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TRIP REPORT

SUBJECT: Saturated Zone Expert Elicitation Meeting (20-5708-861)

DATE/PLACE: June 4–6, 1997
Denver, CO

AUTHOR: Gordon Wittmeyer

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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Saturated Zone Expert Elicitation Meeting (20-5708-861)

DATE/PLACE: June 4–8, 1997
Denver, CO

AUTHORS: Gordon Wittmeyer

PERSONS PRESENT:

The expert elicitation meeting on Saturated Zone Flow and Transport at Yucca Mountain (SZEE) was attended by Neil Coleman and Latif Hamden from the NRC, and Gordon Wittmeyer from the CNWRA. The expert panel consisted of Allan Freeze (Consultant, British Columbia), Lynn Gelhar (Massachusetts Institute of Technology), Donald Langmuir (Colorado School of Mines, Emeritus), Shlomo Neuman (University of Arizona), and Chin Fu Tsang (Lawrence Berkeley National Laboratory). Those conducting the expert elicitation (methodology development team) included Kevin Coppersmith (Geomatrix), William Arnold (Sandia National Laboratories), Pat Tucci (USGS), Dwight Hoxie (USGS), Martha Pendleton (M&O/Woodward-Clyde), and Roseann Perman (Geomatrix). The names of the technical specialists who made presentations to the panel are listed in the attached agenda. Other attendees included were: John Stuckless (USGS), Linda Lehman (State of Nevada, consultant), John Kessler (EPRI), Victor Palciauskas (NWTRB, staff), Maureen McGraw (Golder and Assoc.), and Mary Hill (USGS).

BACKGROUND AND PURPOSE OF TRIP:

The Department of Energy (DOE) has been conducting a series of expert elicitation studies on the Yucca Mountain Project (YMP) to provide a basis for quantifying the present level of knowledge and uncertainty about key issues related to the performance of the waste repository system. This meeting, the first of the SZEE, was primarily conducted to familiarize the experts with the site-scale and regional-scale hydrogeology of Yucca Mountain (YM) and the Death Valley (DV) regional flow system, and to describe the nature, quantity, and to a lesser extent, the quality of the data used to support current conceptual flow models. The second SZEE meeting, to be held the week of July 21 at the Longstreet Inn in the Amargosa Desert, will focus on conceptual and numerical models of the site-scale and regional-scale groundwater flow systems. This meeting will feature a field trip for experts and technical specialists to important regional discharge and recharge sites. The third SZEE meeting, to be held in mid-August, will focus on the experts' preliminary interpretations of models and data and their significance to performance-related flow and transport issues. The experts will also be trained in elicitation methods at this meeting. Final reports will be submitted sometime early this fall.

SUMMARY OF ACTIVITIES:

The summary of presentations and discussions follows the final workshop agenda (attachments) except where the order of presentations was changed.

Wednesday, June 4, 1997 (1:00-5:00 pm)

Kevin Coppersmith (Geomatrix) opened the meeting by providing an overview of the purpose, scope, and schedule of the SZEE project (see attached overheads). Coppersmith stressed that these meeting were intended to provide information to the experts, but that 15 to 30 minutes would be set aside at the end of each day for observers and technical specialists to make comments and ask questions.

Martha Pendleton (M&O) provided an overview of the YM project and stressed that the role of the experts was to help assist in quantifying the present level of knowledge and uncertainty about key, performance-related issues. Apparently, DOE needs to have the expert's input prior to the issuance of the Total System Performance Assessment-Viability Assessment (TSPA-VA). From Pendleton's presentation it appears that DOE's WCIS now consists of four rather than five strategies. According to Pendleton, the "dilution" strategy has now been rolled into the "radionuclide concentration reduction" strategy. The experts, most of whom have some familiarity with the YMP, noted the increased infiltration rates now believed to exist at the site and the increased emphasis on robust waste packages and enhanced engineered barrier systems (EBS). The experts questioned the reduced role of the unsaturated zone (UZ) and increased role of the saturated zone (SZ) in demonstrating performance. Hoxie asserted that the increased role of the SZ in PA has more to do with the anticipated change in the standard from release- to dose-based rather than the reduced radionuclide transport times in the UZ.

Bill Arnold (SNL) discussed the schedule for the TSPA-VA, the role of TSPAs and the role of the SZEE. Arnold noted that the current schedule for the TSPA-VA requires that all models and parameters to be used must be finalized by the end of the FY. When asked by the panel why the stated performance period was 10,000 yrs, Arnold noted that the performance period could not be specified until the EPA standard was promulgated, but that a period as long as 1,000,000 yrs may be required to assess peak doses. A significant change in the TSPA approach to be used in the VA is the use of a site-scale (out to 30-km) three-dimensional (3D) flow and transport model, from which transport convolution functions will be abstracted. This technique is similar to that used in TSPA-93 for the 5-km boundary (conducted by SNL) but different from TSPA-95 (conducted by Intera). Arnold felt that the role of SZEE should be to determine the reasonableness of the saturated zone flow and transport model used in TSPA, suggest alternative models, help to generate appropriate parameter values and parameter distributions, and help with defensible flow and transport analyses.

Pat Tucci (USGS) provided a brief overview of SZ modelling and noted that the 3D site-scale flow model is currently being calibrated and that a report on this model will be submitted to DOE by June 16, 1997. John Czarnecki (USGS) is leading the team developing this model, which is based on FEHM with automatic calibration conducted using the PEST software package.

Claudia Faunt (USGS) presented an overview of the data contained in the USGS regional hydrogeologic geoscientific information system (GSIS) and how this computerized database was used in the development of the 3D regional flow model. The USGS GSIS is an integrated system consisting of a number of proprietary computer programs such as Intergraph MGE, Intergraph ERMA, ARC/INFO, Stratamodel SGM, and CPS-3. Six data categories were used to define the surface and subsurface hydrogeology of

the regional model including: (i) remote sensing (ii) vegetation and land use, (iii) soils, (iv) hydrology, (v) climate, and (vi) topography. Faunt described the general features of the MODFLOWP-based flow model and noted that its three layers were constructed to be "parallel" to the smoothed, but still undulating water table. The regional flow model has a uniform horizontal grid spacing of 1,500 m; however, the site-scale model being constructed by Czarnecki will have a horizontal grid spacing of 250 m.

Thursday, June 5, 1997 (8:30 am - 5:00 pm)

Claudia Faunt (USGS) continued her discussion of the regional hydrogeologic modelling effort by describing the sources of published hydraulic data entered in the GSIS database. There was intense interest on the part of several experts as to the source of the hydraulic conductivity data used in the model. According to Faunt, initial estimates of hydraulic conductivity values were obtained from a table prepared by Bedinger et al. (1989) that lists general hydrostratigraphic units in the DV region and defines a corresponding range or distribution for the unit's hydraulic conductivity. The experts appeared to be concerned that "raw" or measured hydraulic conductivities were not directly incorporated into the GSIS database and asked that someone provide them with a compilation of such data. Faunt stated that there was a large EXCEL spreadsheet of transmissivities and conductivities from pump tests that she could provide. In response to a question posed by one expert, Mary Hill (USGS) noted that the measured hydraulic conductivity data could not be kriged because of the extensive faulting within the region.

Amjad (MJ) Umari (USGS) described the hydraulic and tracer tests conducted at the C-Well complex. Umari noted that the USGS and Los Alamos National Laboratory (LANL) tracer tests are conducted using different techniques; the USGS uses radially converging tests, while LANL uses two-well, partial recirculation tests. Both tests appear to indicate dual-porosity behavior based on the shape of the breakthrough curve at late time (5,000 to 100,000 minutes). Umari stated that the polystyrene microspheres that were injected to simulate colloid transport do not diffuse into the rock matrix. Discussion on the hydraulic tests focussed on the role of local structural features such as the Midway Valley fault, which is intersected by the C-wells. Umari also noted the apparent inconsistency between the orientation of the drawdown ellipse and the orientation of the major principal axes of the measured transmissivity tensor. Neuman noted that more accurate interpretation of the pump tests could be made using the derivative of drawdown.

Grady O'Brien (USGS) discussed single borehole hydraulic tests conducted in WT-10, WT-12, and G-2. A fair amount of this discussion focussed on the techniques used to conduct the pump tests, rather than interpretation of the results. Pump test analyses were done using the Jacob-Cooper straight line method, which precludes estimating storativity. Frequency analyses of barometric and Earth tide responses were conducted in nine of the H-wells. None of the data or inferred hydraulic parameters from the H-wells can be tied to specific hydrostratigraphic units.

Frank D'Agnese (USGS) gave a brief description of the source of water level data and the construction of the regional water table surface. He suggested that this water table surface should not be confused with a true head map; however, it appeared that he felt that this water table surface was still helpful in developing an understanding of the regional flow system. In response to questions from the experts about vertical gradients, D'Agnese noted that in addition to data from UE-25 p#1, which shows the potential for upward flow from the Paleozoic carbonate aquifer into the tuffs at YM, Katy Kilroy (USGS, Carson City, NV) has reported that in the southern Amargosa Desert (south of Amargosa Farms?) measured heads increase with depth.

Robert Graves (USGS) gave a very detailed description of the methods used to monitor continuous water levels in boreholes at YM. Graves provided some description of water level response to seismic activity (Little Skull Mountain and Landers earthquakes), but not much interpretation.

John Czarnecki (USGS) gave an excellent presentation on his hypothesis that the 1,000 m water level in borehole G-2 (and perhaps WT-6 ?) probably indicates perched water and should not be used to infer a steep hydraulic gradient north of YM. His hypothesis is largely based on the apparent similarity of the drilling history in borehole UZ-14, where perched water was definitely encountered, to that of G-2. In borehole UZ-14, water was first encountered at 960 m (elevation msl) in the basal vitrophyre (Topopah Spring?). This zone was pumped and recovery was observed. After drilling resumed, water was again encountered at 630 m, which later rose to a level of 738 m. Czarnecki seemed to suggest that had an identical borehole construction method been used in G-2, a lower final head would have been observed. Additional supporting data include the presence of wet borehole walls above the water table, a permanent residual drawdown of 0.49 m, temperature logs suggestive of downward flow in the upper portion of the saturated zone, and the general observation that the chemistry in G-2 is less evolved than that at YM. Neuman appeared to endorse Czarnecki's argument, but suggested that careful plugging and redrilling be done in G-2 and UZ-14 to verify the hypothesis. O'Brien noted that the residual drawdown in G-2 is continuing to recover, albeit rather slowly.

John Czarnecki (USGS) discussed theories on the origin of water flowing beneath YM. Current conceptual models suggest that water is recharged at Pahute Mesa and Timber Mountain. Groundwater chemistry evolution curves of chloride and ^{14}C look very different in Pahute Mesa and YM. ^{14}C data at Pahute Mesa suggest that these waters are older than those at YM, which would imply that Pahute Mesa is not a recharge area for YM. A possible explanation may be mixing of younger water recharged along Fortymile Wash with water from Pahute Mesa; however, according to Czarnecki, chloride versus $\delta^{13}C$ plots for Pahute Mesa and YM preclude this. Czarnecki also discussed the possibility that Pinnacle Ridge, which forms the southern watershed boundary of westward draining Beatty Wash, may be a local groundwater divide between Timber Mountain and YM.

Chuck Savard (USGS) presented results from a series of studies conducted to estimate recharge along Fortymile Wash (see attached overheads). Savard studied four reaches of Fortymile wash. From north to south the channel reaches are: (i) Fortymile Wash narrows, (ii) Upper Jackass Flats, (iii) Lower Jackass Flats, and (iv) Amargosa Desert. Savard displayed numerous photographs that showed Fortymile prior to major flood events and the extent of lateral stream bank cutting and channel scour that occurred as result of the flow. Savard developed a simple regression model that relates the volumetric streamflow loss to the distance along Fortymile Wash using streamgage data, changes in moisture contents in UZ boreholes near the wash, and from groundwater level changes in boreholes following streamflow. Most recharge occurs in the Amargosa Desert reach where the channel's morphology changes from being well-incised to braided. Small volumes of water are recharged in the narrows area and in Lower Jackass Flats. In upper Jackass Flats the depth to water is too great (>300 m) to allow channel recharge. Savard estimates that total present-day recharge along these reaches of Fortymile Wash is 108,600 m^3/yr compared to a calibrated value of 8,100,000 m^3/yr obtained from the model of Czarnecki and Waddell (1984). Savard also noted that a stable isotope study conducted by Benson and Klieforth (1989) suggested that recharge along Fortymile wash last occurred 9,000-18,500 yrs ago.

Frank D'Agnese (USGS) presented a modification to the empirical Maxey-Eakin method that was used to estimate recharge for the regional groundwater flow model. Four potential recharge indicators were developed from the GSIS database: (i) altitude, (ii) slope-aspect, (iii) relative rock and soil permeability,

and (iv) vegetation. Each data type was used to produce a six-point recharge potential rating scale map, these were then overlaid to construct a composite recharge potential rating map and modified estimated recharge percentage zones. In general the modified Maxey-Eakin method produced larger estimates of recharge.

Frank D'Agnese (USGS) followed up his discussion on estimating areal recharge with a presentation on measured and estimated evapotranspiration (ET) at regional springs and areas with high plant transpiration or bare-soil evaporation. Detailed ET maps were constructed using data on vegetation type, vegetation density, soil classes, and spring locations. D'Agnese described detailed studies of ET that have been conducted at Franklin Lake Playa (22,800 m^3/d) and the Ash Meadows/Peter's Playa/Carson Slough area (74,600 m^3/d). Estimates for ET in DV, which is the largest discharge area, range from 40,000 to 400,000 m^3/d. Estimates of ET in Oasis Valley range from 7,000 to 17,000 m^3/d. In response to an expert's question about boundary conditions D'Agnese indicated that for the calibrated regional flow model underflow from the Pahranagat Lakes region east of Tickaboo Valley was estimated to be 15,000 m^3/d.

John Czarnecki (USGS) discussed his detailed experimental study of ET at Franklin Lake Playa. Numerous shallow boreholes were drilled in Franklin Lake Playa to obtain water level measurements. In the southern part of the playa, significant upward, vertical gradients were measured that in some cases produced flowing artesian conditions. Eddy-correlation station data, heat flux measurements, and neutron probe were all used to estimate an ET rate of 22,800 m^3/d. One interesting photograph showed Czarnecki perched on the mast of a pickup-truck mounted auger rig to measure the head in a guyed PVC well casing that rose approximately 2.5 to 3 m above the playa's surface.

Frank D'Agnese (USGS) presented data about regional spring discharge and regional pumping. Fairly good measurements of discharge appear to have been obtained at the larger regional springs such as those in Ash Meadows, Furnace Creek Ranch, Oasis Valley, Tecopa, Shoshone, Grapevine, and Oasis Valley. Smaller regional springs and flowing wells did not have measured discharge. Estimated pumping in Amargosa Desert during 1996 was 13,613 ac-ft, which is wholly based on the permitted irrigated area registered with the State of Nevada's Engineer's Office.

Friday, June 6, 1997 (8:30 am - 5:00 pm)

William Steinkampf (USGS) gave an overview of the collection methods used to obtain water samples from wells at YM for performing chemical analyses. Steinkampf described possible sources of errors in sampling such as degassing during lift and contamination with J-13 well water based drilling fluids. Steinkampf noted that some water samples were murky, which may indicate the presence of drilling mud. Zell Peterman noted that a lot of clay may be transported downward from the surface to the water table during recharge events and that this may explain the murkiness of the water samples. It was not clear whether Peterman was referring to transport of clay through the borehole and annulus or through the surrounding rock.

Zell Peterman (USGS) gave an excellent presentation describing isotope data and how it has been used to develop conceptual models of the regional and local groundwater flow systems. Although his presentation was focussed on isotope data, Peterman also discussed the use of major ion concentrations to evaluate hydrochemical heterogeneity. Calcium/magnesium to sodium/potassium ratios are generally larger near Fortymile wash than immediately below YM, which suggests that recharge does occur along Fortymile wash. Major ion chemistry indicates that waters in borehole VH-1 bear the chemical signature

of volcanic rocks while VH-2, which lies less than 2 km to the west in Crater Flat, bears the chemical signature of the Paleozoic carbonate rocks. These differences may be due to local lenses of carbonates or carbonate-derived alluvium in the area of VH-2 or from mountain front recharge along the eastern flank of Bare Mountain. Deuterium and $\delta^{18}O$ values for VH-1 and VH-2 also show marked differences. Peterman displayed a map of $^{87}Sr/^{86}Sr$ values measured from regional springs and wells throughout the DV region. These data were presented as $\delta^{87}Sr$ with respect to Standard Mean Ocean Water (SMOW) to magnify local and regional variations. The strontium data suggest that springflow along the northern portion of the Ash Meadows springline may be derived from the Spring Mountains. Data from the southern springs in Ash Meadows have distinctly higher $\delta^{87}Sr$ values. Waters in Fortymile wash have $\delta^{87}Sr$ values around 3-5, while waters beneath YM are in the range of 0-1, again indicative of recharge along Fortymile wash. Peterman presented a plot of $\delta^{87}Sr$ versus $(Ca^{2+}+Mg^{2+})/(Na^{+}+K^{+})$ that showed a very strong linear correlation. Peterman also noted that $\delta^{13}C$ data at YM suggest upward flow from the carbonate aquifer.

Ed Kwicklis (USGS) gave a very detailed presentation about the methods used to correct ^{14}C data from the immediate YM area (attached overheads). Early in his presentation Kwicklis asserted that the ^{14}C data showed little evidence of contamination from polymer-based drilling mud, an assertion that Bill Steinkampf vehemently disagreed with. After explaining how the data were corrected using the NETPATH carbon mass-balance program, Kwicklis outlined the major conclusions that can be drawn from the corrected age dates. Kwicklis claims that plots of chloride versus deuterium indicate little mixing between the Paleozoic carbonate aquifer and the volcanic aquifer, which eliminated mixing as a source of ^{13}C in the tuff aquifer. Corrected ^{14}C indicate that water west and south of YM is 10,000 to 12,000 yrs old, water beneath central and northern YM is 6,000 to 8,000 yrs old, and water east and southeast of YM, beneath Fortymile Wash is 4,000 to 7,000 yrs old.

Jim Paces (USGS) described the work he and his colleagues have conducted on paleodischarge sites throughout the DV region. In particular Paces discussed the Lathrop Wells diatomites, fossil spring mounds in the southwestern Amargosa Desert, and data from old, hand-dug wells in the Stateline spring deposits. Paces noted that $\delta(^{87}Sr/^{86}Sr)$ data in the southern Amargosa Farms area are vertically stratified suggesting that there is no mixing with water discharged at Ash Meadows. Paces followed up on Zell Peterman's discussion of VH-1 and VH-2 noting that the differences in chemistry are consistent with the presence of a buried dike along the Red Cone, Black Cone, and Little Cone trend.

John Sass (USGS) discussed interpretations of regional heat flow data that have been collected in the YM and DV regions. He noted that the heat flow low that exists over the immediate repository area is indicative of downward flow of water. In response to a question from Neuman, Sass agreed that the temperature profiles in the UZ above YM suggest pure conduction, and that the downward movement of water and resultant decrease of the vertical temperature gradient probably occurs in the saturated zone. At UE-25 p#1, where head data show a strong vertically upward gradient from the Paleozoic carbonate aquifer to the overlying tuffs, the temperature profile suggests that water flow is not 1D; flow in the carbonate aquifer may be predominantly lateral.

Bill Dudley (USGS) continued the discussion of the regional heat flow data with emphasis on how these data were used to construct a conceptual model for the steep hydraulic gradient at YM (attached overheads). The YM heat flow low was used to infer downward flow of water from the tuff aquifer to the underlying carbonate aquifer in the region of the steep hydraulic gradient.

Rick Forester (USGS) discussed the data that have been used to infer past climate change in the DV region. The primary evidence comes from ostracodes, diatoms, and packrat middens. Differences in the predominance of different ostracode taxa can be used to determine if the local environment was paludal, lacustrine, or riparian and if the water temperatures were warm or cool. Forester believes the Lathrop Wells diatomite deposits were formed during relatively warm, wet periods. Moreover, the siliceous frustules secreted by the diatoms indicate that the discharging water came from the silica-rich volcanics. Forester speculated that the next full glacial period may be relatively warm, unlike those that occurred approximately 175, 200, and 350 ka. He also estimated that during the Pleistocene winter precipitation was 3.4 times greater than today, while summer precipitation was only 1.2 times greater than today. Mean annual temperatures during the Pleistocene were 5-6 C lower than today.

Inés Triay (LANL) discussed the results of laboratory experiments on the sorption and matrix diffusion of radionuclides in tuff core samples. I did not attend this presentation. See the attached overheads for more information.

David Vaniman (LANL) discussed saturated zone mineralogy at YM. I did not attend this presentation. See attached overheads for more information.

Arend Meijer (LANL) discussed some hydrochemical influences on saturated zone transport of radionuclides at YM. Meijer stated that in water with a pH of 7 ^{237}Np and ^{99}Tc occur in their reduced state at redox potentials at 100 and 200 mV, respectively. Although YM waters appear to be oxidizing in general (+225 mV), borehole H-3 had a measured redox potential of -143 mV and detectable concentrations of methane. Waters in borehole H-6, on the other hand, were very oxidizing having a measured redox potential of +395 mV. Meijer finished his brief presentation by stressing that obtaining accurate measurements of *in situ* redox potentials was very important to determining the performance of the repository.

CONCLUSIONS:

Although the primary purpose of this meeting was to provide the SZEE panel with detailed information on the type, quantity, and quality of data for the saturated zone, there was considerable discussion of current conceptual models of the regional flow system. It was apparent from the presentations that there are still regional hydrogeologic phenomena for which a single, well-accepted explanation has yet to be developed. There is still great uncertainty about the cause of the steep hydraulic gradient, the age of waters recharged along Fortymile Wash, the volume of water currently recharged along Fortymile Wash, and the degree of mixing between waters from the Paleozoic carbonate and Tertiary tuff aquifers. The experts appeared to be well aware of the subject areas where professional differences of opinion exist and those uncertainties that apparently cannot be resolved unless further investigations are conducted. Although the panel has been charged with helping DOE to quantify the degree of uncertainty associated with the conceptual models used in their TPA code, comments from the experts suggested that at least at this stage of the expert elicitation process, they are more focussed on examining the underlying science.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

RECOMMENDATIONS:

None

SIGNATURES:

Gordon W. Wittmeyer
Senior Research Scientist

6/26/97
Date

CONCURRENCE:

English C. Pearcy, Manager
Geohydrology/Geochemistry, Element

6/27/97
Date

Budhi Sagar
Technical Director

6/27/97
Date

GEOMATRIX

FINAL AGENDA

WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA SATURATED ZONE EXPERT ELICITATION (SZEE) PROJECT

June 4-6, 1997
Building 810, Core Research Center Lecture Hall
Denver Federal Center

Purpose: The purpose of the workshop is to introduce the expert panel to the SZEE project, to summarize the significant issues related to the saturated zone process models for the total system performance assessment (TSPA), and to summarize the various available data sets related to these significant issues.

Approach: Significant issues will be discussed that have emerged from previous modeling of the saturated zone flow and transport system and from incorporation of that modeling into the TSPA. The bulk of the workshop will entail presentations and discussions of the various data developed over the past several years to characterize the saturated zone in the Yucca Mountain region. The workshop provides an opportunity for the experts on the panel to gain a first-hand understanding of the data, their uncertainties, and the course of the remainder of the project.

WEDNESDAY, JUNE 4

1:00 - 1:05	Welcome (T. Bjerstedt, DOE)
1:05 - 1:45	Introduction to SZEE and Purpose of Workshop (K. Coppersmith, Geomatrix)
1:45 - 2:15	Overview of Yucca Mountain Project (M. Pendleton, M&O)
2:15 - 3:00	SZ Flow and Transport: Issues of Importance to Total System Performance Assessment (W. Arnold, SNL)
3:00 - 3:15	**Break**
3:15 - 4:00	Overview of Site and Regional Hydrology & Modeling (P. Tucci, USGS)
4:00 - 4:45	Regional and Site Hydrogeologic Framework (C. Faunt, USGS)
4:45 - 5:00	**Comments from Observers**

THURSDAY, JUNE 5

HYDRAULIC CHARACTERISTICS

8:30 - 9:00	Previously Published Regional and Site Hydraulic Data (C. Faunt, USGS)
9:00 - 9:45	C-Well Testing (M.J. Umari, USGS)
9:45 - 10:15	WT-Well and G-2 Testing, and Frequency-Response Analysis (G. O'Brien, USGS)
10:15 - 10:30	**Break**

WATER LEVEL DATA AND TRENDS

10:30 - 11:00	Regional Water-Level Data and Estimated Potentiometric Surface (F. D'Agnese, USGS)

11:00 - 11:30 Water-Level Data and Trends at Yucca Mountain (R. Graves, USGS)
11:30 - 12:00 Water-Level Data at Well USW G-2 and Possible Implications (J. Czarnecki, USGS)
12:00 - 1:00 Lunch

RECHARGE

1:00 - 1:30 Recharge in the Yucca Mountain Area (J. Czarnecki, USGS)
1:30 - 2:00 Fortymile Wash Recharge Estimates (C. Svard, USGS)
2:00 - 2:45 Regional Recharge Estimates Using a Modified Maxey-Eakin Approach (F. D'Agnese, USGS)

DISCHARGE

2:45 - 3:15 Regional Evapotranspiration Estimates Using Remote Sensing and 3-D GIS (F. D'Agnese, USGS)
3:15 - 3:30 Break
3:30 - 4:00 Evapotranspiration at Franklin Lake Playa (J. Czarnecki, USGS)
4:00 - 4:30 Regional Springs and Pumpage (F. D'Agnese, USGS)
4:30 - 4:45 Comments from Observers

FRIDAY, JUNE 6

HYDROCHEMISTRY

8:30 - 9:15 Site and Regional Hydrochemical Data (W. Steinkampf, USGS)
9:15 - 10:00 Isotope Data (Z. Peterman, USGS)
10:00 - 10:15 Break
10:15 - 10:45 Radiocarbon Data (E. Kwicklis, USGS)

PALEODISCHARGE

10:45 - 11:15 Isotopic Data (J. Paces, USGS)

HEAT FLOW

11:15 - 12:00 Regional Data (W. Dudley, USGS)
12:00 - 1:00 Lunch
1:00 - 1:30 Regional Setting and Available Temperature/Heat Flow Data (J. Sass, USGS)

CLIMATE CHANGE

1:30 - 2:00 Scenarios (R. Forester, USGS)

RADIONUCLIDE SORPTION AND SOLUBILITY

2:00 - 2:45 Laboratory Sorption and Diffusion Studies (I. Triay, LANL)
2:45 - 3:00 Break
3:00 - 3:30 SZ Mineralogy (D. Vaniman, LANL)
3:30 - 4:00 Hydrochemical influences (A. Meijer, LANL)
4:00 - 4:30 Where do we go from here? (K. Coppersmith)
4:30 - 5:00 Comments from Observers
5:00 Adjourn

OVERVIEW OF PROCESS AND GUIDELINES FOR WORKSHOPS

WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA

SATURATED ZONE EXPERT ELICITATION (SZEE) PROJECT

Kevin J. Coppersmith
Geomatrix Consultants

June 4-6, 1997
Bldg 810, Core Research Center Lecture Hall
Denver Federal Center

SZEE PROJECT ORGANIZATION

- **Experts:** technical experts who provide their judgments regarding saturated zone flow and transport at Yucca Mountain
- **Methodology Development Team (MDT)**: a team that designs, conducts, and manages the project
- **Technical Specialists**: individuals who provide and present specialized data and interpretations to the experts; members of the expert panel may also be technical specialists
- **Facilitators**: individuals who elicit the judgments of the experts; includes technical facilitators and normative experts

METHODOLOGY DEVELOPMENT TEAM (MDT)
SZEE PROJECT

Bill Arnold	Sandia National Laboratories
Kevin Coppersmith	Geomatrix
Dwight Hoxie	U.S. Geological Survey
Peter Morris	Applied Decision Analysis
Russ Patterson	Department of Energy
Martha Pendleton	M&O/Woodward-Clyde
Roseanne Perman	Geomatrix
Pat Tucci	U.S. Geological Survey
Bob Youngs	Geomatrix

SZEE PROCEDURES

The principal steps in the SZEE project are as follows:

1. Selecting the Expert Panel

2. Meetings of the Expert Panel

3. Elicitation of Expert Interpretations

4. Feedback and Finalization of Interpretations

5. Documentation

SELECTING THE SZEE EXPERT PANEL

Goal: To identify a group that: *individually* consists of experts who evaluate a full range of possible models and parameters, and *collectively* express a diverse range of views

Selection Process

1. Candidates obtained by seeking nominations from knowledgeable individuals who are actively involved in related research studies.

2. Names of individuals nominated compiled into a pool of candidates.

3. Five experts selected by the MDT in accordance with the selection guidelines, with special consideration given to balancing the panel to include experts with different areas of technical expertise and institutional/organizational backgrounds.

SZEE EXPERT SELECTION CRITERIA

1. Engineer or scientist having a good professional reputation and widely recognized competence based on academic training and relevant experience. Tangible evidence of expertise, such as written documentation of research in refereed journals and reviewed reports is required.

2. Understanding of the problem area through experience in one or more of the following areas: field and laboratory methods for characterizing and/or methods for analyzing and numerically modeling groundwater flow and radionuclide transport in saturated fractured rock. Individuals that have had a major role in the Yucca Mountain Site Characterization Project may be included on the expert panel, however, such experience is not a requirement for participation.

3. Availability and willingness to participate as a named panel member, including a commitment to devoting the necessary time and effort to the project and a willingness to explain and defend technical positions.

4. Personal attributes that include strong communication and interpersonal skills, flexibility and impartiality, and the ability to simplify. Individuals will be asked specifically <u>not</u> to act as representatives of technical positions taken by their organizations, but rather to provide their individual technical interpretations and assessments of uncertainties.

5. Help to provide a panel balanced to include experts with diverse opinions, areas of technical expertise and institutional/organizational backgrounds (e.g., from government agencies, academic institutions, and private industry).

MEMBERS OF THE SZEE EXPERT PANEL

Allan Freeze	Consultant
Lynn Gelhar	Massachusetts Institute of Technology
Don Langmuir	Colorado School of Mines, Emeritus
Shlomo Neuman	University of Arizona
Chin-Fu Tsang	Lawrence Berkeley National Laboratory

EXPERT *ROLES*

EVALUATOR

An evaluator is capable of listening to, understanding, interpreting, and evaluating the relative credibility of alternative models and interpretations. An evaluator recognizes that uncertainties exist and he/she expresses those uncertainties by assigning weights to alternative models and parameter values, based on his/her interpretation of the available data.

PROPONENT

A proponent is an advocate of a particular model, hypothesis, or point of view. It is common for scientists to act as proponents for ideas that they believe are most consistent with the available data. A proponent does not recognize the credibility of alternative hypotheses and does not focus on quantifying uncertainties.

TECHNICAL FACILITATOR/INTEGRATOR (TFI)

A TFI is an individual or small team that is responsible for facilitating the interactions of multiple evaluator experts and for integrating their interpretations.

MEETINGS OF THE SZEE EXPERT PANEL

Structured, facilitated interaction among the members of the expert panel will occur in three two-to-three-day workshops designed to focus on the following:

Workshop #1 Significant Issues and Available Data (June 4-6, 1997)

- Identification of the technical issues that have been identified related to saturated zone flow and transport.
- Presentation and discussion of the data that are available to address the technical issues, including both Yucca Mountain and analogue data sets.

Workshop #2 Alternative Models and Interpretations (Mid-July, 1997)

- Presentation and discussion of alternative methods, conceptual models, and parameters consistent with the data
- Presentation and discussion of interpretations by technical specialists and proponents of alternative models.

Workshop #3 Preliminary Interpretations (Mid-August, 1997)

- Presentation and discussion of preliminary expert interpretations related to key issues regarding SZ flow and transport. Discussion of technical basis for assessments and estimates of uncertainty. Technical challenge and open debate of issues/models/uncertainties will be encouraged

- Elicitation training: methods of eliciting expert interpretations, including methods for quantifying uncertainties.

ELICITATION OF EXPERT INTERPRETATIONS

Elicitation Interviews

- One-day interviews with each expert following Workshop #2
- Elicitation team: generalist, specialist, normative expert
- Quantification of uncertainties regarding key technical issues
- Documentation of assessments

Feedback

- Following elicitation interviews, feedback package will provided to experts consisting of:
    - Elicitation summaries for all experts
    - Summary of assessments for key issues across entire panel
    - Calculations and sensitivity analyses
- Experts will have opportunity to review feedback and revise/refine their interpretations

Documentation

- Elicitation summaries will be the primary documentation by each expert
- SZEE report will document process, summarize assessments, and include summaries

EXPERT ELICITATION STUDIES ON THE YUCCA MOUNTAIN PROJECT

Multiple- expert elicitation studies provide a basis for quantifying the present level of knowledge and uncertainty about key issues related to the performance of the waste repository system and to design of the facility.

RECENT AND ONGOING STUDIES

- Probabilistic Volcanic Hazard Analysis
- Probabilistic Seismic Hazard Analysis (ground motions and fault displacement)
- Unsaturated Zone Flow Model
- Waste Package Degradation
- Saturated Zone Flow and Transport

PLANNED STUDIES

- Drift-scale Thermo-hydrology
- Waste-form Dissolution and Near-field Transport

GROUND RULES FOR WORKSHOPS

1. The workshops are an opportunity for the Expert Panel to:

- Exchange data
- Present interpretations
- Challenge and defend technical hypotheses
- Be trained in elicitation procedures
- Gain information on the project
- Interact and ask questions

Therefore, the focus of each workshop is the *Expert Panel*

2. The MDT runs the workshops and is responsible for keeping to the schedule, logistics, etc.
3. The conduct of the technical discussions at the workshops will be at the highest professional level. Personal attacks or confrontations will not be permitted (especially those directed at the MDT)
4. Discussions will be among the Expert Panel and the Presenters
5. Observers are provided with a period each day for brief statements or questions (3 minutes each)
6. If an Observer has a burning question, please write it down and give to a member of the MDT; they will attempt to have it answered during the course of the discussions
7. The data bases supplied to the Expert Panel will not be supplied to the Presenters or Observers; a list of all materials supplied will be available
8. A workshop summary will be supplied to all workshop participants who have signed in

WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA

Purpose of Workshop

- Introduce expert panel to SZEE project
- Summarize key issues related to SZ in TSPA
- Summarize available data sets related to the key issues

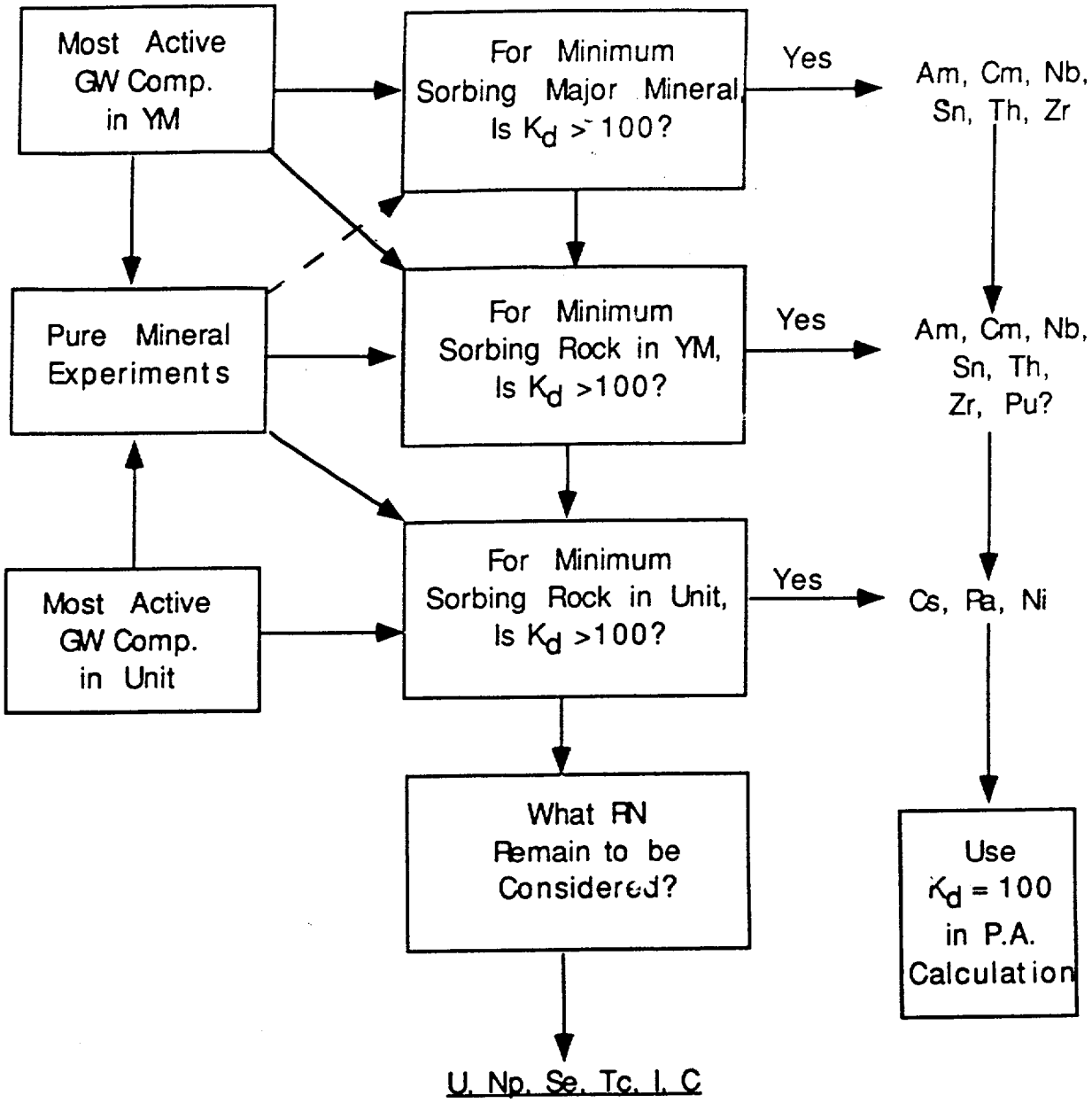
Approach

- Introductory talks describing Yucca Mountain project
- Key issues regarding SZ flow and transport that have emerged from modeling and TSPA
- Presentations and discussions of data developed for YMP
- Questions and discussions of data by panel encouraged

