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SUMMARY OF ISSUES SATURATED ZONE HYDROLOGY YUCCA MOUNTAIN, NV

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Expert Elicitation Panel

OUTLINE OF PRESENTATION

BACKGROUND

- Hydrogeology of Site
- Groundwater Flow System:
  - Regional, Local, and Site Scales
  - Scoping Calculations, Computer Models

ISSUES

- Role of Faults
- Large Hydraulic Gradient
- Role of Carbonate Aquifer
- Potential Dilution
- Potential Changes to the System
  - Due to Climate Change
  - Due to Tectonic Events
  - Due to Repository Heating

CLOSURE

- Summary of Conclusions
- Implications for Program at Yucca Mountain
- Comments on Elicitation Process

NOT DISCUSSED:
- Mechanisms of Transport: Dispersion, Matrix Diffusion, Retardation
- Transport Parameters
- Hydrogeochemistry

3D HYDROGEOLOGIC FRAMEWORK: HYDROSTRATIGRAPHIC UNITS

<u>Regional Scale</u>

- Valley Fill
- Volcanic Rocks
- Carbonate Aquifer
- Clastic Aquitards
- Basement Rocks

<u>Regional Model</u>

FD, 75000 cells
1500x1500x500 m
9 hydrogeologic units

<u>Site Scale</u>

- Geologic Units (eg. Bullfrog tuff)
- Hydrogeologic Units (eg. Upper volcanic aquifer)

<u>Site Model</u>

FE, 30000 cells
1000x125 m
16 hydrogeologic units

<u>Detailed Scale (Intra-unit): Tuffs</u>

- Ash-flow tuffs (100s m thick)
  - Welded, fractured, low-n, high-K aquifers
  - Nonwelded, sparsely fractured, mod-n, low-K aquitards
  - Zeolitized, unfractured, high-n, very-low-K aquitards
- Bedded tuffs (10s m thick)
  - Bedded, unfractured, high-n, mod-K aquitards

Note: - Geologic units may have multiple flows, each with non-welded tops and bottoms and welded middles. Welding can vary laterally and vertically within a single unit. Similarily, devitrification and zeolitization can be heterogeneously distributed.

