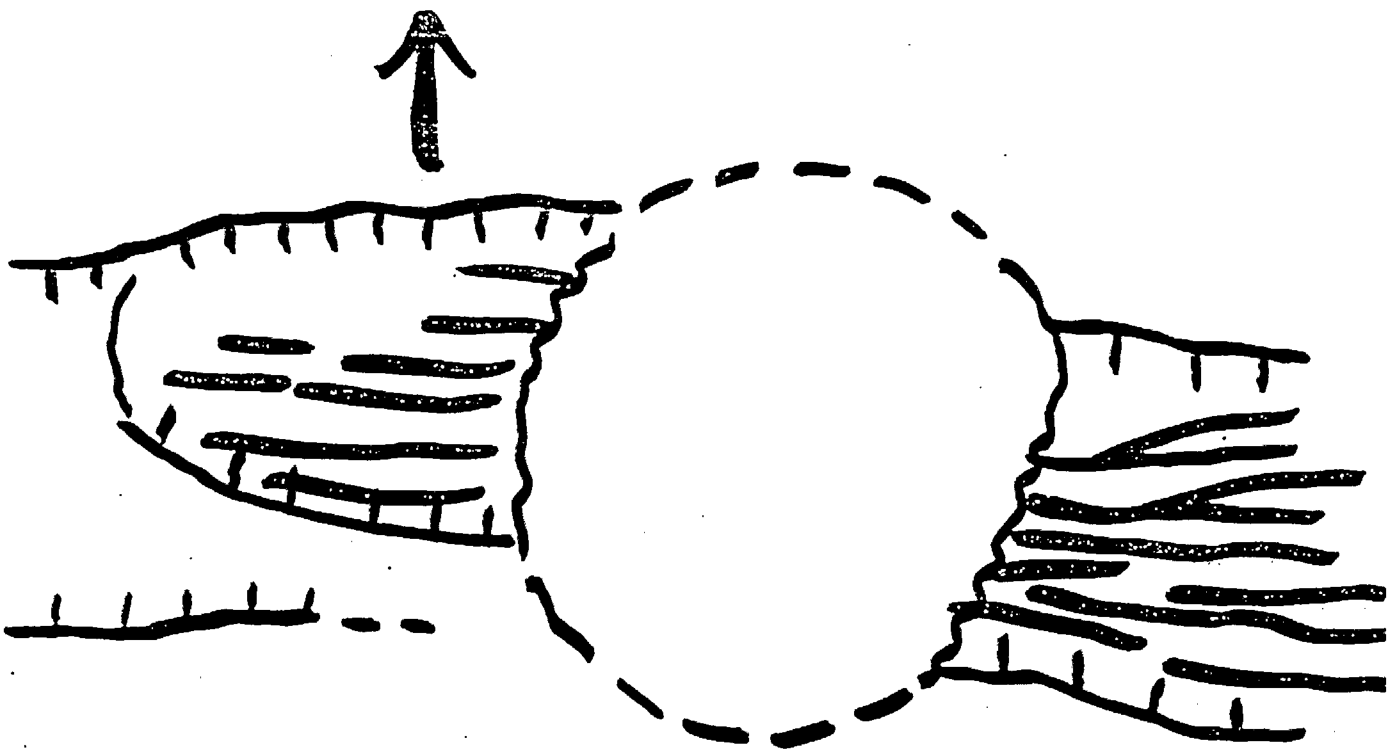
EXPLANATION

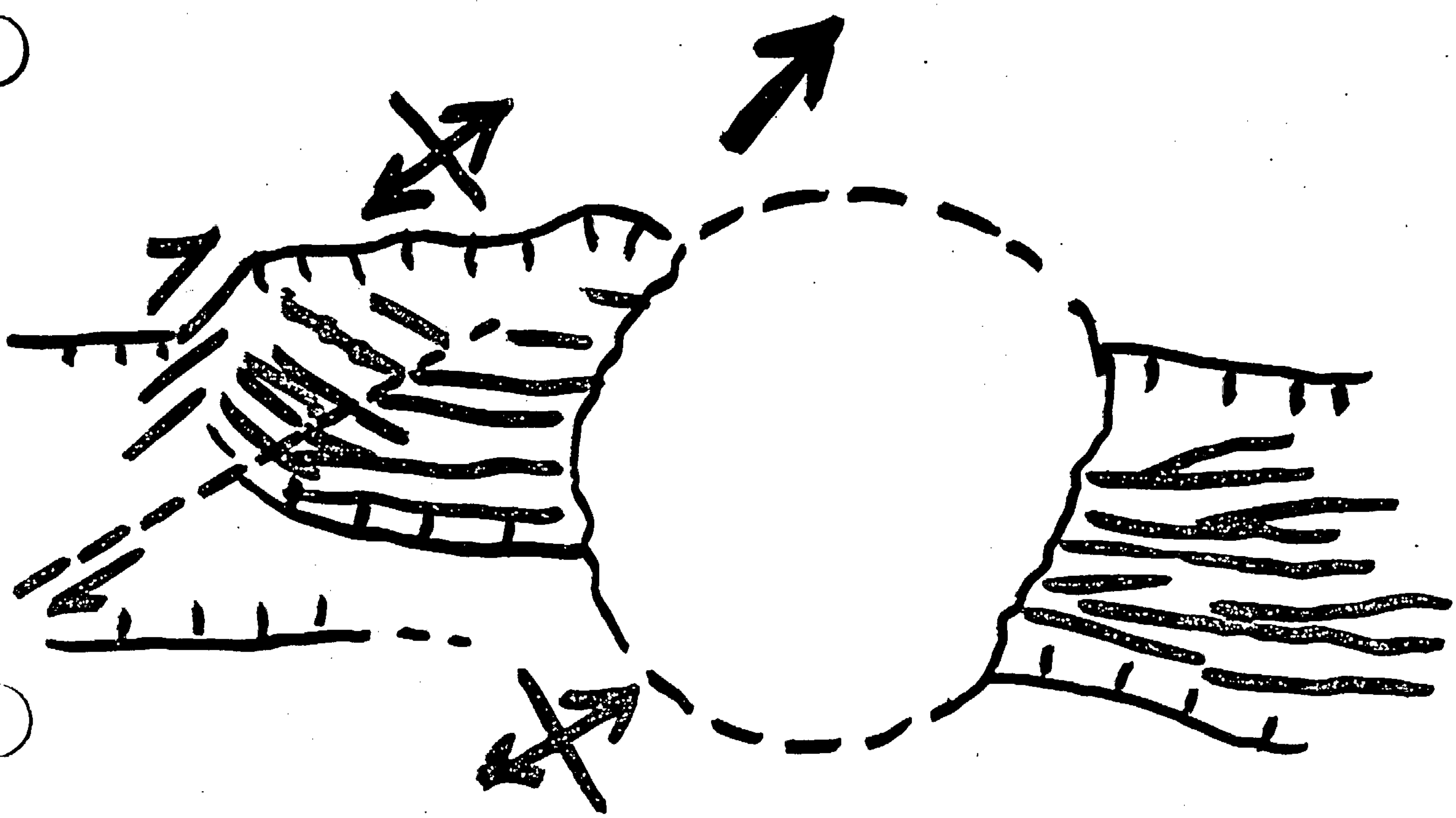
- QUATERNARY-PLIOCENE
- MIOCENE-OLIGOCENE
- PALEOZOIC-PROTEROZOIC
- ★ BASALTIC CENTERS
- NORMAL FAULT
- STRIKE-SLIP FAULT
- DETACHMENT FAULT
- CALDERA

CNS-UNR TECTONICS PROGRAM 6/94



ATTACHMENT 2



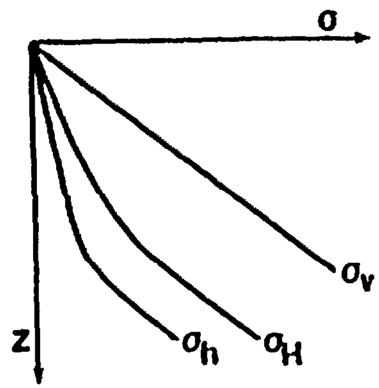


$$R = \frac{\sigma_1 - \sigma_2}{\sigma_1 - \sigma_3}$$

At some shallow depth R becomes approximately constant

R > 0.5

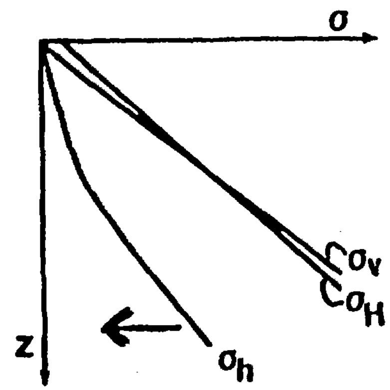
Yucca Mountain Hydrofrac Data (Stock and others, 1985).