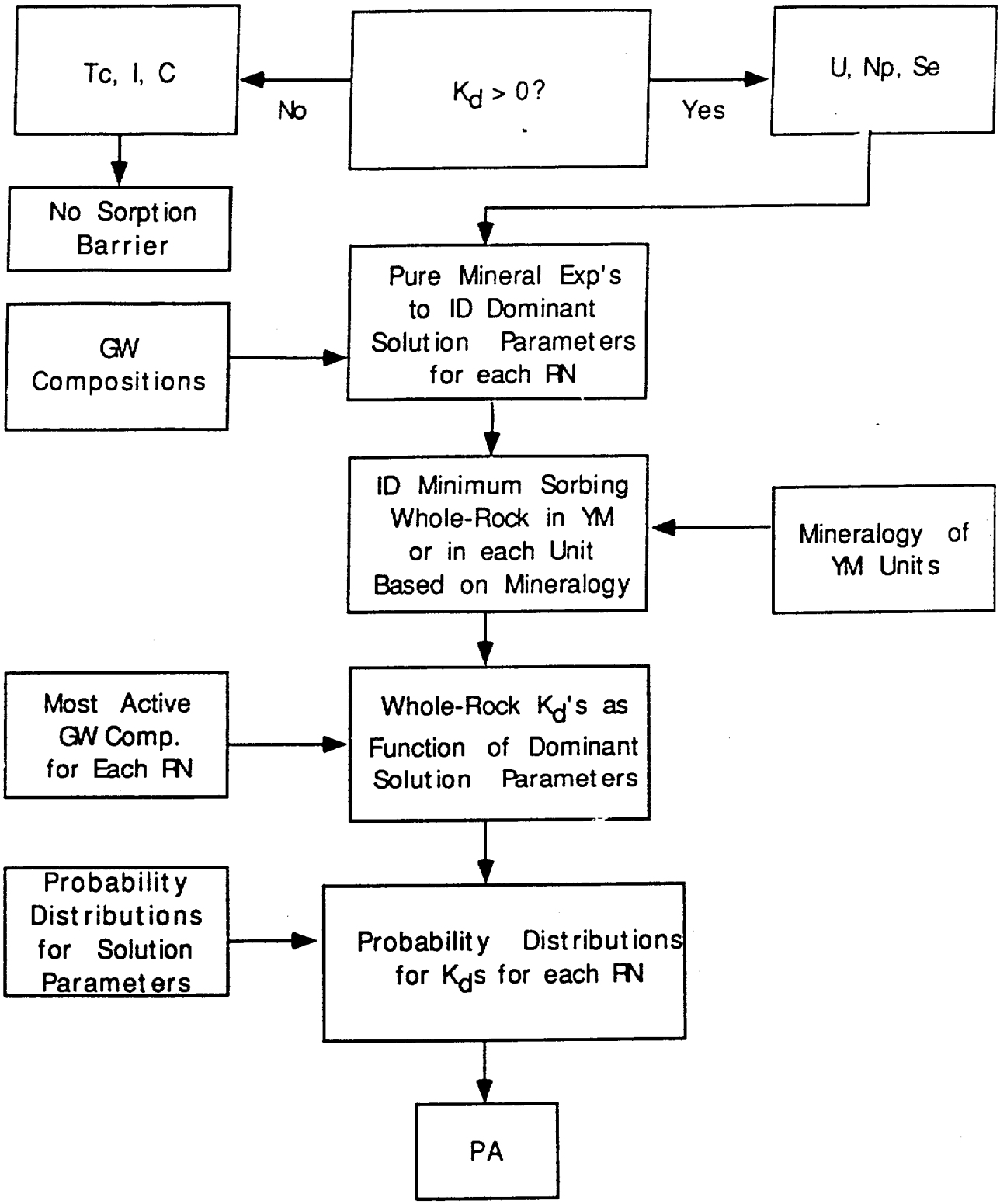
Status and Priorities Regarding Sorption of Long-Lived Radionuclides

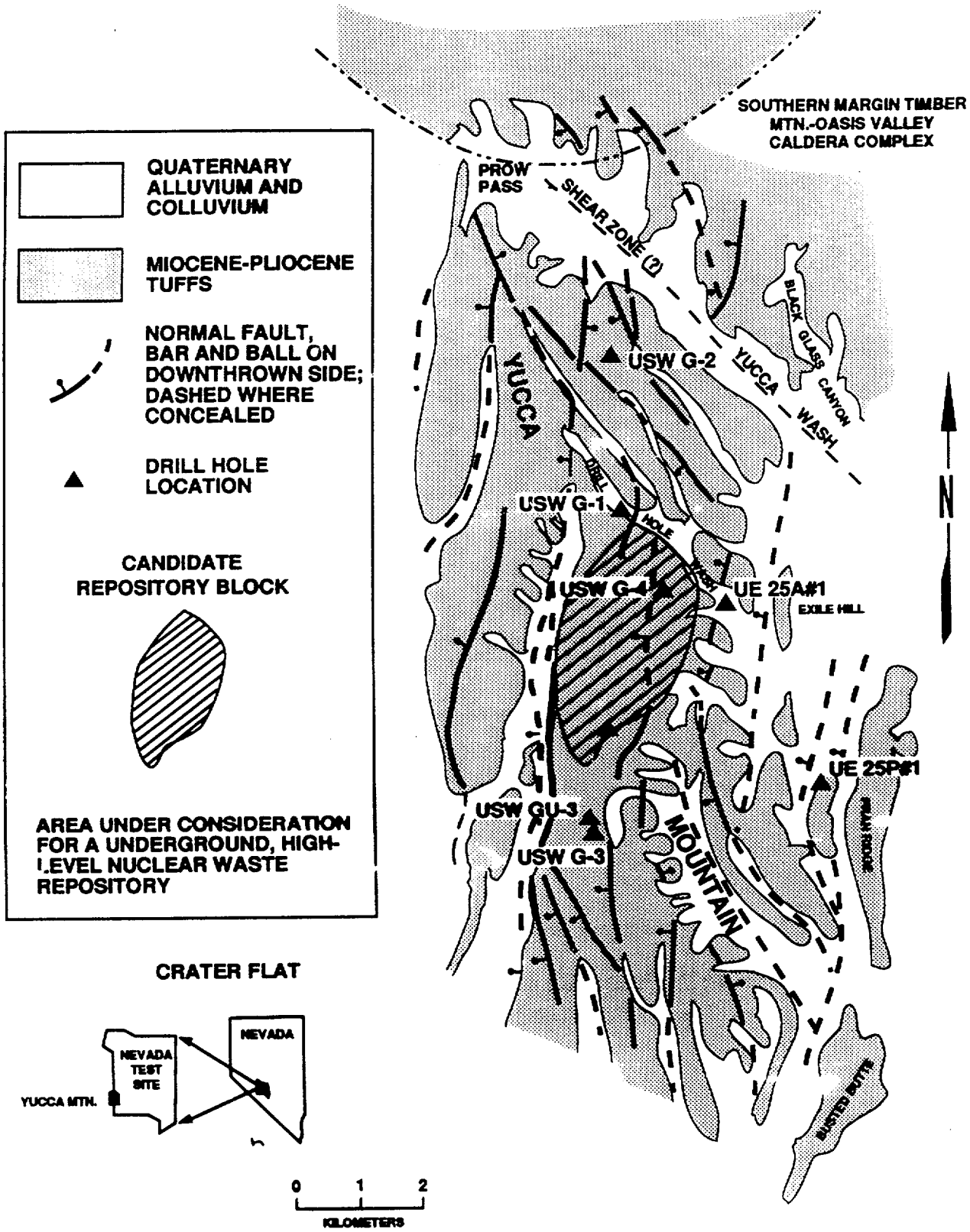
Inés R. Triay
LANL

MINIMUM K_d STRATEGY

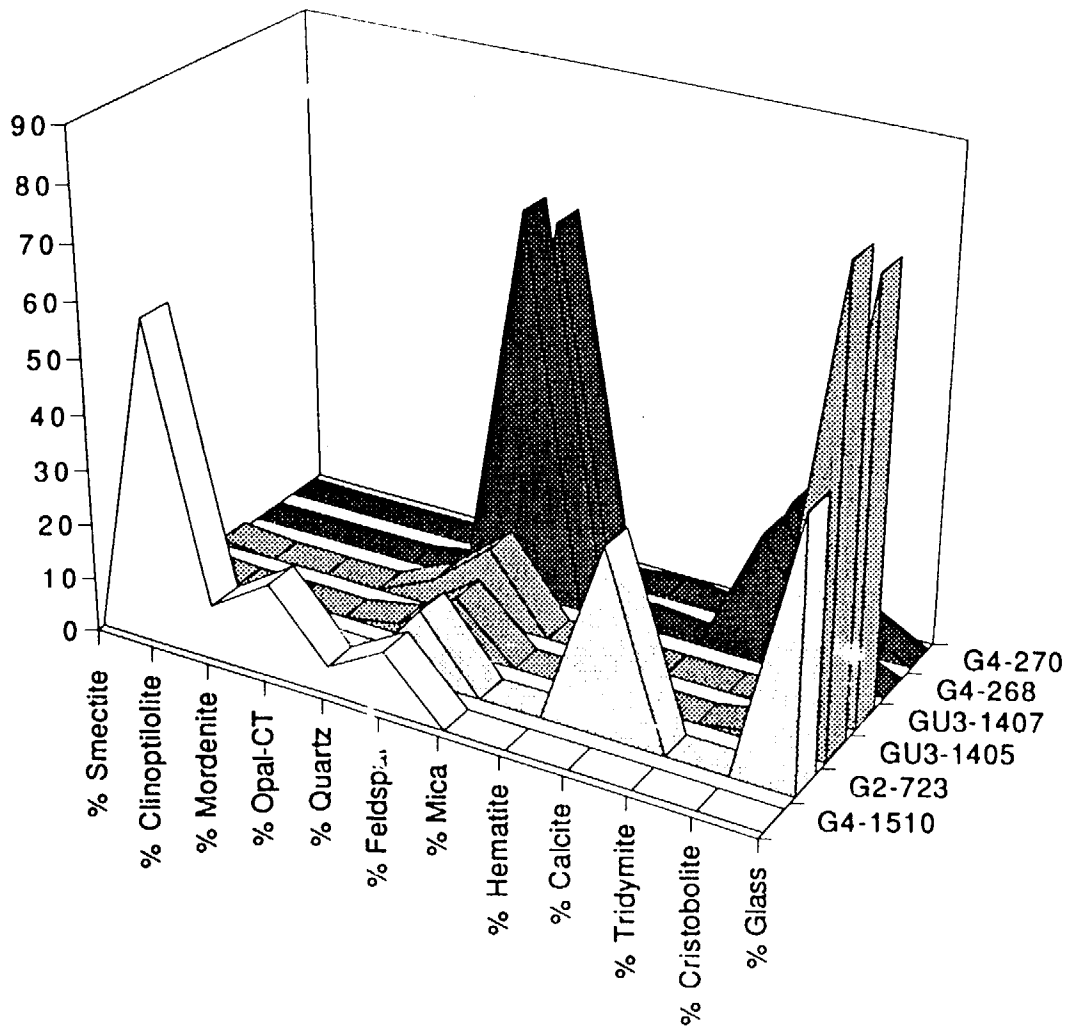


STRATEGY FOR "POORLY SORBING" RN (i.e., U, Se, Np, Tc, I, C)




QUATERNARY ALLUVIUM AND COLLUVIUM
MIOCENE-PLIOCENE TUFFS
NORMAL FAULT, BAR AND BALL ON DOWNTHROWN SIDE; DASHED WHERE CONCEALED
DRILL HOLE LOCATION
CANDIDATE REPOSITORY BLOCK
AREA UNDER CONSIDERATION FOR A UNDERGROUND, HIGH-LEVEL NUCLEAR WASTE REPOSITORY
CRATER FLAT
NEVADA
NEVADA TEST SITE
YUCCA MTN.
SOUTHERN MARGIN TIMBER MTN.-OASIS VALLEY CALDERA COMPLEX
PROW PASS
SHEAR ZONE (?)
BLACK GLASS CANYON
YUCCA WASH
YUCCA
USW G-2
USW G-1
USW G-4
UE 25A#1
EXILE HILL
UE 25P#1
USW GU-3
USW G-3
MOUNTAIN
BUSTED BUTTE
N
0 1 2
KILOMETERS

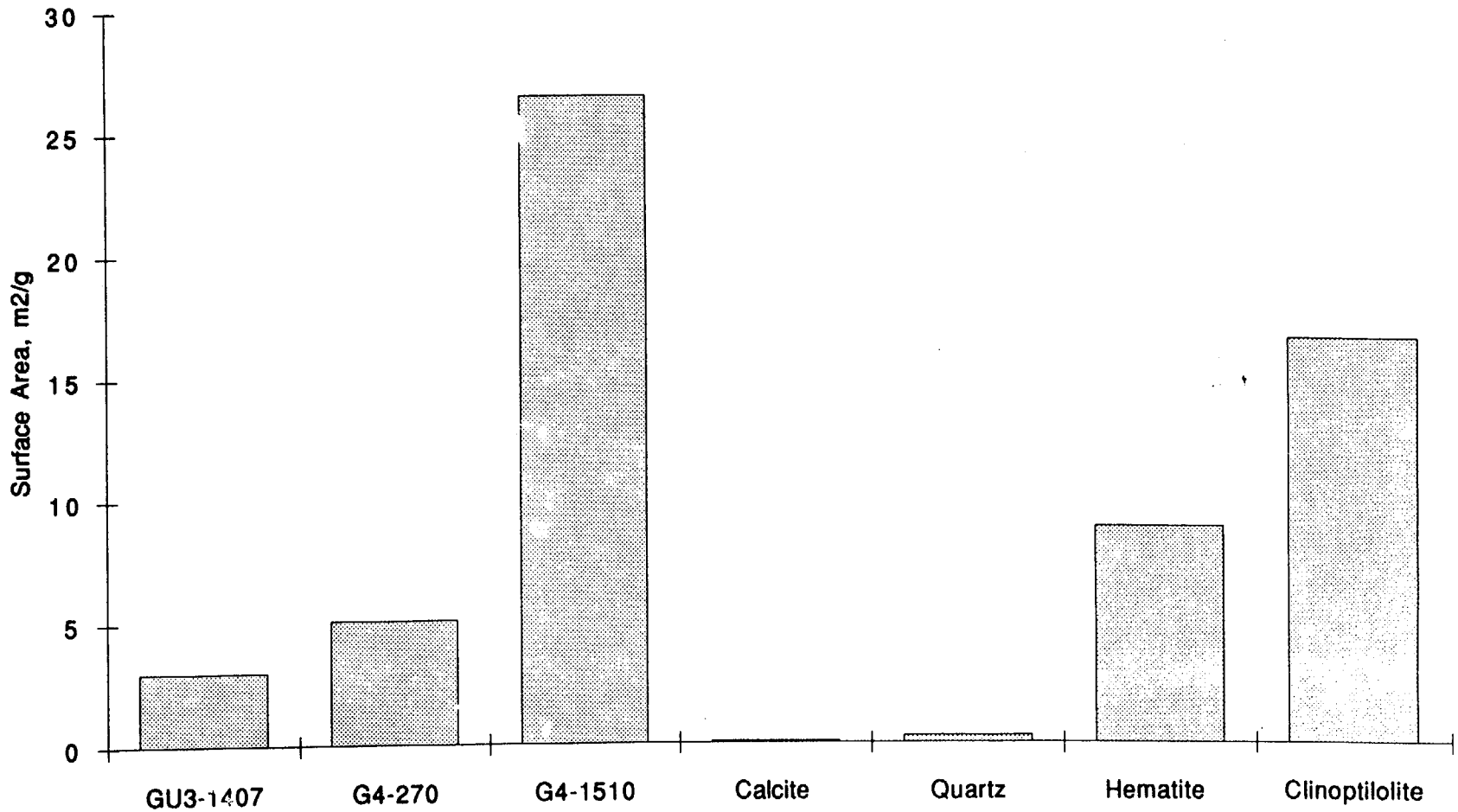
Mineralogy of Tuff Samples



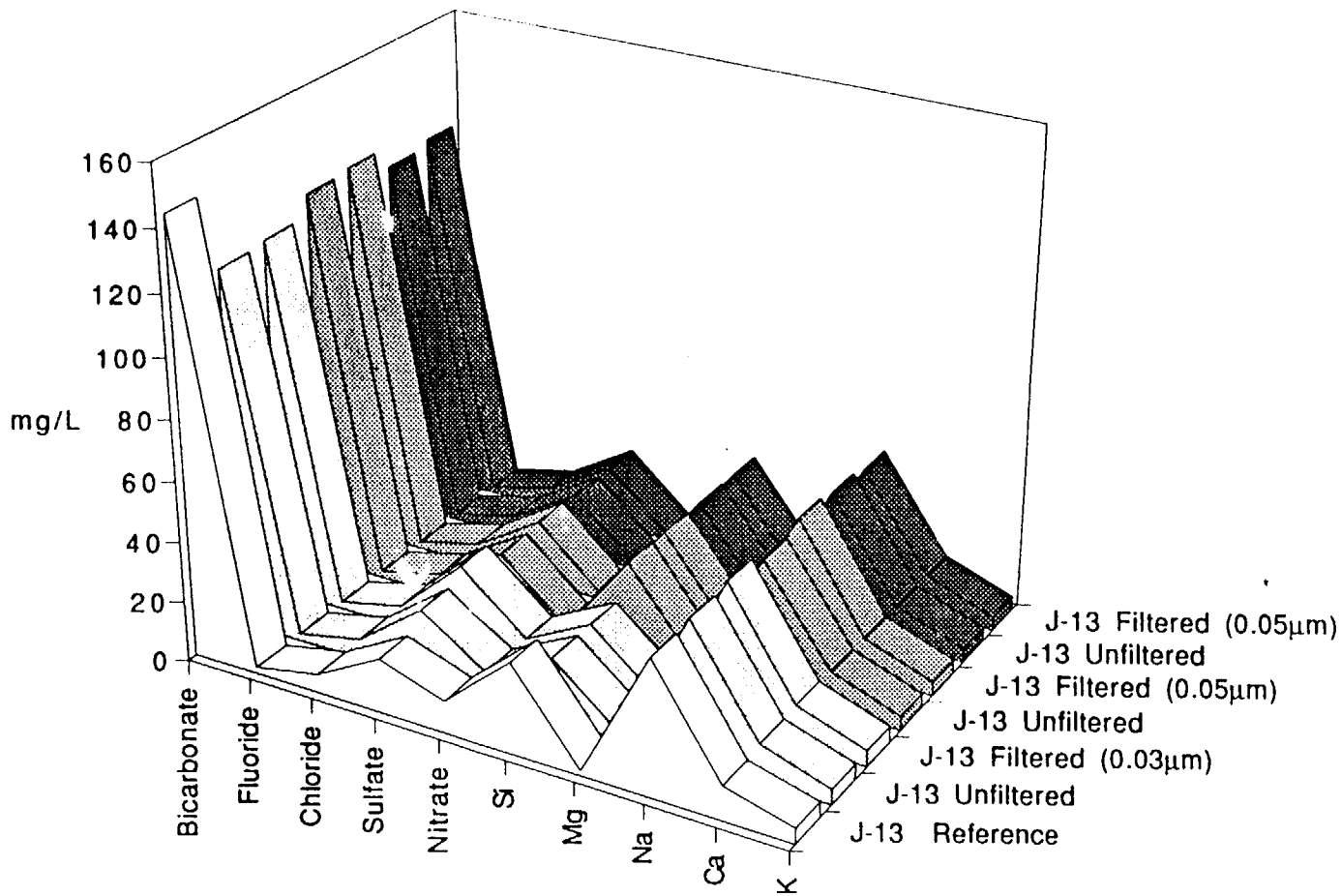
XRD Data Plotted for Tuffs Wet Sieved with J-13 (if available); G2-723 Dry Sieved; GU3-1405 Not Ground

Surface Area of Tuffs and Minerals

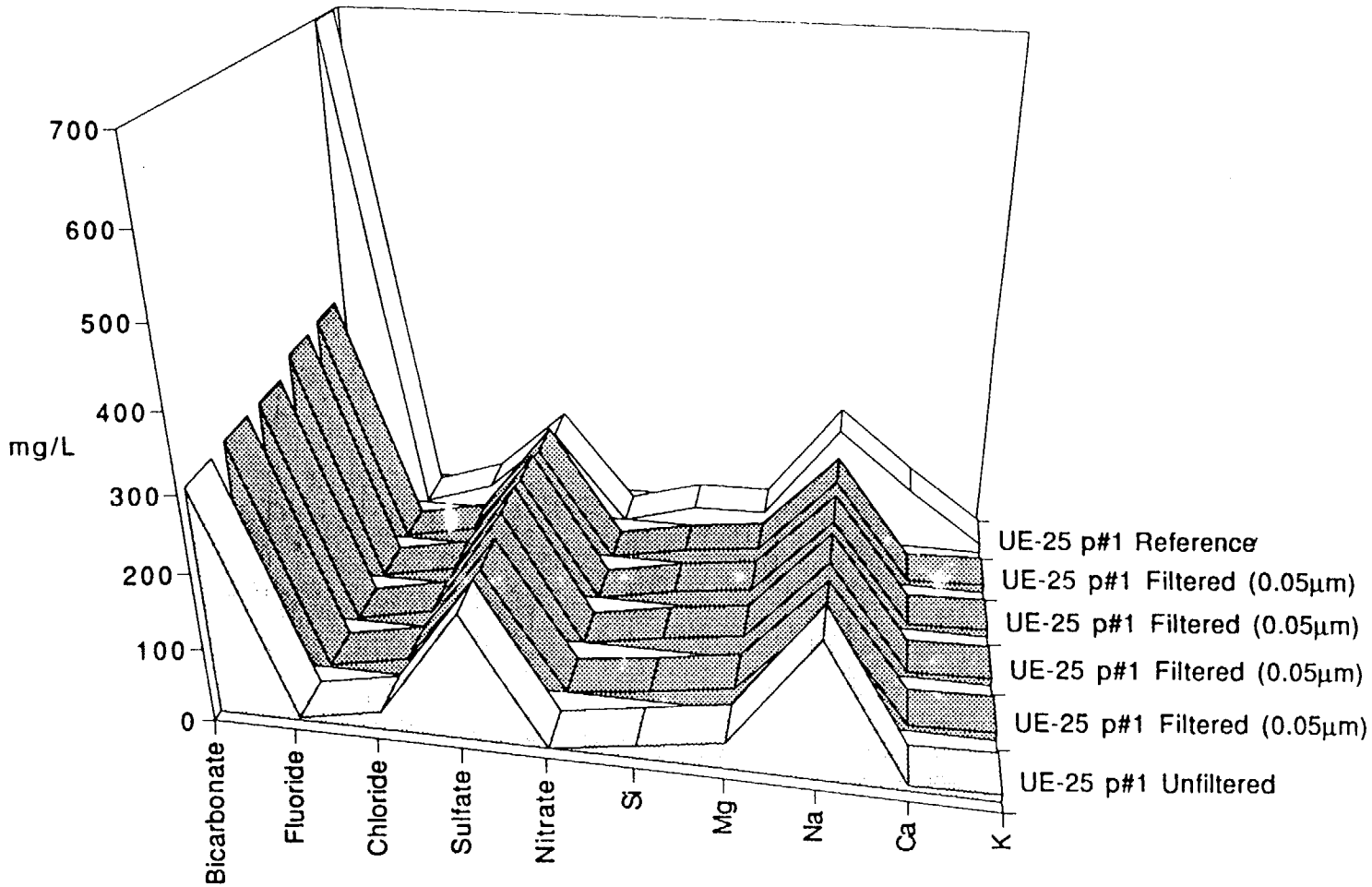
BET Data Plotted for Wet-Sieved Samples; Hematite and Clinoptilolite Not Sieved

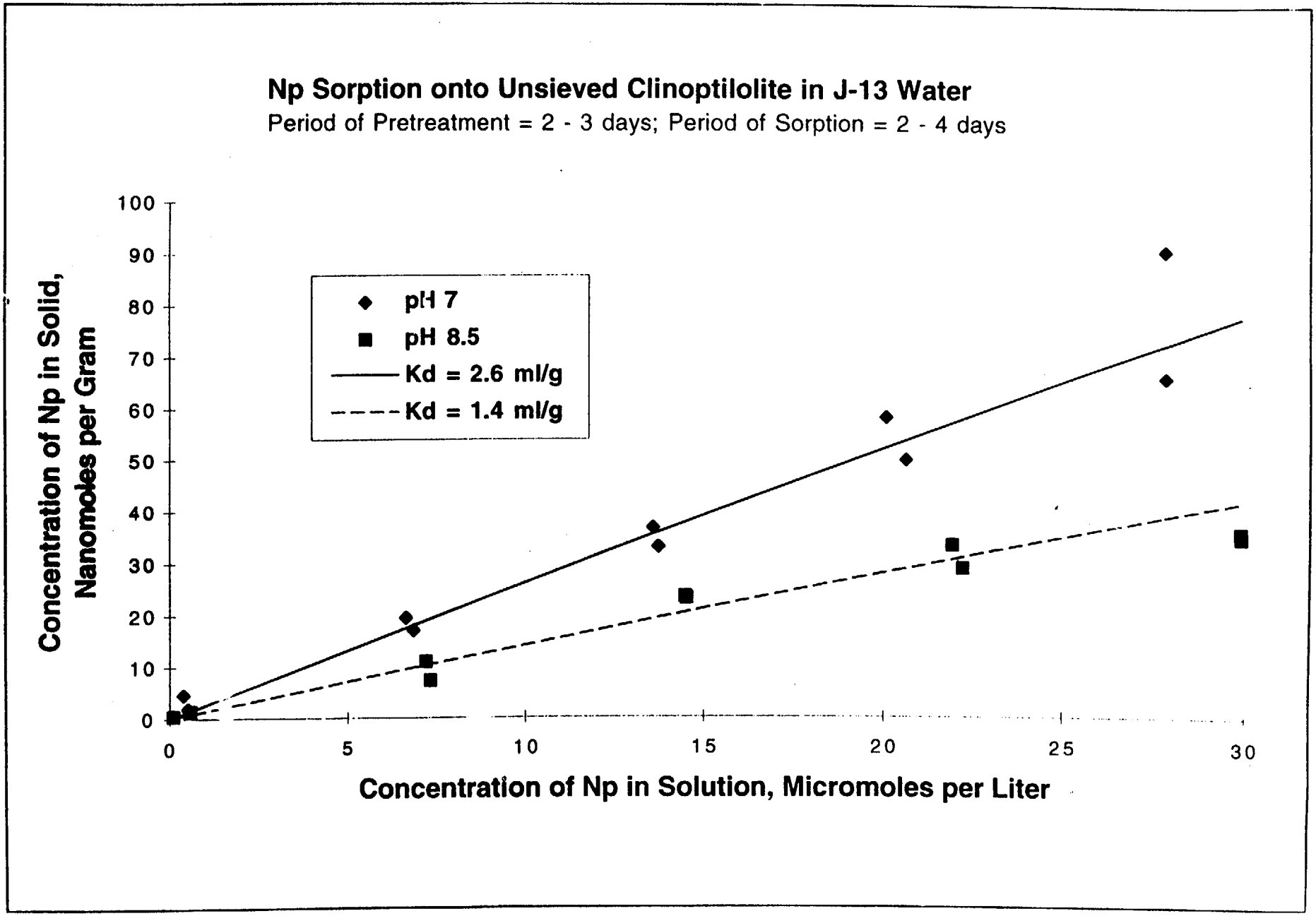


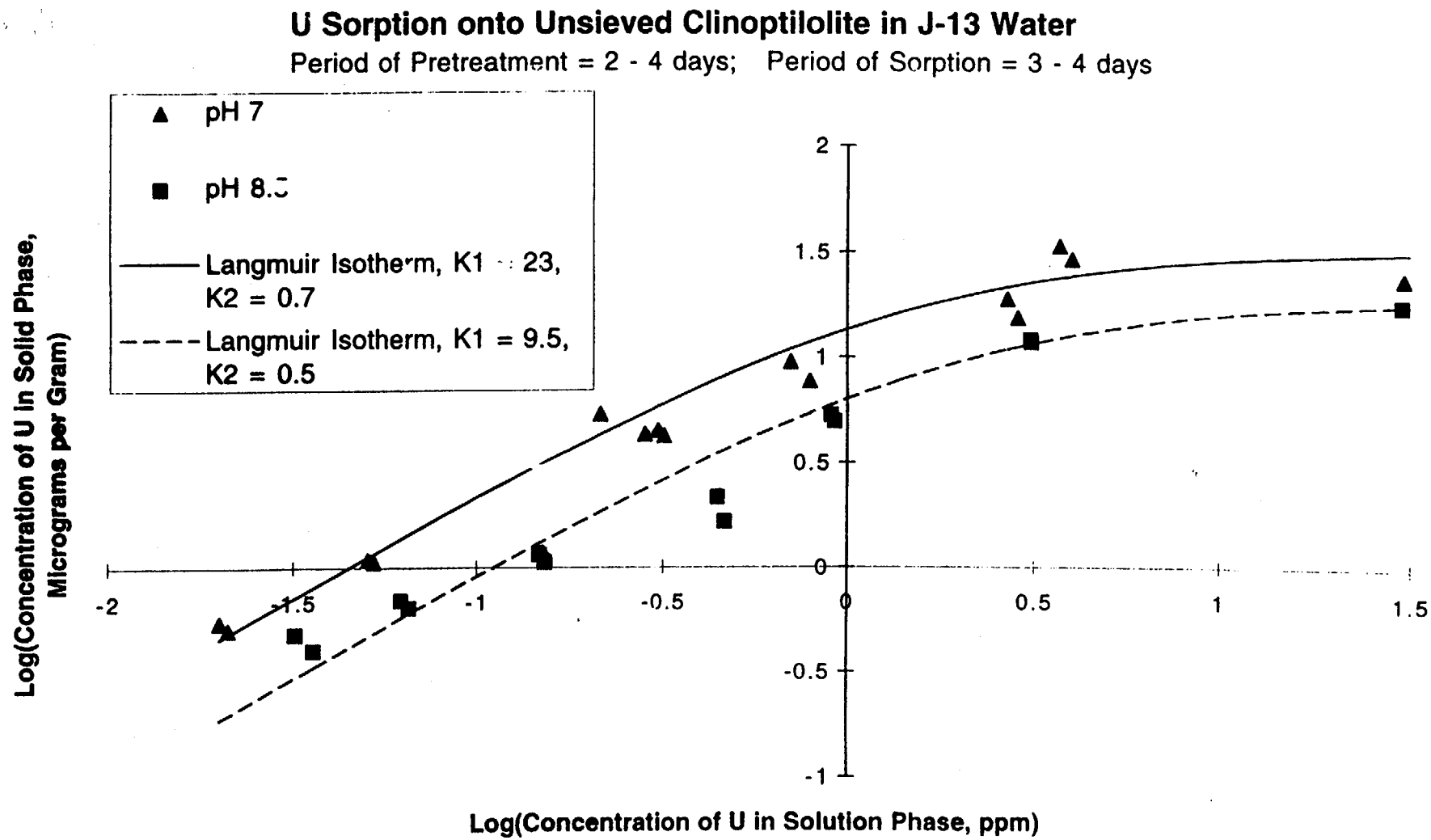
Chemical Analysis of J-13



Chemical Analysis of UE-25 p#1 Water



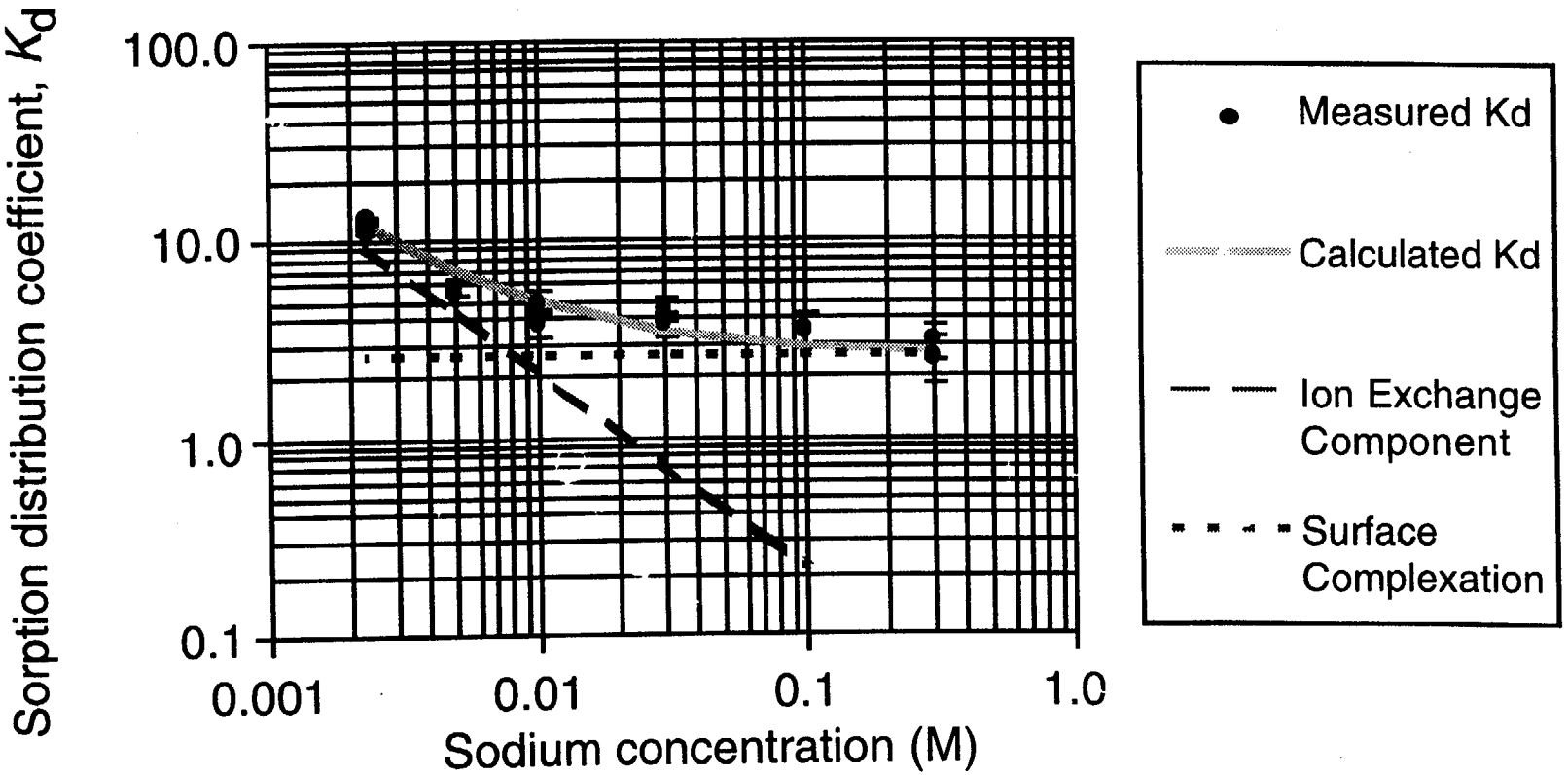

Np Sorption onto Unsieved Clinoptilolite in J-13 Water
Period of Pretreatment = 2 - 3 days; Period of Sorption = 2 - 4 days
pH 7
pH 8.5
Kd = 2.6 ml/g
Kd = 1.4 ml/g
Concentration of Np in Solid, Nanomoles per Gram
Concentration of Np in Solution, Micromoles per Liter
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30


U Sorption onto Unsieved Clinoptilolite in J-13 Water
Period of Pretreatment = 2 - 4 days; Period of Sorption = 3 - 4 days
pH 7
pH 8.3
Langmuir Isotherm, K1 = 23, K2 = 0.7
Langmuir Isotherm, K1 = 9.5, K2 = 0.5
Log(Concentration of U in Solid Phase, Micrograms per Gram)
Log(Concentration of U in Solution Phase, ppm)
2
1.5
1
0.5
0
-0.5
-1
-2
-1.5
-1
-0.5
0
0.5
1
1.5

Np Sorption in J-13 onto Tuffs (under atmospheric conditions)

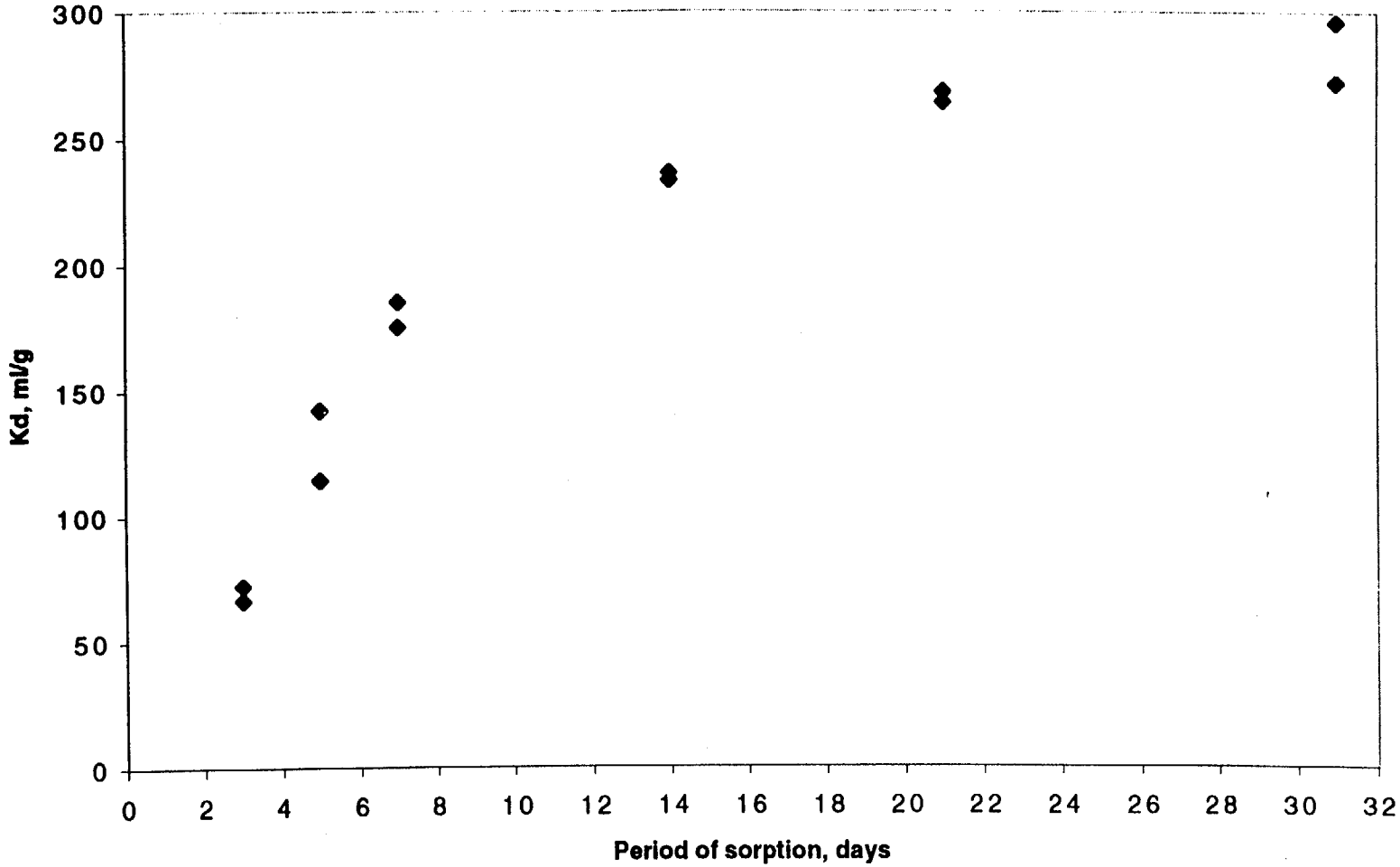
Solid	Ka, m	Predicted Ka, m	% Clinoptilolite	% Hematite
G1-732	3E-07		0	Trace
G1-1405	1E-07	1E-07	68 ± 7	0
G1-1936	5E-07		0	0
G2-767	3E-07		0	1 ± 1
G4-268	6E-08		0	1 ± 1
G4-270	2E-08		0	1 ± 1
G4-272	3E-07		0	1 ± 1
G4-1505	9E-08	1E-07	74 ± 7	0
G4-1506	1E-07	1E-07	62 ± 7	0
G4-1510	8E-08	1E-07	59 ± 7	0
G4-1529	7E-08	1E-07	59 ± 8	0
G4-1625	9E-08	1E-07	61 ± 7	0
G4-1772	1E-07	1E-07	63 ± 5	0
G4-2077	5E-08	8E-08	51 ± 8	0
G4-2570	2E-07		0	Trace
GU3-747	3E-07		0	Trace
GU3-1394	2E-07		0	0
GU3-1405	2E-07		0	Trace
GU3-1407	3E-07		0	0
GU3-1555	2E-07		1 ± 1	0
GU3-2325	8E-07		0	1 ± 1

Initial [Np] ranging from 6 to 8 x 10^{-7} M;
Tuffs Wet Sieved; Tuffs Particle Size = 75-500 micrometers;
Period of Prettreatment = 2-14 d; Period of Sorption = 3-23 d

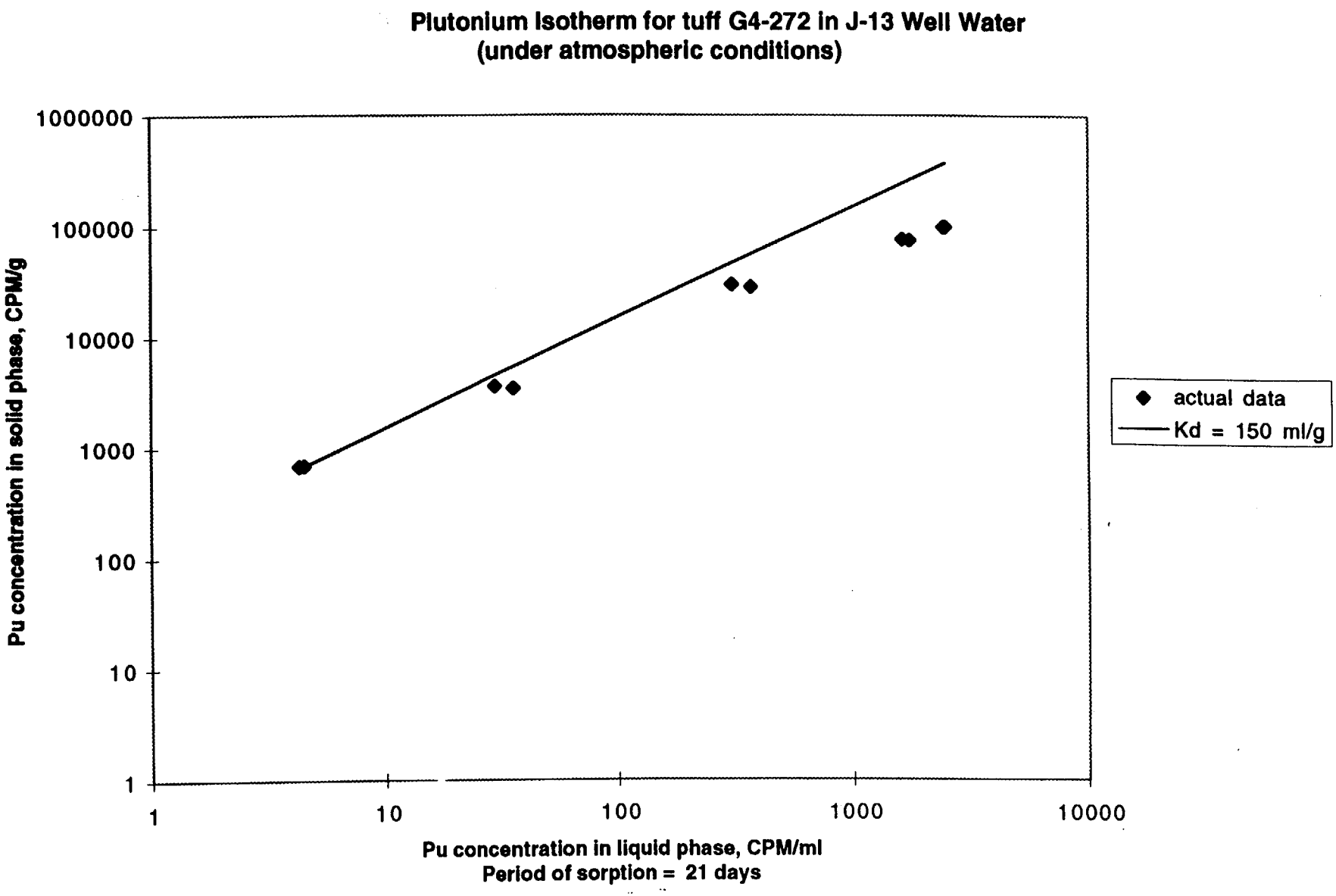


Modeling of Neptunium Sorption. The plot shows data points for the sorption distribution coefficient of neptunium on the zeolitic tuff sample G4-1506 at a pH of 8.4 as a function of sodium ion concentration.