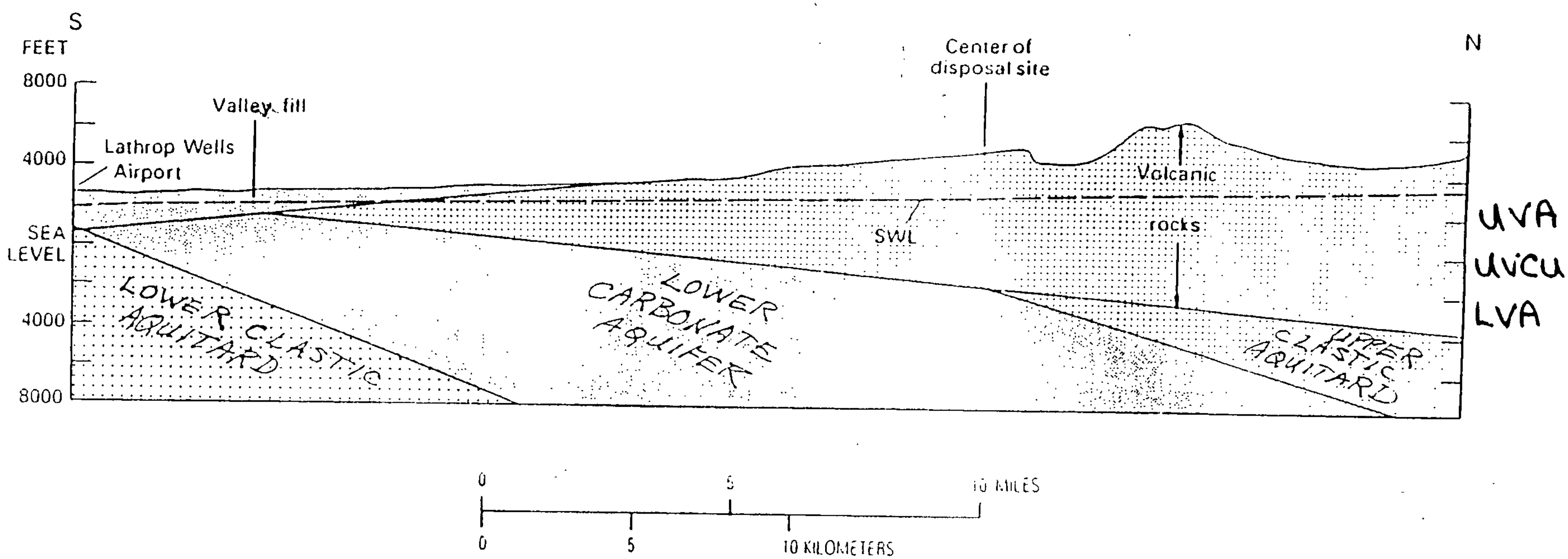
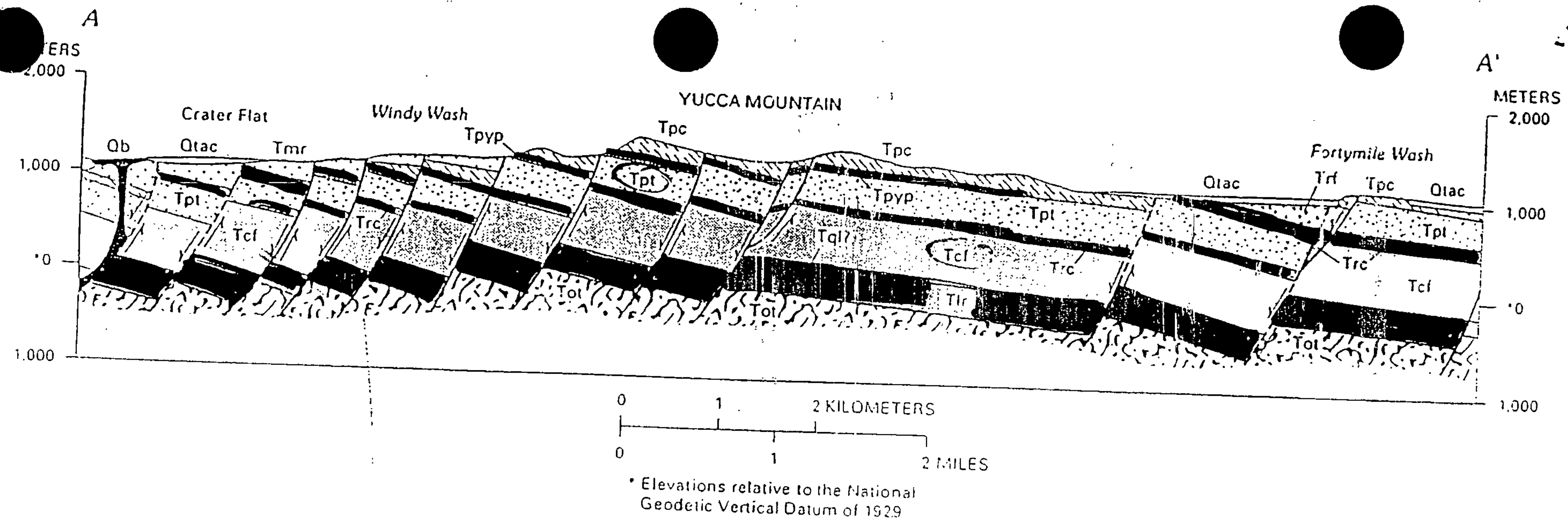


FIGURE 9.—Simplistic hydrogeologic map of Proterozoic and Paleozoic rocks and diagrammatic hydrogeologic cross section of the Yucca Mountain study area. Location of section is the same as A-A′ of Waddell (1982, pl. 1) and the static water level (SWL) is also from Waddell's plate 1. On the basis of aeromagnetic maps, the cross section represents the volcanic rocks as thinning to zero near Lathrop Wells.

(4)