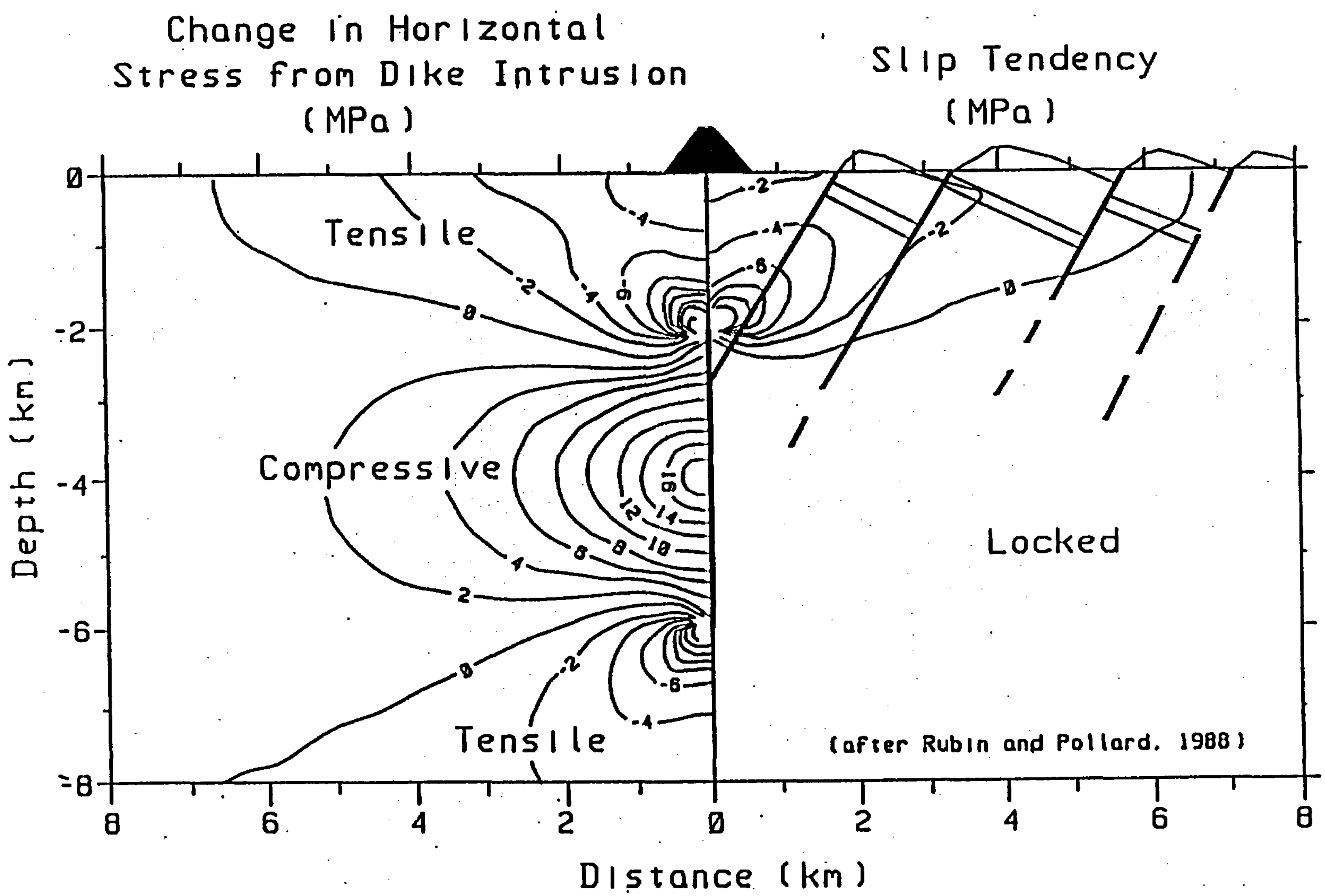


At some shallow depth R becomes approximately constant

R ≈ 0.0 - 0.3

Hypothetical model accounting for the existence of both strike - slip and normal fault events throughout the seismogenic crust.



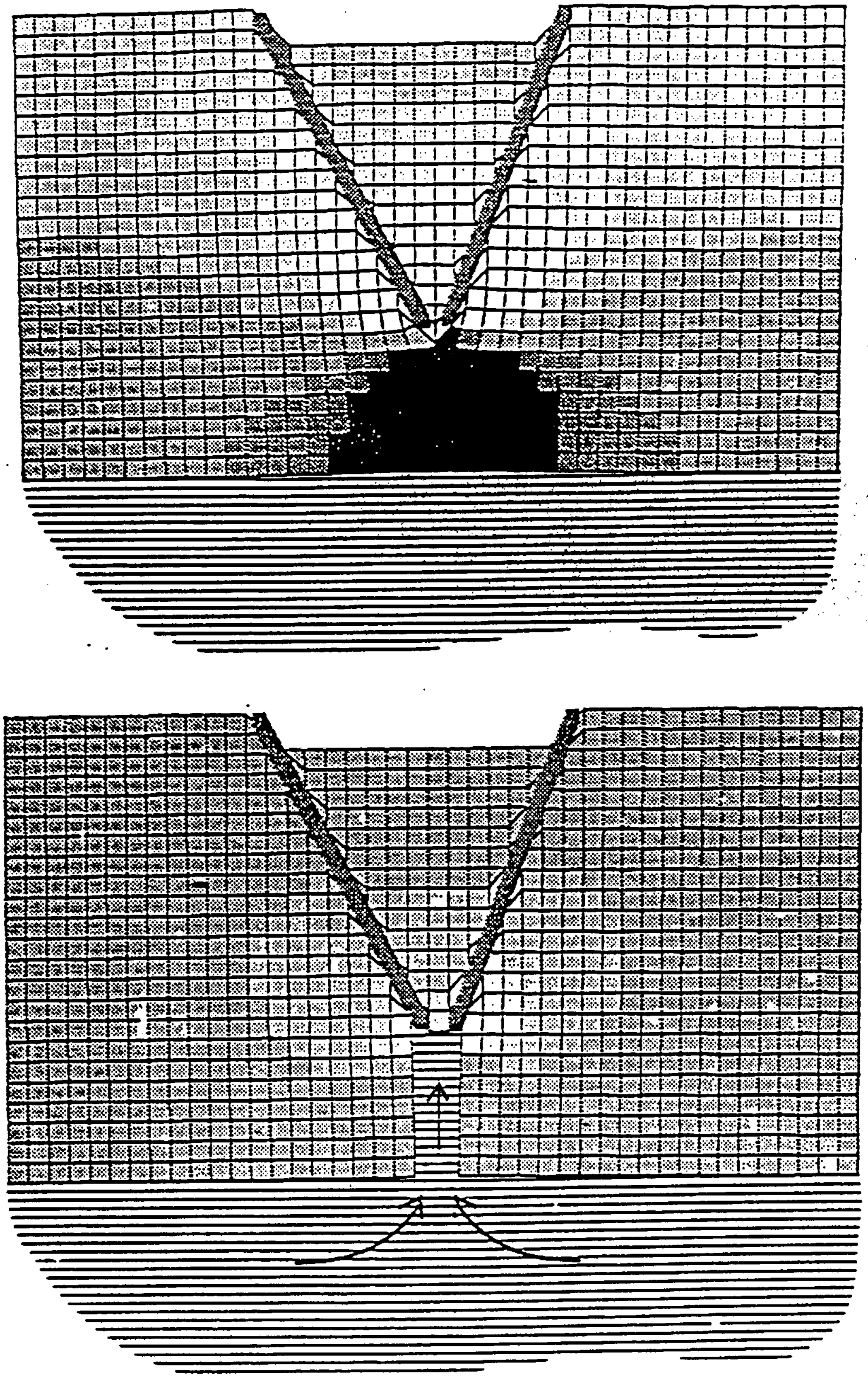


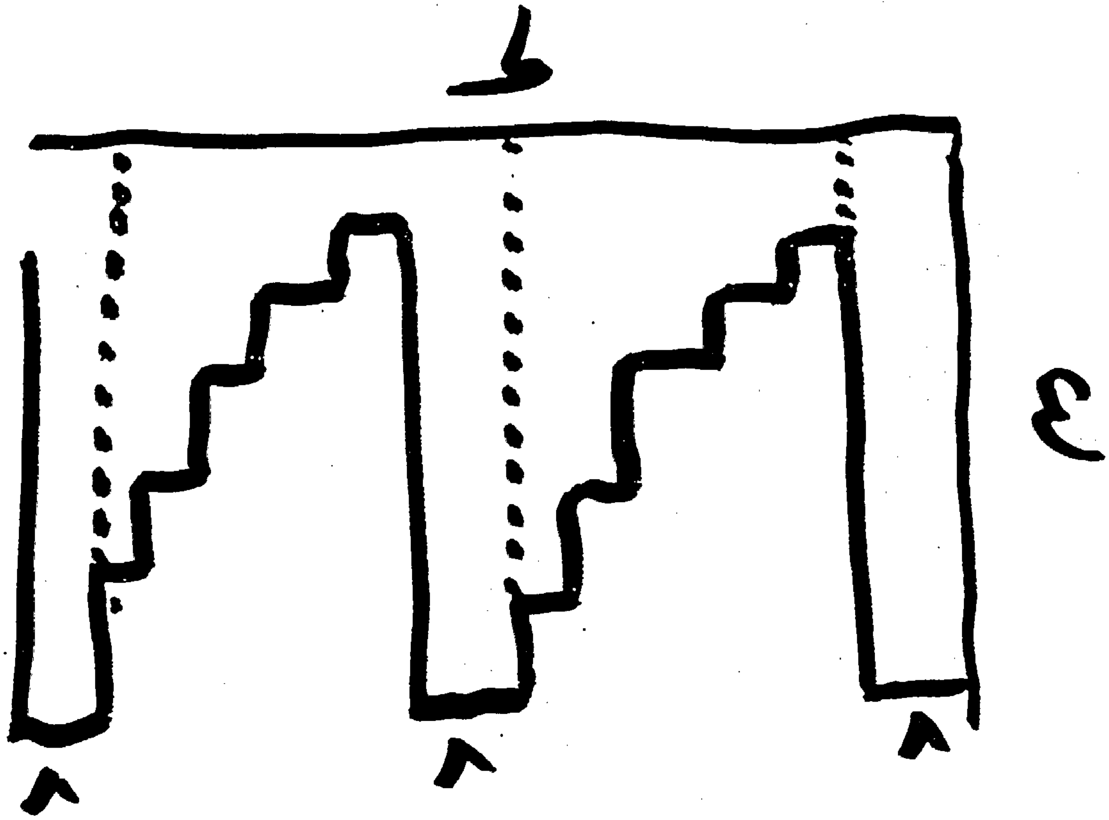
Change In Horizontal Stress from Dike Intrusion (MPa)
Slip Tendency (MPa)
Tensile
Compressive
Tensile
Locked
(after Rubin and Pollard, 1988)
Depth (km)
Distance (km)