Plutonium sorption onto G4-1515 in J-13 Well Water as a function of time (under atmospheric conditions)



Kd based on original Pu solution with a concentration of 2.4E-07 M


Plutonium Isotherm for tuff G4-272 in J-13 Well Water
(under atmospheric conditions)
1000000
100000
10000
1000
100
10
1
Pu concentration in solid phase, CPM/g
1
10
100
1000
10000
Pu concentration in liquid phase, CPM/ml
Period of sorption = 21 days
actual data
Kd = 150 ml/g

Sorption-coefficient Distributions for Saturated-zone Units

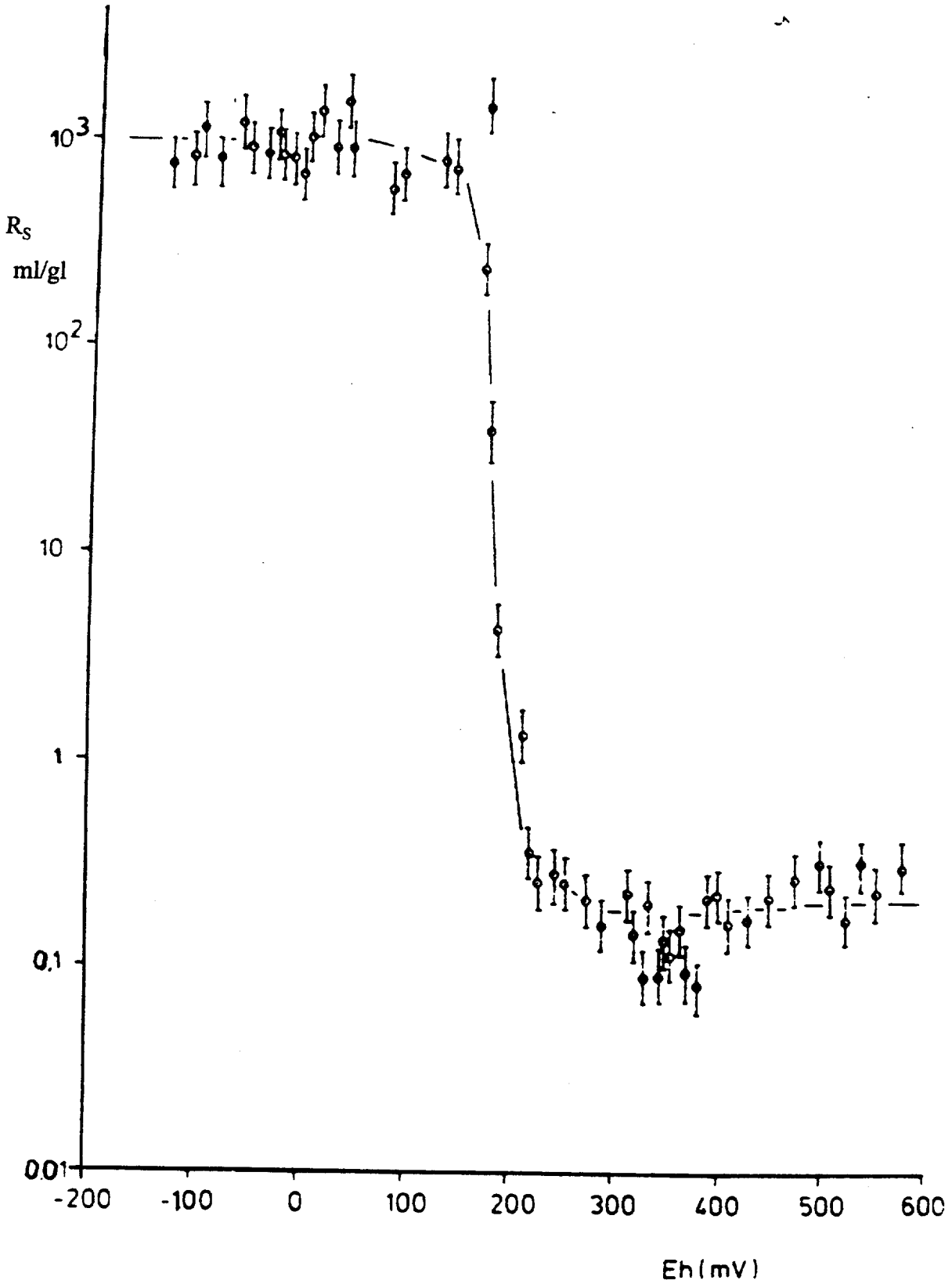
Element	Rock type	Min K_d (ml/g)	Max K_d (ml/g)	$E[x]$	COV*	Distribution type
Americium	Devitrified	100	2000			Uniform
	Vitric	100	1000	400	0.20	Beta
	Zeolitic	100	1000			Uniform
	Iron oxide	1000	5000			Uniform
Plutonium	Devitrified	50	300	100	0.15	Beta
	Vitric	50	300	100	0.15	Beta
	Zeolitic	30	300	100	0.15	Beta
	Iron oxide	1000	5000			Uniform
Uranium	Devitrified	0	5.0	2.0	0.3	Uniform
	Vitric	0	4.0	1.0	0.3	Uniform
	Zeolitic	5	20.0	7.0	0.3	Beta
	Iron oxide	100	1000			Uniform
Neptunium	Devitrified	0	10.0	3.0	0.3	Beta
	Vitric	0	15.0	1.5	1.0	Beta(exp)
	Zeolitic	0	12.0	4.0	0.25	Beta
	Iron oxide	500	1000			Uniform
Radium	Devitrified	100	500			Uniform
	Vitric	100	500			Uniform
	Zeolitic	1000	5000			Uniform
	Iron oxide	0	1500	30	1.0	Beta(exp)
Cesium	Devitrified	20	1000			Uniform
	Vitric	10	100			Uniform
	Zeolitic	500	5000			Uniform
	Iron oxide	0	500	30	1.0	Beta(exp)
Strontium	Devitrified	10	200			Uniform
	Vitric	20	50			Uniform
	Zeolitic	2000	5000			Log uniform
	Iron oxide	0	30	10	0.25	Beta
Nickel	Devitrified	0	500	100	0.33	Beta
	Vitric	0	200	100	0.33	Beta
	Zeolitic	0	500	100	0.33	Beta
	Iron oxide	0	1000			Uniform
Lead	Devitrified	100	500			Uniform
	Vitric	100	500			Uniform
	Zeolitic	100	500			Uniform
	Iron oxide	100	1000			Uniform
Tin	Devitrified	20	200			Uniform
	Vitric	20	200			Uniform
	Zeolitic	100	300			Uniform
	Iron oxide	0	5000			Uniform
Protactinium	Devitrified	0	100			Uniform
	Vitric	0	100			Uniform
	Zeolitic	0	100			Uniform
	Iron oxide	500	1000			Uniform
Selenium	Devitrified	0	30	3	1.0	Beta(exp)
	Vitric	0	20	3	1.0	Beta(exp)
	Zeolitic	0	15	2	1.0	Beta(exp)
	Iron oxide	0	500	30	1.0	Beta(exp)
Carbon	Iron oxide	10	100			Uniform
Actinium, Niobium, Samarium, Thorium, Zirconium: see Americium						
Chlorine, Technetium, Iodine		0	0			

*Coefficient of variation: COV = $\sigma[x]/E[x]$

Sorption-coefficient Distributions for Unsaturated-zone Units

Element	Rock type	Min K_d (ml/g)	Max K_d (ml/g)	$E[x]$	COV*	Distribution type
Americium	Devitrified	100	2000			Uniform
	Vitric	100	1000	400	0.20	Beta
	Zeolitic	100	1000			Uniform
	Iron oxide	1000	5000			Uniform
Plutonium	Devitrified	20	200	100	0.25	Beta
	Vitric	50	200	100	0.25	Beta
	Zeolitic	30	200	100	0.25	Beta
	Iron oxide	1000	5000			Uniform
Uranium	Devitrified	0	4.0	2.0	0.3	Beta
	Vitric	0	3.0	1.0	0.3	Beta
	Zeolitic	0	30.0	7.0	1.0	Beta(exp)
	Iron oxide	100	1000			Uniform
Neptunium	Devitrified	0	6.0	1.0	0.3	Beta
	Vitric	0	15.0	1.0	1.0	Beta(exp)
	Zeolitic	0	3.0	0.5	0.25	Beta
	Iron oxide	500	1000			Uniform
Radium	Devitrified	100	500			Uniform
	Vitric	50	100			Uniform
	Zeolitic	1000	5000			Uniform
	Iron oxide	0	500	30	1.0	Beta(exp)
Cesium	Devitrified	20	1000			Uniform
	Vitric	10	100			Uniform
	Zeolitic	500	5000			Uniform
	Iron oxide	0	500	30	1.0	Beta(exp)
Strontium	Devitrified	10	50			Uniform
	Vitric	0	20			Uniform
	Zeolitic	500	2000			Uniform
	Iron oxide	0	30	10	0.25	Beta
Nickel	Devitrified	0	500	100	0.33	Beta
	Vitric	0	100	50	0.33	Beta
	Zeolitic	0	500	100	0.33	Beta
	Iron oxide	0	1000			Uniform
Lead	Devitrified	100	500			Uniform
	Vitric	100	500			Uniform
	Zeolitic	100	500			Uniform
	Iron oxide	100	1000			Uniform
Tin	Devitrified	20	200			Uniform
	Vitric	20	200			Uniform
	Zeolitic	100	300			Uniform
	Iron oxide	0	5000			Uniform
Protactinium	Devitrified	0	100			Uniform
	Vitric	0	100			Uniform
	Zeolitic	0	100			Uniform
	Iron oxide	500	1000			Uniform
Selenium	Devitrified	0	30	3	1.0	Beta(exp)
	Vitric	0	20	3	1.0	Beta(exp)
	Zeolitic	0	15	2	1.0	Beta(exp)
	Iron oxide	0	500	30	1.0	Beta(exp)
Carbon	Iron oxide	10	100			Uniform
Actinium, Niobium, Samarium, Thorium, Zirconium: see Americium						
Chlorine, Technetium, Iodine		0	0			

*Coefficient of variation: COV = $\sigma[x]/E[x]$


10^3
R_S
ml/gl
10^2
10
1
0.1
0.01
-200
-100
0
100
200
300
400
500
600
Eh (mV)

K_d, m^3/kg

	Bentonite				Granite				Crystalline Rock	
	Oxidizing best estimate	min - max	Reducing best estimate	min - max	Oxidizing best estimate	min - max	Reducing best estimate	min - max	Oxidizing best estimate	Reducing best estimate
Am	2	0.25 - 10	2	0.25 - 10	5	0.5 - 80	5	0.5 - 80	0.05	3
Np	0.1	0.05 - 0.12	1	0.1 - 5	0.01	0.001 - 10	5	0.1 - 10	0.002	0.2
Pu	1	0.1 - 3.5	1.5	0.1 - 5	3	1 - 80	5	0.5 - 80	0.03	0.3
Th	1	0.002 - 6	1	0.002 - 6	5	0.1 - 10	5	0.1 - 10	0.2	0.2
U	0.02	0 - 0.1	0.2	0.1 - 1	0.01	0.002 - 1	5	0.01 - 10	0.002	0.2

Radionuclide Sorption Irreversibility

- Sorption followed by colloid aggregation

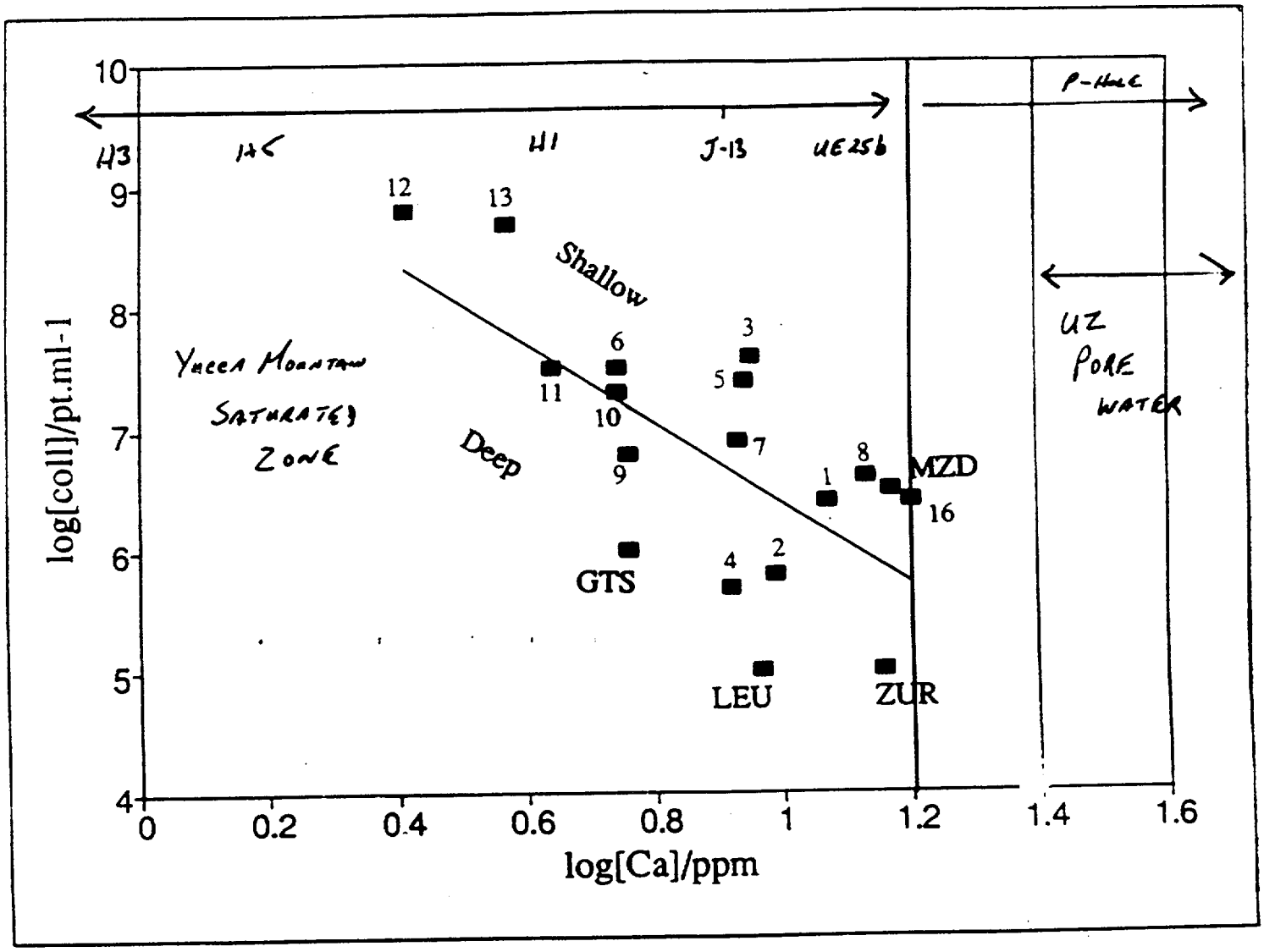
$$\text{coll SOM}^{+} + \text{HOS coll} \rightleftharpoons \text{coll SOMOS coll} + \text{H}^{+}$$

- Sorption followed by coating
- Sorption by coprecipitation
- Sorption into internal sites (e.g., in clay interlayer)

If Reversible Sorption,

- Sorption onto colloids is negligible compared to sorption onto rock (rock surface much larger than surface of colloids for low colloid concentration)

Degueldre, 1994



Correlation between colloid and Ca concentration in granitic groundwaters.

Conditions: [coll] for size > 100 nm, sites:

Transitgas tunnel (N° label), Menzenschwand (MZD)

Grimsel Test Site (GTS), Zurzach (ZUR), Leugern (LEU) .

Radionuclide Transport through Fractures

I. Triay, D. Ware, and B. Robinson

- One of the main concerns of the Yucca Mountain Project regarding the ability of the natural barrier to retard radionuclides is the existence of fast paths (from the repository to the water table)

- In these transport paths, water flows through fractures and the coatings on the fractures prevent radionuclides from diffusing into the matrix

- If diffusion were to occur, despite the fracture coatings, this would be the most important retardation mechanism since it applies to strongly sorbing radionuclides, poorly sorbing radionuclides (such as Np), and non-sorbing radionuclides (such as Tc and Se)

- Experimental Studies used natural rock fractures lined with stellerite, magnetite, hollandite, and romanechite from Yucca Mountain

  - fractured tuff column experiments

  - diffusion cells using fractured tuff

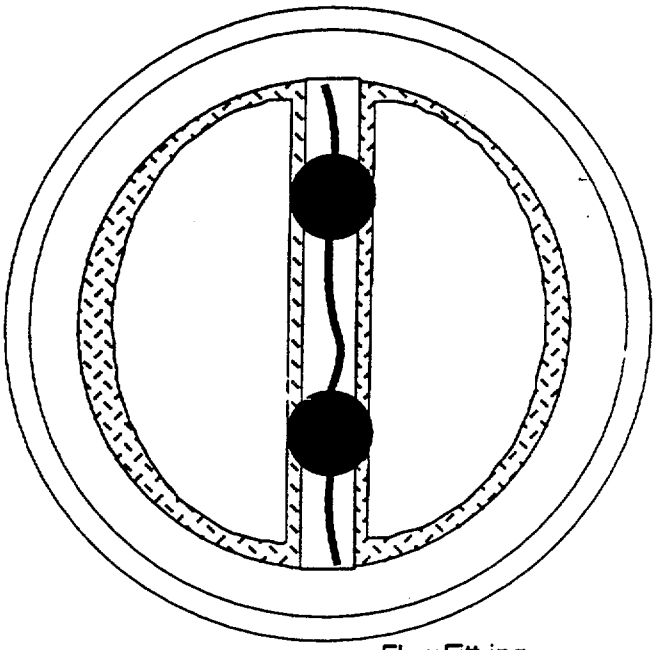
Experimental Procedure for Radionuclide Transport through Fractured Tuff Columns

- Fractured cores were saturated and a flow of groundwater was initiated
- Various radionuclides were injected (H-3, Tc-95m, Np-237)
- Fracture elutions were collected as a function of time and analyzed for the percentage of radionuclide recovered

Experimental Procedure for Radionuclide Transport through Diffusion Cells

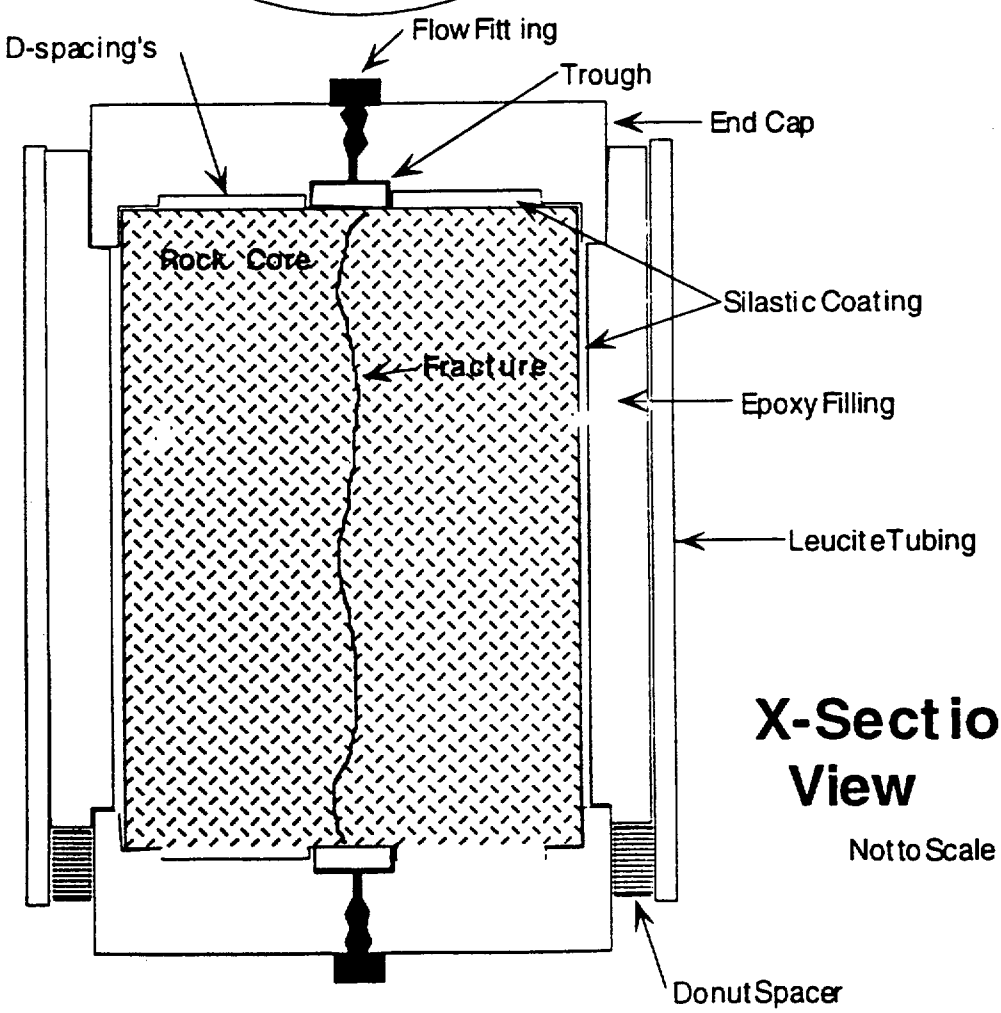
- Radionuclides are in contact with a coated fracture in one of the cell's chambers
- The appearance of the radionuclides (that have diffused through the fracture and the matrix) is monitored in the other cell chamber (which is in contact with the tuff matrix itself)

Fracture Column Assembly



Top View

Not to Scale



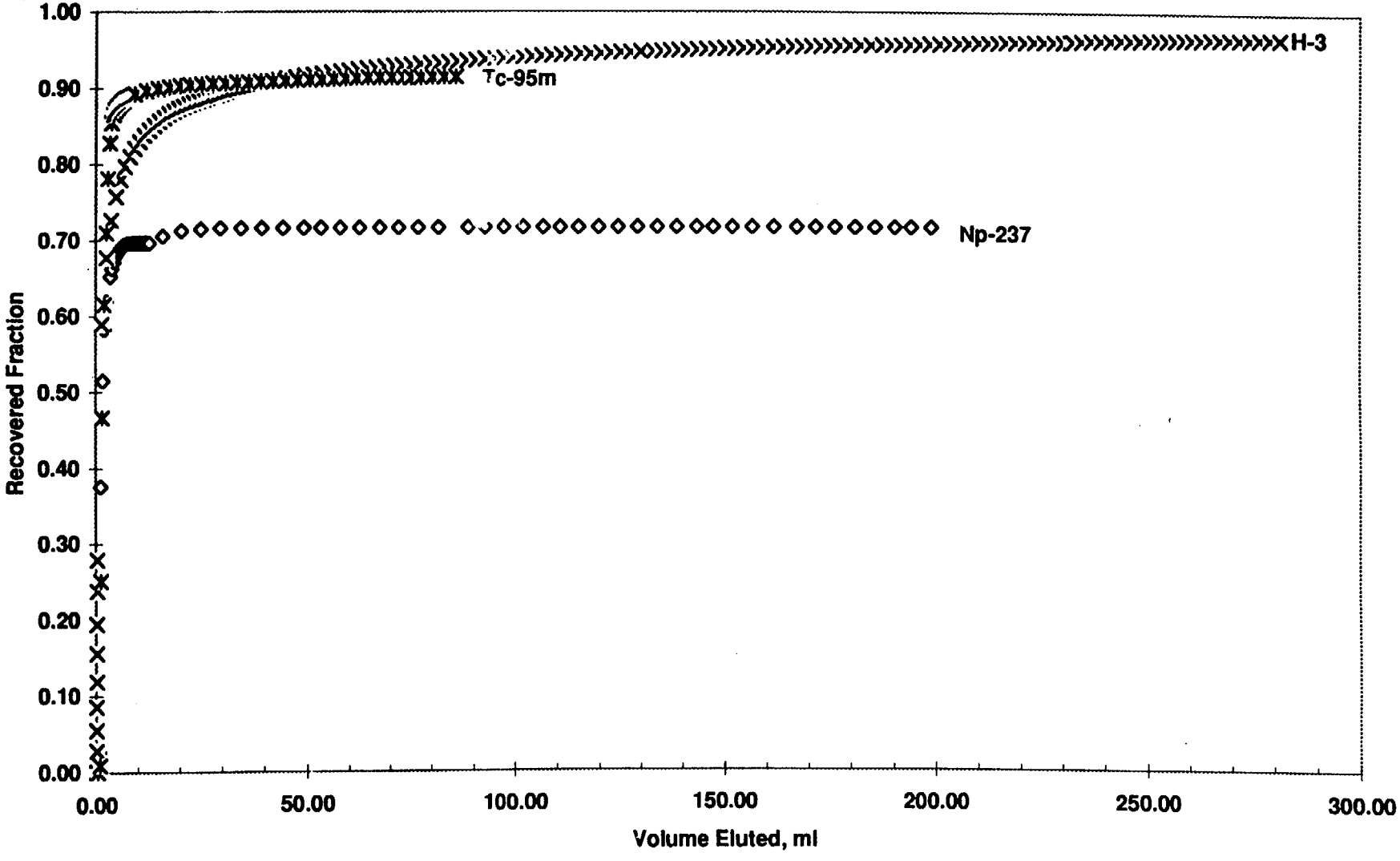
X-Sectional View

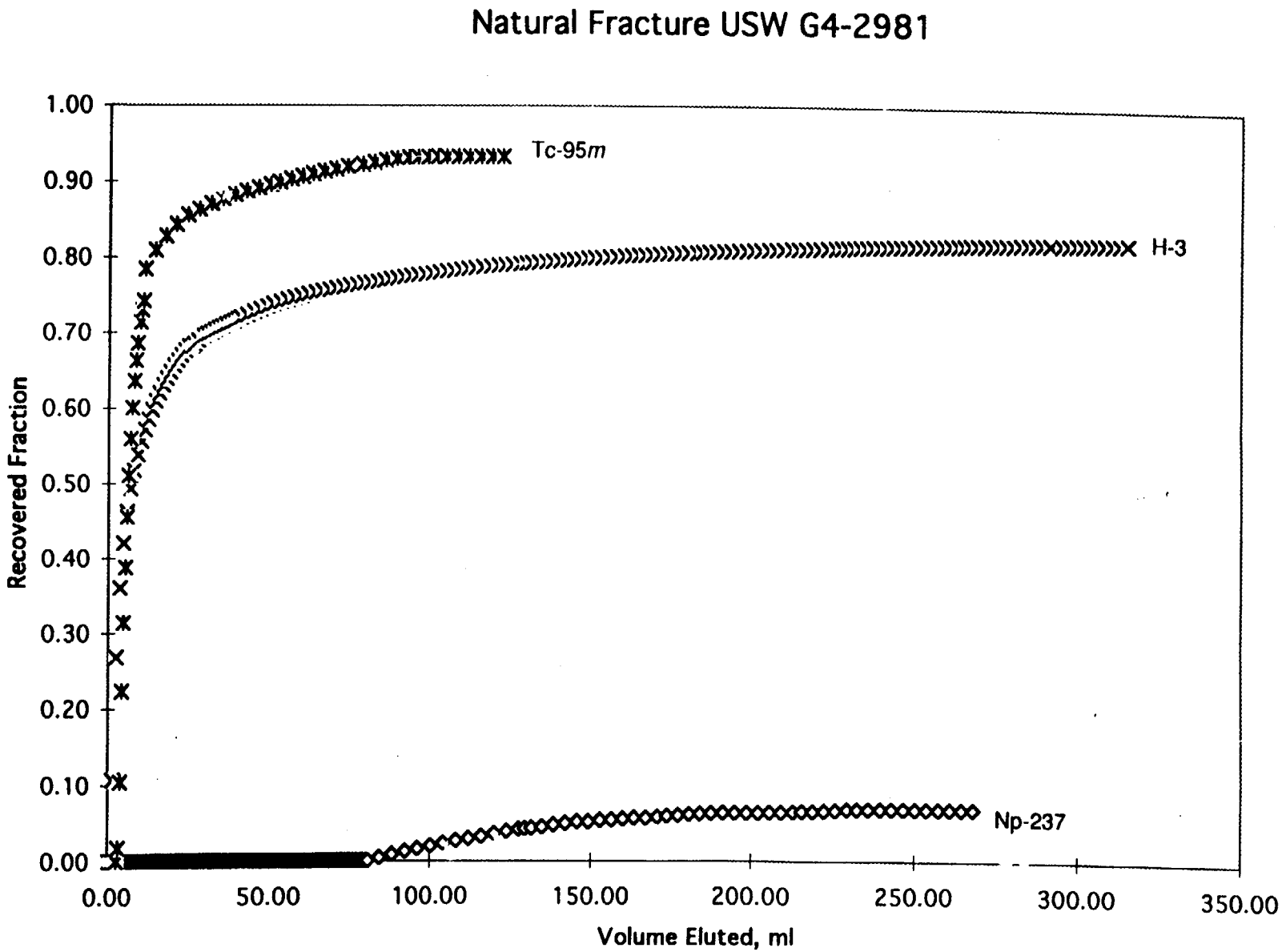
Not to Scale

Fractured Columns

Tuff	UE-25 UZ#16 919	USW G-4 2980	USW G-4 2981	USW G-4 2954	UE-25 UZ#16 595	UE-25 UZ#16 1336
Matrix Minerals	Alkali Feldspar and Quartz	Alkali Feldspar and Opal	Alkali Feldspar and Opal	Alkali Feldspar and Opal	Alkali Feldspar and Quartz	Alkali Feldspar and Quartz
Fracture Coating Minerals	Stellerite Magnetite	Hollandite Romanechite	Hollandite Romanechite	Hollandite Romanechite	To be determined (Oxide minerals)	To be determined (Oxide minerals)
Tuff Type	Devitrified	Devitrified	Devitrified	Devitrified	Devitrified	Devitrified
Water Type	Synthetic UE-25 p#1	Synthetic UE-25 p#1	Synthetic J-13	Synthetic J-13	Synthetic J-13	Synthetic J-13
Length (cm)	5.2	9.2	5.2	5.2	9.9	9.1
Diameter (cm)	6.1	6.1	6.0	6.3	6.1	6.1
Flow Rate (ml/hr)	~0.5	~0.5	~0.5	~0.5	~1.0	~1.0
Flow Velocity (cm/hr)	2.2	0.9	0.4	0.4	5.7	2.2
^{3}H % Recovery	97	108	82	96	90	93
^{95m}Tc % Recovery	91	96	92	95	91	91
^{237}Np % Recovery	72	9	7	18	61	69
R_f ^{237}Np	1.3	30.8	17.6	6.9	4.6	1.4

Natural Fracture UE-25 UZ#16 919




Natural Fracture USW G4-2981
Tc-95m
H-3
Np-237
Recovered Fraction
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
Volume Eluted, ml

Simulation of Fractured Tuff Column

- Model
  - one-dimensional axial dispersion in the fracture
  - molecular diffusion occurs into an infinite medium (the rock matrix)
  - linear reversible sorption is assumed, with different retardation factors for the fracture surface and the rock matrix

- Parameters
  - fracture volume = 1 ml
  - fracture aperture = 0.32 mm
  - dispersivity = 0.3 cm
  - matrix porosity = 0.1

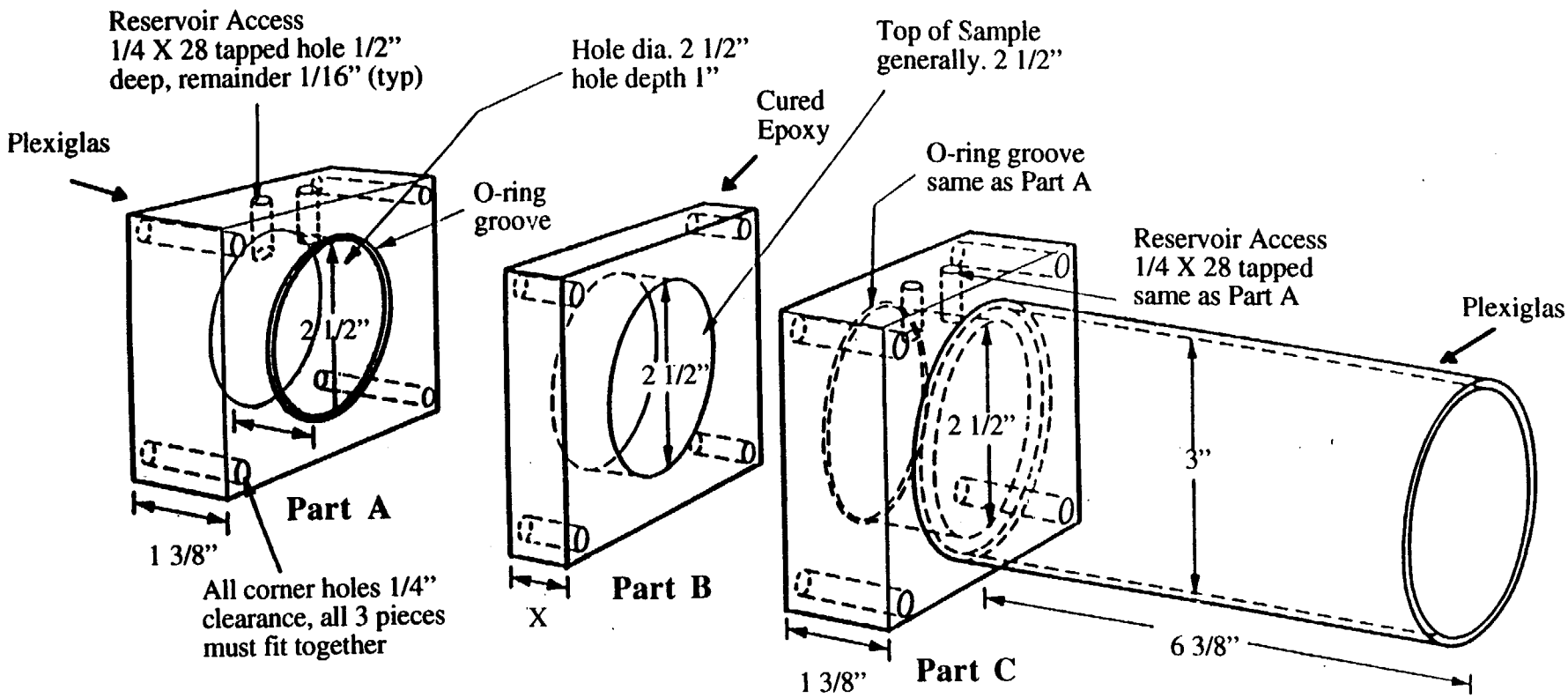
- Good fits were obtained for ^{95m}Tc and ^{3}H elutions using a difference in the diffusion coefficient of a factor of five