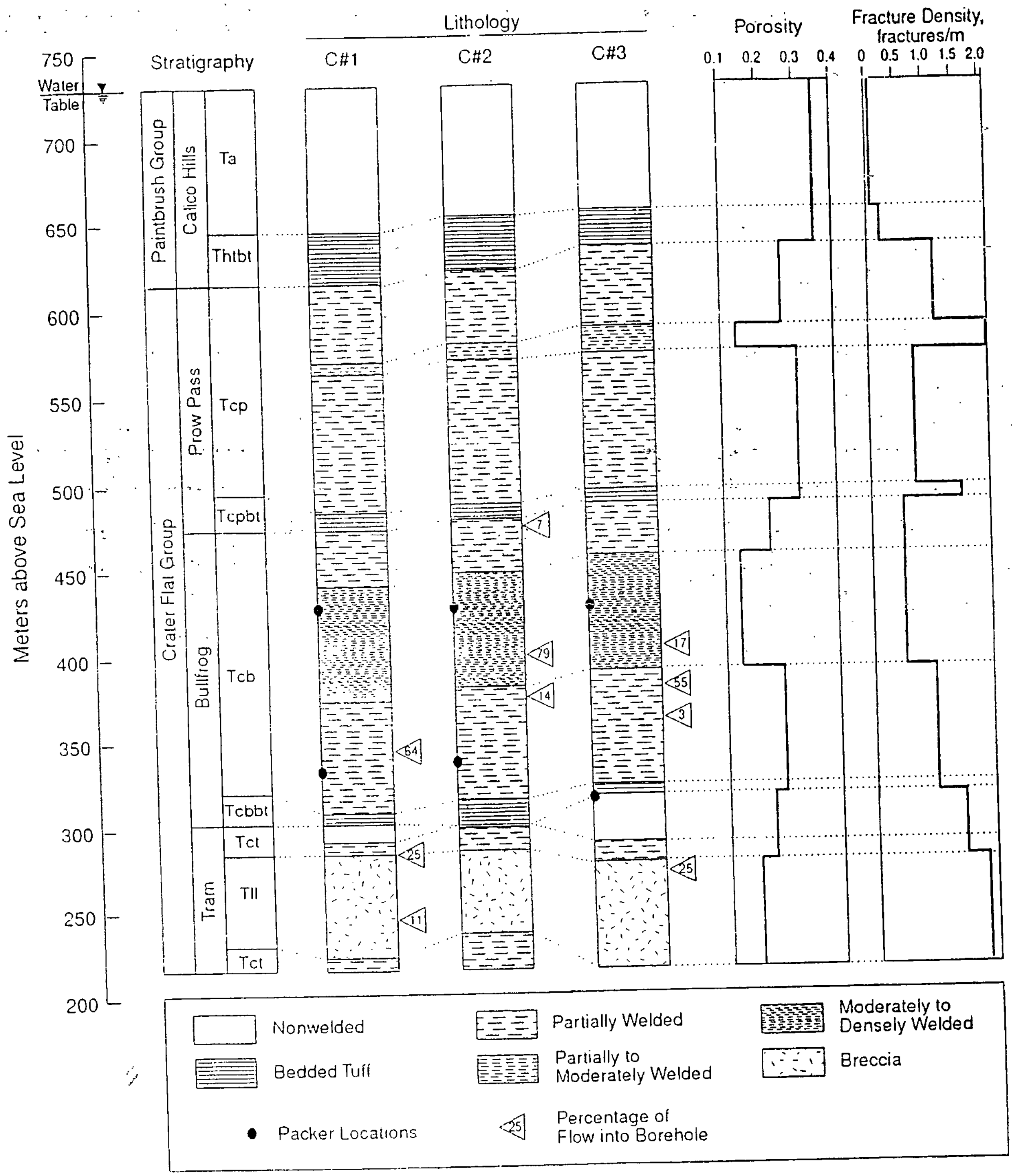
After Dudley



EXPLANATION

- Qtac — ALLUVIUM
- Qb — QUATERNARY BASALT
- Trf — RHYOLITE LAVAS OF FORTYMILE CANYON
- Tmr — RAINIER MESA MEMBER OF TIMBER MOUNTAIN TUFF
- Tpc — TIVA CANYON MEMBER OF PAINTBRUSH TUFF
- Tpyp — YUCCA MOUNTAIN AND PAH CANYON MEMBERS OF PAINTBRUSH TUFF
- UVA — Tpt — TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF
- Trc — RHYOLITE LAVAS AND TUFFS OF CALICO HILLS — UVCU
- Tcf — CRATER FLAT TUFF — LVA
- Tql? — QUARTZITE
- Tlr — LITHIC RIDGE TUFF — LVCU
- Tot — OLDER TUFFS, UNDIVIDED
- CONTACT
- FAULT—Dashed where inferred. Arrows indicate relative direction of movement. Many minor faults mapped by Scott and Bonk (1984) are not shown.

Figure 17.--Geologic section across Yucca Mountain from Crater Flat to Fortymile Wash (from Frizzell and Shulters, 1990; location shown in figure 1).