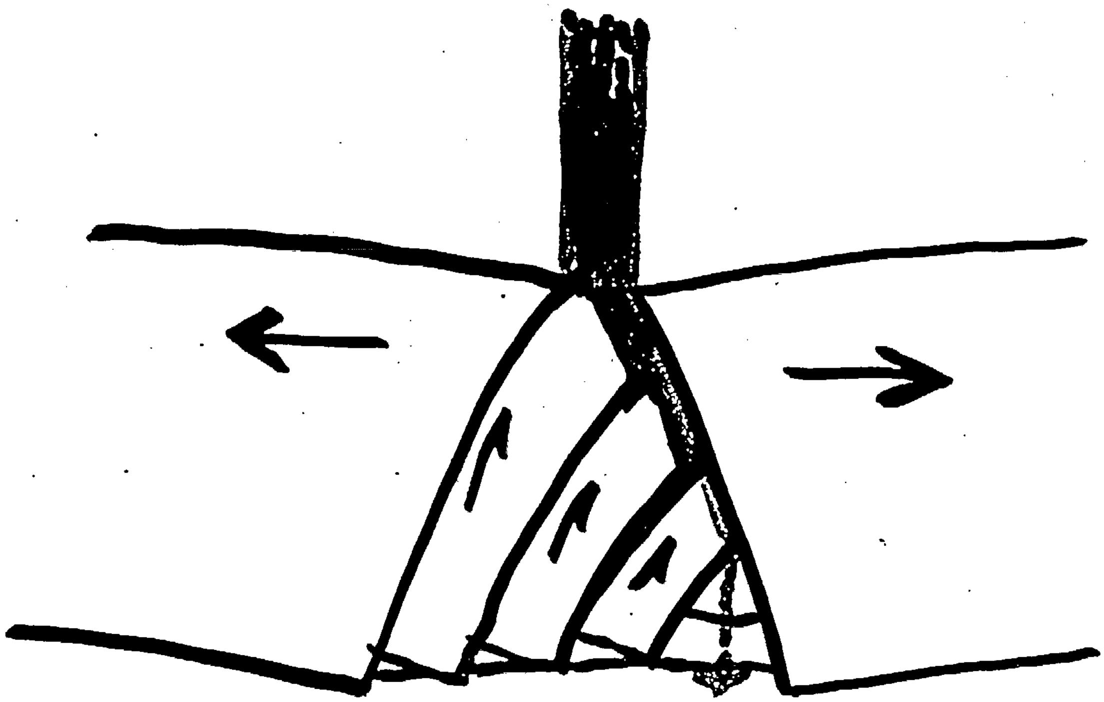
Figure 25

a)

b)