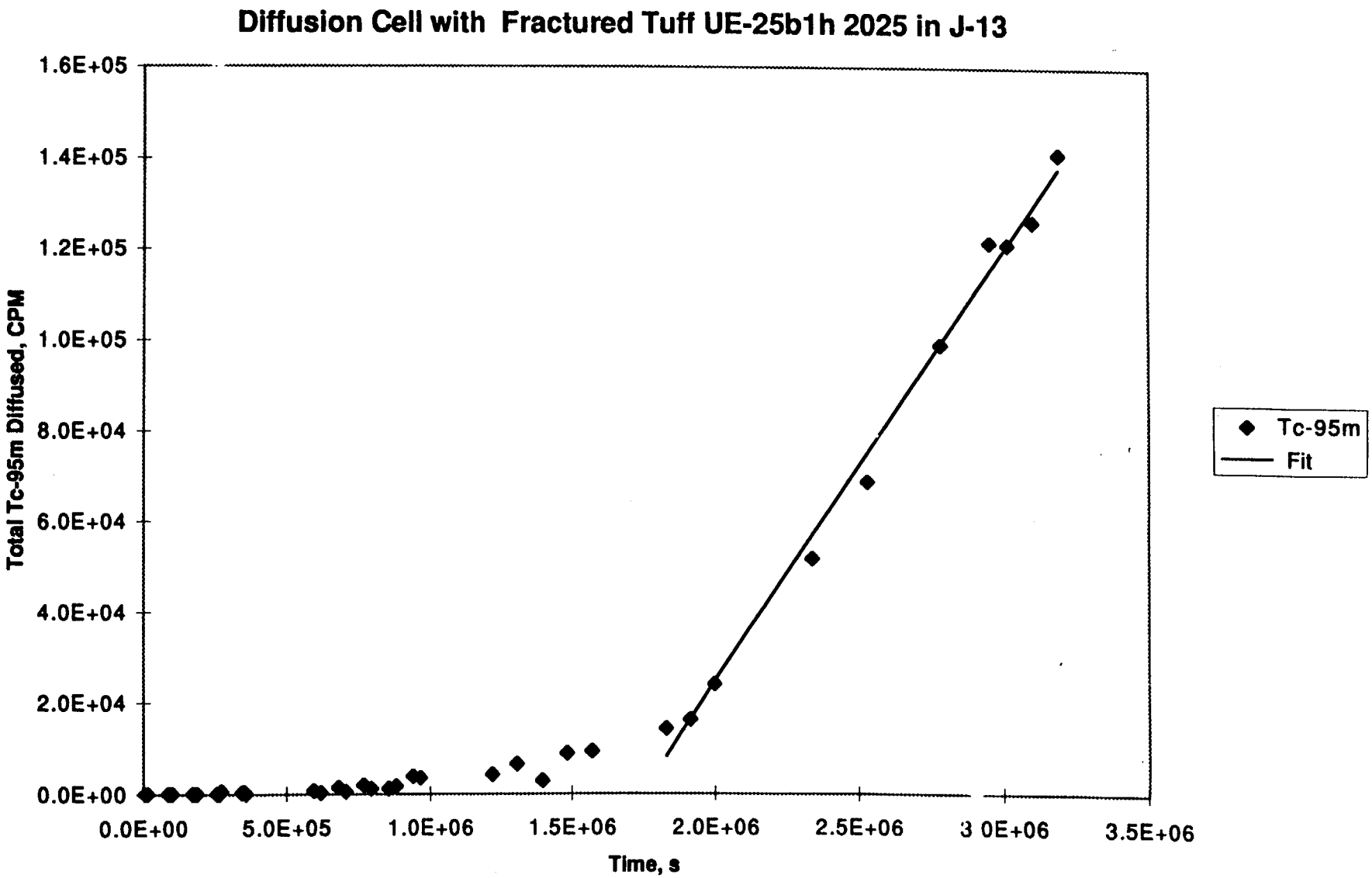
- The ^{237}Np elution can be fitted assuming
  - Matrix sorption only
  - Fracture and matrix sorption

Batch Results for **Np Sorption** in J-13 Well Water

Major Minerals in Solid Phase	Kd (ml/g)	Solid Phase Composition (determined by XRD)
Stellerite	~0	N/A
Hollandite	7×10^2	100% Hollandite
Romanechite	6×10^2	N/A
Magnetite	7	85% Magnetite, 12% Hematite, and 3% Goethite

Schematic X-Section of Diffusion Cell Assembly




Diffusion Cell with Fractured Tuff UE-25b1h 2025 in J-13
Total Tc-95m Diffused, CPM
1.6E+05
1.4E+05
1.2E+05
1.0E+05
8.0E+04
6.0E+04
4.0E+04
2.0E+04
0.0E+00
0.0E+00
5.0E+05
1.0E+06
1.5E+06
2.0E+06
2.5E+06
3.0E+06
3.5E+06
Time, s
Tc-95m
Fit

Diffusion Cells

Diffusion Cell Tuff	USW G4-2954	USW G4-2954	UE-25b1h 2025
Matrix Minerals	Quartz Feldspar Mica Hematite	Quartz Feldspar Mica Hematite	Quartz Feldspar Smectite
Fracture Coating	Manganese Oxides	Non-Coated	Stellerite
Tuff Type	Devitrified	Devitrified	Devitrified
Volume of Untraced Chamber, ml	85	85	85
Volume of Traced Chamber, ml	800	800	800
Sample Diameter, cm	5	5	5
Sample Width, cm	1.5	1.5	1.5
Water Type	J-13	J-13	J-13
^{3}H Fraction Diffused at t=3 E 6 secs	0.02	0.03	0.007
^{95m}Tc Fraction Diffused at t = 3 E 6 secs	0.01	0.02	0.002
^{237}Np Fraction Diffused at t = 3 E 6 secs	0.004	0.01	0.002
^{3}H Fitted Parameters	$D = 3 \times 10^{-6}\ cm^2/s$	$D = 4 \times 10^{-6}\ cm^2/s$	$D = 4 \times 10^{-7}\ cm^2/s$
^{95m}Tc Fitted Parameters	$D = 1 \times 10^{-6}\ cm^2/s$	$D = 1 \times 10^{-6}\ cm^2/s$	$D = 2 \times 10^{-7}\ cm^2/s$
^{237}Np Fitted Parameters	$D = 1 \times 10^{-6}\ cm^2/s$ Kd = 3 ml/g	$D = 1 \times 10^{-6}\ cm^2/s$ Kd = 0	$D = 2 \times 10^{-7}\ cm^2/s$ Kd = 0

Results of Radionuclide Transport Experiments through Fractured Tuff

- Diffusion from the fracture into the matrix can take place even at relatively fast flow rates

- Np can be significantly retarded, even during a fracture-flow scenario
  - Neptunium retardation in fractures could be due to both diffusion into the matrix and sorption onto the minerals lining the fracture walls

- Contrary to previous assumptions about the role of fractures in radionuclide retardation, preliminary results from these experiment indicate that fracture flow does not necessarily result in a fast pathway for actinide migration through fractures

- There is no evidence that fracture coatings (in the diffusion cells studied) prevent the diffusion of the radionuclides from the fracture into the matrix

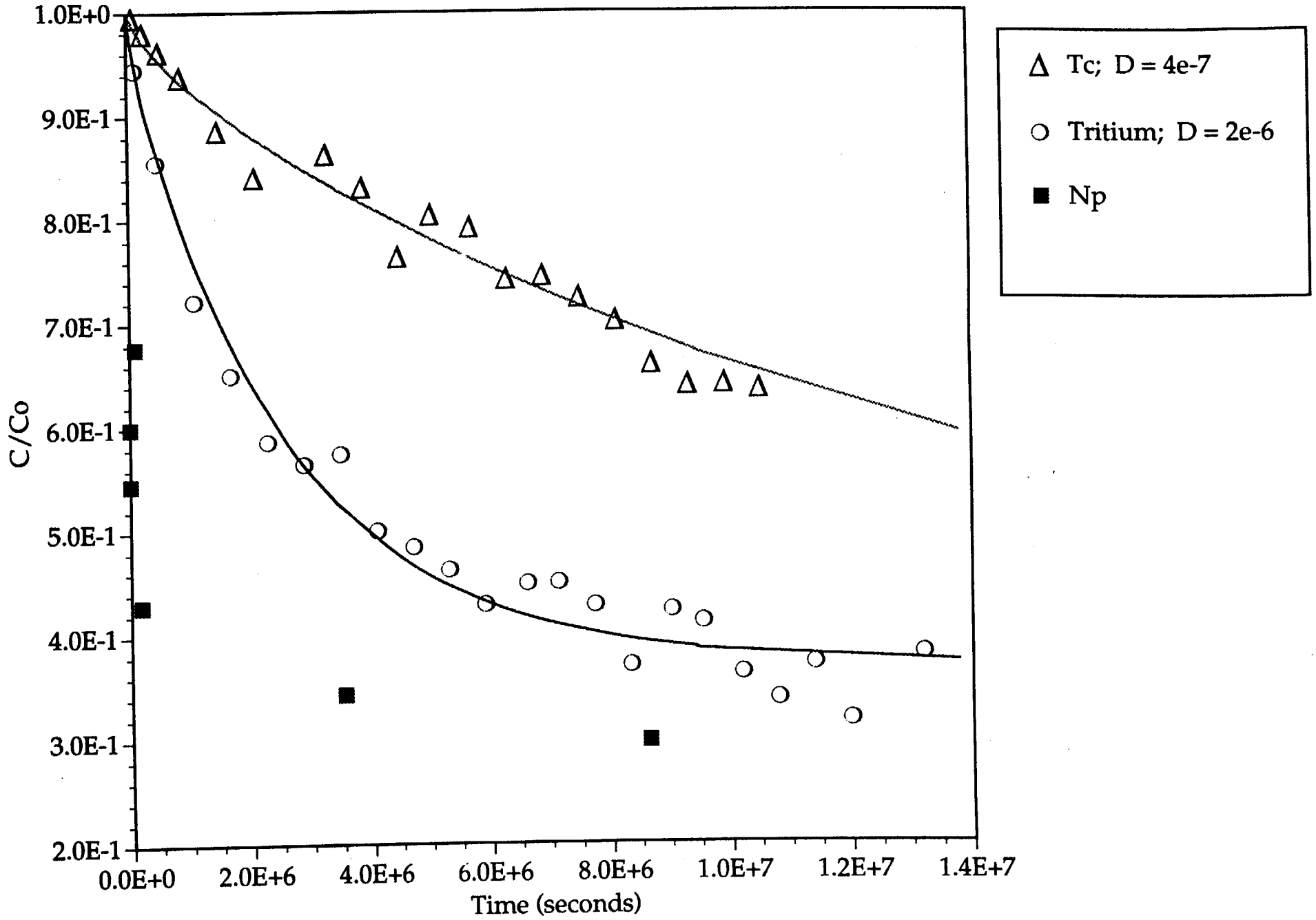
Radionuclide Migration Under Diffusive Conditions

Objective: Study the diffusion of radionuclides in Yucca Mountain tuffs under varying degrees of saturation

Experimental Techniques

- Wafers
- Diffusion Cells
- Rock Beakers
- Blocks of Tuff

G4 - 737


1.0E+0
9.0E-1
8.0E-1
7.0E-1
6.0E-1
5.0E-1
4.0E-1
3.0E-1
2.0E-1
C/Co
0.0E+0
2.0E+6
4.0E+6
6.0E+6
8.0E+6
1.0E+7
1.2E+7
1.4E+7
Time (seconds)
Tc; D = 4e-7
Tritium; D = 2e-6
Np

Diffusion Results

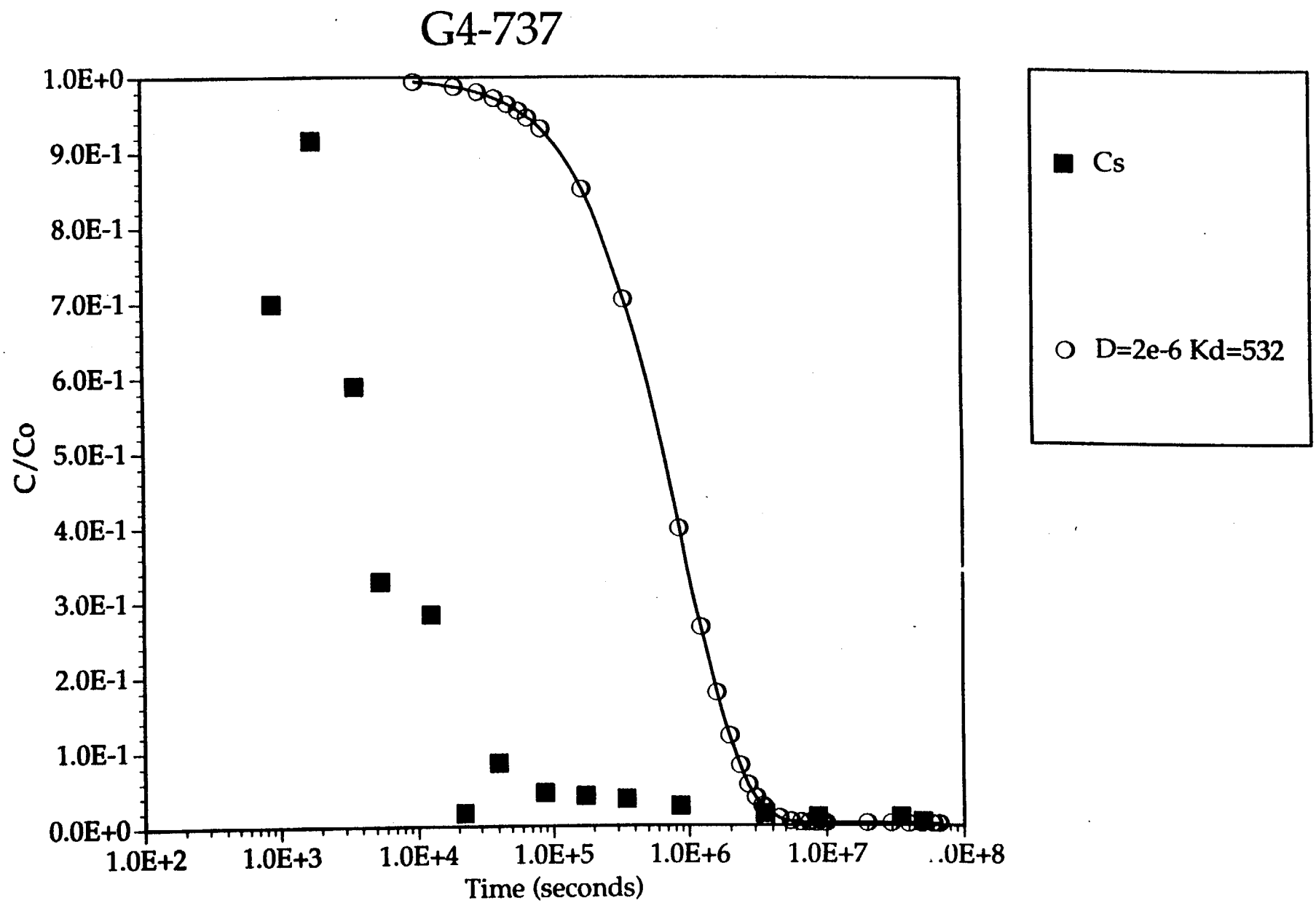
Tuff Sample	Major Minerals, %	Porosity	D (cm^2/s)	
			HTO	TcO_4^-
G4-737	alkali feldspar, 68 cristobalite, 28	0.07	2.2×10^{-6}	3.9×10^{-7}
GU3-304 #1	alkali feldspar, 75	0.06	1.5×10^{-6}	3.0×10^{-7}
GU3-304 #2	cristobalite, 25		1.6×10^{-6}	3.0×10^{-7}
GU3-433	alkali feldspar, 76 cristobalite, 15	0.10	3.5×10^{-6}	
GU3-1119	alkali feldspar, 70 quartz, 19	0.10	2.0×10^{-6}	4.9×10^{-7}
Topopah Outcrop	alkali feldspar, 59 cristobalite, 23 quartz, 12	0.07	1.0×10^{-6}	1.0×10^{-7}

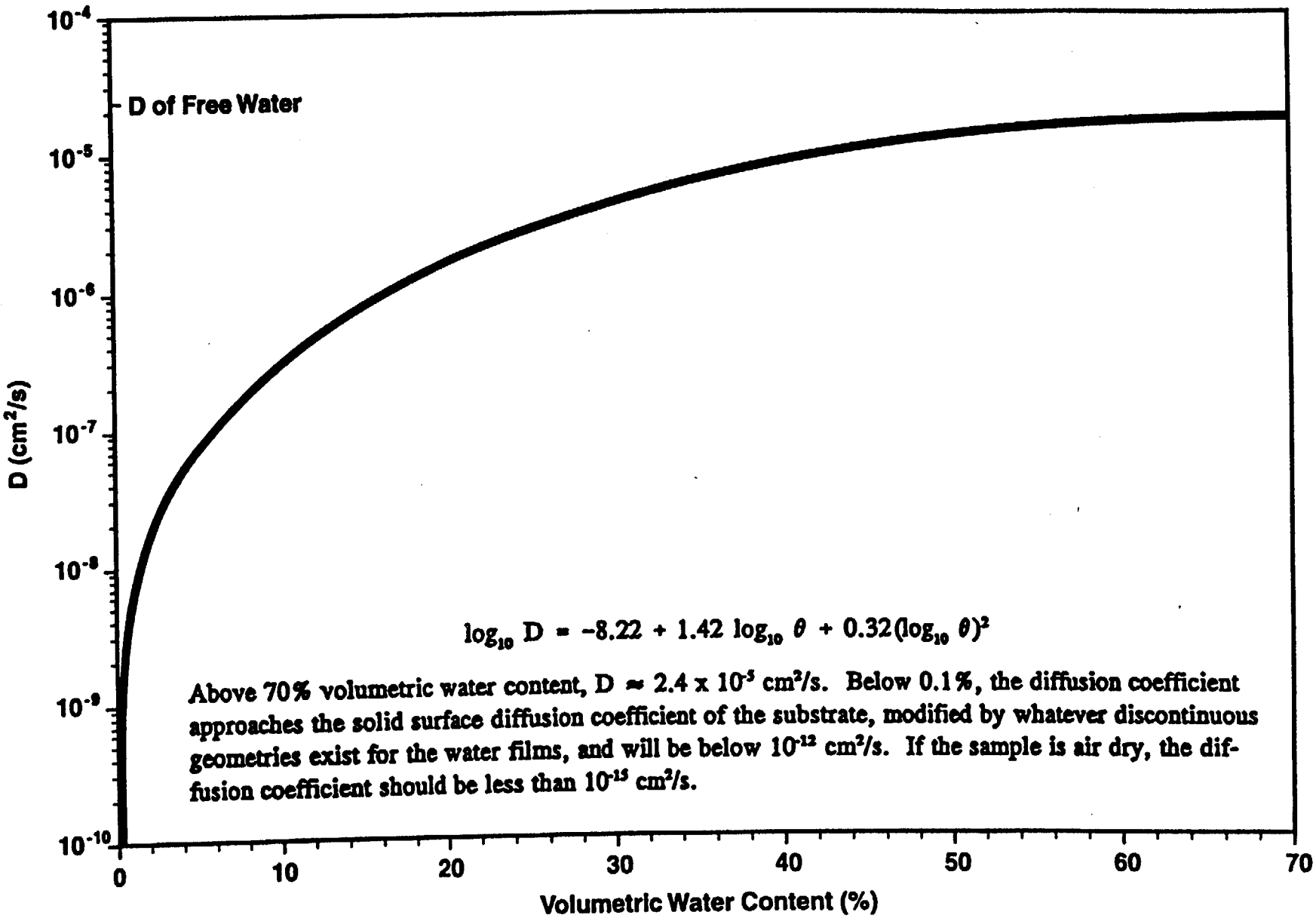
Diffusion Results (Continued)

Tuff Sample	Major Minerals, %	Porosity	D (cm^2/s)	
			HTO	TcO_4^-
†G4-1067 #1	alkali feldspar, 61	~0.1	1.1×10^{-6}	
†G4-1067 #2	quartz, 12		1.1×10^{-6}	
†G4-1067 #3	cristobalite, 10		1.0×10^{-6}	
	tridymite, 10			
†G4-1502	clinoptilolite, 71	~0.3	1.6×10^{-6}	*4.8×10^{-7}
	opal-CT, 15			
†G4-1607 #1	clinoptilolite, 63	~0.3	2.0×10^{-6}	*2.1×10^{-7}
†G4-1607 #2	opal-CT, 18		2.0×10^{-6}	*3.2×10^{-7}
†G4-1608	clinoptilolite, 63	~0.3	1.6×10^{-6}	*3.0×10^{-7}
	opal-CT, 18			

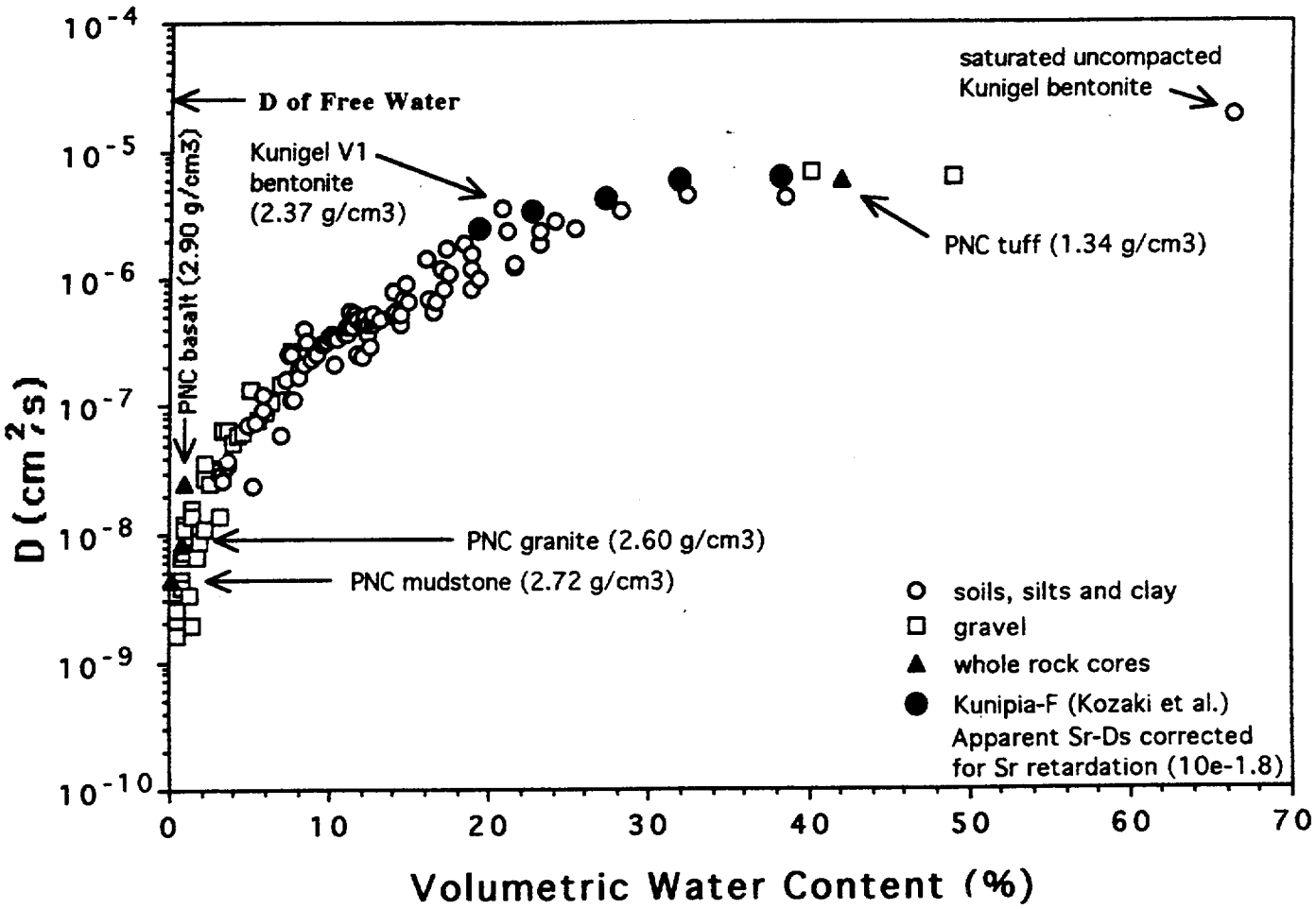
† from YMP Milestone R524

* values calculated from YMP Milestone R524 assuming unitary retardation factors


G4-737
1.0E+0
9.0E-1
8.0E-1
7.0E-1
6.0E-1
5.0E-1
4.0E-1
3.0E-1
2.0E-1
1.0E-1
0.0E+0
C/Co
1.0E+2
1.0E+3
1.0E+4
1.0E+5
1.0E+6
1.0E+7
..0E+8
Time (seconds)
Cs
D=2e-6 Kd=532


D of Free Water
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
D (cm^2/s)
0
10
20
30
40
50
60
70
Volumetric Water Content (%)
$\log_{10} D = -8.22 + 1.42 \log_{10} \theta + 0.32(\log_{10} \theta)^2$
Above 70% volumetric water content, D ≈ 2.4 x 10^{-5} cm^2/s. Below 0.1%, the diffusion coefficient approaches the solid surface diffusion coefficient of the substrate, modified by whatever discontinuous geometries exist for the water films, and will be below 10^{-12} cm^2/s. If the sample is air dry, the diffusion coefficient should be less than 10^{-15} cm^2/s.

UFA9605.001


D of Free Water
saturated uncompacted Kunigel bentonite
Kunigel V1 bentonite (2.37 g/cm3)
PNC tuff (1.34 g/cm3)
PNC basalt (2.90 g/cm3)
PNC granite (2.60 g/cm3)
PNC mudstone (2.72 g/cm3)
soils, silts and clay
gravel
whole rock cores
Kunipia-F (Kozaki et al.)
Apparent Sr-Ds corrected for Sr retardation (10e-1.8)
D (cm²/s)
Volumetric Water Content (%)

PRESENTATION TO THE SATURATED ZONE EXPERT ELICITATION WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA

RADIOCARBON DATA AND ANALYSIS

PRESENTER: EDWARD M. KWICKLIS, U.S. GEOLOGICAL SURVEY
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E-MAIL: emkwickl@usgs.gov

June 6, 1997
Denver, Colorado

Talk Outline

- Motivation
- Background Information
- Data Reliability
- Potential Carbon Sources
- Basis for NETPATH Corrections to ^{14}C age estimates
  - example calculations
- Potential reaction models
- Application of NETPATH to Yucca Mountain ^{14}C Data
- Corrected ^{14}C ages and their implications
- Check for reasonableness
  - $\delta^{13}C$ data
  - $\delta^{18}O$ and δD data
- Summary and Conclusions

MOTIVATION

- Corrected ^{14}C ages provide an indication of
  - Groundwater flow directions
  - Groundwater travel times
  - Recharge areas

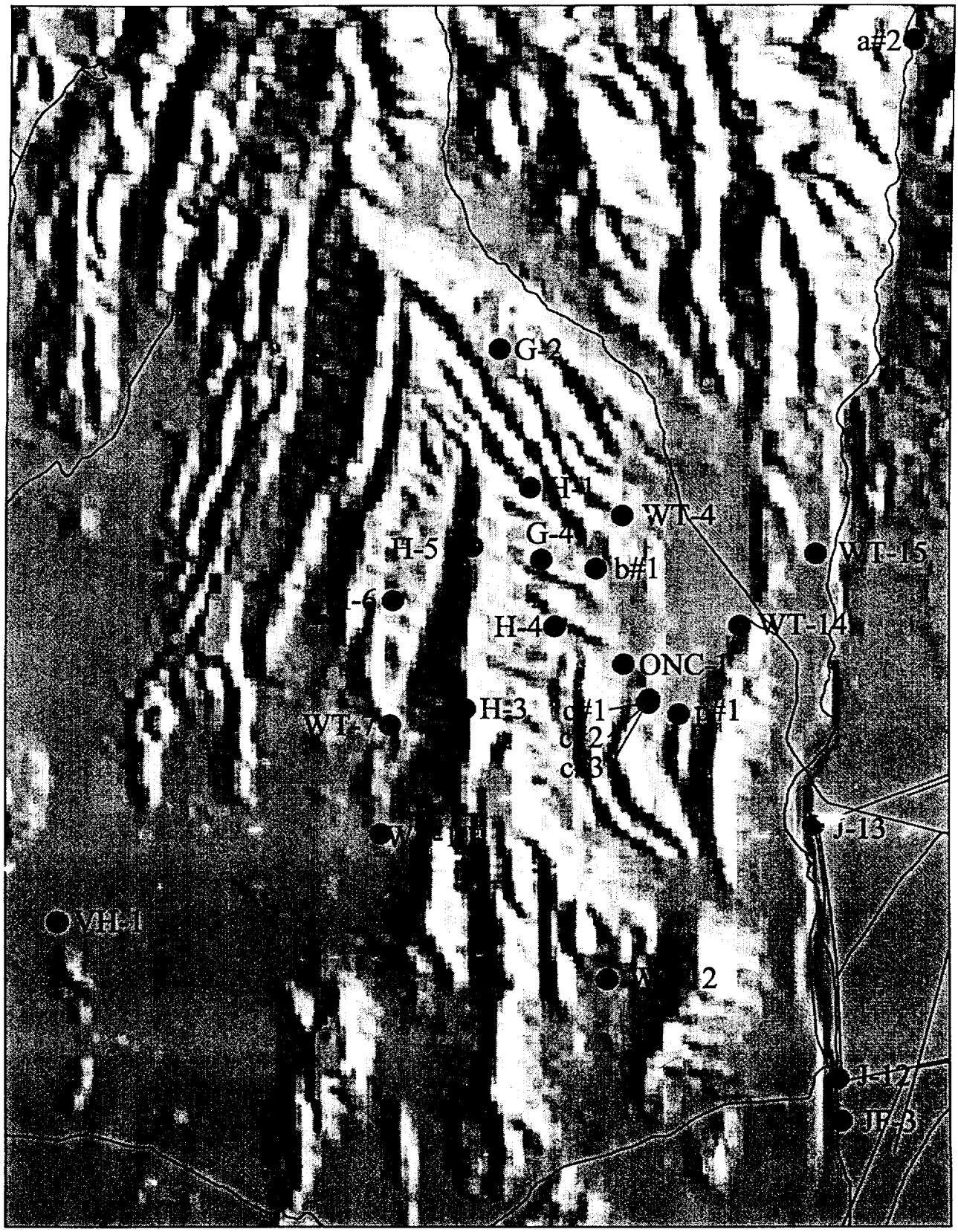
Background Information

- $$\delta_x = (R_x/R_{std} - 1) \times 1000$$
  where R_x represents isotopic ratios of a sample ($^{13}C/^{12}C$, $^{2}H/^{1}H$, $^{18}O/^{16}O$, etc., and R_{std} is the corresponding ratio in the standard. The δ-value is expressed in parts per thousand (per mil). The standards are VPDB (Vienna Pee Dee Belemnite) for carbon, and VSMOW (Vienna Standard Mean Ocean Water) for hydrogen and oxygen.

- $$^{14}A = ((^{14}C/^{12}C)_{sample}/(^{14}C/^{12}C)_{standard}) \times 100 \text{ (pmc)}$$
  where ^{14}C activity modern carbon = 0.95 ^{14}C activity NBS oxalic acid in 1950.

- The half-life of ^{14}C is 5,730 years.

- The equilibrium enrichment factor $\epsilon \approx \delta_a - \delta_b$ for ^{13}C at 25 ^{0}C is about 8 per mil between $CO_{2(g)}$ and $HCO_3^-{}_{(aq)}$ and 2.1 per mil between $HCO_3^-{}_{(aq)}$ and $CaCO_{3(s)}$.


a#2
G-2
H-1
WT-4
G-4
H-5
b#1
WT-15
-6
H-4
WT-14
ONC-1
H-3
c#1
b#1
c#2
c#3
J-13
VH-1
2
J-17
JF-3

Data Reliability

- All water analyses have good to excellent electrical balance.

- Where lithium was used as a tracer of drilling fluid, lithium concentrations indicated only a small fraction of drilling fluid was present in the water sample.
  - However, lithium may have sorbed onto the rock, and no mass-balances of the lithium injected and lithium recovered were made.

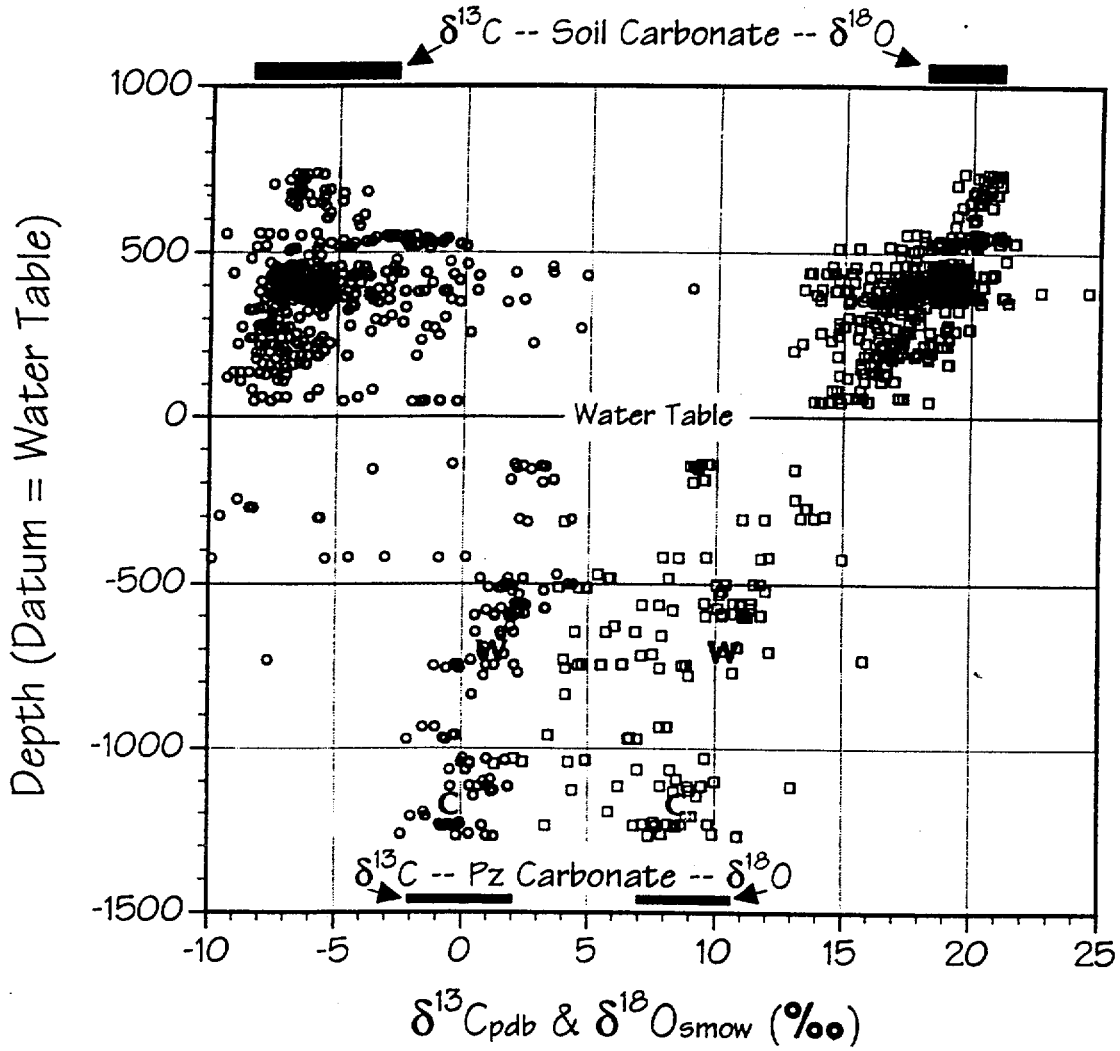
- Chemical analyses of recently collected groundwater samples from boreholes c#3 and WT-10 resulted in generally good agreement with water samples collected from these boreholes in the early and middle 1980's.

- Recent chemical analyses from previously unsampled borehole G-2 fit well with the trends defined by the older data.

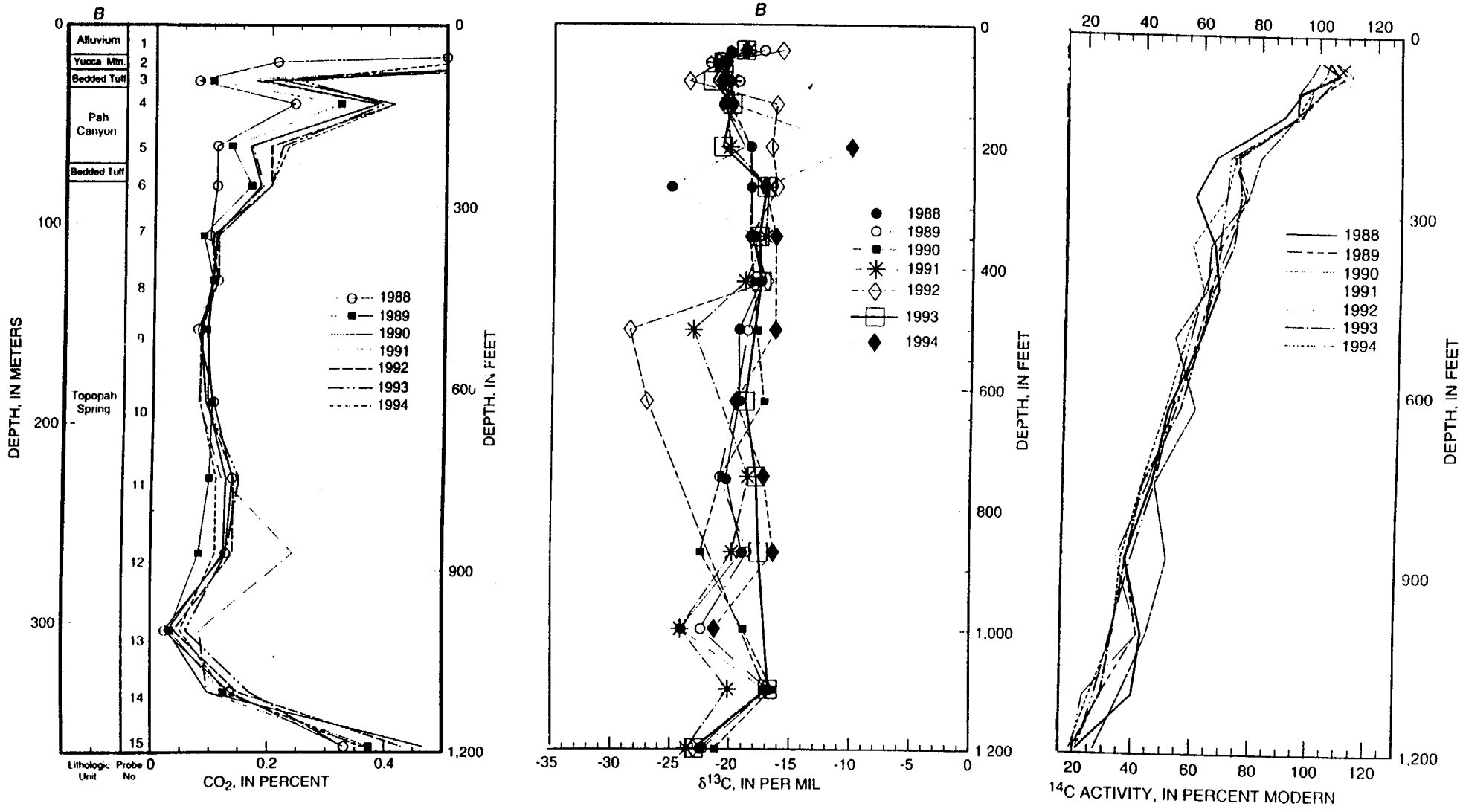
- The data describe spatial patterns and internal relationships that are interpretable and unlikely to have arisen through random contamination.