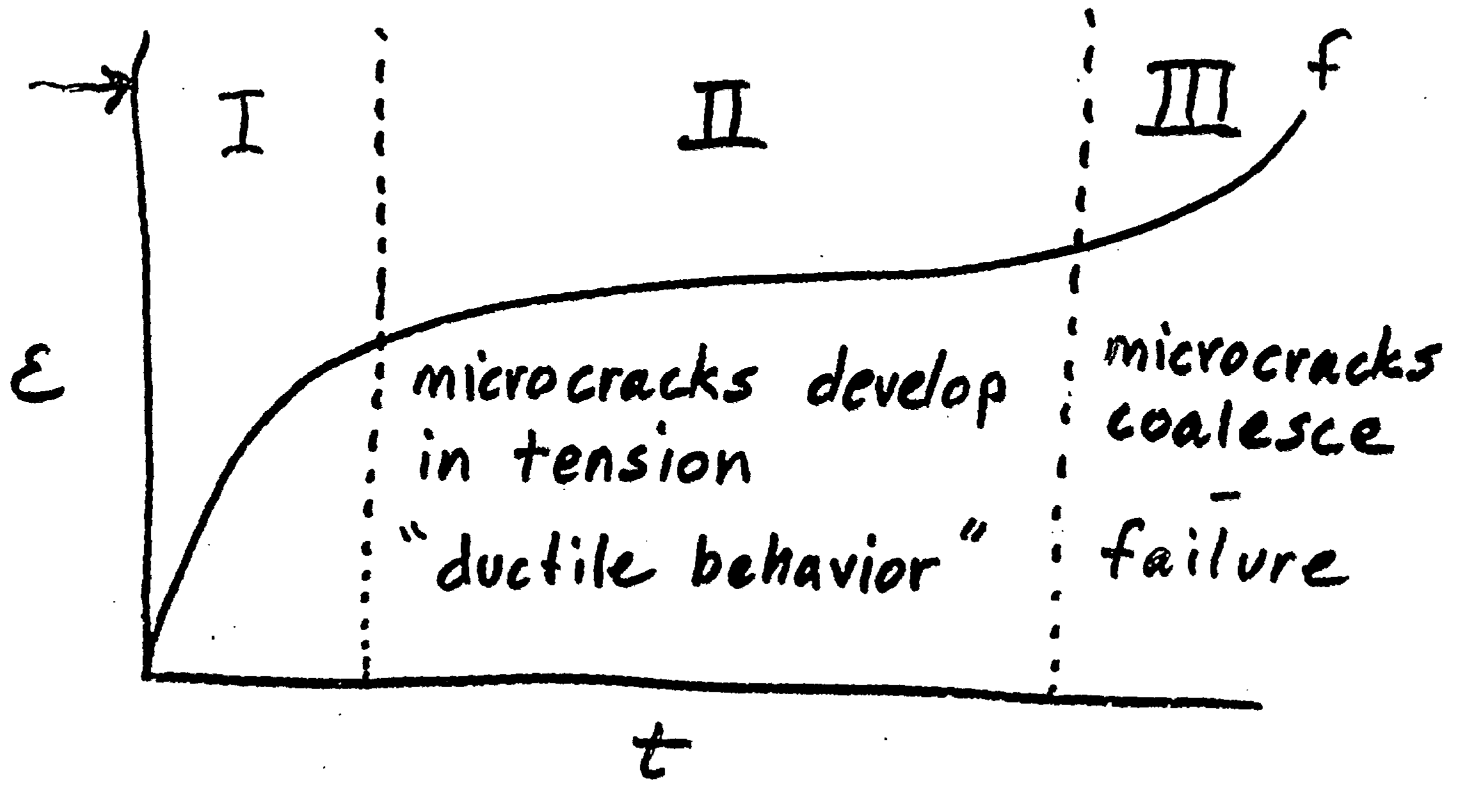






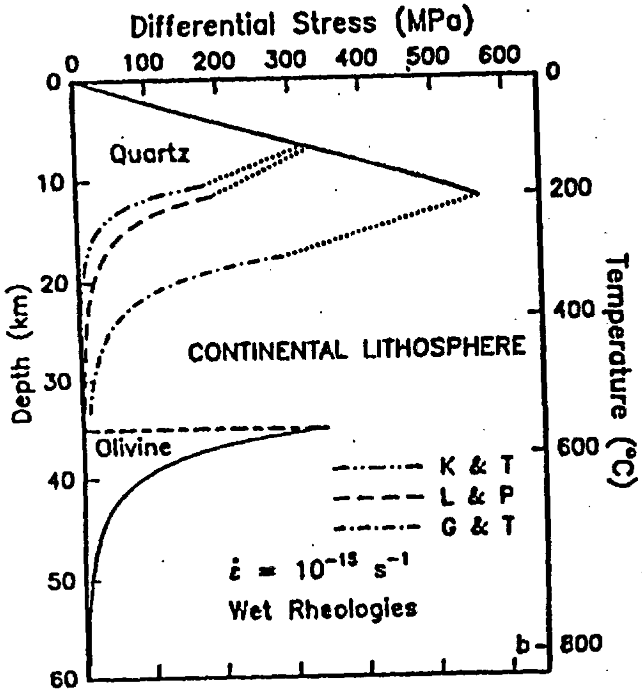
Creep in the lower crust / lithosphere

$\varepsilon = f A \sigma^n$ function of stress corrosion



$$t = f\left[a(H_2O)^n \exp\left[(E - \bar{V}\sigma)/RT\right]\right]$$

time to failure a function of static fatigue



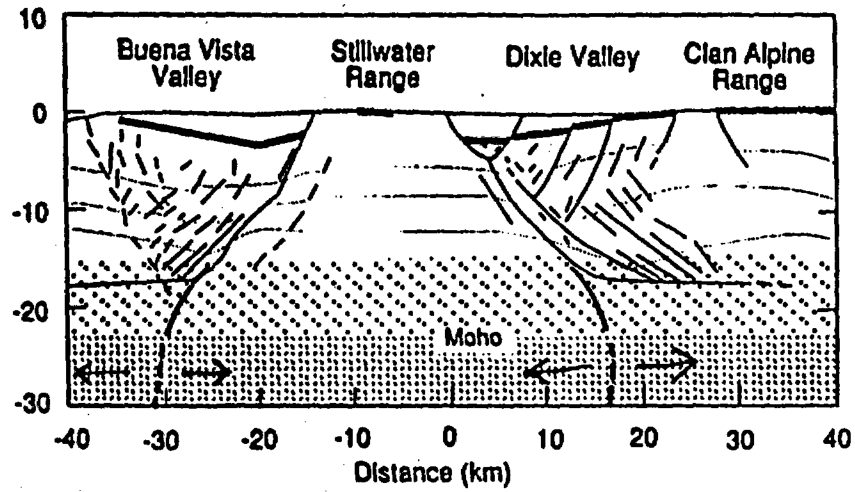
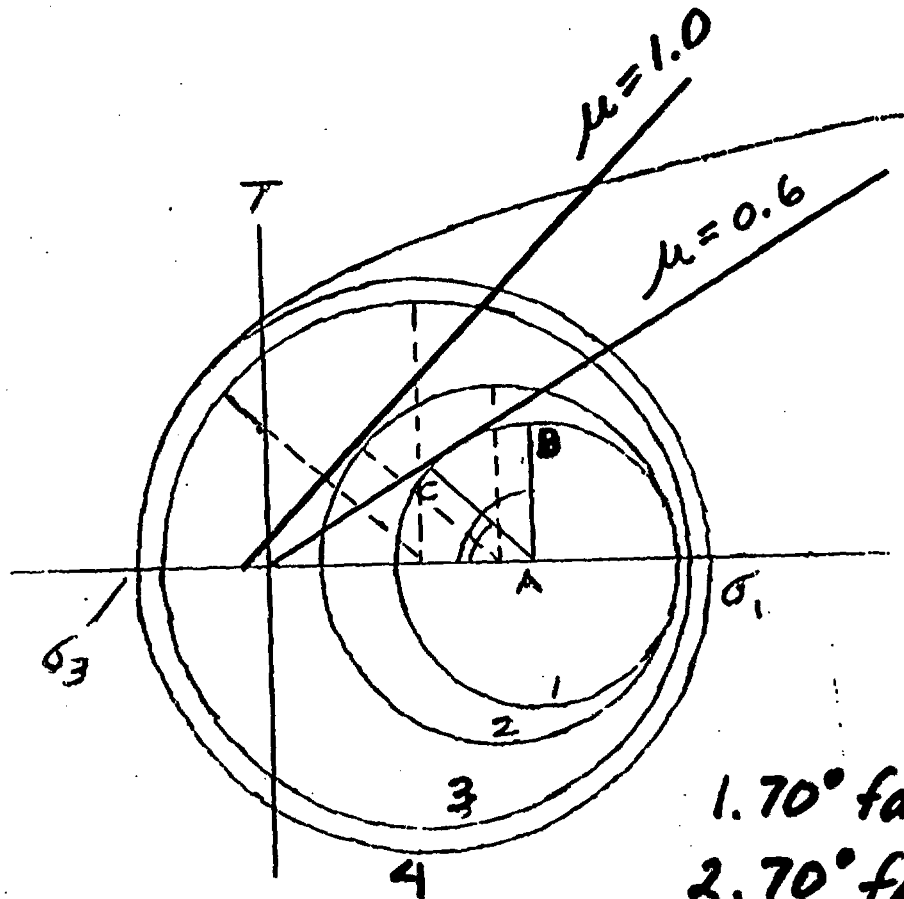


Figure 12. Okaya's (1985) model of deformation, which is ap-



AB = 45° fault
AC = 70° fault

1. 70° fault slip, μ = 0.6
2. 70° fault slip, μ = 1.0
3. 70° fault pulls apart
4. vertical tensile failure

ATTACHMENT 11

YUCCA
MOUNTAIN
PROJECT

Studies

Criticality Evaluations in Degraded Waste Packages

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:
Peter Gottlieb, Senior Engineer
CRWMS M&O/Waste Package Development
TRW, Las Vegas, Nevada

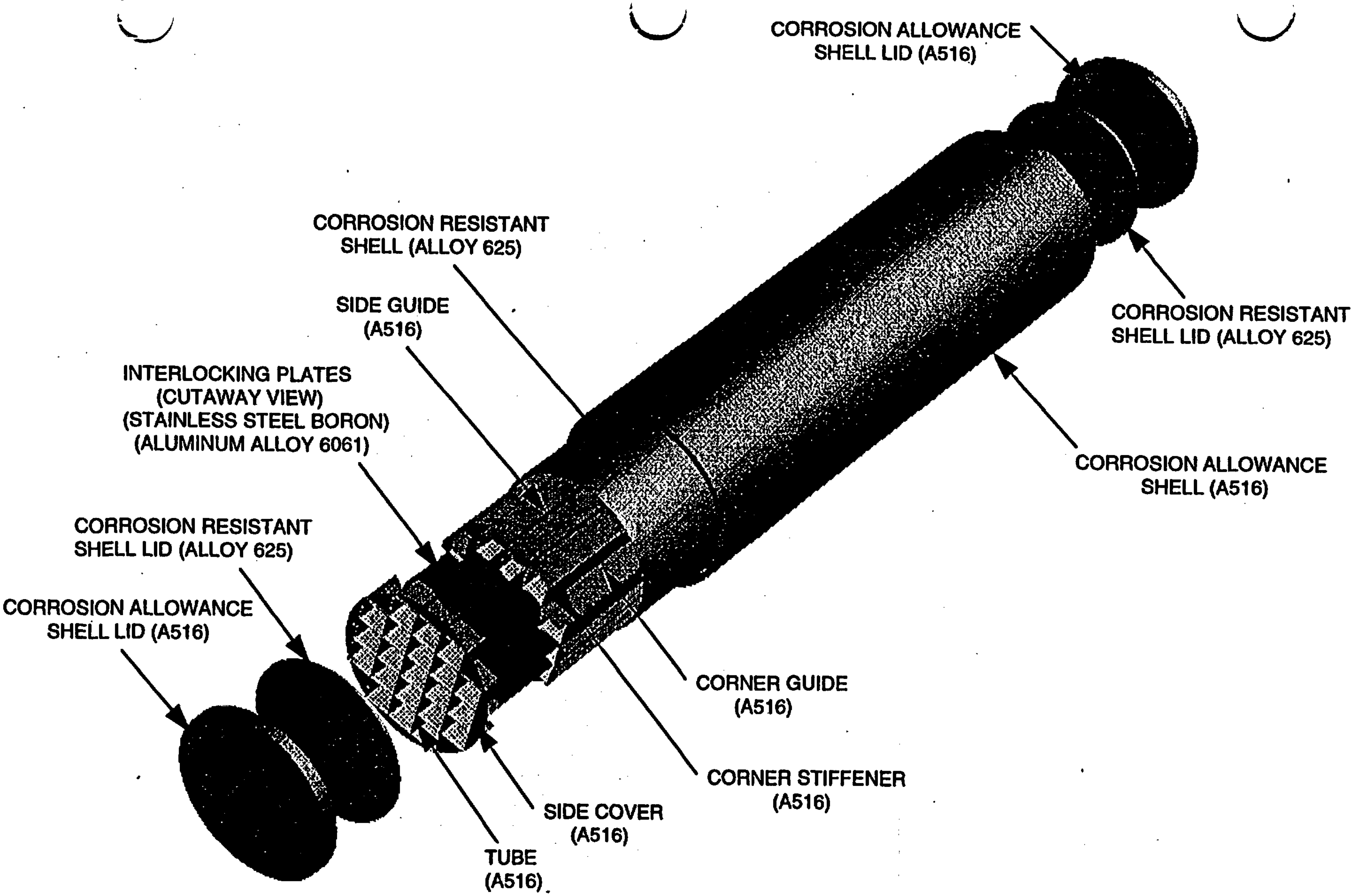
November 5, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Regulatory Status

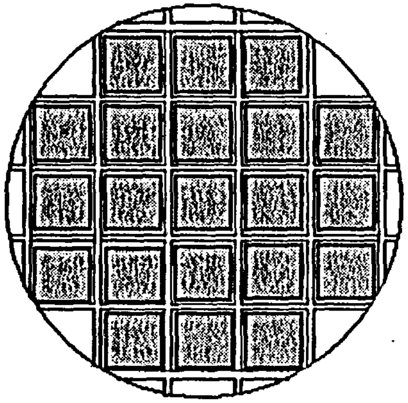
- Present rule: 10CFR60.131(h)
  - Control criticality for all repository systems, and all phases, including isolation
  - No criticality for design basis events
  - Criticality may be caused by the occurrence of two unlikely, independent, and concurrent or sequential changes (events)

- NRC analysis of comments (particularly DOE) on the rule
  - Uncertainty remains with respect to ... applicability.... to the postclosure period.
  - NRC intends to address the remaining uncertainty in a future rulemaking (to be consistent with the yet-to-be-released EPA standards)

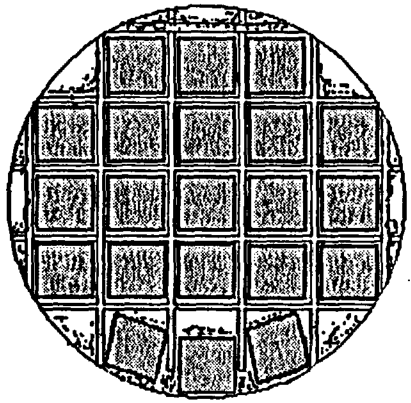


21-PWR UCF
WASTE PACKAGE ASSEMBLY

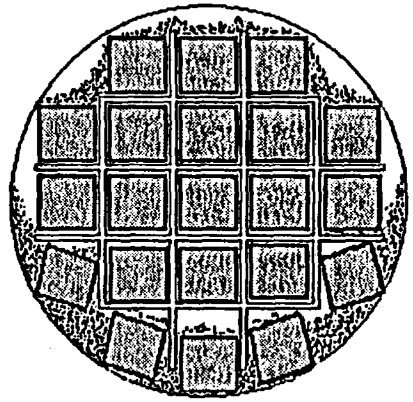
Waste Package Degraded Internal Configurations for Commercial PWR SNF (Schematic)



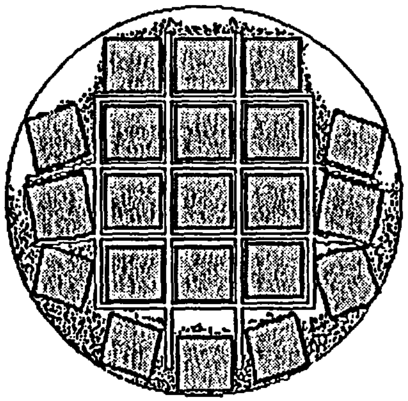
Initial Configuration



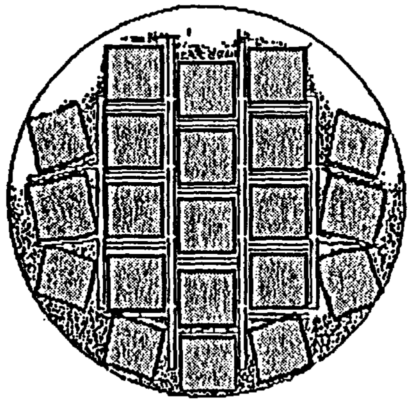
Side Guide Failure



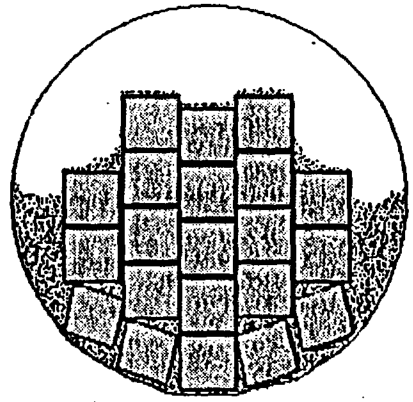
Corner Guide Failure



Long Criticality Control Plates Bend at Ends

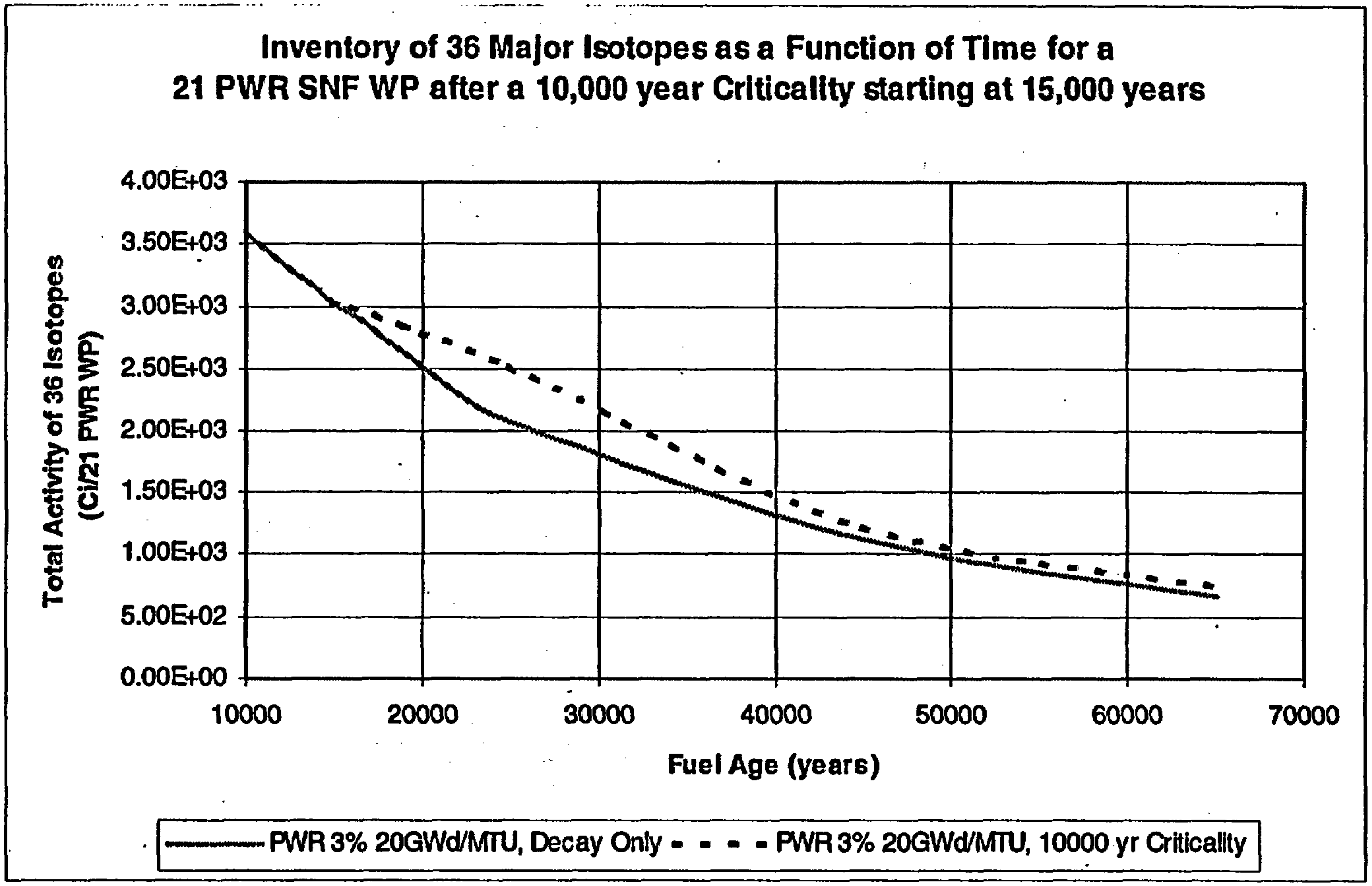


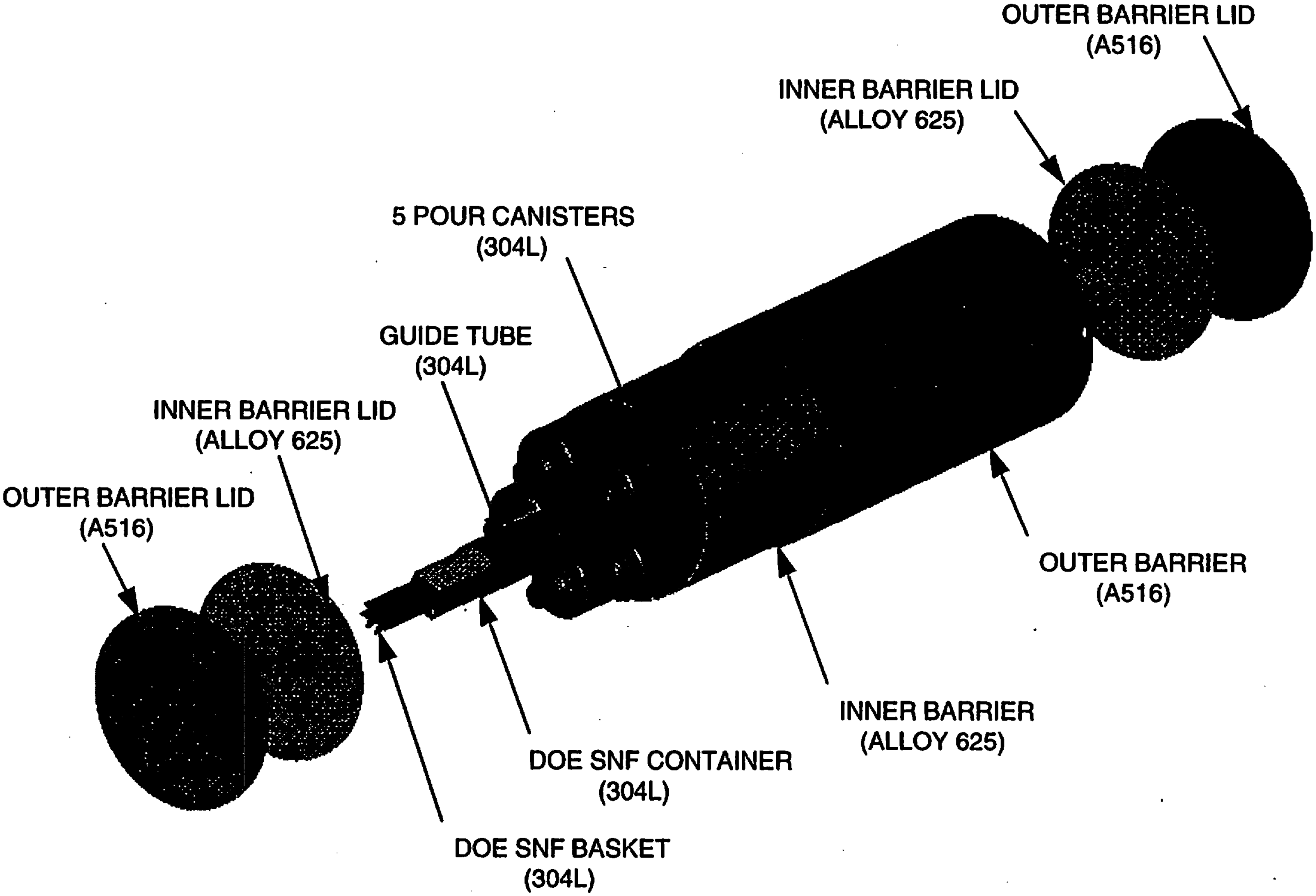
Fully Collapsed Basket with Partial Criticality Control Plate Degradation