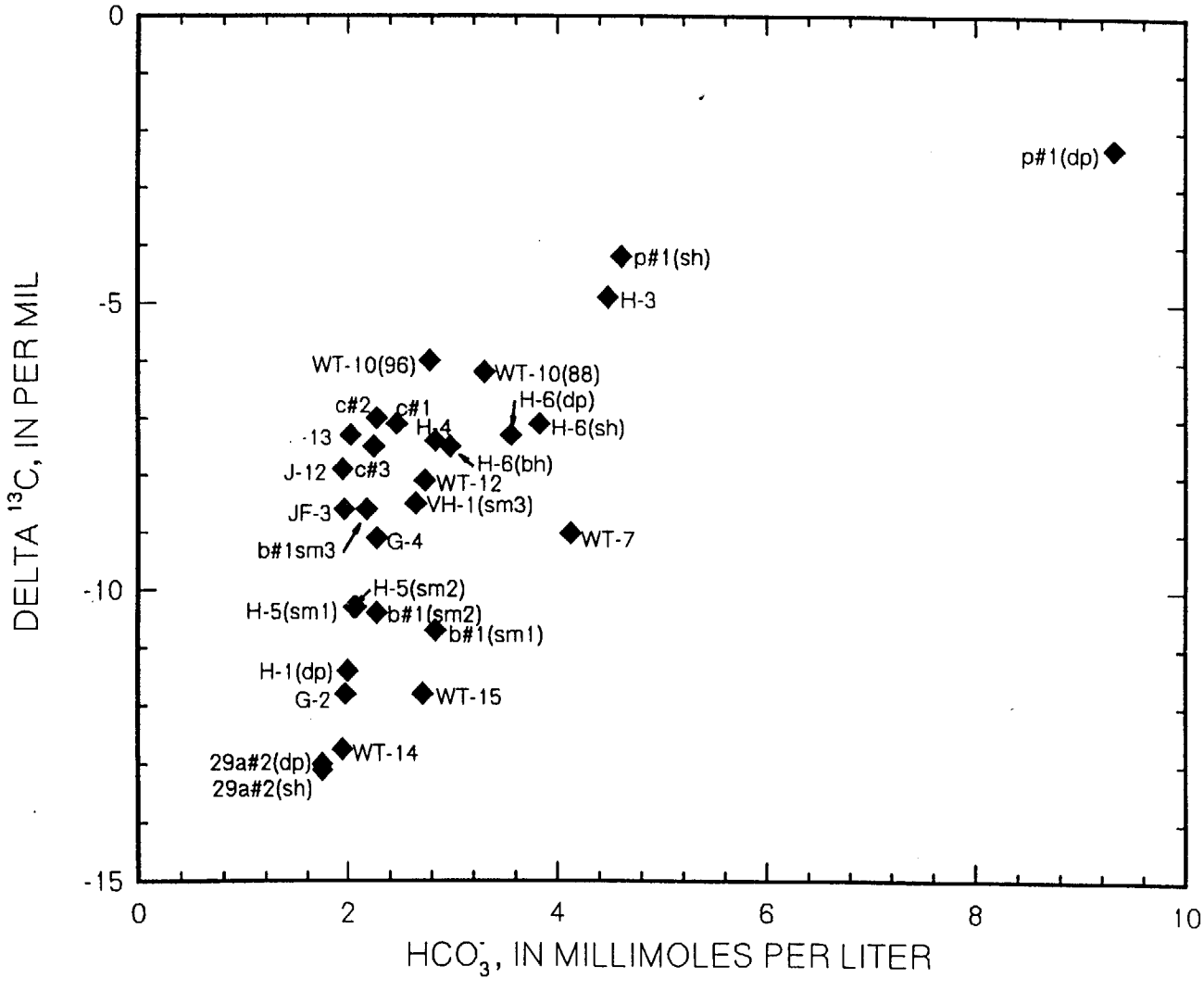
- Final verdict is possible only after resampling additional boreholes.

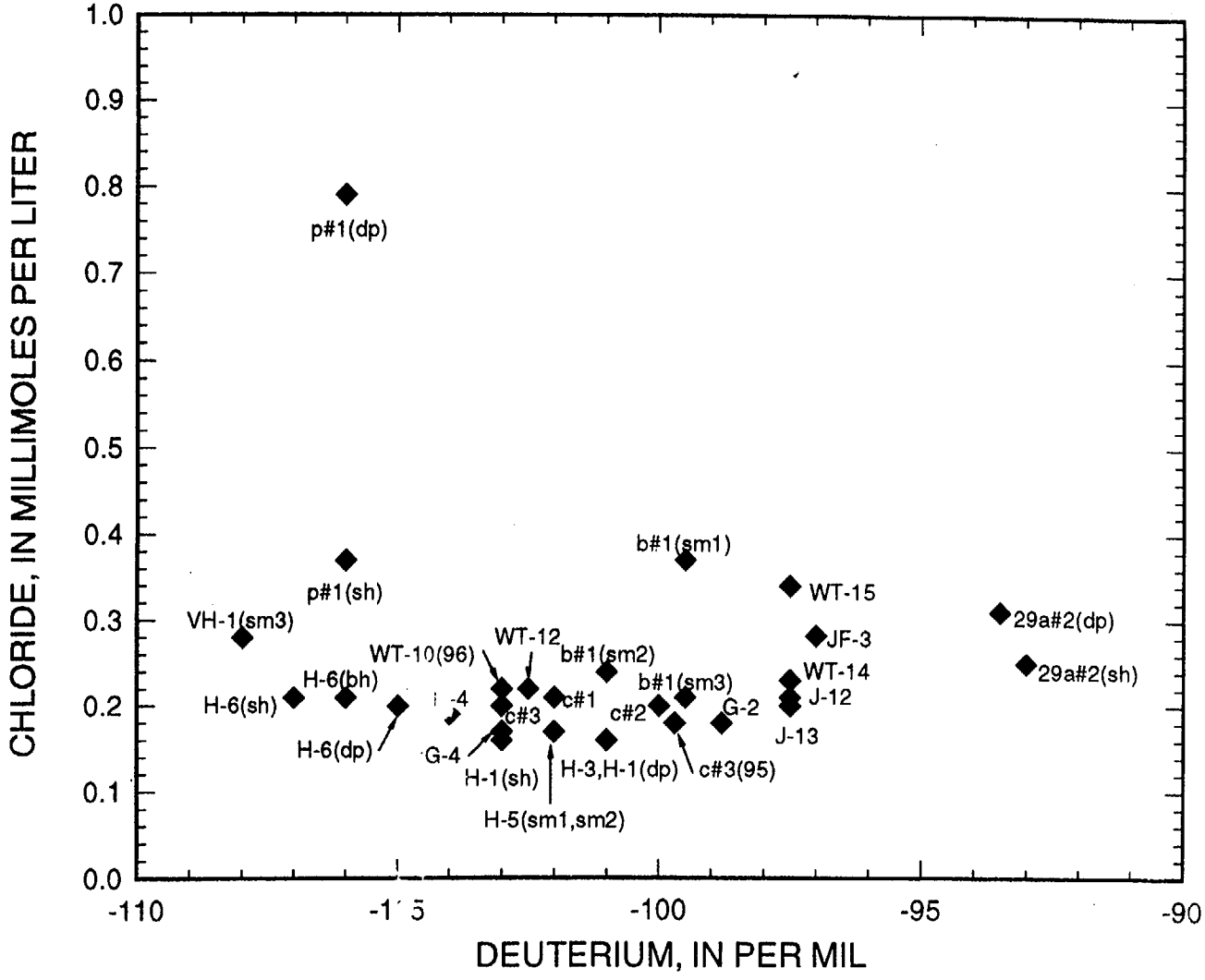
Isotopic data from calcite fracture coatings
(From Whelan and Moscati, 1995)



Gas chemistry data from borehole UZ-1
(From Yang and others, 1996)




DELTA ^{13}C, IN PER MIL
0
-5
-10
-15
0
2
4
6
8
10
HCO_3^-, IN MILLIMOLES PER LITER
p#1(dp)
p#1(sh)
H-3
WT-10(96)
WT-10(88)
H-6(dp)
c#2
c#1
H-4
H-6(sh)
-13
H-6(bh)
J-12
c#3
WT-12
JF-3
VH-1(sm3)
b#1sm3
G-4
WT-7
H-5(sm2)
H-5(sm1)
b#1(sm2)
b#1(sm1)
H-1(dp)
G-2
WT-15
WT-14
29a#2(dp)
29a#2(sh)


CHLORIDE, IN MILLIMOLES PER LITER
DEUTERIUM, IN PER MIL
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-110
-100
-95
-90
p#1(dp)
p#1(sh)
VH-1(sm3)
H-6(sh)
H-6(bh)
H-6(dp)
WT-10(96)
G-4
WT-12
c#3
c#1
b#1(sm2)
b#1(sm1)
c#2
b#1(sm3)
G-2
WT-15
JF-3
WT-14
J-12
J-13
29a#2(dp)
29a#2(sh)
H-1(sh)
H-3,H-1(dp)
c#3(95)
H-5(sm1,sm2)

Basis for NETPATH Corrections to ^{14}C age estimates

- NETPATH (Plummer and others, 1994) used a mass-balance approach to compute the contributions of various carbon sources to the total dissolved carbon.

- NETPATH then used the calculated contributions from different carbon sources, along with their known or estimated ^{14}C activities, to determine the initial ^{14}C activity of carbon in the water prior to decay ($^{14}A_{init}$).

- The corrected ^{14}C age of the groundwater sample was then calculated by NETPATH as

$$t=(5730/\ln 2)\ \ln(^{14}A_{init}/^{14}A_{meas})$$

where $^{14}A_{meas}$ is the measured ^{14}C activity of the groundwater sample.

Example Calculation

Assume a system that contains the phases calcite, dolomite, gypsum, $CO_{2(g)}$, NaCl, and in which Ca^{2+} exchanges for Na^{+} on an unspecified exchanger. The elemental mass balances can be written in terms of these phases (or exchange reactions) as

$$
\begin{aligned}
m_{Ca} &= \Delta m_{cal} + \Delta m_{dol} + \Delta m_{gyp} - \Delta m_{Ca/Na} \\
m_{Mg} &= \Delta m_{dol} \\
m_{SO4} &= \Delta m_{gyp} \\
m_{C} &= \Delta m_{cal} + 2\Delta m_{dol} + \Delta m_{CO2(g)} \\
m_{Na} &= 2\Delta m_{Ca/Na} + \Delta m_{NaCl} \\
m_{Cl} &= \Delta m_{NaCl}
\end{aligned}
$$

Then,

$$
\begin{aligned}
\Delta m_{NaCl} &= m_{Cl} \\
\Delta m_{dol} &= m_{Mg} \\
\Delta m_{gyp} &= m_{SO4} \\
\Delta m_{Ca/Na} &= 0.5 \times (m_{Na} - m_{Cl}) \\
\Delta m_{cal} &= m_{Ca} - m_{Mg} - m_{SO4} + 0.5 \times (m_{Na} - m_{Cl}) \\
\Delta m_{CO2(g)} &= m_{C} - m_{Ca} - m_{mg} + m_{SO4} - 0.5 \times (m_{Na} - m_{Cl})
\end{aligned}
$$

Example Calculation (continued)

Given the assumed reactions and the available elemental constraints,

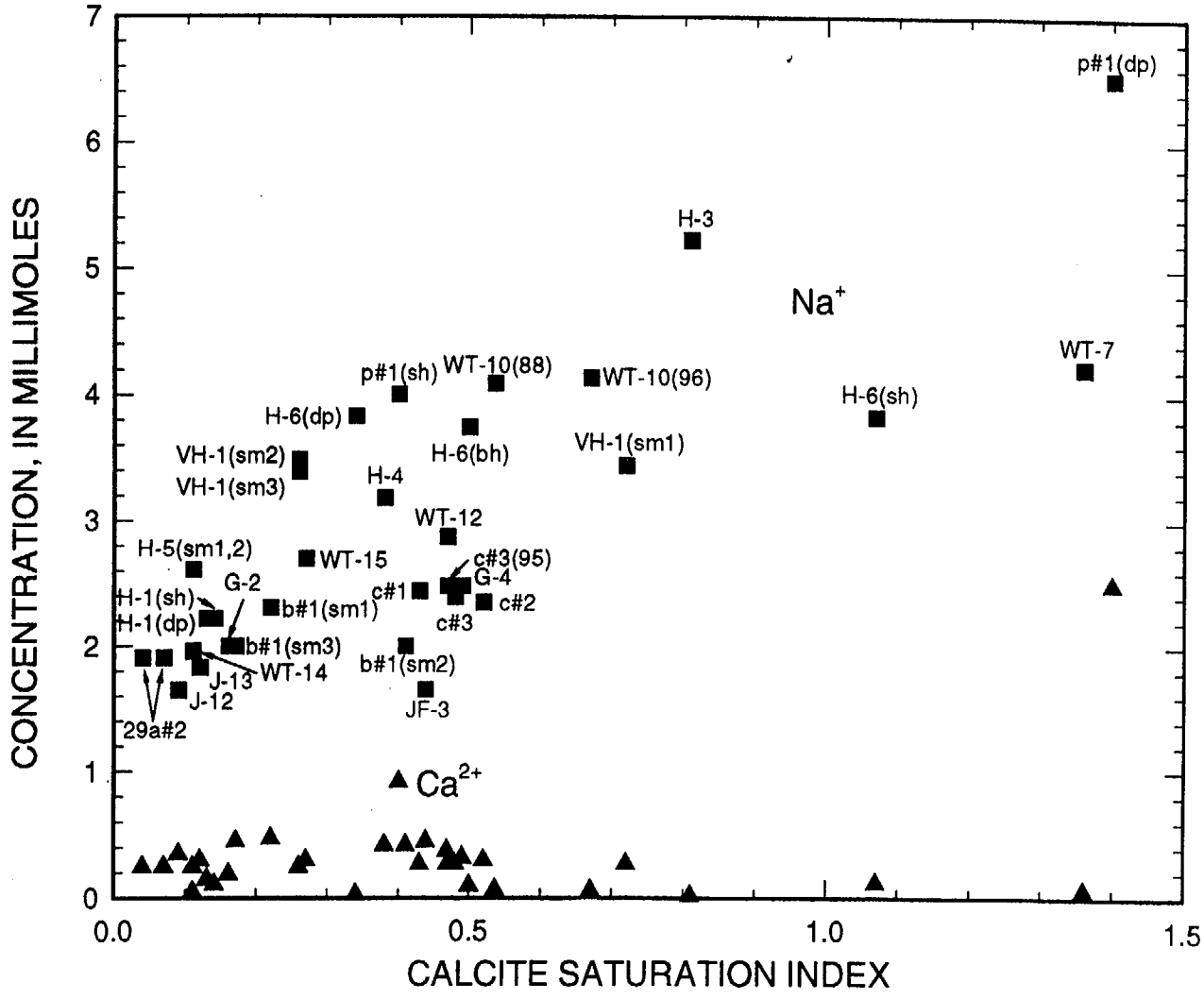
$$^{14}A_{init} = (2\Delta m_{dol} \times {}^{14}C_{dol} + \Delta m_{cal} \times {}^{14}C_{cal} + \Delta m_{CO2(g)} \times {}^{14}C_{CO2(g)})/m_C$$

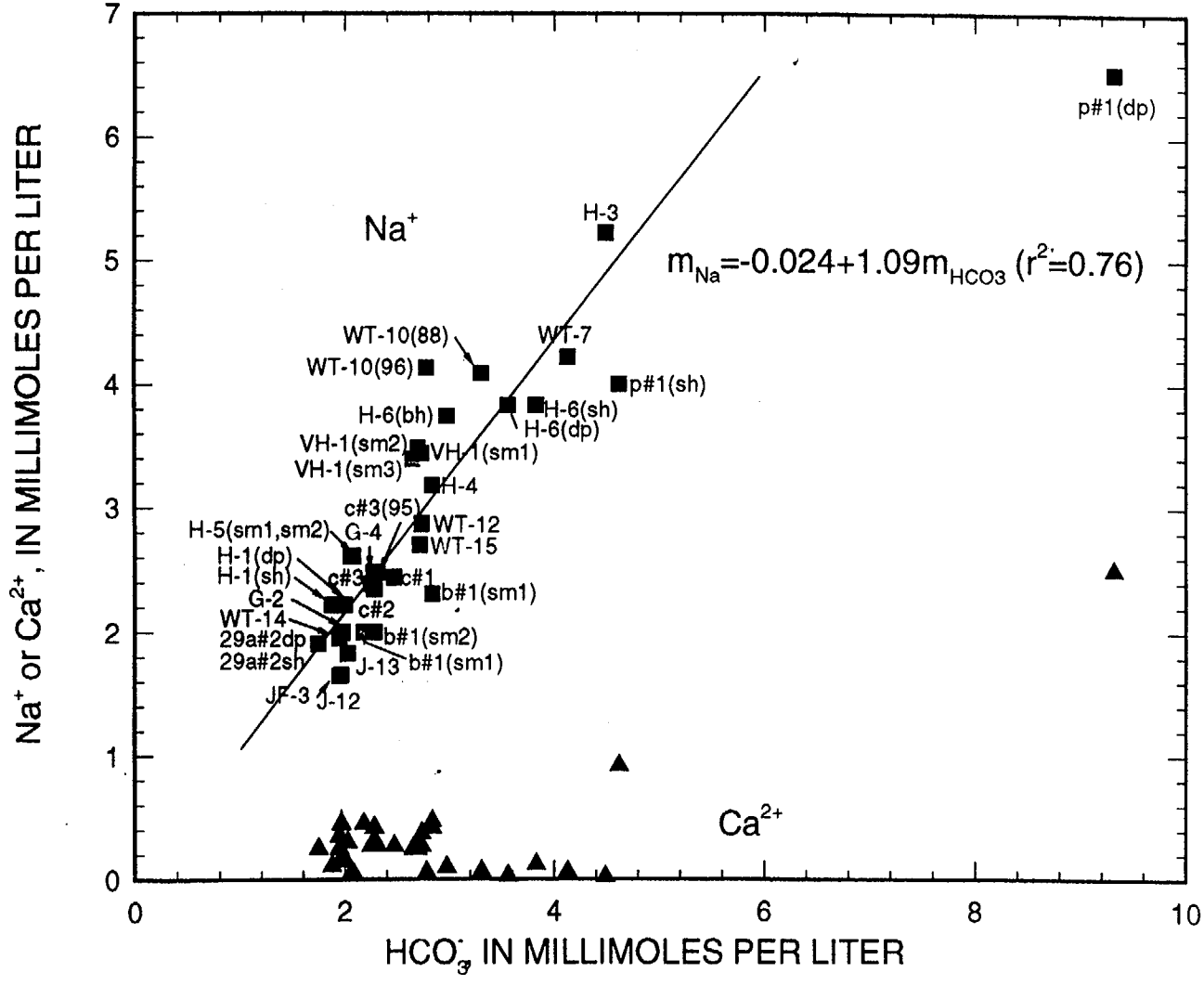
As an example, if the calculated sources of carbon are Δm_{dol} = 0.1 mmol/l, Δm_{cal} = 1 mmol/l, $\Delta m_{CO2(g)}$ = 1 mmol/l, and the ^{14}C activities of the various phases are $^{14}C_{dol}$ = 0 pmc, $^{14}C_{cal}$ = 0 pmc, and $^{14}C_{co2(g)}$ = 100 pmc, then $^{14}A_{init}$ = 45.45 pmc

If the measured ^{14}C activity ($^{14}A_{meas}$) is 20 pmc, the corrected age is then

$$t = (5730\text{yrs}/\ln 2) \ln(45.45/20) = 6786 \text{ years}$$

whereas the uncorrected age (assuming $^{14}A_{init}$ = 100 pmc) is 13,305 years.


CONCENTRATION, IN MILLIMOLES
CALCITE SATURATION INDEX
0.0
0.5
1.0
1.5
0
1
2
3
4
5
6
7
Na+
Ca2+
p#1(dp)
H-3
WT-7
p#1(sh)
WT-10(88)
WT-10(96)
H-6(sh)
H-6(dp)
H-6(bh)
VH-1(sm1)
VH-1(sm2)
VH-1(sm3)
H-4
WT-12
H-5(sm1,2)
WT-15
c#3(95)
G-4
G-2
c#1
c#2
H-1(sh)
H-1(dp)
b#1(sm1)
c#3
b#1(sm3)
b#1(sm2)
WT-14
J-13
J-12
JF-3
29a#2


Na+ or Ca2+, IN MILLIMOLES PER LITER
HCO3- IN MILLIMOLES PER LITER
Na+
Ca2+
mNa=-0.024+1.09mHCO3 (r2=0.76)
p#1(dp)
H-3
WT-10(88)
WT-10(96)
WT-7
p#1(sh)
H-6(bh)
H-6(sh)
H-6(dp)
VH-1(sm2)
VH-1(sm1)
VH-1(sm3)
H-4
c#3(95)
WT-12
H-5(sm1,sm2)
G-4
WT-15
H-1(dp)
H-1(sh)
c#3
c#1
b#1(sm1)
G-2
c#2
WT-14
29a#2dp
b#1(sm2)
29a#2sh
J-13
b#1(sm1)
JF-3
J-12
0
1
2
3
4
5
6
7
0
2
4
6
8
10

Possible Reaction Models

(1) Ca-Na exchange and calcite dissolution

$$CO_{2(g)} + H_2O + CaCO_{3(s)} + Na_2X = 2HCO_{3\,(aq)}^{-} + 2Na^{+}_{(aq)} + CaX$$

(2) Glass dissolution (After White and Chuma, 1987)

$$[Na_{0.0442}K_{0.0325}Ca_{0.0023}Mg_{0.0001}Fe_{0.0029}Al_{0.0789}Si_{0.419}O_{1.0}] + 0.1625\ H_2O + 0.3249CO_2 = 0.0422Na^{+} + 0.0325K^{+} + 0.0023Ca^{2+} + 0.0001\ Mg^{2+} + 0.0029Fe^{2+} + 0.0789Al^{3+} + 0.419SiO_2 + 0.3249\ HCO_3^{-}$$

- The observed trend toward enriched $\delta^{13}C$ values with increasing HCO_3^- concentration, along with the observed ratio of Na^+:HCO_3^- of approximately 1:1, indicate the dominance of the first reaction. However, the second model, along with the possibility of clay, zeolite and silica precipitation, is included as a possibility in the NETPATH calculations.

Application of NETPATH to Yucca Mountain ^{14}C Data

- Start with initially pure water (plus HCO_3^- in equilibrium with atmospheric $CO_2 = 10^{-3.5}$).

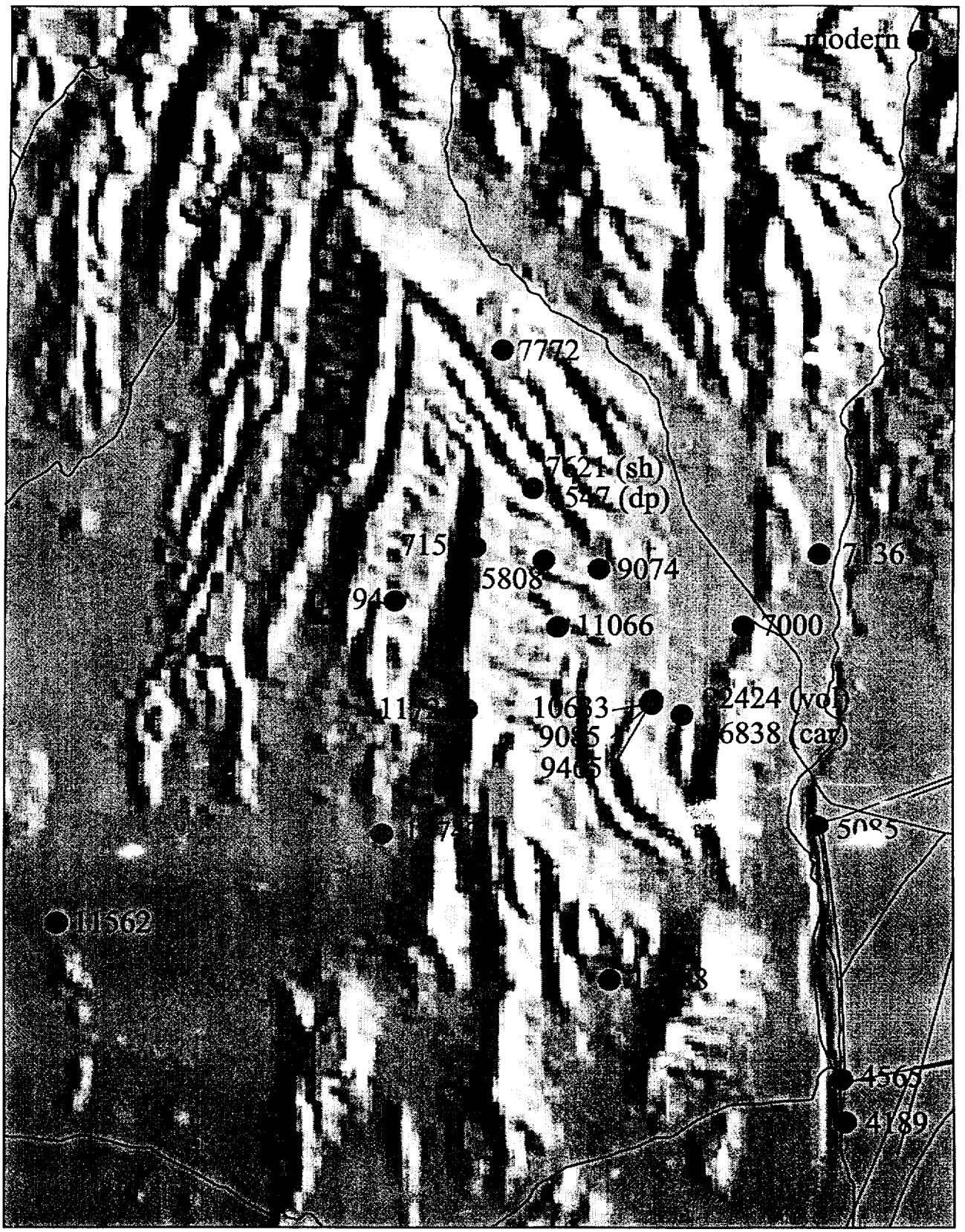
- Determine the plausible chemical reactions that resulted in the observed water chemistry of the groundwater samples.
  - -constraints include C, Ca, Na, Cl, S, Mg, K, Si, Fe, and Al
  - -potential phases included calcite, Ca/Na exchange, $CO_{2(g)}$, NaCl, gypsum, dolomite, Mg/Na exchange, glass, zeolites, clay, pyrite and SiO_2

- Phase composition for glass, zeolite and clay defined as

glass: $K_{0.402}Na_{0.368}Ca_{0.023}Fe(3+)_{0.026}Al_{0.7826}Si_{4.190}O_{10.0}$

zeolite: $K_{0.017}Na_{0.021}Ca_{0.344}Mg_{0.079}Al_{0.968}Si_{4.053}O_{10.0}$

clay: $K_{0.027}Na_{0.127}Ca_{0.164}Mg_{0.245}Fe(3+)_{0.1186}Al_{1.646}Si_{3.434}O_{10.0}$


modern
7772
7621 (sh)
547 (dp)
715
5808
9074
7 36
94
11066
7000
10633
2424 (vol)
9085
6838 (car)
9465
5085
11562
4565
4189

Estimation of the $\delta^{13}C$ values of calcite

- Evaluate the assumed reaction model
  - should be consistent with the observed values

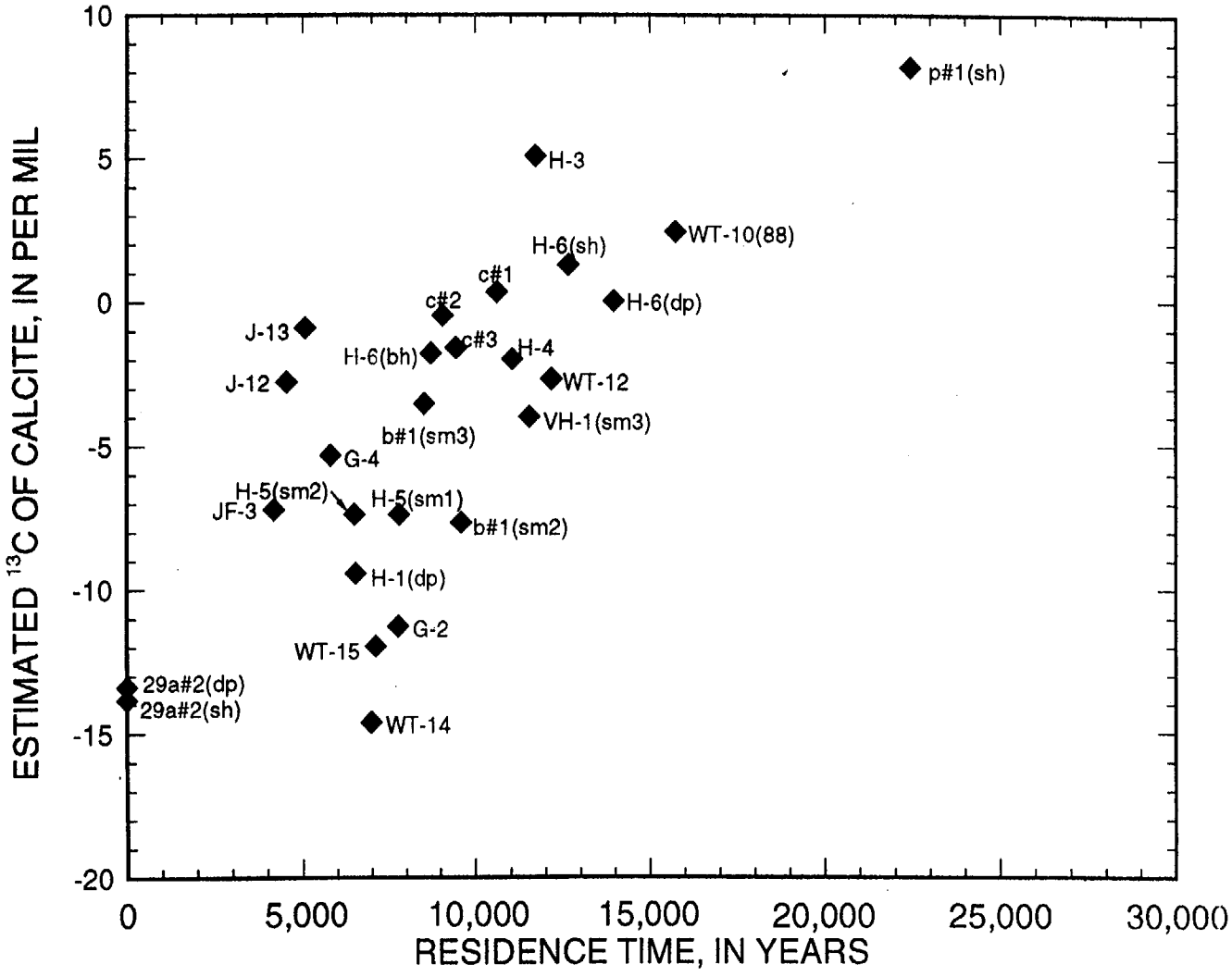
- Determine the probable source (unsaturated zone, saturated zone) of the dissolved carbon.

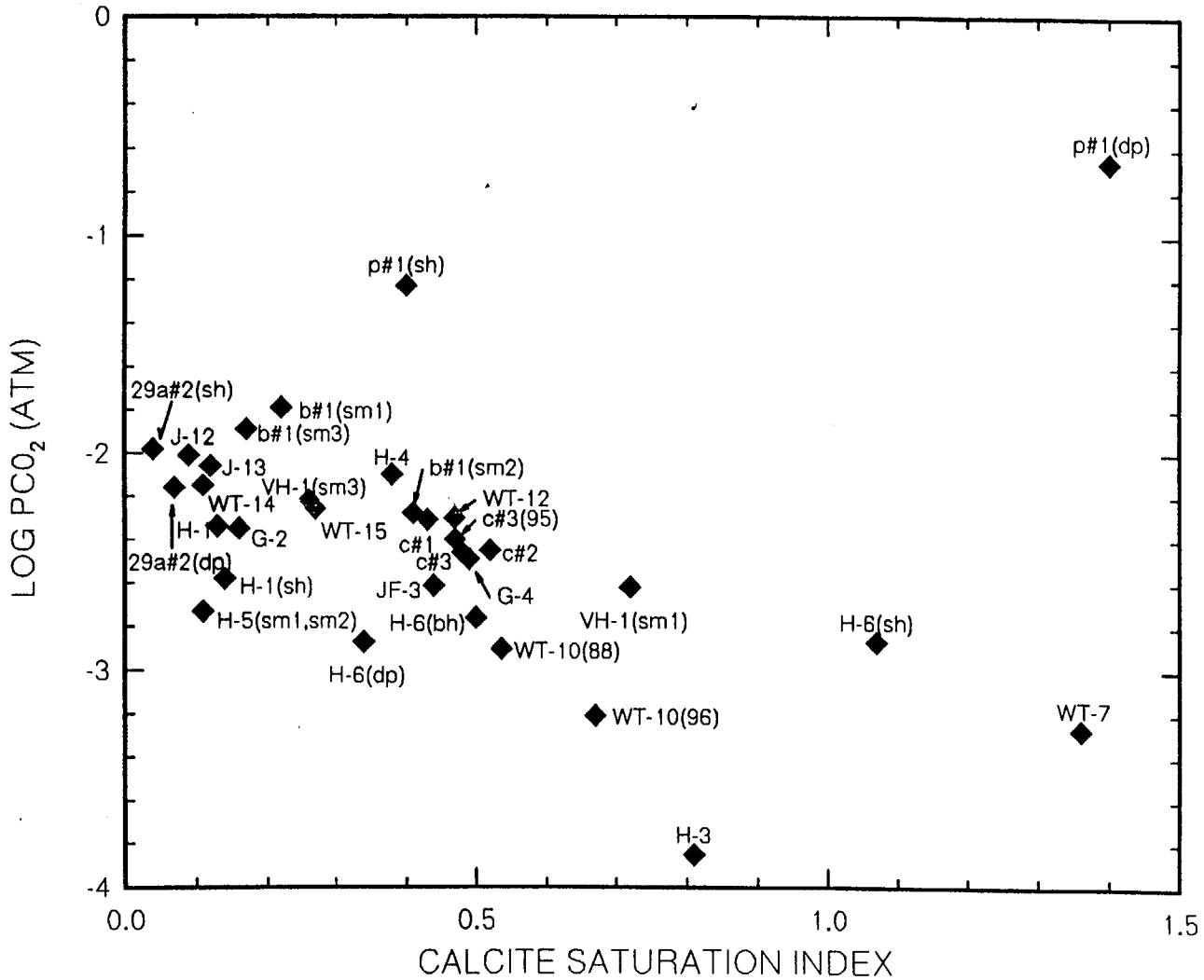
- The $\delta^{13}C$ value of calcite was estimated using

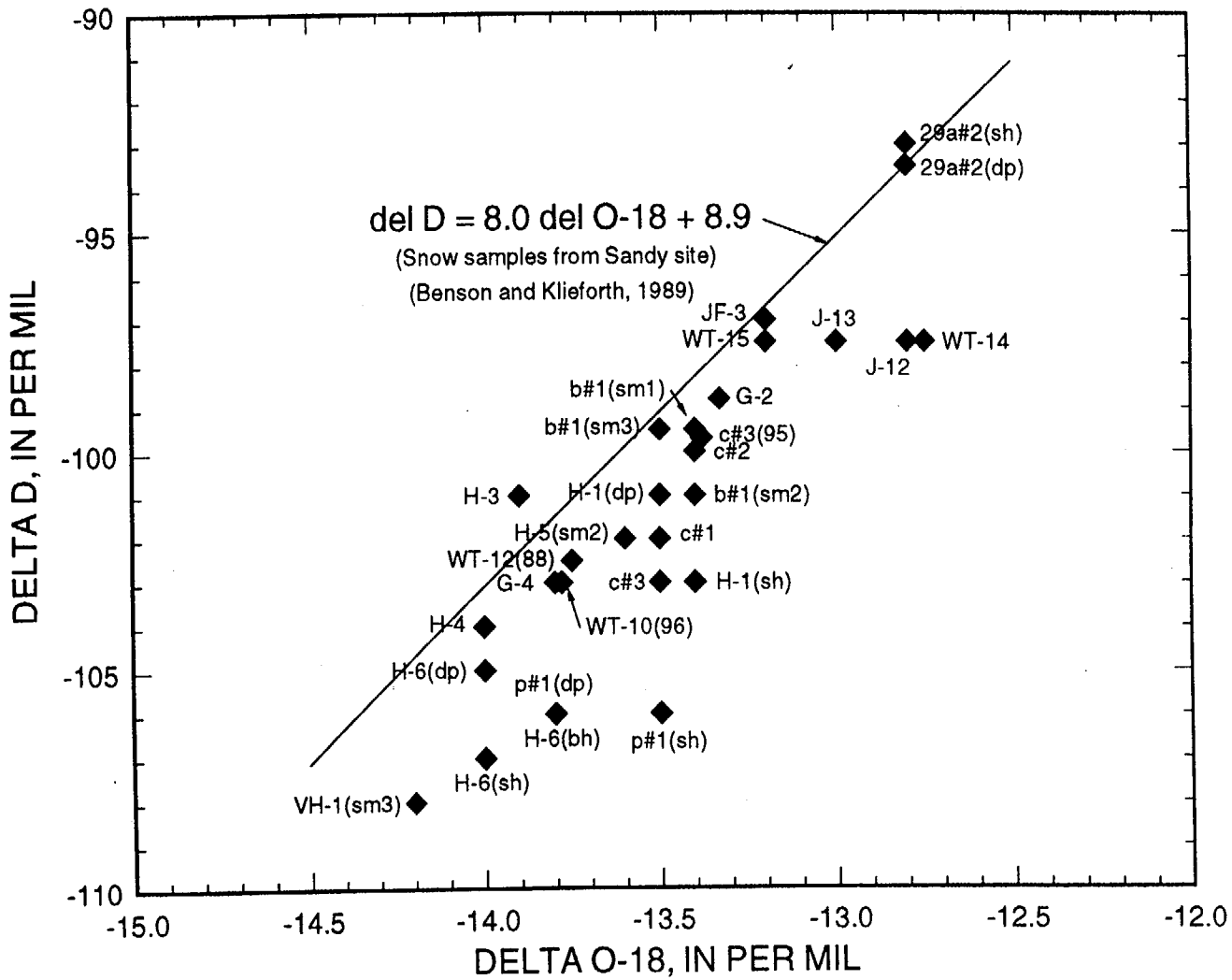
$$\delta^{13}C_{cal} - 2‰ = \frac{(\delta^{13}C_{sample})(m_c) - 2\,(\Delta m_{dol})(\delta^{13}C_{dol}) - (\Delta m_{co2(g)})(\delta^{13}C_{co2(g)})}{\Delta m_{cal}}$$

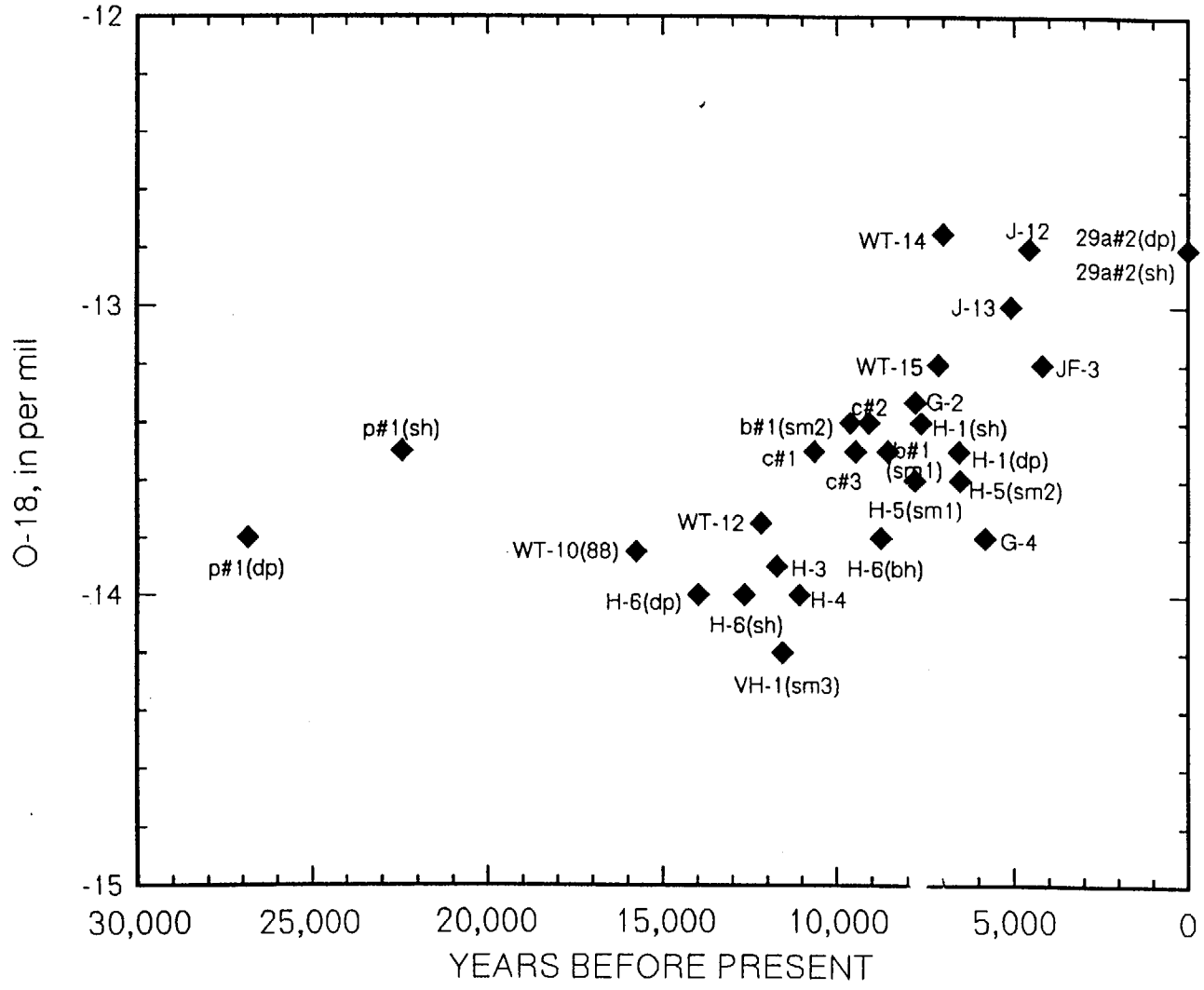
where m_c is the total dissolved carbon, Δm_{dol}, $\Delta m_{co2(g)}$ and Δm_{cal} are the carbon contributions calculated by NETPATH from dolomite, CO_2 gas, and calcite, and $\delta^{13}C_{dol}$ (-1.0 per mil), $\delta^{13}C_{co2(g)}$ (-12 per mil) and $\delta^{13}C_{cal}$ are the $\delta^{13}C$ values for dolomite, $CO_{2(g)}$ and calcite, respectively.