Fully Degraded Basket

Example Showing Increase of Radionuclide Inventory due to Internal Criticality

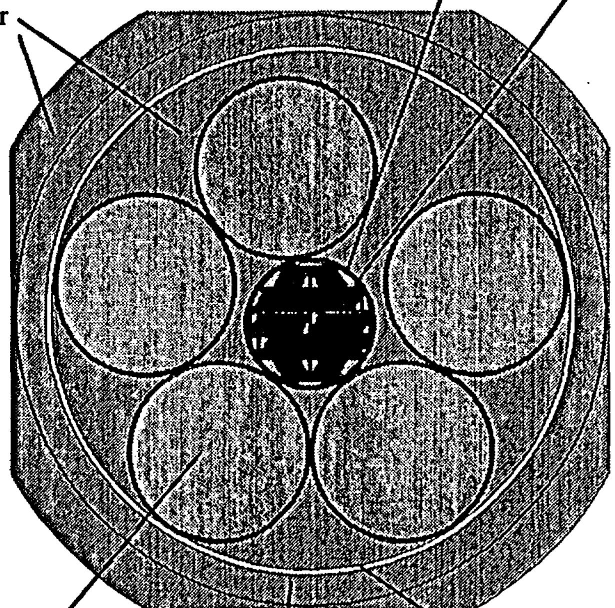




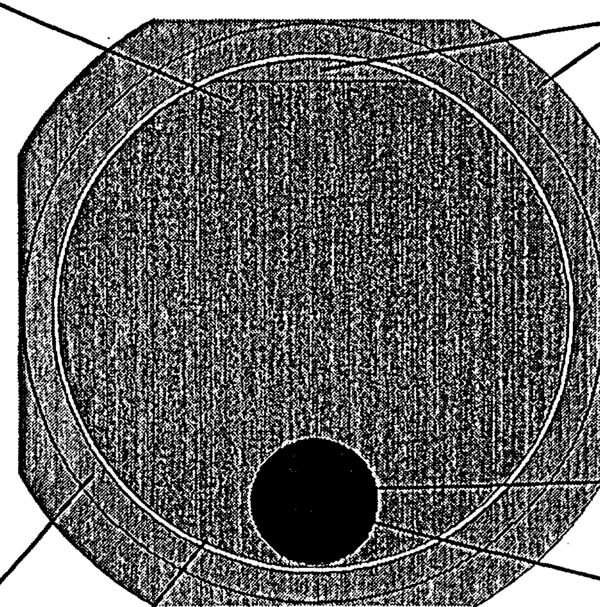
5-DHLW/DOE SPENT FUEL ASSEMBLY

Separate Degradation of DHLW Canisters and DOE SNF Canisters in Codisposal Waste Package

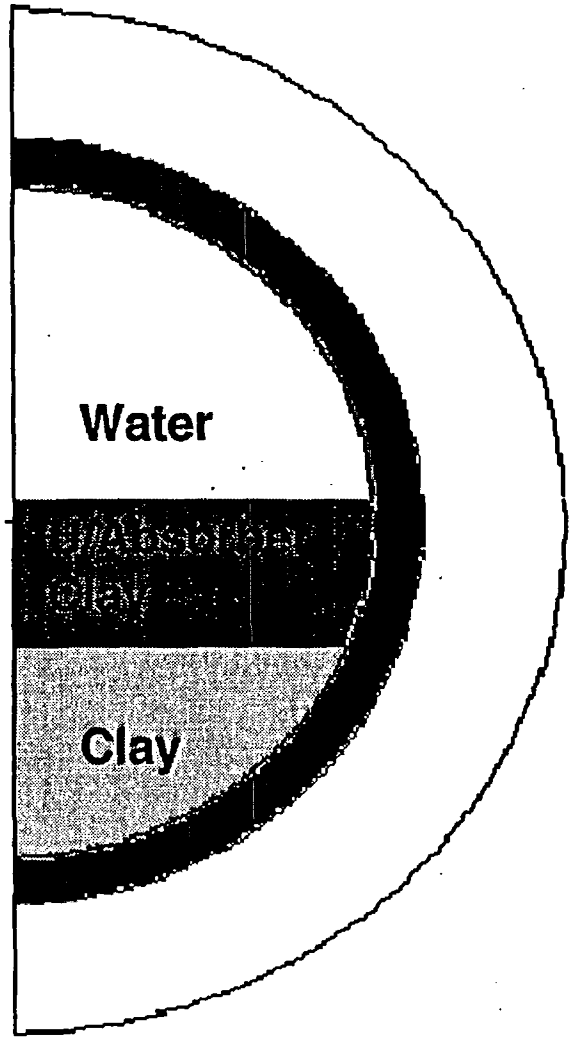
Intact MIT Codisposal WP

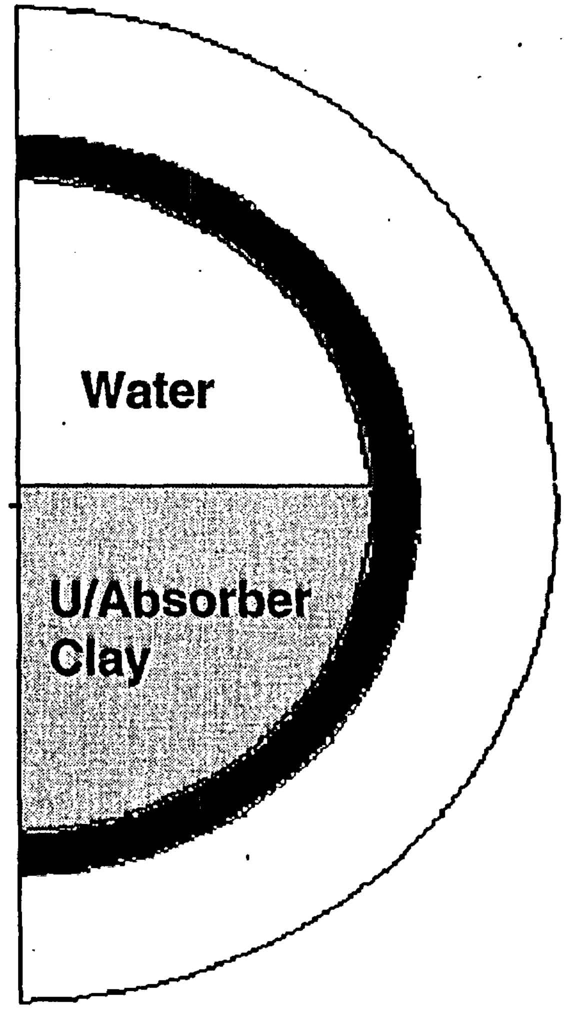


Degraded MIT Codisposal WP



Degraded DOE SNF Codisposal Waste Package





ATTACHMENT 12

DISRUPTIVE SCENARIO ABSTRACTIONS IN TPA 3.1 CODE

November 5-6, 1997
DOE/NRC Technical Exchange on
Total System Performance Assessments for Yucca Mountain

Tim McCartin
(301) 415-6681
Performance Assessment and HLW Integration Branch
Division of Waste Management

ABSTRACTIONS IN TPA 3.1 CODE

- Site information (including laboratory experiments and information from analogous environments) and results from detailed process models support PA abstractions

- TPA 3.1 Code developed to provide insights in areas generally considered important to performance and/or very uncertain
  - model abstraction
  - sensitivities of approach

- Disruptive scenarios considered in TPA3.1

  - seismicity and faulting

  - igneous activity

PRESENTATION WILL EMPHASIZE APPROACHES IN THE TPA 3.1 CODE AND TOUCH ON THE INFORMATION AND MODELING THAT SUPPORTS THE ABSTRACTIONS
(CAUTION: PARAMETER AND MODEL DEVELOPMENT IS CONTINUING - INSIGHTS AND ASSERTIONS ARE PRELIMINARY)

SEISMICITY AND FAULTING

Scenario

- Seismicity and Faulting Leads to Mechanical Disruption of the Waste Package
  - no affect on water flow nor water table (at this time)

SEISMICITY AND FAULTING (cont.)

Model Abstraction

- **Seismically Induced Disruption**
  - seismic activity leads to rock fall in emplacement drifts which cause stress, deformation and failure of the waste package
  - ultimate strength of waste package is used to determine waste package integrity
  - drift stability analysis used to determine weight of rock fall on waste packages
  - seismic event history developed from probabilistic and deterministic seismic hazard analyses

- **Fault Induced Disruption**
  - fault geometry (fault location, displacement, displacement rate, fault-zone width, and subarea containing fault) are used to determine the number of waste packages affected
  - assumes fault attributes similar to those observed at the site
  - threshold fault displacement value used to determine if fault disruption caused failure of the waste packages (susceptibility of waste packages to failure assumed constant throughout)
  - use of recurrence rates for faulting based on results from paleoseismic and neotectonic investigations

Sensitivities of Seismicity and Faulting Abstraction

- Influence of seismicity and faulting on flow patterns at the repository level (evaluation of focussed flow may be important)

- Rock conditions and drift design (e.g., backfill versus no backfill) are key to estimating damage

IGNEOUS ACTIVITY

Scenario

- Igneous Activity has the potential to release radionuclides directly to the surface and disrupt waste packages in the repository (current focus primarily on direct release)

Model Abstraction

1) MAGMA-WASTE PACKAGE INTERACTION

2) MAGMA-SPENT FUEL INTERACTIONS

3) VOLCANOLOGICAL PROCESSES

MAGMA-WASTE PACKAGE INTERACTION

- Basaltic Magma:
  - temperature of 1100 °C
  - Density 1300-2600 kg/m^3
  - Viscosity 10-100+ Pa s
  - Velocity 1 m/s initial to 100 m/s eruption
  - Acidic gases present

- Waste packages fail when intercepted by basaltic magma (all waste in waste package available for direct release)

- Extrusive event within repository footprint will fail between 1 and 10 waste packages
  - volcanic conduits produce a roughly circular area of disruption up to about 50 meters in diameter

MAGMA-SPENT FUEL INTERACTIONS

- Transport of radionuclides directly related to spent fuel particle size (fuel particle size varies from 1 micron to 100 microns)

  - median grain size of spent fuel is 10 microns prior to cintering
  - in situ fracturing of fuel pellets results in 1000-100 micron diameter particles
  - crush impact studies (NUREG-1320) give median particle diameters on the order of 100 microns from falling concrete roof panels

- Initial conservative assumption is that basaltic volcanic disruption reduces median diameter of particle to 10 microns

- Transport of spent fuel particles requires incorporation into basaltic particles

  - basaltic particles (i.e., tephra) must be 3 to 10 times the diameter of the dense spent fuel particles for transport to occur
  - grain size distributions of tephra and spent fuel limit amounts of waste transported to environment

VOLCANOLOGICAL PROCESSES

- Subsurface area of disruption determines number of waste packages affected
  - volcanic conduit widening on the order of 10's of meters (disrupts 1-10 waste packages)

- Dispersal characteristics depend on wind speed, wind direction, size of eruption, and particle size
  - YMR Quaternary eruptions likely sustained kilometers-high columns and transported material 10's of km down wind
  - current modeling indicates centimeters to millimeters of tephra deposits possible at 20 km from YM (calculations tested with analog eruptions)

Sensitivities of Igneous Activity Abstraction

- Waste package behavior under magmatic conditions is poorly known
  - magma thermal effects likely to cause failure between seconds and 1 year (physical loads from eruption likely to shorten failure times)

- Tephra volumes, eruption durations, mass-flow rates, and tephra characteristics must be estimated from sparse data for previous YMR eruptions

- Exposure scenario parameters are very uncertain
  - resuspension factor for air-pathway (influence of wind stress and mechanical processes)
  - lifestyle assumptions affecting air-pathway exposures (occupancy factors, mechanical factors such as plowing)

ATTACHMENT 13

NRC VIEWS ON AN ACCEPTABLE APPROACH TO THE SELECTION AND SCREENING OF SCENARIOS

November 5-6, 1997
DOE/NRC Technical Exchange on
Total System Performance Assessments for Yucca Mountain

Norman A. Eisenberg
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Division of Waste Management

BACKGROUND

- IN MANY RESPECTS, SUBSTANTIAL PROGRESS HAS BEEN MADE IN THE RESOLUTION OF THE NRC CONCERNS RELATED TO DOE'S PLANS FOR A SCENARIO SELECTION AND SCREENING METHODOLOGY
  - 133 OPEN ITEMS IDENTIFIED IN STAFF'S 1989 SITE CHARACTERIZATION ANALYSIS (SCA)
  - 17 WERE SCENARIO-RELATED (8 PERCENT)
  - PRE-LICENSING CONSULTATION RESOLVED 15, AT THE STAFF LEVEL
- HOWEVER, DESPITE PROGRESS OVER THE YEARS, 2 OPEN ITEMS REMAIN OUTSTANDING:
  - SCA COMMENT 95
  - SCA COMMENT 105
- DOE'S TSPA-VA PLAN IS SILENT REGARDING A SCENARIO SELECTION/SCREENING METHODOLOGY
- ALTHOUGH NRC'S GEOLOGIC REPOSITORY REGULATION IS EXPECTED TO UNDERGO REVISION IN THE FUTURE, SOME PROVISION IS EXPECTED TO REMAIN THAT WOULD INVOLVE THE SELECTION AND SCREENING OF SCENARIOS
- IN THE SPIRIT OF "NO SURPRISES", WHAT ARE DOE'S PLANS ?

APPROACHES TO THE TREATMENT OF SYSTEM FUTURES

- ENVIRONMENTAL SIMULATION —
  - *AEGIS (ONWI)*
  - *HMIP*
- TREE APPROACH —
  - *EPRI*
- SCENARIO APPROACHES —
  - *OECD/NEA FEP*
  - *EXPANDED SNL APPROACH (SNL & SKI)*
  - *WIPP*
  - *NRC IPA APPROACH*

NRC APPROACH

- FUNDAMENTAL CAUSATIVE EVENTS DEFINED AS LARGE CLASSES (e.g., MAGMATIC EVENTS, SEISMIC ACTIVITY)

- COMBINATIONS OF FUNDAMENTAL EVENTS, OR THEIR ABSENCE, PRODUCE *SCENARIO CLASSES*

- SCENARIO CLASSES, SO DEFINED, COVER THE ENTIRE PROBABILITY SPACE

- OTHER EFFECTS, E.G. CLIMATE CHANGE, WASTE PACKAGES DAMAGED AT THE TIME OF EMPLACEMENT, ARE CONSIDERED TO AFFECT ALL SCENARIO CLASSES

- VARIABILITY IN THE MAGNITUDE, TIMING, LOCATION, AND OTHER PROPERTIES OF EVENTS ARE TREATED IN THE CONSEQUENCE ANALYSIS THROUGH THE USE OF RANDOM VARIABLES

KEY DIFFERENCES BETWEEN DOE AND NRC APPROACHES

- Mutual exclusivity
  - NRC "scenario classes" are defined to be mutually exclusive
  - DOE "scenarios" are not mutually exclusive
- Coverage of probability space
  - NRC "scenario classes" completely cover probability space for included fundamental causative events
  - DOE "trees" appear to cover space, but may be redundant
- Determination of probabilities
  - Probabilities of NRC's fundamental causative events determined largely as objective frequencies
  - DOE's probabilities of scenarios depend on subjective evaluations of combinations

NRC EXPECTATIONS

- ARTICULATION OF A COMPREHENSIVE SCENARIO METHODOLOGY THAT ADDRESSES:

1. COMPLETENESS (consideration of all events and rationale for screenting and selection of some for analysis)

2. CORRECT CHARACTERIZATION AND TREATMENT OF EVENTS AS SINGULAR OR UNIVERSAL

3. CORRECT PROBABII ISTIC CALCULUS

   - MUTUALLY EXCLUSIVE EVENT SETS
   - COMPLETE COVERAGE OF PROBABILITY SPACE (EXCEPT FOR INCONSEQUENTIAL CONTRIBUTORS TO RISK)

4. CONSIDERATION OF REPRESENTATIVENESS AND TREATMENT OF VARIABILITY

5. LOGICAL AND TRANSPARENT RELATIONSHIP OF SCENARIOS TO PERFORMANCE MEASURES AND THEIR GRAPHICAL DEPICTION

ATTACHMENT 14

YUCCA MOUNTAIN PROJECT

Studies

Results/Conclusions from the DOE Expert Elicitation and Project Responses

Presented to:
DOE/NRC Technical Exchange on
Total System Performance Assessment
Las Vegas, Nevada

Presented by:David Stahl, Ph. D.
Manager, Waste Package Materials Department
M&O/Framatome Cogema Fuels
Yucca Mountain Site Characterization Project
Las Vegas, Nevada

November 5-6, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Waste Package Degradation Expert Elicitation (WPDEE)

Objectives

- To quantify uncertainties in key aspects of waste package degradation process model
- Use panel of experts to provide perspective and experience
- Provides a 'snapshot' of uncertainties; augments available data
- Part of series of expert elicitations being conducted for TSPA-VA