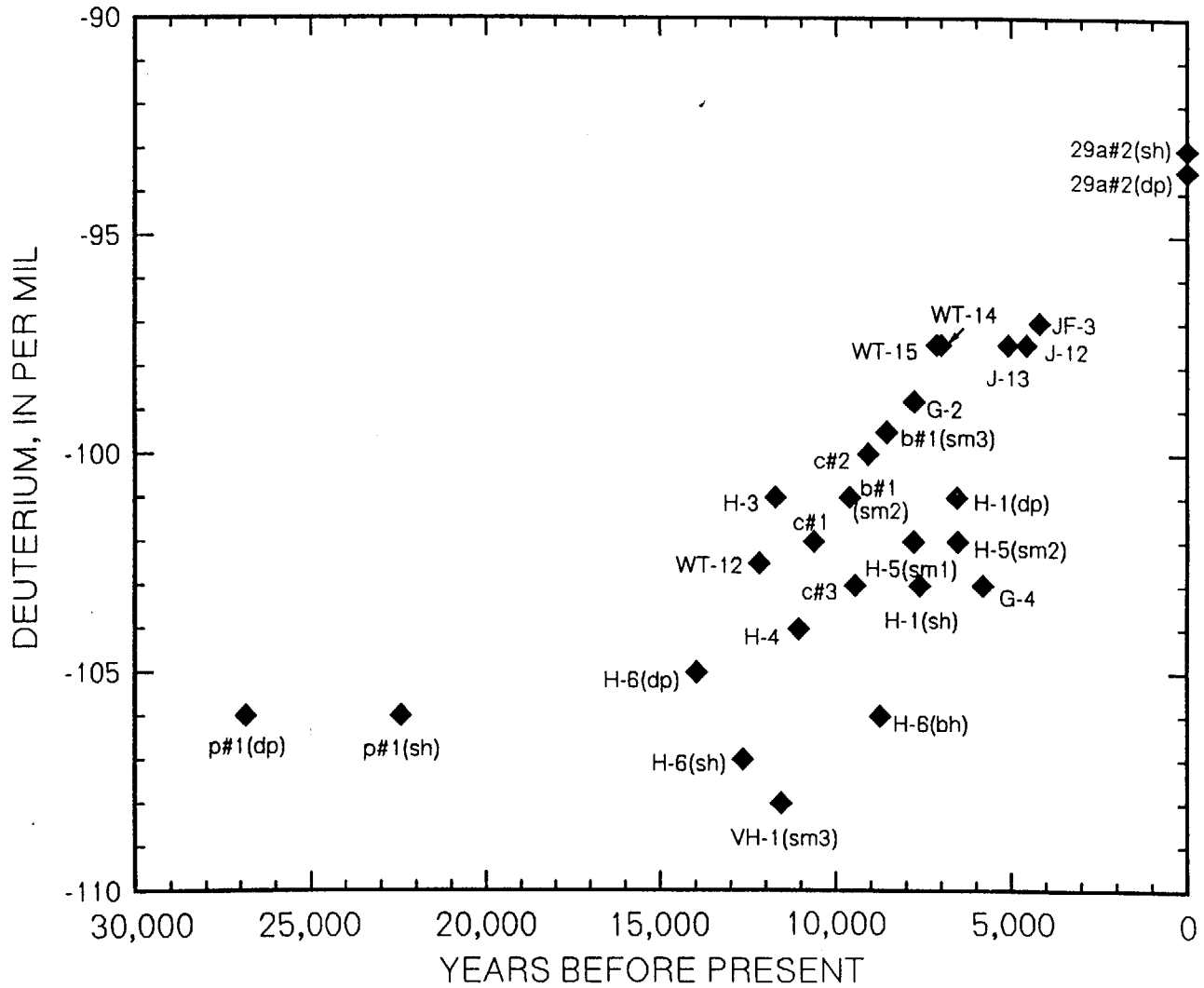
borehole and sample #	del C-13 per mil	C-14 pmc	uncorrected age(years)	delC-atm mmol/l	delC-dol mmol/l	delC-cal mmol/l	delC-co2 mmol/l	corrected age(years)	calculated C-13 calcite
J-12	-7.900	32.200	9367.790	0.026	0.167	0.664	1.240	4565.000	-2.767
J-13	-7.300	29.200	10176.249	0.026	0.125	0.799	1.205	5085.000	-0.880
b#1(sm1)	-10.700	NA	NA	0.026	0.058	1.126	1.982	NA	-7.819
b#1(sm2)	-10.400	16.700	14795.318	0.026	0.045	1.031	1.253	9607.000	-7.659
b#1(sm3)	-8.600	18.900	13772.295	0.026	0.051	1.067	1.302	8551.000	-3.531
c#1	-7.100	15.000	15682.813	0.026	0.029	1.115	1.367	10633.000	0.347
c#2	-7.000	16.600	14844.968	0.026	0.033	1.107	1.138	9085.000	-0.466
c#3	-7.500	15.700	15305.767	0.026	0.031	1.105	1.110	9465.000	-1.603
p#1(sh)	-4.200	3.500	27713.152	0.026	0.444	1.901	3.081	22424.000	8.187
p#1(dp)	-2.300	2.300	31183.934	0.026	1.698	1.973	7.736	26838.000	32.890
a#2(dp)	-13.000	62.300	3911.848	0.026	0.017	0.803	1.121	0.000	-13.375
a#2(sh)	-13.100	60.000	4222.813	0.026	0.022	0.838	1.224	0.000	-13.834
G-4	-9.100	22.000	12516.753	0.026	0.024	1.254	1.015	5808.000	-5.313
H-1(sh)	NA	19.900	13346.085	0.026	0.022	0.925	0.946	7621.000	NA
H-1(dp)	-11.400	23.900	11831.977	0.026	0.016	0.964	1.088	6547.000	-9.433
H-3	-4.900	10.500	18631.317	0.026	0.009	2.219	2.522	11721.000	5.070
H-4	-7.400	11.800	17666.399	0.026	0.032	1.606	1.340	11066.000	-1.993
H-5(sm1)	-10.300	18.200	14084.281	0.026	0.016	1.078	0.950	7800.000	-7.380
H-5(sm2)	-10.300	21.400	12745.338	0.026	0.016	1.081	0.964	6514.000	-7.360
H-6(bh)	-7.500	16.300	14995.732	0.026	0.014	1.547	1.368	8745.000	-1.789
H-6(dp)	-7.300	10.000	19034.648	0.026	0.011	1.574	1.862	13971.000	0.033
H-6(sh)	-7.100	12.400	17256.399	0.026	0.014	1.577	2.134	12665.000	1.283
VH1(sm1)	NA	NA	NA	0.026	0.080	1.295	1.283	NA	NA
VH1(sm2)	NA	NA	NA	0.026	0.075	1.265	1.356	NA	NA
VH1(sm3)	-8.500	12.200	17390.819	0.026	0.075	1.265	1.356	11562.000	-3.995
WT-7	-9.010	NA	NA	0.026	0.020	1.897	1.989	NA	-4.195
c#3(95)	NA	NA	NA	0.026	0.027	1.323	0.976	NA	NA
WT14	-12.750	24.100	11763.088	0.026	0.071	0.800	1.183	7000.000	-14.630
WT15	-11.800	21.600	12668.439	0.026	0.105	1.196	1.450	7136.000	-11.977
G-2	-11.800	20.500	13100.523	0.026	0.050	0.894	1.072	7772.000	-11.281
WT-10(88)	-6.200	7.300	21636.249	0.026	0.011	1.634	1.924	15742.000	2.437
WT-10(96)	-6.000	NA	NA	0.026	0.008	1.666	1.948	NA	2.863
WT-12	-8.100	11.400	17951.484	0.026	0.032	1.370	1.397	12188.000	-2.681
JF-3	-8.600	30.700	9762.140	0.026	0.196	0.604	1.009	4189.000	-7.187


ESTIMATED ^{13}C OF CALCITE, IN PER MIL
RESIDENCE TIME, IN YEARS
10
5
0
-5
-10
-15
-20
0
5,000
10,000
15,000
20,000
25,000
30,000
p#1(sh)
H-3
WT-10(88)
H-6(sh)
c#1
c#2
H-6(dp)
J-13
c#3
H-4
H-6(bh)
J-12
WT-12
b#1(sm3)
VH-1(sm3)
G-4
H-5(sm2)
H-5(sm1)
JF-3
b#1(sm2)
H-1(dp)
G-2
WT-15
29a#2(dp)
29a#2(sh)
WT-14


LOG PCO2 (ATM)
CALCITE SATURATION INDEX
0
-1
-2
-3
-4
0.0
0.5
1.0
1.5
p#1(dp)
p#1(sh)
29a#2(sh)
b#1(sm1)
b#1(sm3)
J-12
J-13
H-4
b#1(sm2)
VH-1(sm3)
WT-14
WT-12
c#3(95)
H-1
G-2
WT-15
c#1
c#2
c#3
29a#2(dp)
H-1(sh)
JF-3
G-4
H-5(sm1,sm2)
H-6(bh)
VH-1(sm1)
H-6(sh)
WT-10(88)
H-6(dp)
WT-10(96)
WT-7
H-3


del D = 8.0 del O-18 + 8.9
(Snow samples from Sandy site)
(Benson and Klieforth, 1989)
29a#2(sh)
29a#2(dp)
JF-3
WT-15
J-13
WT-14
J-12
b#1(sm1)
G-2
b#1(sm3)
c#3(95)
c#2
H-3
H-1(dp)
b#1(sm2)
H-5(sm2)
c#1
WT-12(88)
G-4
c#3
H-1(sh)
WT-10(96)
H-4
H-6(dp)
p#1(dp)
H-6(bh)
p#1(sh)
H-6(sh)
VH-1(sm3)
-90
-95
-100
-105
-110
-15.0
-14.5
-14.0
-13.5
-13.0
-12.5
-12.0
DELTA D, IN PER MIL
DELTA O-18, IN PER MIL


-12
-13
-14
-15
O-18, in per mil
30,000
25,000
20,000
15,000
10,000
5,000
0
YEARS BEFORE PRESENT
WT-14
J-12
29a#2(dp)
29a#2(sh)
J-13
WT-15
JF-3
G-2
c#2
b#1(sm2)
H-1(sh)
p#1(sh)
c#1
b#1
(sm1)
H-1(dp)
c#3
H-5(sm2)
H-5(sm1)
WT-12
G-4
WT-10(88)
p#1(dp)
H-3
H-6(bh)
H-6(dp)
H-4
H-6(sh)
VH-1(sm3)


-90
-95
-100
-105
-110
DEUTERIUM, IN PER MIL
30,000
25,000
20,000
15,000
10,000
5,000
0
YEARS BEFORE PRESENT
29a#2(sh)
29a#2(dp)
WT-14
JF-3
WT-15
J-12
J-13
G-2
b#1(sm3)
c#2
b#1
(sm2)
H-3
H-1(dp)
c#1
H-5(sm2)
WT-12
H-5(sm1)
c#3
G-4
H-1(sh)
H-4
H-6(dp)
H-6(bh)
p#1(dp)
p#1(sh)
H-6(sh)
VH-1(sm3)

Summary and Conclusions

- Groundwater samples from Yucca Mountain and vicinity become enriched in ^{13}C with increasing concentrations of HCO_3^-, indicating an isotopically heavy source for the additional HCO_3^-.

- A plot of Cl^- versus D indicates little mixing between the Paleozoic carbonate aquifer and the volcanic aquifer, eliminating mixing as potential source of the isotopically heavy carbon in the volcanic aquifer.

- The large variability in $\delta^{13}C$ of the surface and fracture-lining calcites precludes their use in making corrections to the ^{14}C data.

- Corrections to the ^{14}C ages were done using NETPATH (Plummer and others, 1994), which used element mass balances to calculate the amount of carbon contributed to the groundwater samples from various potential carbon sources.

Summary and Conclusions (continued)

- Based on the trend toward enriched ^{13}C values with increasing HCO_3^- concentrations, and a Na:HCO_3^- ratio of approximately 1:1, the predominant reaction affecting the carbon budget appears to be Ca^{2+}/Na^+ exchange and calcite dissolution.
  - However, the NETPATH calculations also considered glass dissolution, and clay, zeolite and silica deposition.

- Corrected ^{14}C ages showed consistent spatial patterns. West and south of Yucca Mountain groundwater is approximately 11,000 to 12,000 years old. Beneath central and northern Yucca Mountain, groundwater is 6,000 to 8,000 years old. East and southeast of Yucca Mountain, beneath Forty-Mile Wash, groundwater is estimated to be 4,000 to 7,000 years old.

- The estimated average $\delta^{13}C$ value of calcite contributing carbon to the groundwater increases as a function of groundwater age, reflecting increasing contact of groundwater with isotopically enriched fracture calcite in the saturated zone.

Estimated Ground-water Recharge from Streamflow in Fortymile Wash near Yucca Mountain

Chuck Savard - USGS - YMP

Outline

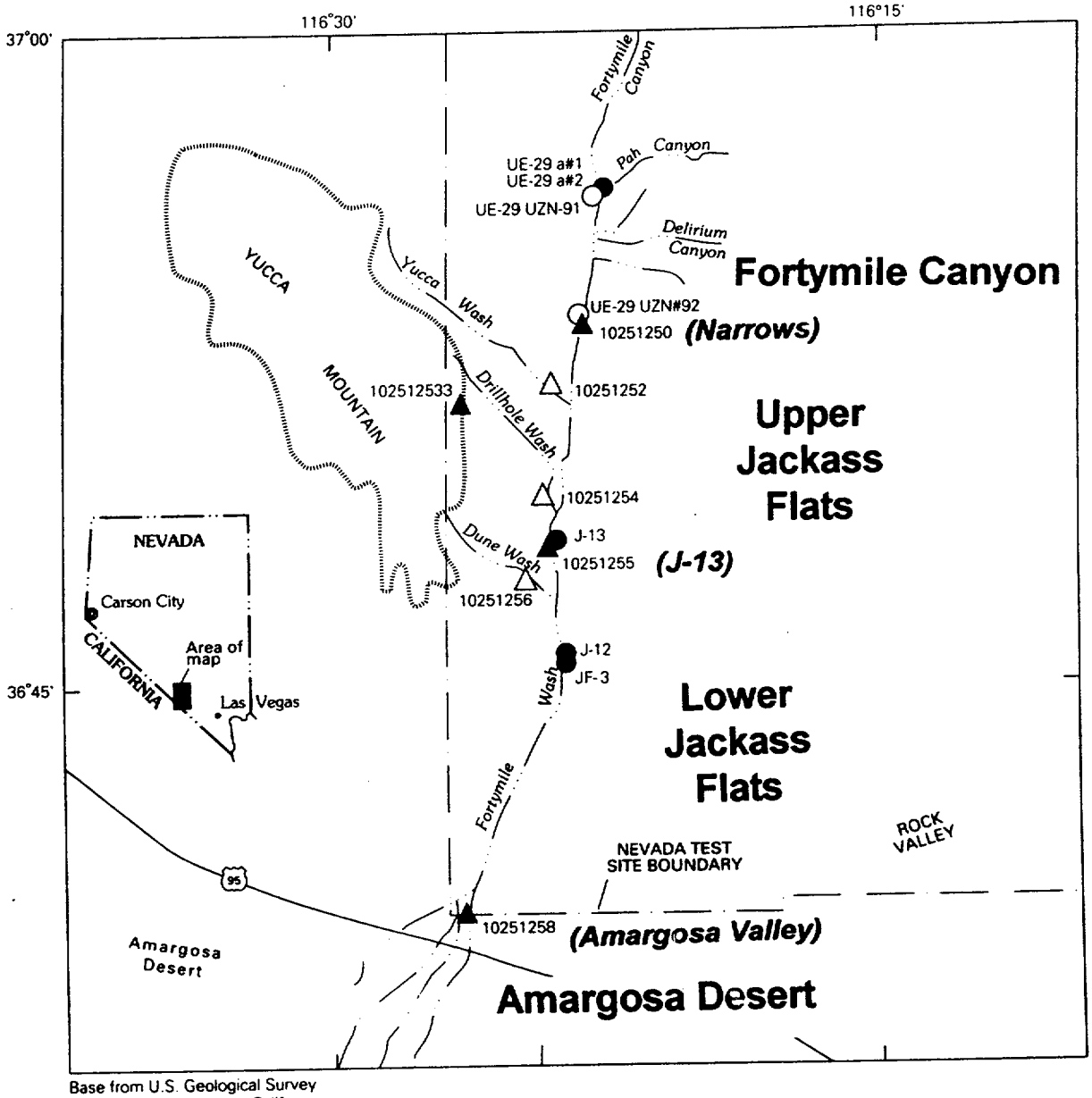
Objectives
Location
Streamflow
Ground-water Recharge
Comparison
Summary

Objectives

Document gw recharge
GW recharge volume from streamflow
- Streamflow volume
- Infiltration loss volume
- GW recharge volume

GW recharge rate

Fortymile Wash Reaches



Base from U.S. Geological Survey 1:250, 000 Death Valley, California; Nevada, 1970

0 5 10 15 KILOMETERS

0 5 MILES

EXPLANATION

10251258 ▲ GAGING STATION AND NUMBER

10251256 △ CREST-STAGE GAGE AND NUMBER

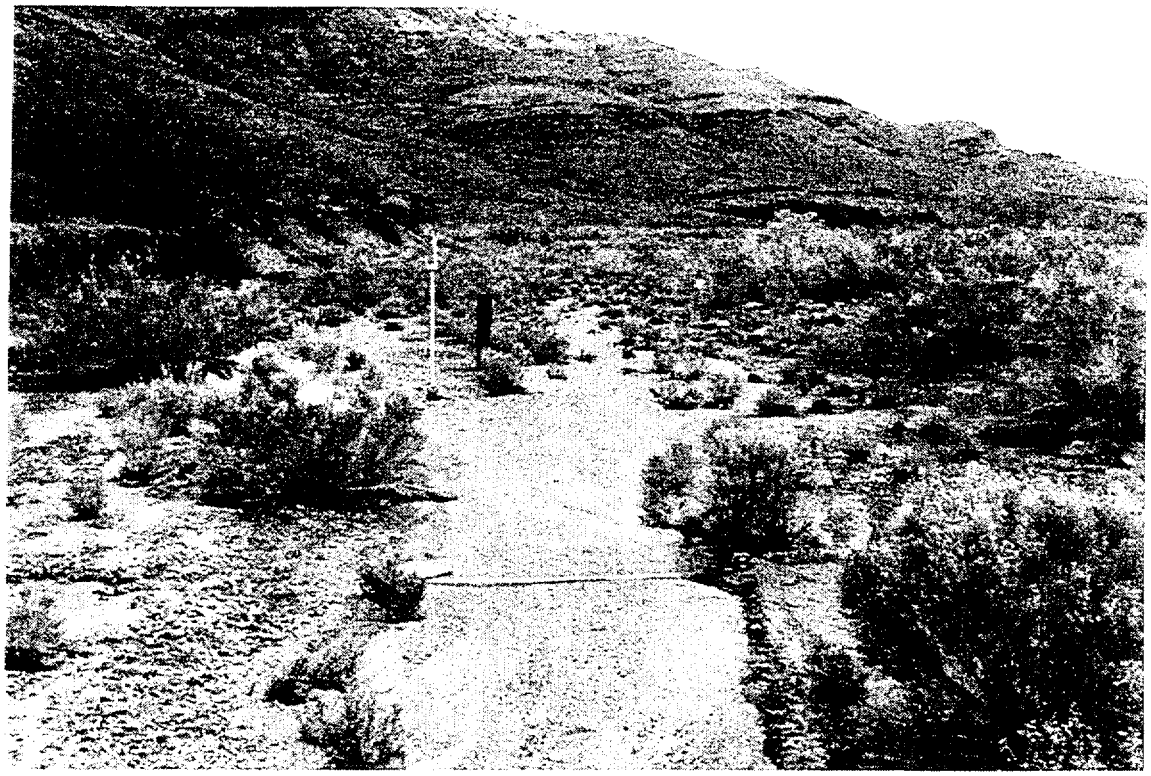
JF-3 ● WELL AND NUMBER

UE-29 UZN#92 ○ NEUTRON-ACCESS BOREHOLE AND PRECIPITATION GAGES

Streamflow

- Winter/Spring
  - Frontal storms
  - El Nino events
    - 1969, 83, 92, 93, 95
- Summer/Fall
  - Convective storms
    - 1984, 85, 91

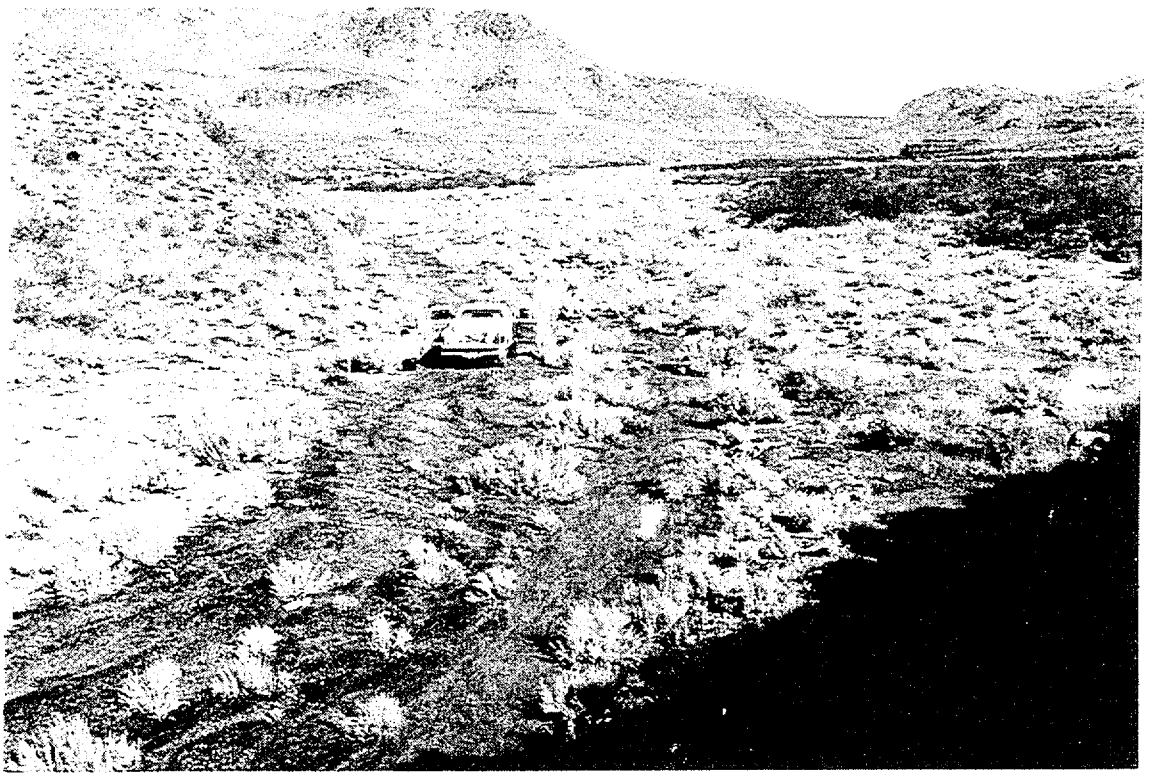
Fortymile Wash at UE-29 UZN#91
Feb. 18, 1992



Mar. 24, 1995

Fortymile Wash at UE-29 UZN#92-Narrows

Jan. 20, 1993



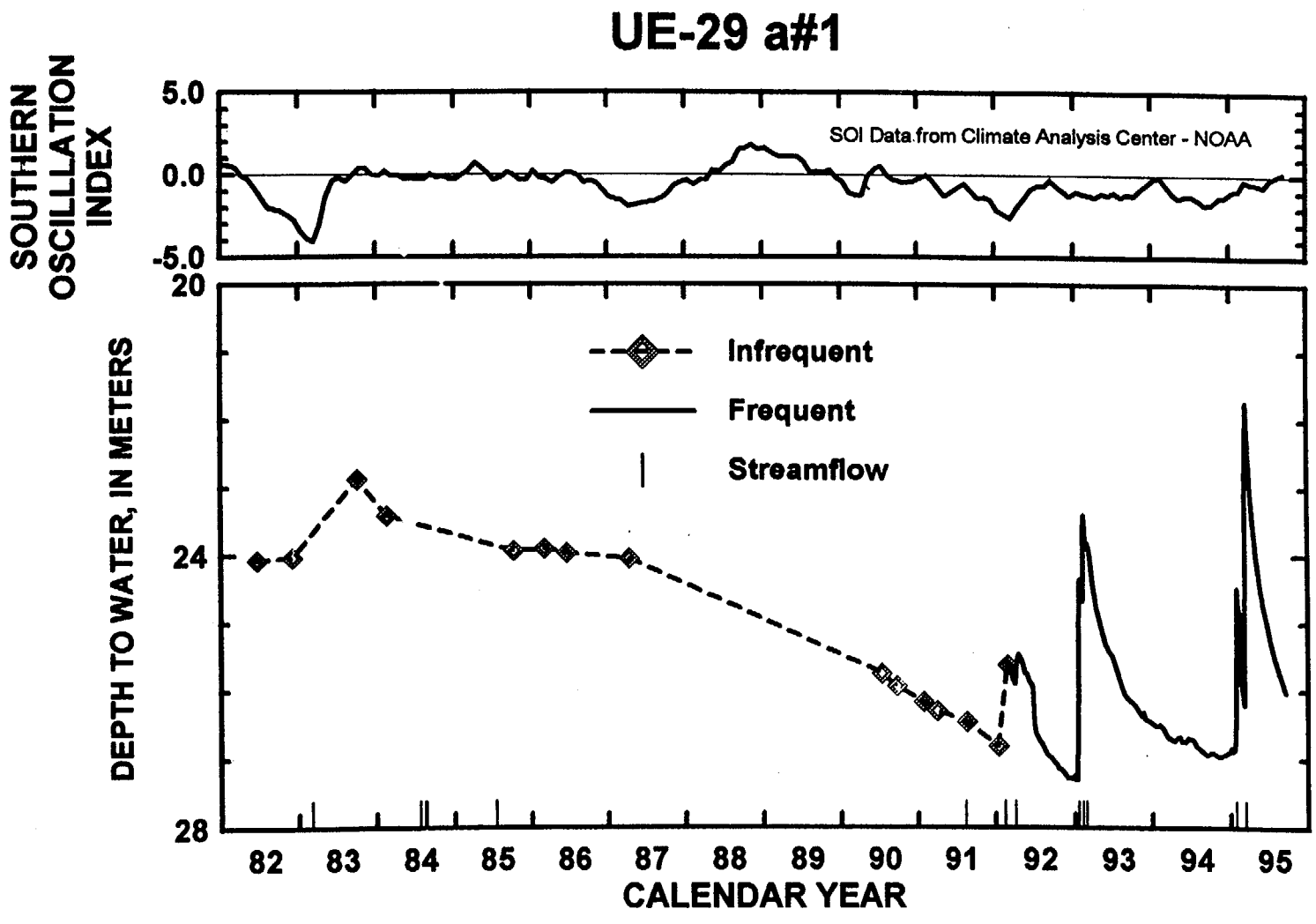
Mar. 13, 1995

Yucca Wash - Feb. 12, 1992

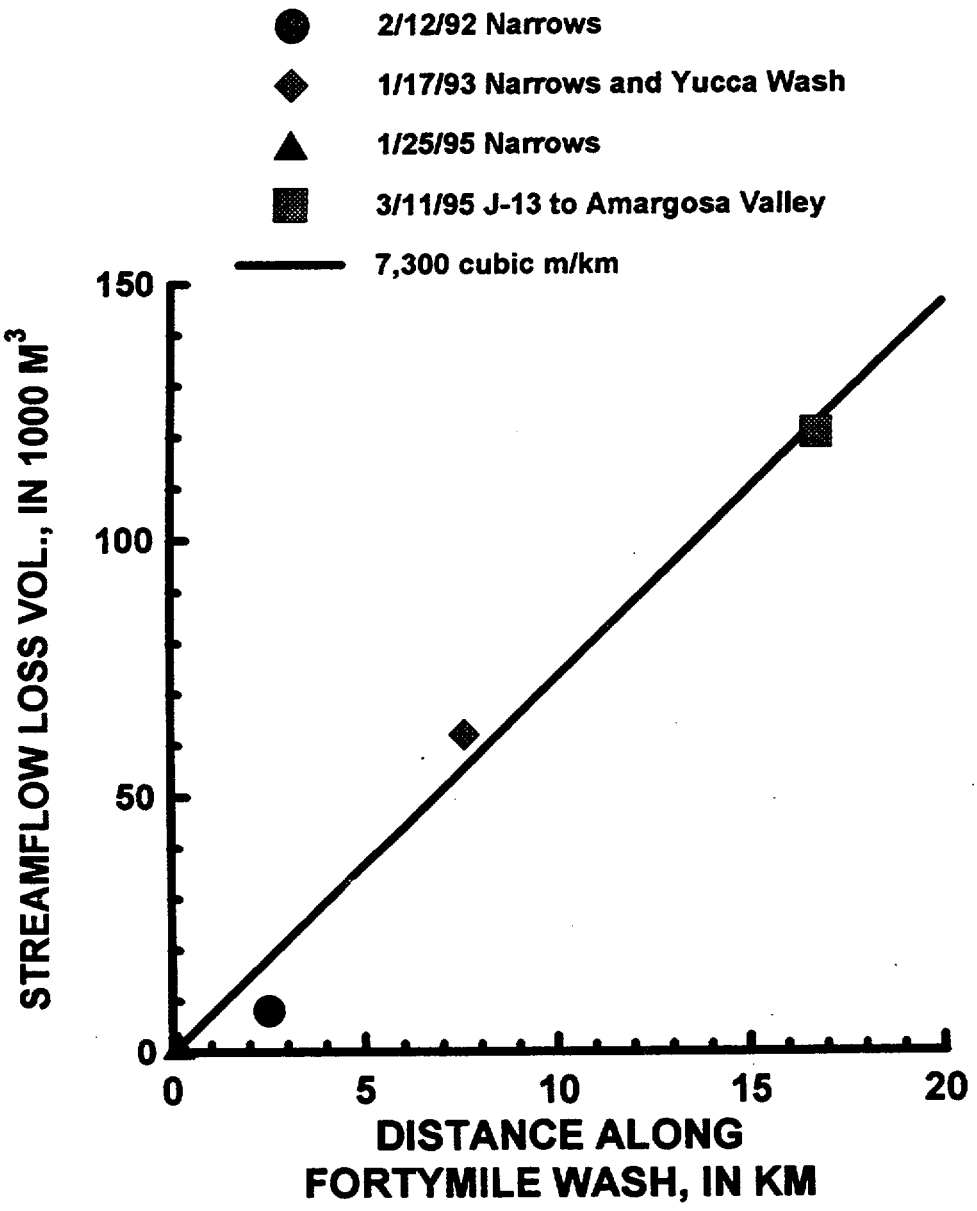
Pah Canyon Wash - Jan. 26, 1995

Document GW Recharge

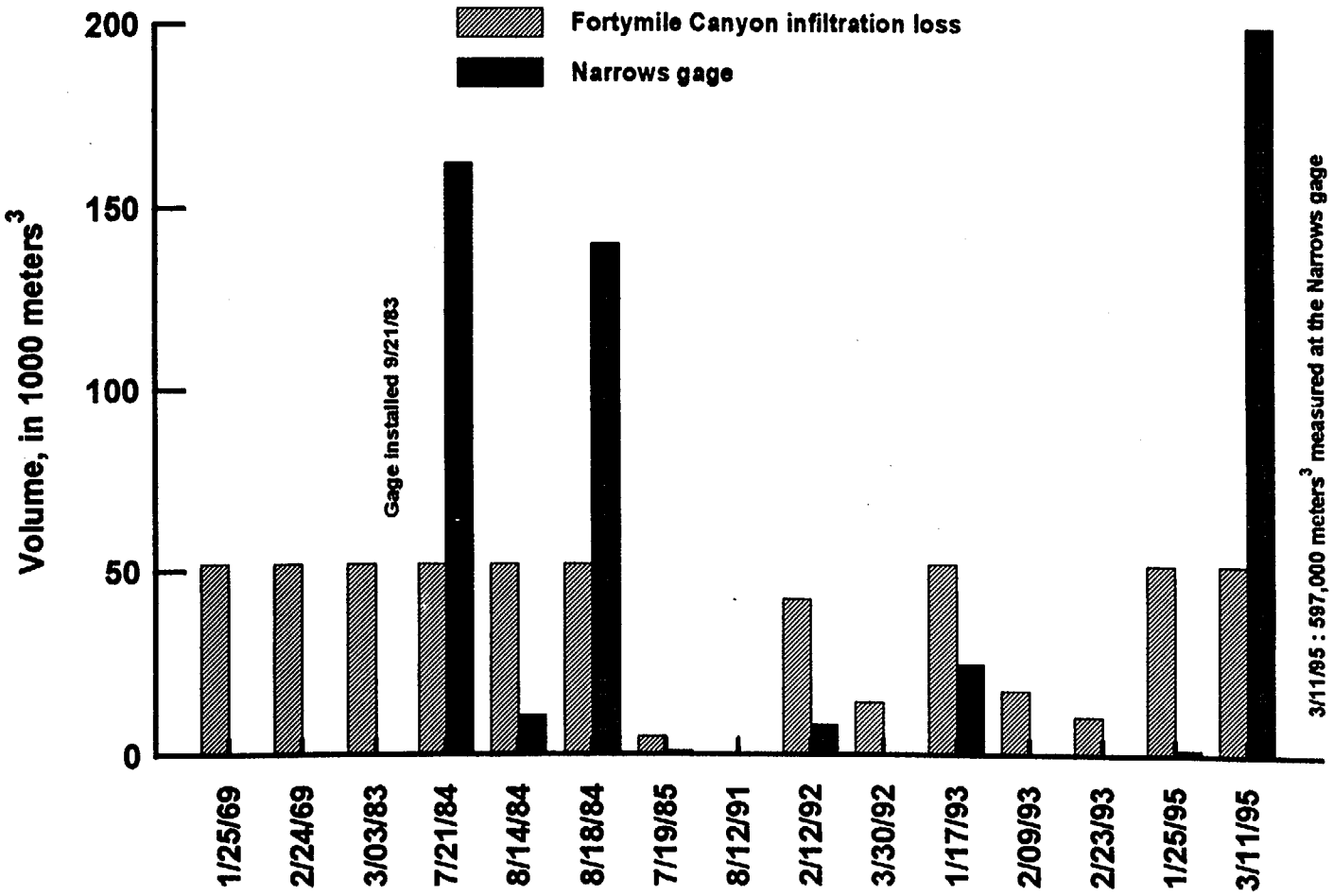
- Occurences of streamflow
  - Gaging stations
  - Ungaged locations
- Changes in unsaturated zone moisture
  - Fortymile Canyon neutron holes
    - UE-29 UZN-91
    - UE-29 UZN-92
- GW level rises after streamflow
  - Fortymile Canyon boreholes
    - UE-29 a#1
    - UE-29 a#2
    - UE-29 UZN-91


UE-29 a#1
SOUTHERN OSCILLATION INDEX
5.0
0.0
-5.0
SOI Data from Climate Analysis Center - NOAA
DEPTH TO WATER, IN METERS
20
24
28
Infrequent
Frequent
Streamflow
82
83
84
85
86
87
88
89
90
91
92
93
94
95
CALENDAR YEAR