Members Of The Expert Panel

Dr. Peter L. Andresen, GE Corporate R&D

Dr. Joseph C. Farmer, Lawrence Livermore National Laboratory

Dr. Brenda J. Little, Naval Research Laboratory, Stannis Space Center

Dr. R. Daniel McCright, Lawrence Livermore National Laboratory

Dr. John R. Scully, University of Virginia

Dr. David W. Shoesmith, Atomic Energy of Canada Limited

Waste Package Degradation Expert Elicitation (WPDEE) Process

Steps Followed:

- Expert Selection
- Data Workshop #1: Issues and Available Data
- Data Dissemination
- Workshop #2: Alternative Models and Interpretations
- Field trip to ESF
- Elicitation Training
- Workshop #3: Preliminary Expert Interpretations
- Elicitation Interviews
- Feedback
- Documentation

Summary of Key Assessments

Corrosion Allowance Material (CAM)

- Dry oxidation (thickness of layer, spalling potential)
- Relative thresholds for humid air corrosion and aqueous corrosion
- Importance of drips
- Corrosion modes (general vs. high-aspect ratio pitting)
- Geometry of corrosion processes
- Pit density and pit diameter
- Corrosion rates

Summary of Key Assessments
(Continued)

Corrosion Resistant Material (CRM)

- Galvanic protection
- Pit density, pit diameter
- Pit/crevice growth rates

Other Issues

- Microbiologically influenced corrosion
- Ceramic coatings
- Stress corrosion cracking

Recommendations for Additional Work to Reduce Uncertainties (added later)

Assumed Environmental and Design Conditions

Environmental Conditions

- Temperature
- Relative Humidity (O_2, CO_2)
- Water Seepage Flux
- Water Chemistry (Cl, pH)

Design Conditions

- Waste Package
- Materials/Alloys
  - CAM: carbon steel, or Monel 400
  - CRM: Alloy 625, or C-22
- Mechanical Loads
- Fabrication and Assembly
- Radiation/Waste Package Shielding

Summary of Key Assessments Corrosion Allowance Material (CAM)

1. Dry oxidation of carbon steel
   - Most experts expect a very thin oxide layer to develop during dry, hot period
   - Differences of opinion regarding spalling potential
   - Oxygen depletion may be significant
2. Temperature threshold for corrosion of CAM
3. Relative humidity thresholds for humid air corrosion and aqueous corrosion
4. Importance of drips
   - Location, frequency, persistence of drips is very important
   - Drips on hot package will evaporate and leave salts/saturated solutions
   - Alkaline solutions from dripping through concrete liner

Summary of Key Assessments Corrosion Allowance Material (CAM)

(Continued)

5. Corrosion modes
   - Neutral pH (4-9): general corrosion
   - High pH (≥10): potential for high depth/diameter pits
6. Geometry of corrosion processes
   - Top of package (upper 90-180°) subject to drips (salts), and high pH
   - Bottom of package may experience bulk water conditions
7. Pit density and pit diameter
8. Corrosion rates (general corrosion and pits)
   - Corrosion rates follow this form: Rate= $C_G + C_P\ t^n$

where C_G is the general corrosion rate (from TSPA-95, and includes temperature, time and RH dependence), C_p is the constant for pit growth rate, and n specifies the nature of decay with time

Summary Of Key Assessments
Alternative CAM: Monel 400

1. Corrosion Modes
    - General corrosion without deep pits
2. Pros and Cons
    - General corrosion rates lower than carbon steel
    - Passive in most environments, including high pH
    - Resistant to SCC and hydrogen embrittlement
    - May undergo dealloying as a result of MIC
    - Fewer data to establish rates than carbon steel
    - Susceptible to radiolytic corrosion

Summary Of Key Assessments Corrosion Resistant Material (CRM)

1. Galvanic Protection

- Extent determined by throwing power, which is a function of ion conductivity and geometry of CAM penetration
- Throwing distance: millimeters to few centimeters
- Neutral conditions: galvanic protection for tens of years
- High pH, CAM pits: few hundreds of years for expected aspect ratios

2. Corrosion Modes

- General corrosion under expected bulk environmental conditions
- Expected localized mode is crevice corrosion, perhaps pitting
- Localized corrosion function of Cl^-, pH, Fe^{+3}, T, O_2, anions, and drips
- Gap between CAM and CRM may serve as pathway for moisture

3. Pit Density, Pit Diameter

4. Corrosion Rates

Summary Of Key Assessments
Other Issues

1. Microbiologically Influenced Corrosion (MIC)

- Controlled by availability of nutrients, water, and electron acceptors
- <80°C, RH>60% potential for MIC begins
- Iron-reducing bacteria most important organisms for carbon steel
- For CRM, drips are required
- Importance of MIC is in probability of initiation of localized corrosion and pit/crevice density, rather than affect the corrosion rate

2. Welds

- Enhanced potential for SCC can be mitigated by full stress relief anneal
- Don't expect enhanced potential for localized corrosion or MIC

Summary of Key Assessments
Other Issues
(Continued)

3. Ceramic Coating

- Ceramic coatings subject to cracking and spalling due to mechanical loads
- Volume expansion of carbon steel corrosion products will lead to cracking
- Not recommended

4. Stress Corrosion Cracking

- Residual stresses due to shrink-fit may lead to SCC; mitigate with larger gap
- Mitigate weld stresses with narrow-gap welding and full stress anneal

5. Radiolysis

- Radioactive decay will have lowered dose by the time conditions reach 100°C and RH 65%

Summary of Key Assessments
Other Issues
(Continued)

6. Recommendations for Additional Work to Reduce Uncertainties

- Establish near-field environments: drip frequency, volume, and distribution; pH of drips, T, RH
- Testing of carbon steel in high pH conditions to establish pit density, passive dissolution, and growth rate
- Perform experiments to evaluate localized corrosion initiation and potential for stifling crevices/pits in CRM as function of temperature and materials
- Conduct mass-balance inventory to assess potential for MIC

Modifications to the Waste Package Materials Testing Program

- Alternative Materials
- Carbon Steel Pitting
  - Coupon thickness increased to study pit propagation and geometry
  - Vessels started up with concrete modified pH
- Ceramic Testing Program
- Cladding Testing Program (not from WPDEE)
- Galvanic Protection
- Microbiologically Influenced Corrosion

Modifications to the Waste Package Materials Testing Program
(Continued)

- **Alternative Materials**
  - WPDEE indicated that C-22 was preferred over Alloy 625 based on available short-term corrosion data
  - Current data from long-term corrosion testing are not able to differentiate between these two corrosion-resistant materials
  - Short-term tests under aggressive chemistries will be performed to differentiate the materials and obtain parameter values for the crevice corrosion model
  - Crevice corrosion probe will be developed to determine the pH (suppression) and chloride content (enhancement) in the crevice as corrosion proceeds as input to the model

Modifications to the Waste Package Materials Testing Program

(Continued)

- **Ceramic Testing Program**
  - WPDEE concern for flaking or spalling of ceramic coating will be eliminated by the utilization of backfill prior to closure
  - Program modified to emphasize density of coatings and resistance to handling loads
  - Coating composition will be adjusted to match thermal expansion requirements

Modifications to the Waste Package
Materials Testing Program
(Continued)

- Ceramic Testing Program (Continued)
  - Coatings will be generated by several thermal spray methods including high velocity oxy-fuel and detonation gun
  - Coatings will be tested to determine bond strength
  - Corrosion resistance will be determined for notched and un-notched specimens

Modifications to the Waste Package Materials Testing Program

(Continued)

- Cladding Testing Program
  - Several experts have suggested that credit be taken for cladding performance, however data under prototypic conditions are needed
  - Fuel performance tests are being initiated at ANL to study restraint of cladding on fuel expansion as a result of humid air and dripping water alteration
  - Mechanical tests are being planned to evaluate the the response of rod segments to rock loads
  - Zircaloy corrosion tests will be started shortly in the long-term corrosion test facility (supported by the Navy)

Modifications to the Waste Package Materials Testing Program

(Continued)

- Galvanic Protection
  - WPDEE concern that pits in corrosion-allowance material will be wide and not offer much galvanic protection to the corrosion-resistant material
  - However, the experience base on thick-walled carbon steel vessels and pipes is not conclusive regarding pit geometry
  - Long-term experiments were recently initiated under several environmental conditions to determine the degree of galvanic protection

Modifications to the Waste Package Materials Testing Program

(Continued)

- Galvanic Protection (continued)
  - Throwing power and the corrosion geometry particularly the pit geometry, will be evaluated
  - Specimens are couples of corrosion-allowance and corrosion-resistant materials
  - Vessel chemistry includes the concentrated solutions previously tested and a concrete modified chemistry utilized for the corrosion-allowance material vessels

Modifications to the Waste Package Materials Testing Program

(Continued)

- **Microbiologically Influenced Corrosion (MIC)**
  - MIC may be possible when the repository cools (<80°C) and the relative humidity increases (>60%)
  - Current experimental and analytical approach involves answers to an event tree of questions:
    - Are microbes present or can they enter later?
    - If they are present after 1,000 years, are there sufficient nutrients to permit microbial colonization?
    - Will they colonize on the corrosion-allowance material?
    - If they colonize, will they enhance corrosion rates?
  - Answers to these questions and development of models are being developed in cooperation with performance assessment

Summary

- In response to WPDEE concerns, modifications to the testing program have been made which address these concerns and focus on:
  - Corrosion-resistant material selection
  - Pitting of carbon steel and the viability of galvanic protection
  - Viability of ceramic coatings
- In response to other concerns, cladding will be tested and evaluated to determine whether cladding credit can be taken