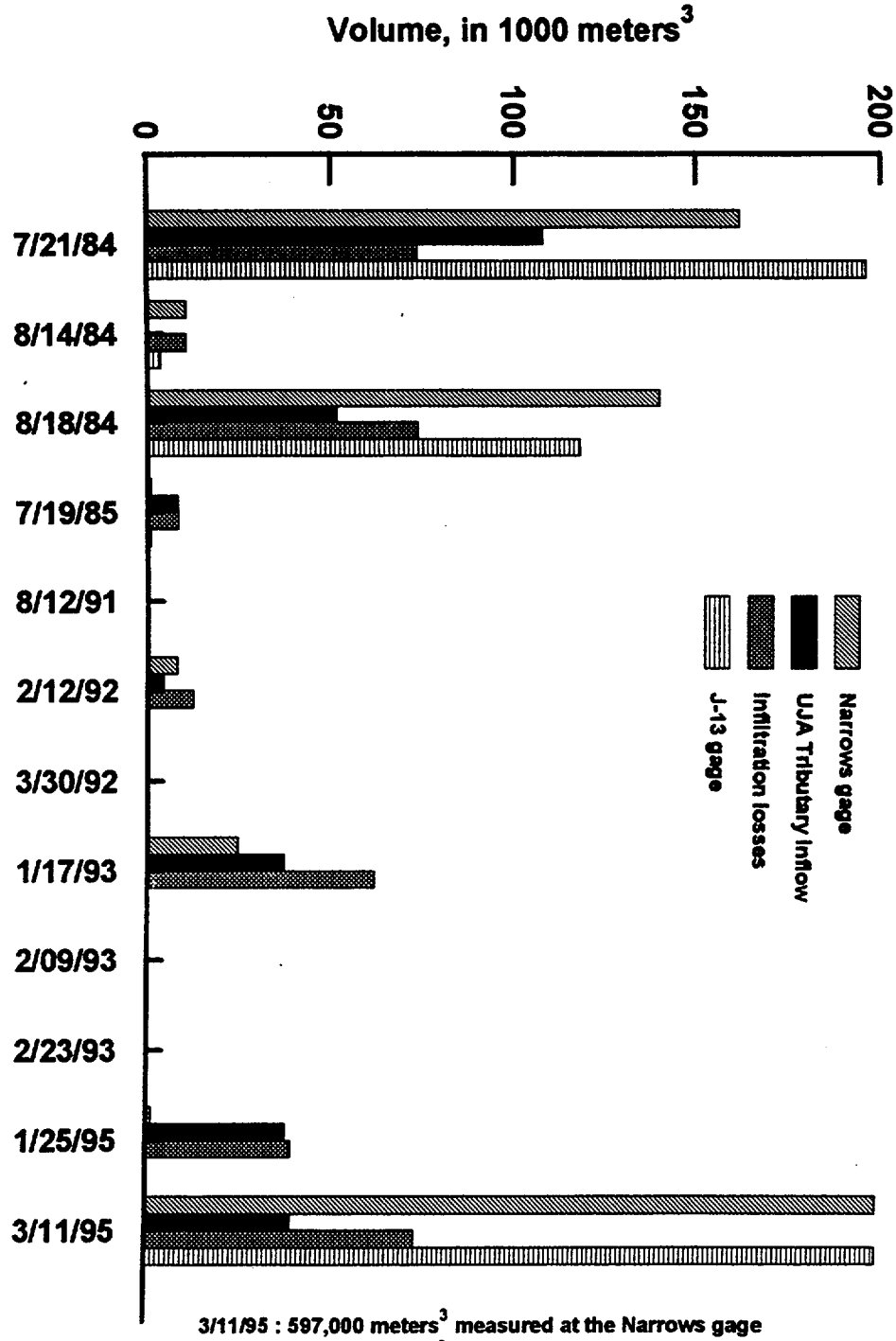
Fortymile Wash
Streamflow Loss Factor



Fortymile Canyon Streamflow Events

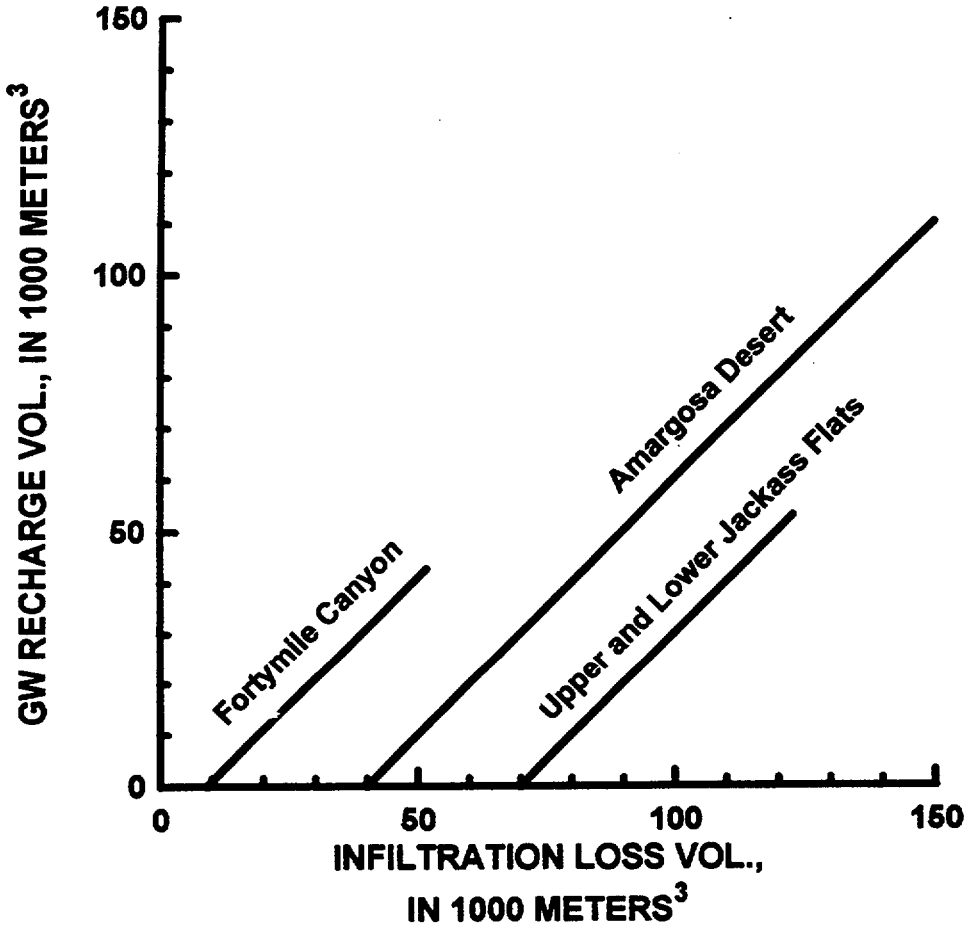


Upper Jackass Flats Streamflow Events

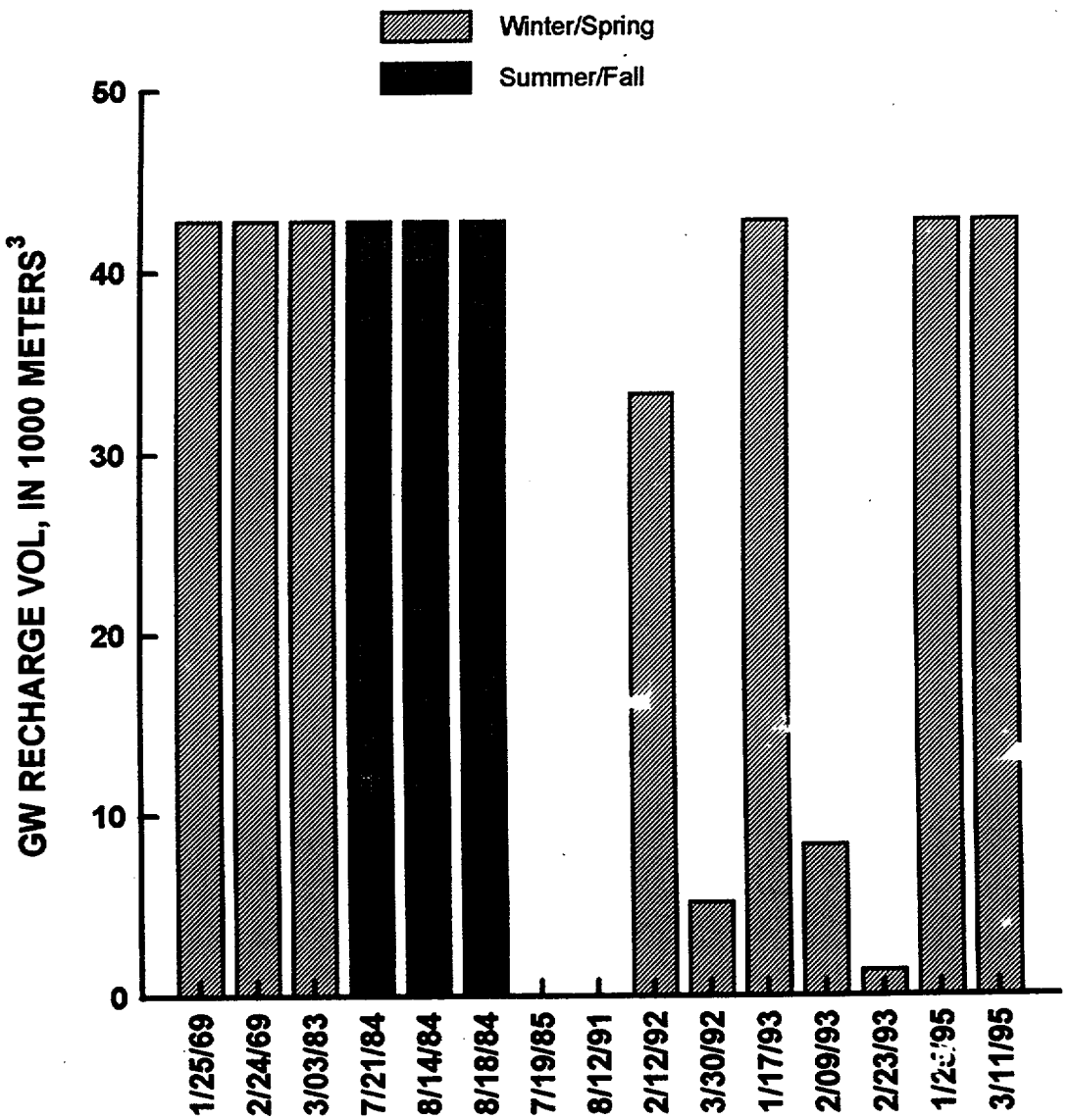


3/11/95 : 597,000 meters^3 measured at the Narrows gage
563,000 meters^3 measured at the J-13 gage

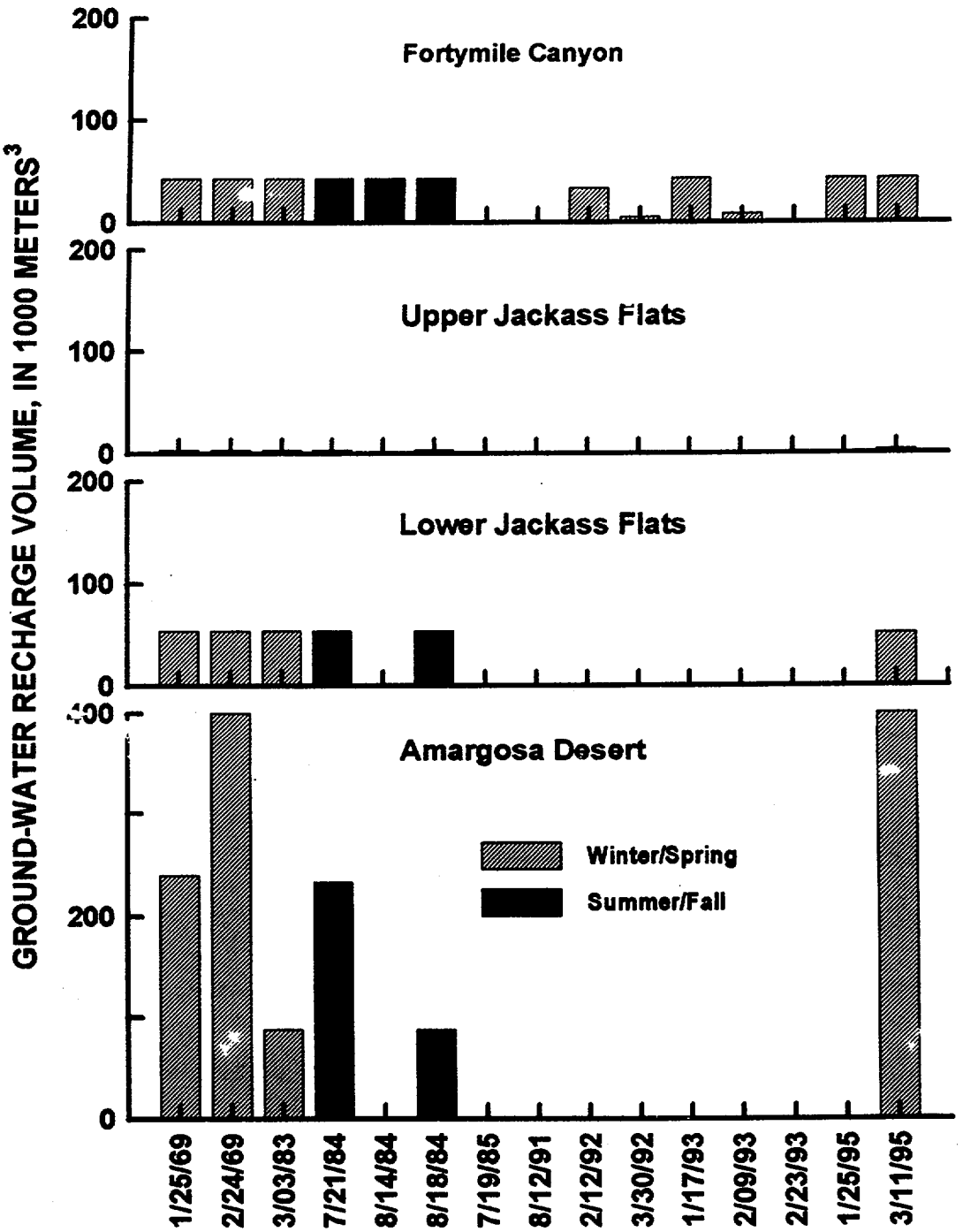
Fortymile Wash GW Recharge from Streamflow Infiltration Losses



Ground-water Recharge Volumes from Streamflow Event Infiltration for Fortymile Canyon



Ground-water Recharge Volumes from Streamflow Event Infiltration for each Reach



Estimated GW recharge rate for Fortymile Canyon reach

Period	Length (years)	Winter/ Spring (meters^3/year)	Summer/ Fall (meters^3/year)
1992-95	4	44,100	0
1983-95	13	16,900	9,900
1969-95	27	11,300	4,800
Long-Term Rate		17,000	10,000
Combined		27,000	

Estimated GW recharge rates for all reaches

Reach	Winter/ Spring	Summer/ Fall	Combined
	(meters^3/year)		
FMC	17,000	10,000	27,000
UJA	570	570	1,100
LJA	8,000	8,200	16,200
AD	39,600	24,700	64,300
Total			108,600

Comparisons

Previous work	From streamflow
---	---
Claassen (1985) Geochem Study	
FMW recharge in AD	Yes
Snowmelt	Yes
8000-12000 years ago	Last 25 yrs
Czarnecki & Waddell (1984) Computer Simulation	
8,100,000 m3/yr (0.2563 m3/s)	108,600 m3/yr
FMW abv AD	No upper FMW/Tribs
Steady state	Last 25 yrs

Claassen, H.C., 1985, Sources and mechanisms of recharge for ground water in the West-central Amargosa Desert, Nevada - a geochemical interpretation: U.S. Geological Survey Profesional Paper 712-F, 31 p.

Czarnecki, J.B. and Waddell, R.K., 1984, Finite-element simulation of ground-water flow in the vicinity of Yucca Mountain, Nevada-California: U.S. Geological Survey Water-Resources Investigation Report 84-4349, 38 p.

Comparisons

Previous work	From streamflow
Benson & Klieforth (1989)	
Stable Isotope Study	
YM gw from FMC	Yes
Snowmelt	Yes
9000-18500 years ago	Last 25 yrs
No recent gw recharge	Yes-there is

Osterkamp & others (1994)	
Geomorph study	
GW recharge	Infiltration loss
FMC 50,000 m3/yr	36,000 m3/yr
UJA 510,000 m3/yr	71,100 m3/yr
LJA 10,000 m3/yr	86,200 m3/yr
AD 20,000 m3/yr	104,300 m3/yr

Benson, L. and Klieforth, H., 1989, Stable isotopes in precipitation and ground water in the Yucca Mountain region, southern Nevada: paleoclimatic implications: in Peterson, D.H., ed., Aspects of climate variability in the Pacific and Western Americas: American Geophysical Union Geophysical Monograph 55, p. 41-59.

Osterkamp, W.R., Lane, L.J., and Savard, C.S., 1994, Recharge estimates using a geomorphic/distributed-parameter simulation approach, Amargosa River basin: Water Resources Bulletin, v. 30, n. 3, p. 493-507.

Summary

GW levels rise after winter/spring streamflow in Fortymile Canyon (El Nino events)

Estimated GW recharge volumes from streamflow volumes for fours reaches

- FMC - Estimated
- UJA - Not much
- LJA - Potential for some
- AD - Potential for a lot

Summary

GW recharge rates for four reaches

Combination of winter/spring and summer/fall estimates

Do the last 25 years represent steady state?

What about gw recharge rates for upper Fortymile Wash and tributaries to Fortymile Wash?

Delirium Canyon Wash
Feb. 12, 1992

Jan. 26, 1995

HYDROLOGIC IMPLICATIONS OF TEMPERATURE AND HEAT FLOW DATA IN THE VICINITY OF YUCCA MOUNTAIN

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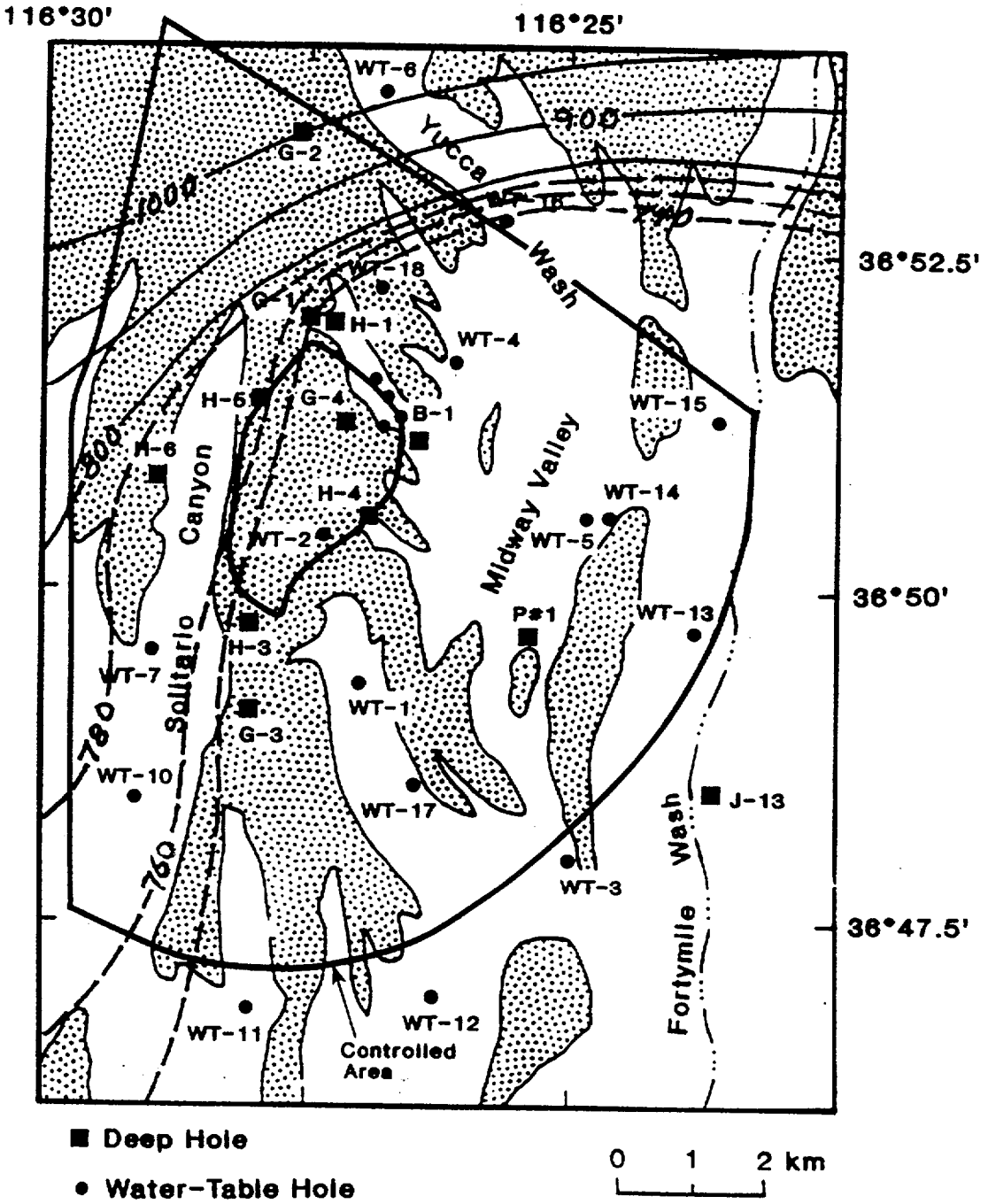
Saturated Zone Expert Elicitation

Workshop on Significant Issues and Available Data
Denver, Colorado
June 6, 1997

WATER-TABLE CONTOURS AND

OBSERVATION HOLES FOR HEAT FLOW



Water-table contours adapted from Ervin and others, 1994 and Robison, 1984

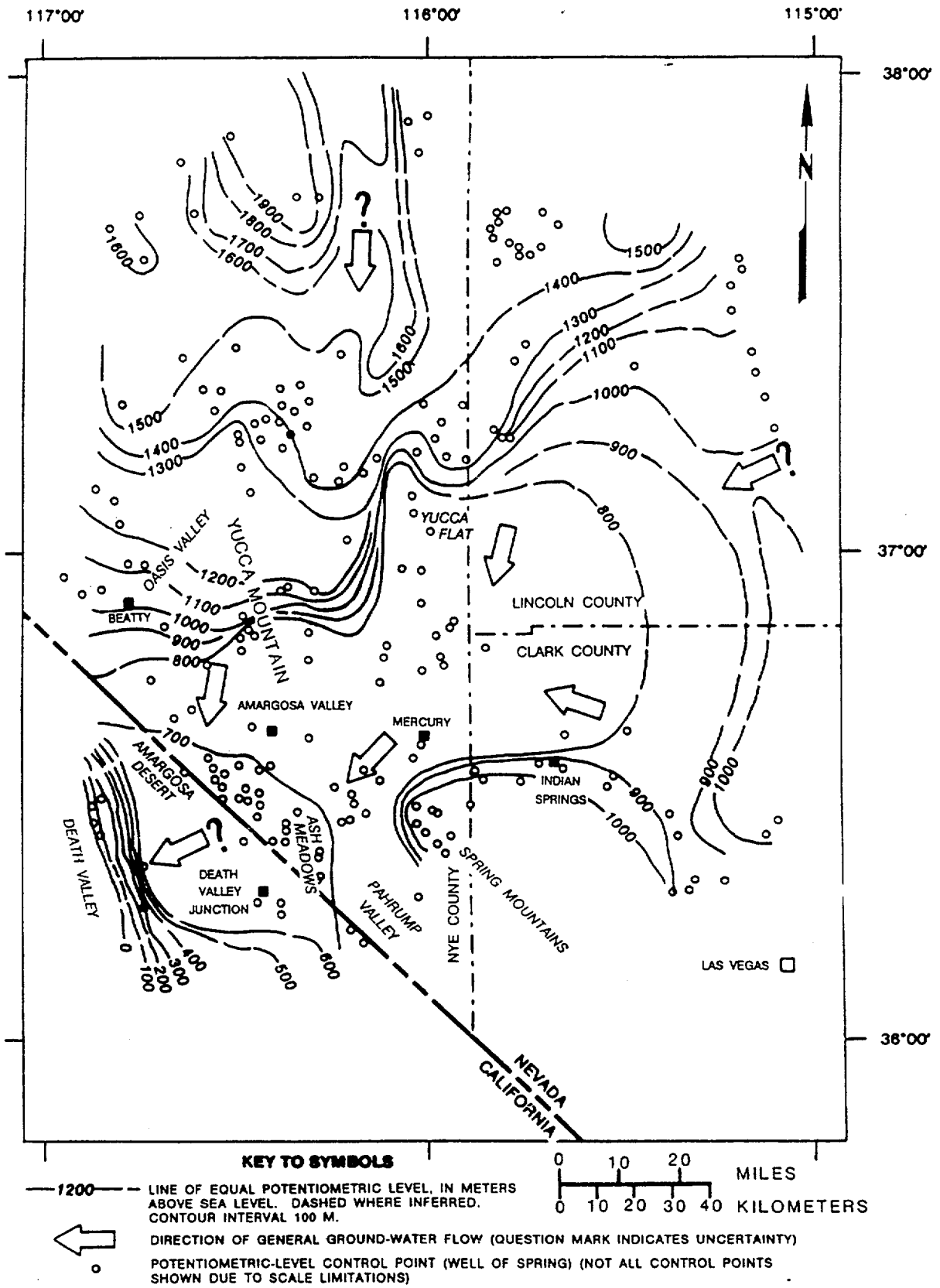
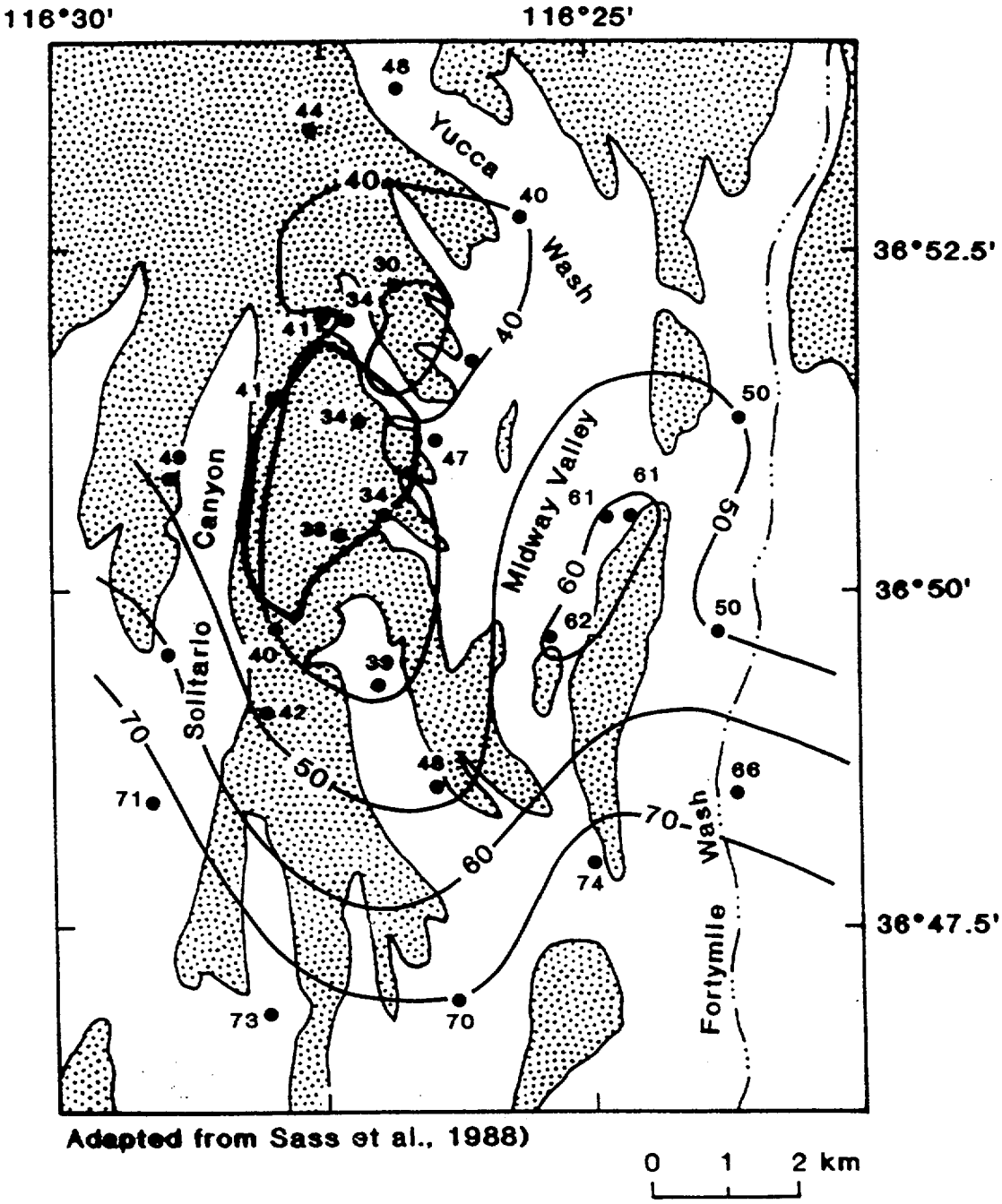


Figure 3-10. Regional ground-water flow paths. Modified from Waddell et al. (1984).

From U.S. Department of Energy, 1988

HEAT FLOW IN UNSATURATED ZONE

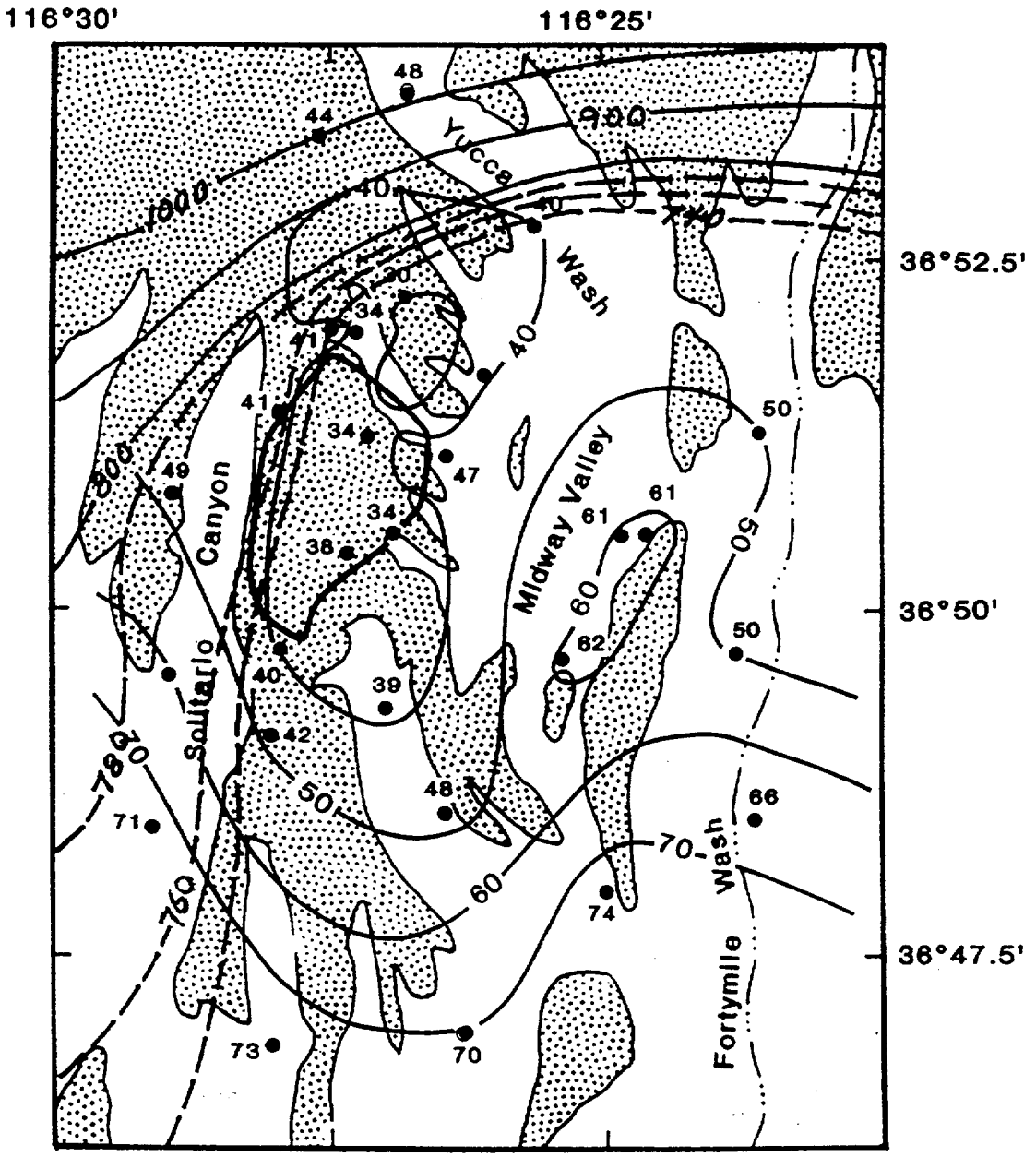


Adapted from Sass et al., 1988)

0 1 2 km

WATER-TABLE CONTOURS AND

HEAT FLOW IN UNSATURATED ZONE



Adapted from Sass et al., 1988)

0 1 2 km

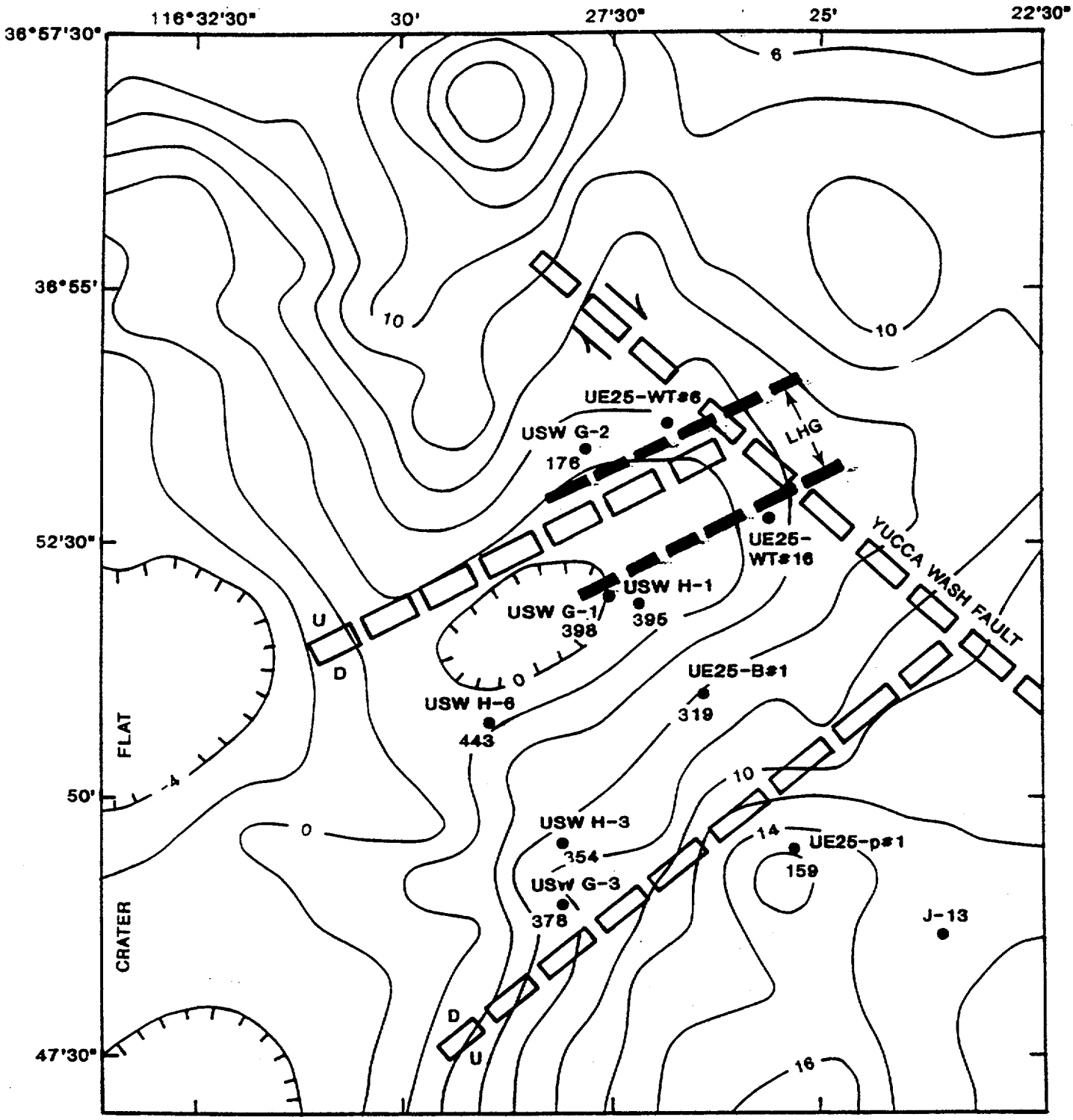


Fig. 10. Map of the residual gravity field in the Yucca Mountain vicinity, modified from Snyder and Carr (1982). Lines of equal gravitational intensity have units of milligals. Data points at deep drill holes are thicknesses from the top of the Tram Member of the Crater Flat Tuff to the top of the Lithic Ridge Tuff, in meters. The changes in thickness of this interval across the area reflect the buried graben.

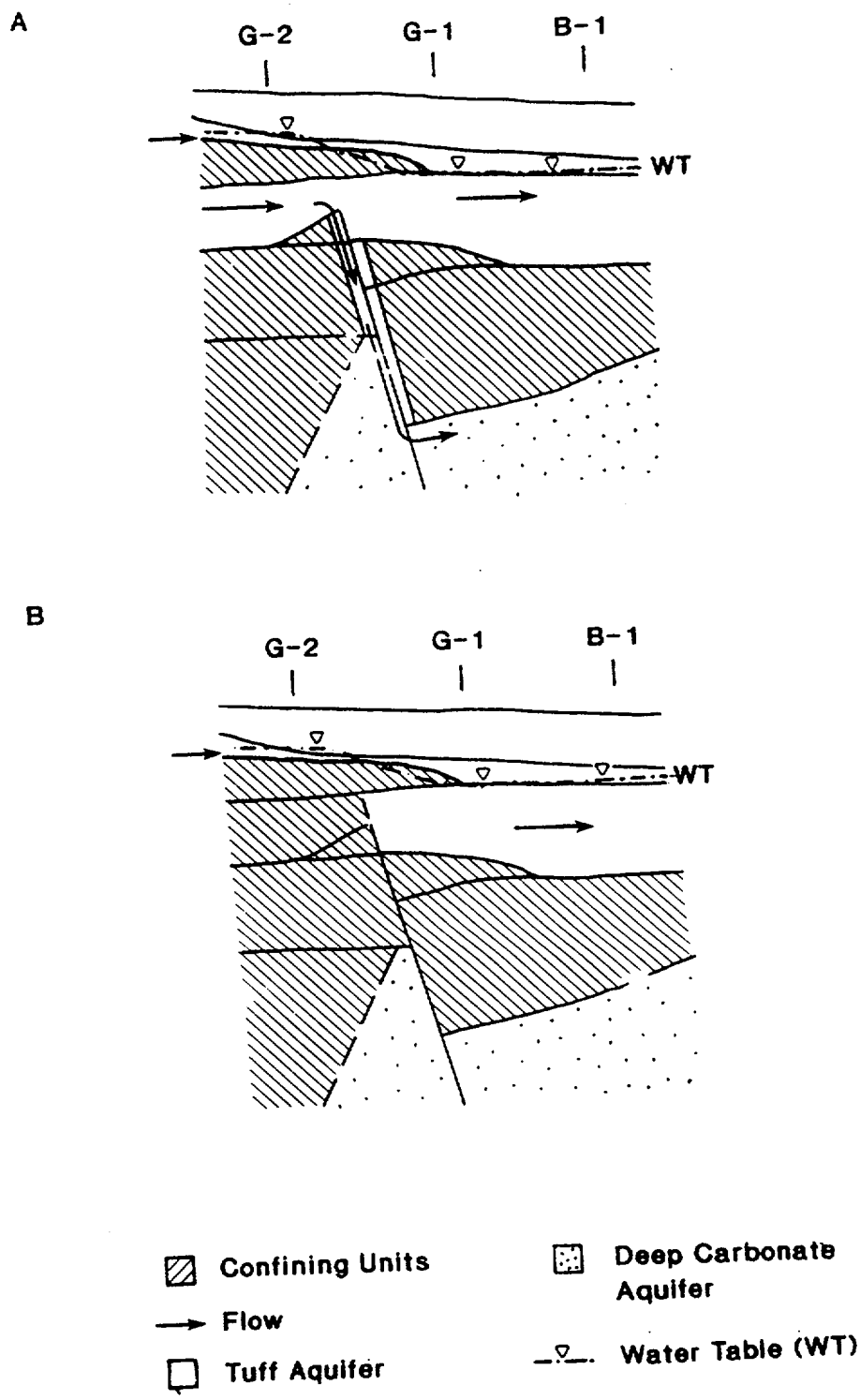


Fig. 12. Schematic diagrams showing (A) the drain model and (B) the spillway model. Distribution of major hydrostratigraphic units is based on the geology shown in Fig. 11.

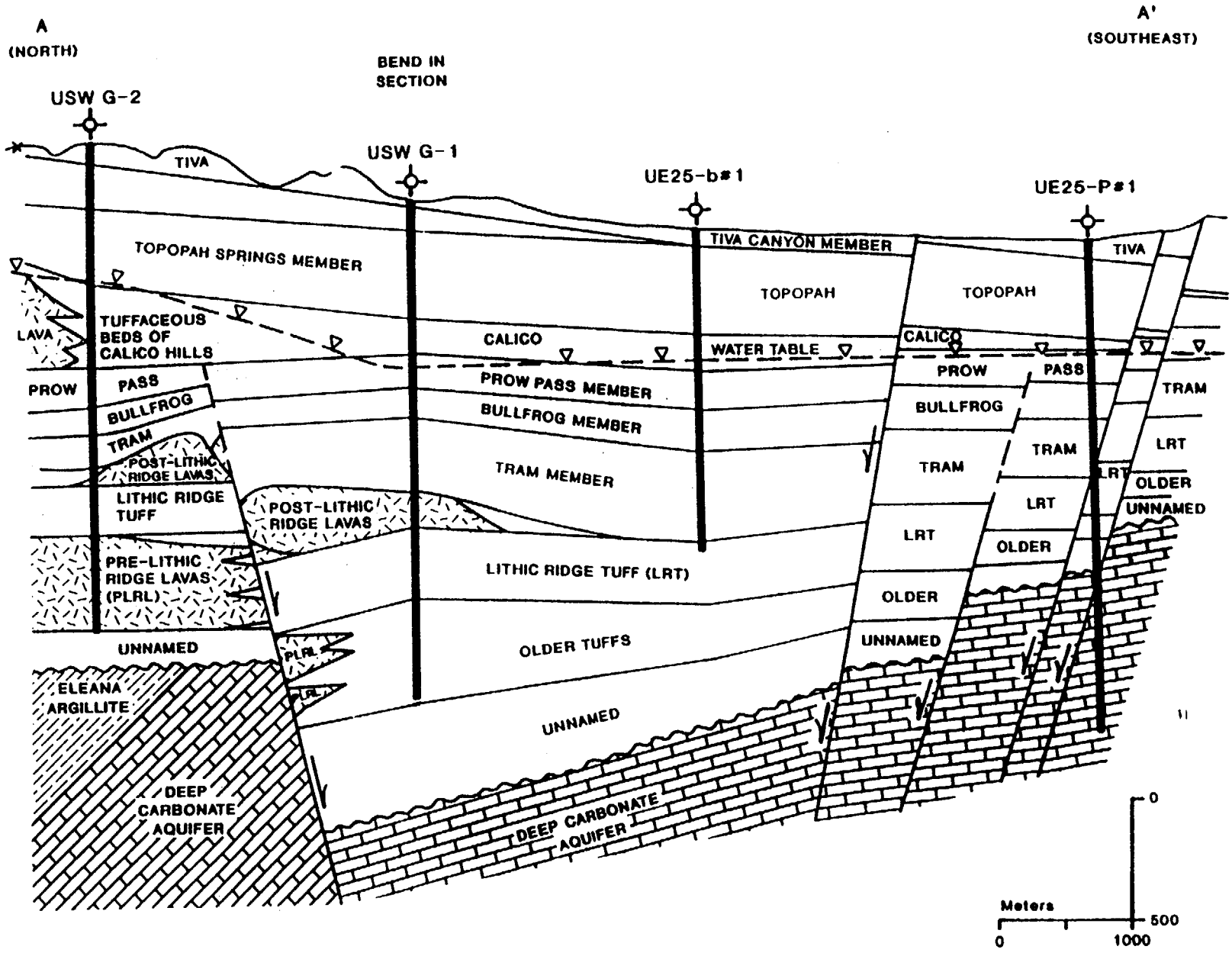
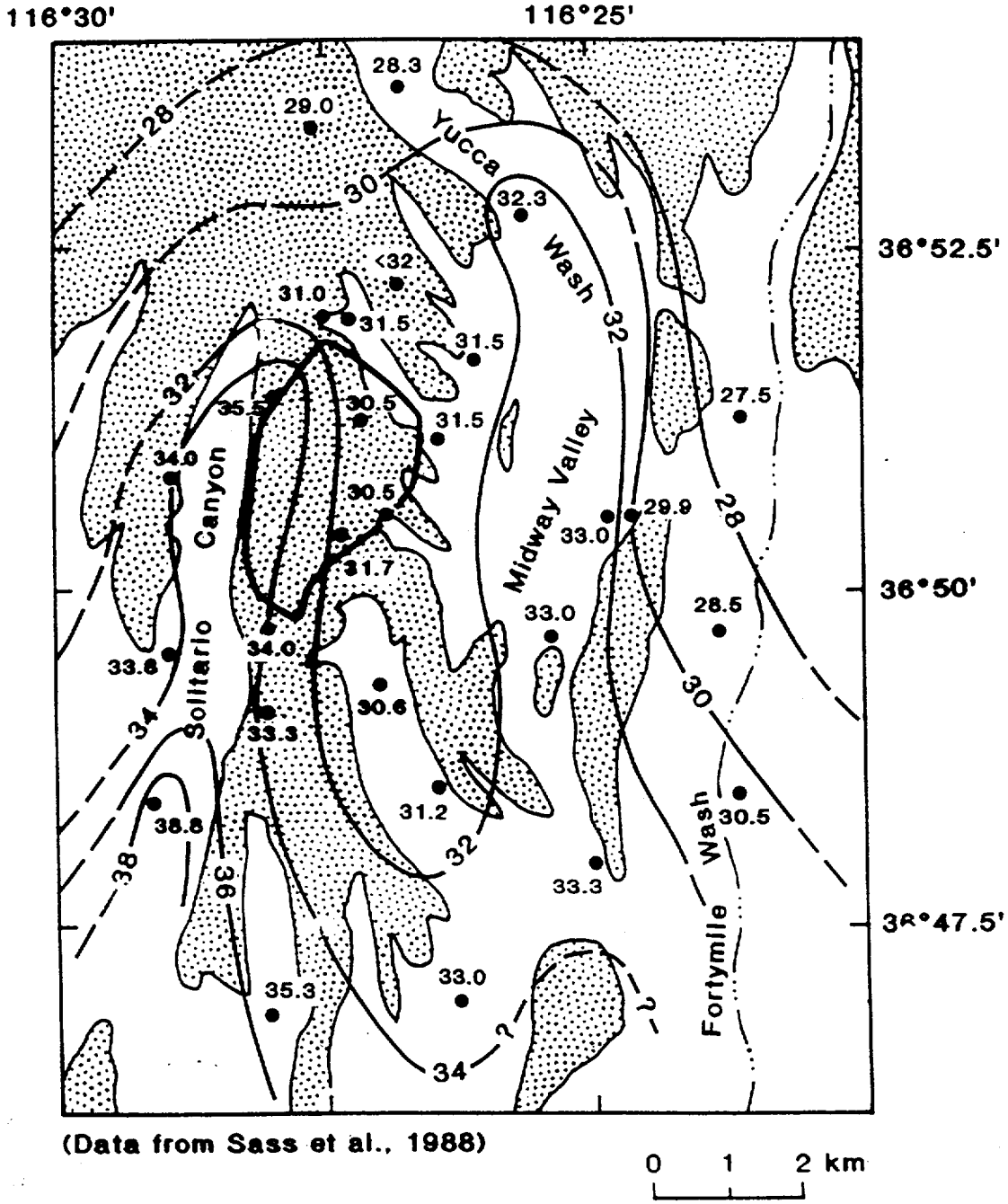


Fig. 11. North-to- southeast geologic section across Yucca Mountain showing the interpreted buried graben. Line of section shown in Fig. 5. Constructed using data from the full suite of lithology logs, cited in the caption of Fig. 4.

TEMPERATURE (°C) AT WATER TABLE



(Data from Sass et al., 1988)

0 1 2 km

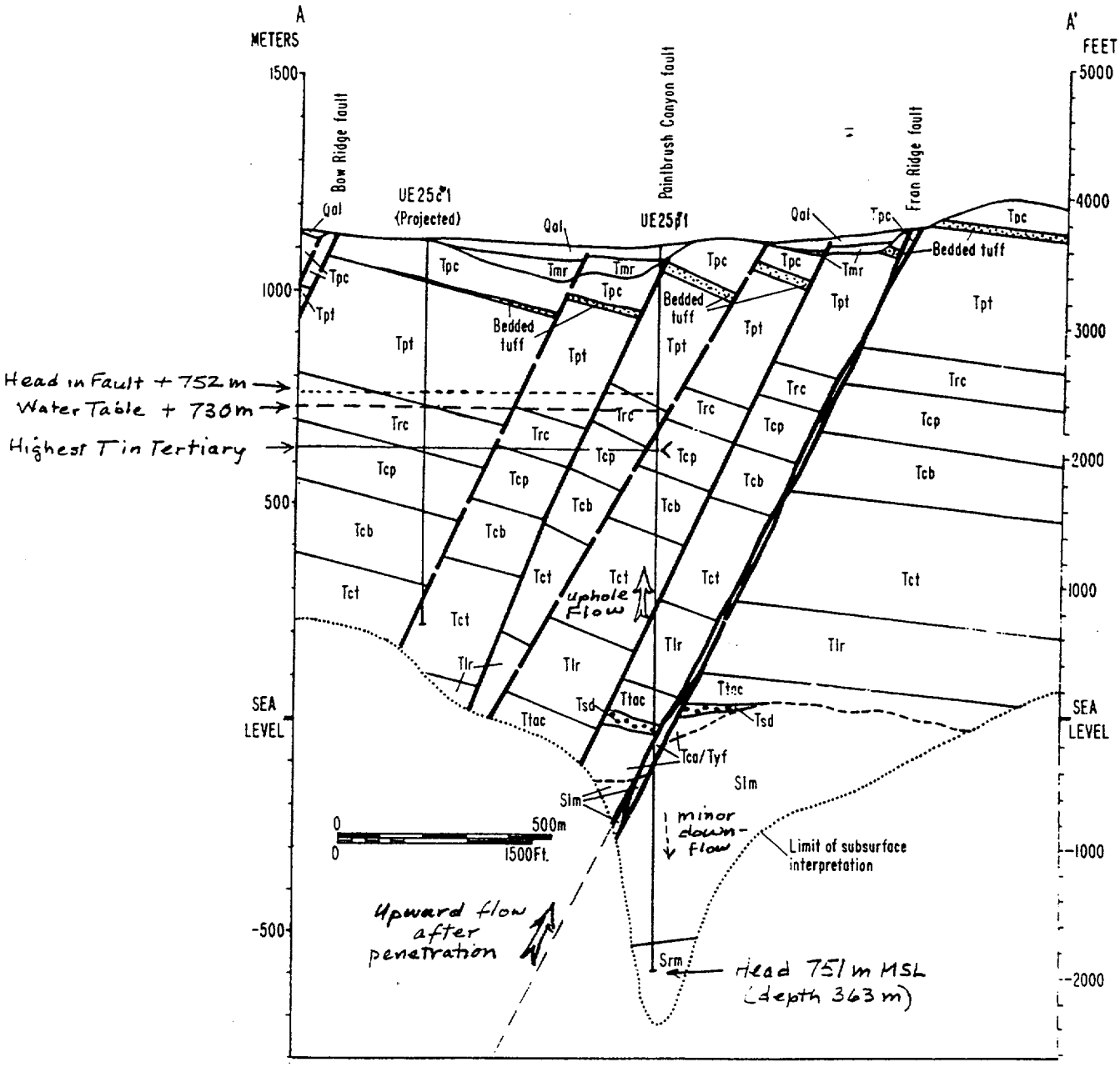


Figure 12. Interpretive geologic section in the vicinity of drill hole UE25p#1. Unit thicknesses not controlled by drill hole UE25p#1 were interpolated from thicknesses in UE25c#1 (R. W. Spengler, USGS, written commun., 1984) and well J-13 (Byers and Warren, 1983). Symbols: Qal--Quaternary deposits, Tmr--Rainier Mesa Member, Tpc--Tiva Canyon Member, Tpt--Topopah Spring Member, Trc--Rhyolite of Calico Hills, Tcp--Prow Pass Member, Tcb--Bullfrog Member, Tct--Tram Member, Tlr--Lithic Ridge Tuff, Ttac--Older tuffs of drill hole USW-G1, Tsd--sedimentary deposits, Tca/Tyf--calcified ash flow tuff and tuff of Yucca Flat(?), Slm--Lone Mountain Dolomite, Srm--Roberts Mountain Formation. See figure 6 for line of section.

-1100 - Source of 58°C water with head of 752 m above MSL (Depth 362m)

From Carr and others, 1986

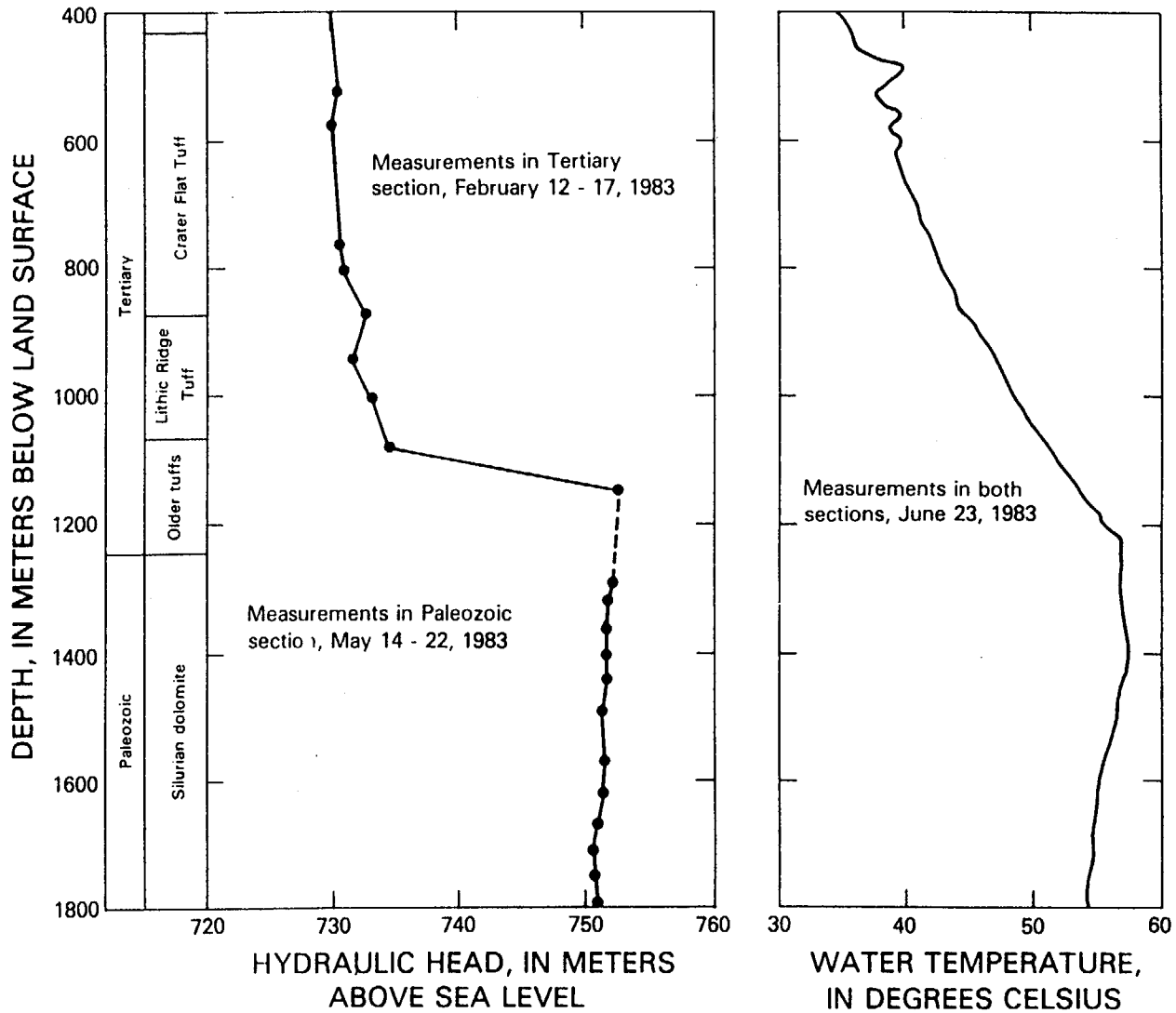
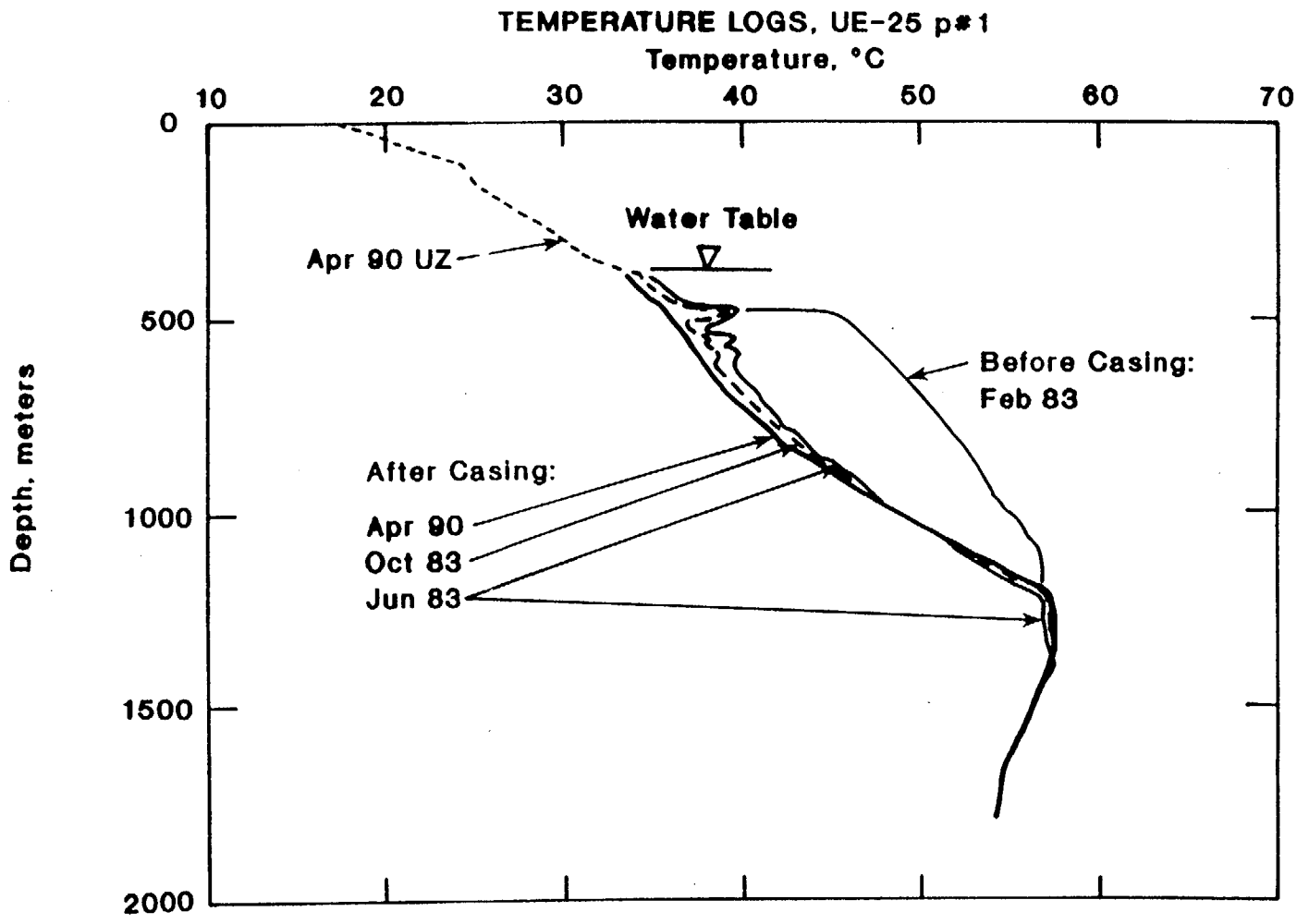
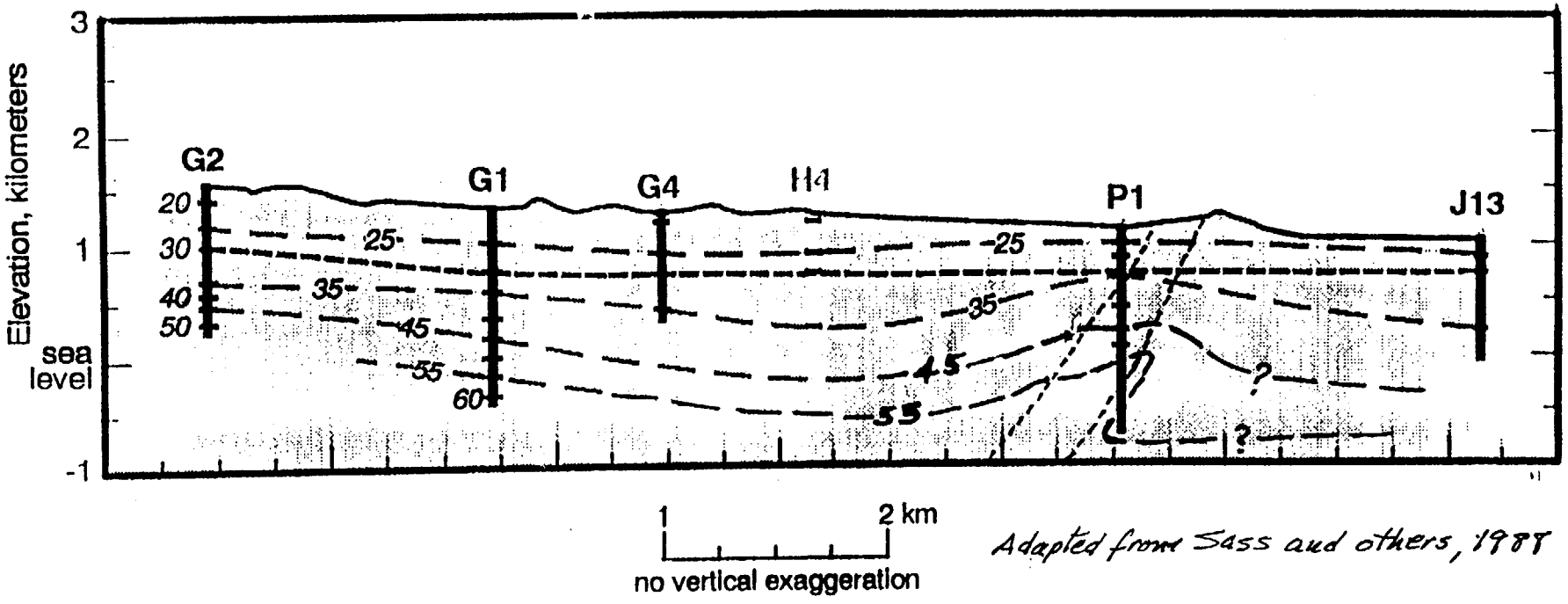


Figure 4.--Variation of hydraulic head and water temperature with depth.
(From Craig and Robison, 1984, USGS/WRI 84-4248)



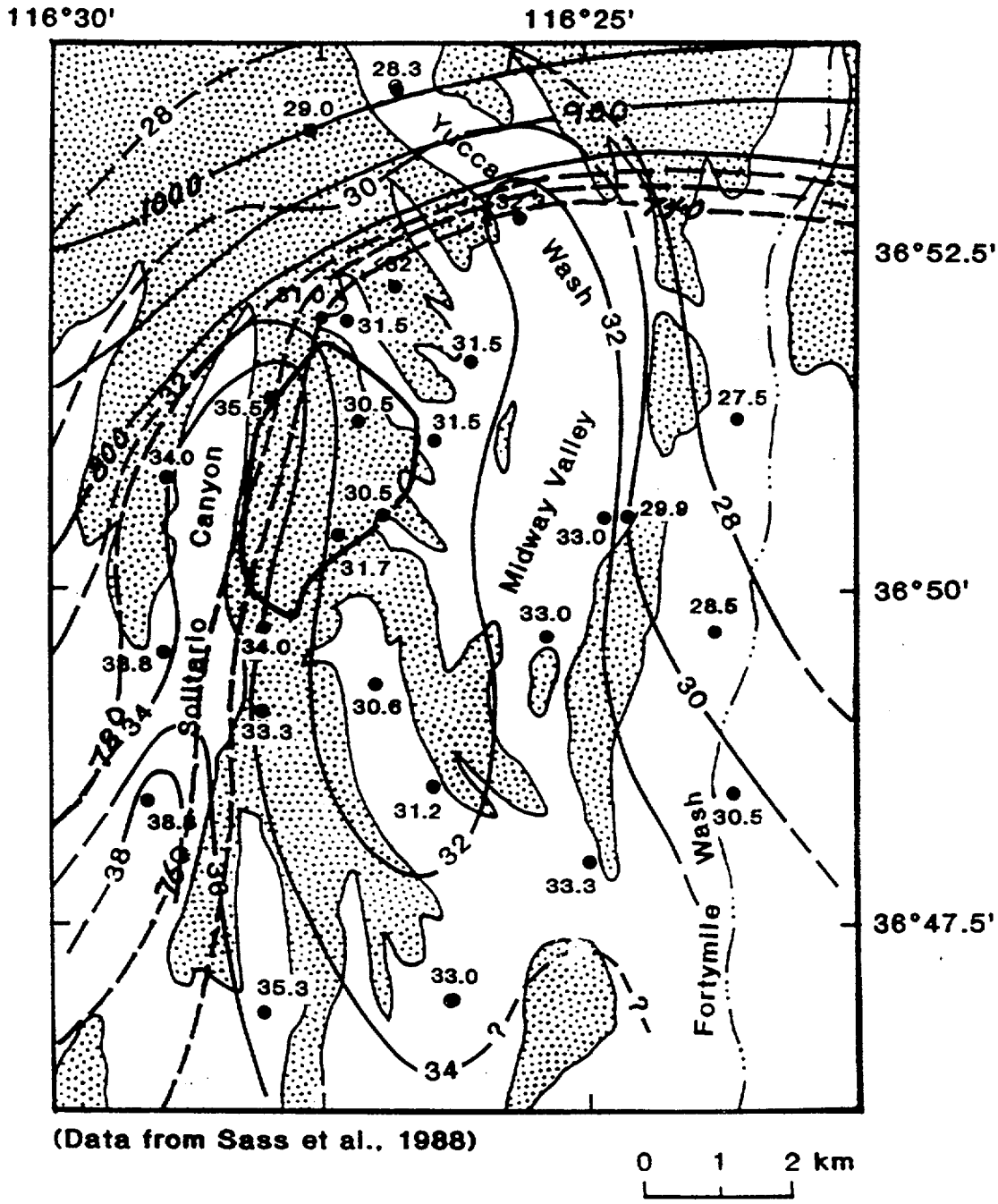
February 1983 log from Craig and Robison, 1984;
other logs from J. Sass, written commun., 1990

Figure 5



Adapted from Sass and others, 1988

WATER-TABLE CONTOURS AND
TEMPERATURE (°C) AT WATER TABLE



(Data from Sass et al., 1988)

0 1 2 km

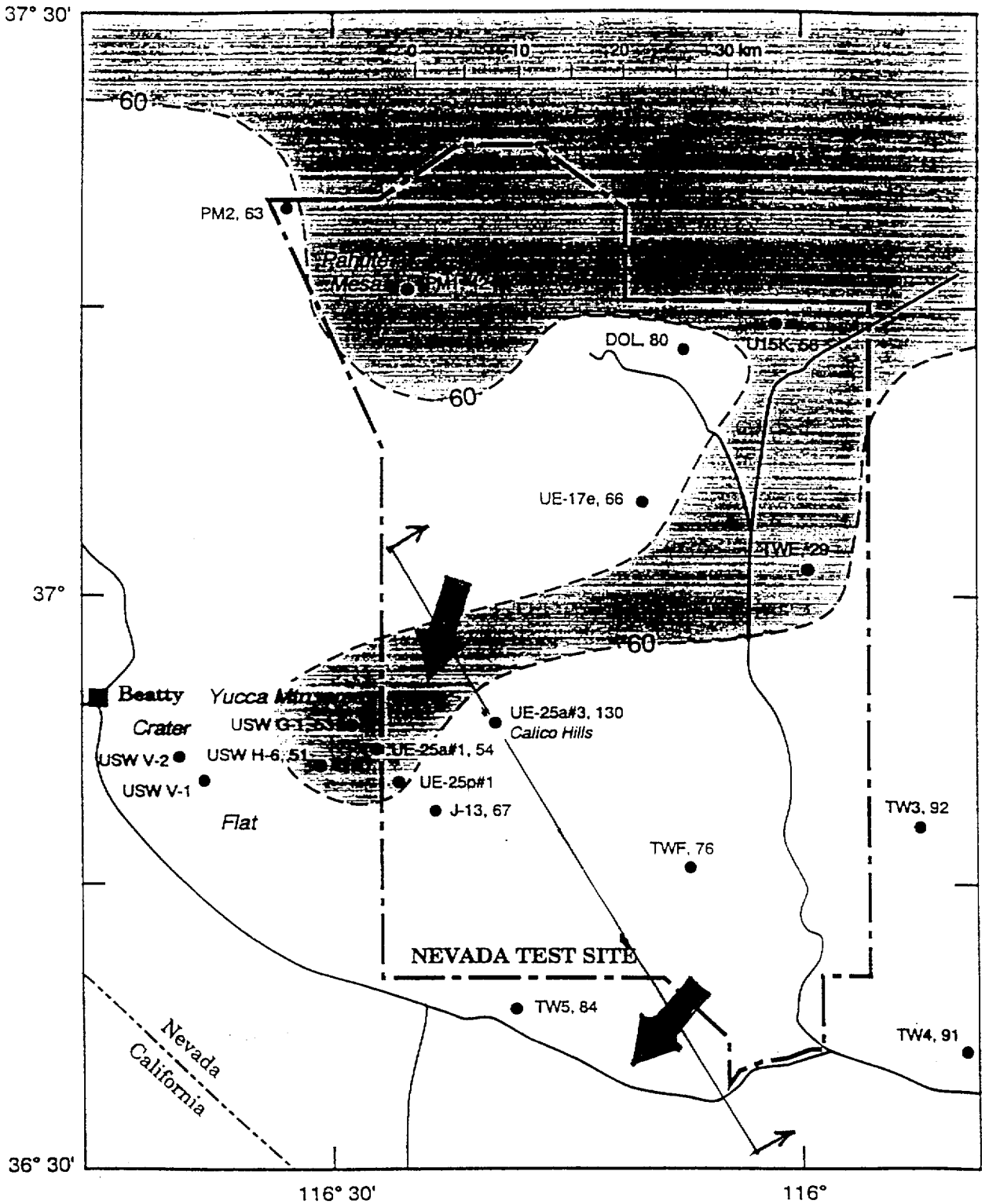
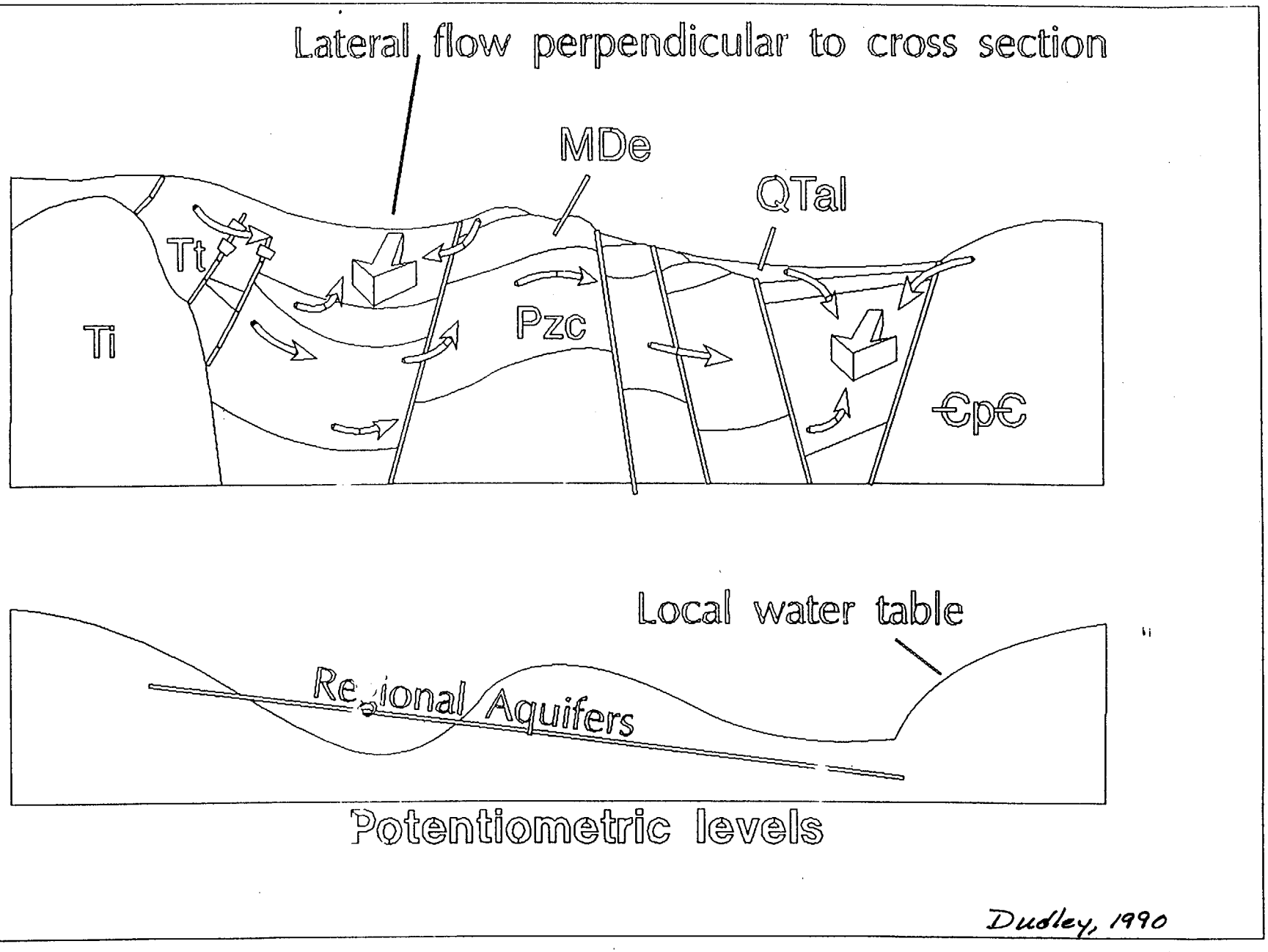


Figure 8.2. Configuration of 60 mW m^{-2} contour in the vicinity of the Nevada Test Site. Shaded area defines the southernmost part of the Eureka Low (see fig. 8.1). All heat flows shown were determined in the saturated zone (SZ). Where a heat flow could not be determined for the SZ (drill holes V-1, V-2, UE-25p#1), no value is plotted.

Adapted from Sass and others, 1995



Dudley, 1990

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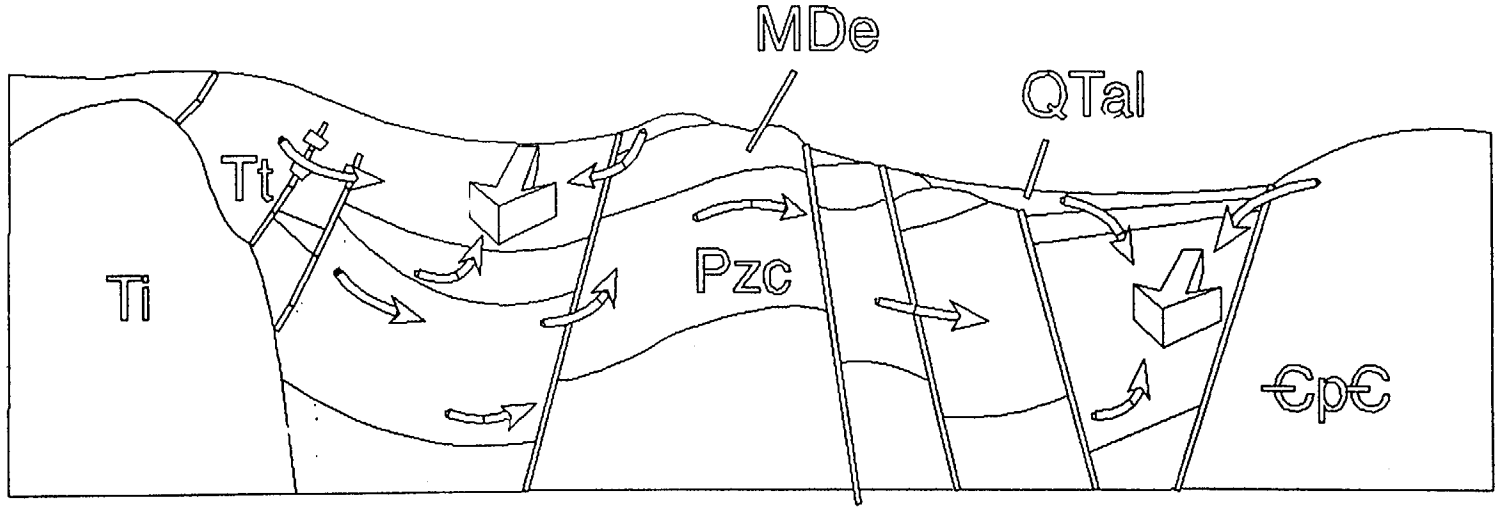

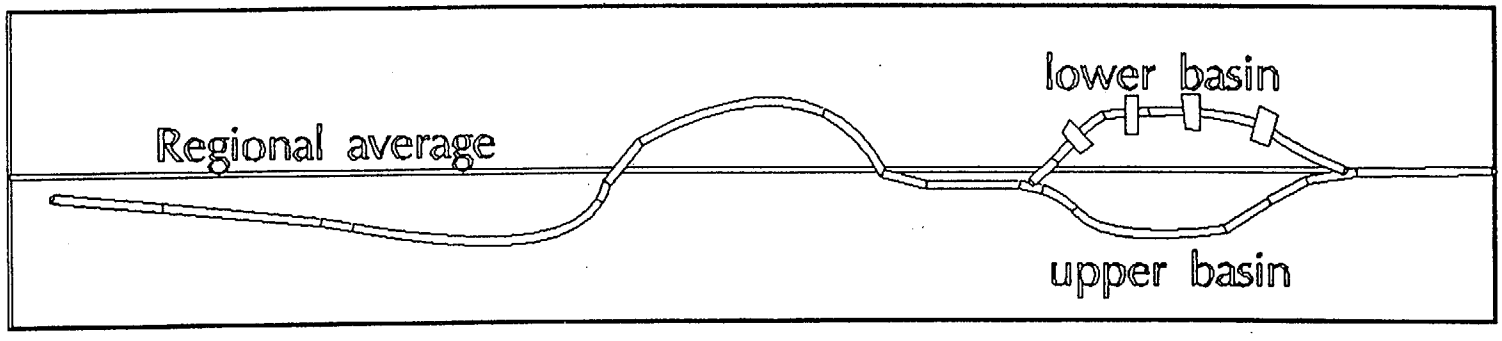

Heat flow

Dudley, 1990

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