After Robinson

3D HYDROGEOLOGIC FRAMEWORK: STRUCTURAL FEATURES

Regional Scale

- Deep low-angle thrust faults in Carbonate aquifer
    - more highly fractured and brecciated on the upper plate
- Large-scale NE-SW normal faults: Solitario Canyon, Ghost Dance, Bow Ridge
    - disruption of hydrostratigraphic units
    - steps in water-table configuration
    - potential high-K tabular pathways
- Medium-scale NW-SE faults: Yucca Wash(?), Drill Hole Wash, Sundance
    - potential high-K planar pathways

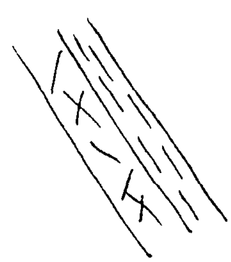
Site Scale

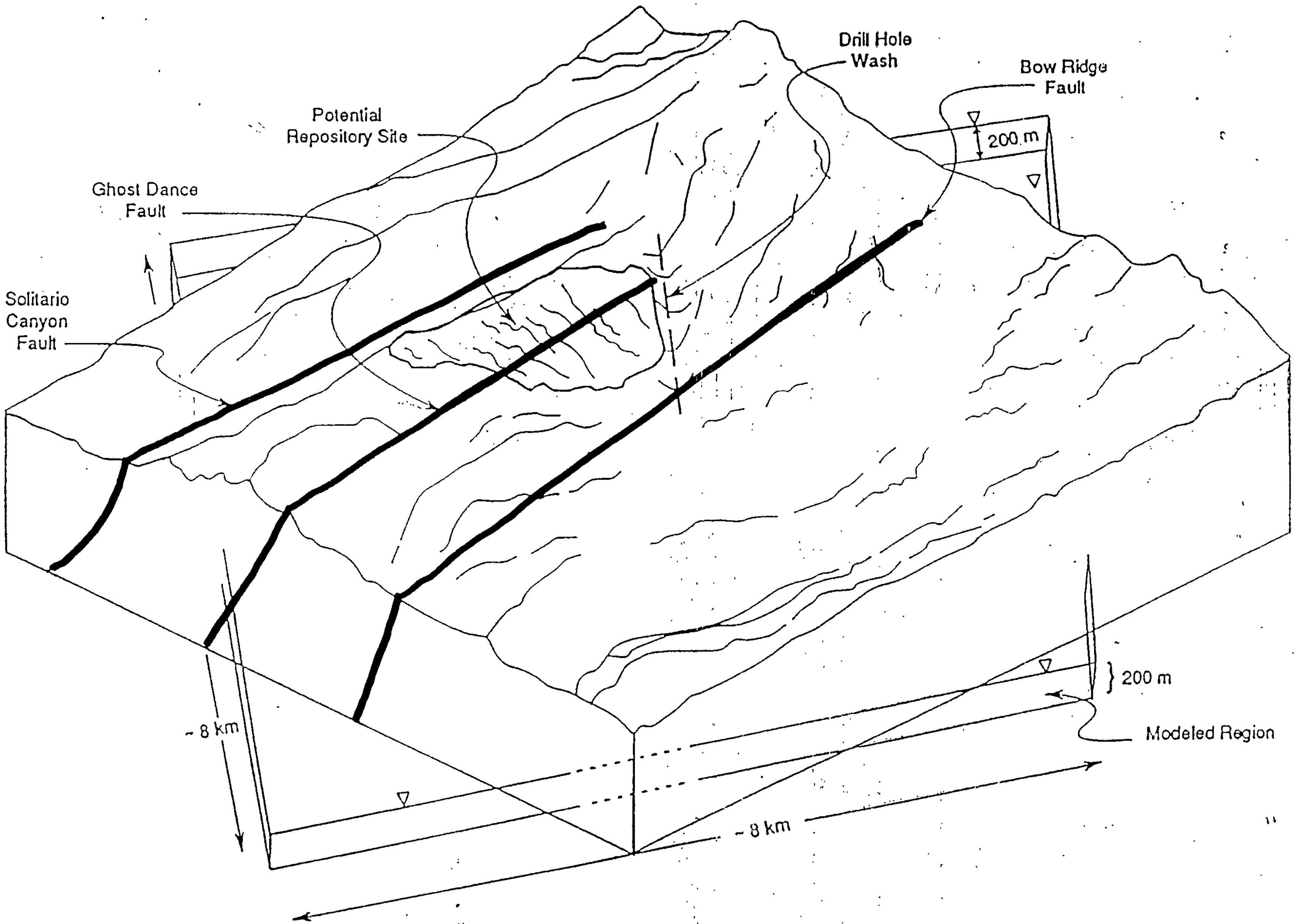
- Local faults
    - potential disruption of stratigraphic units
    - K-values may depend on lithology of units traversed
    - NE-SW may have greater K than NW-SE

Detailed Scale

- Fracture system
    - often stratabound
    - fracture density depends on unit

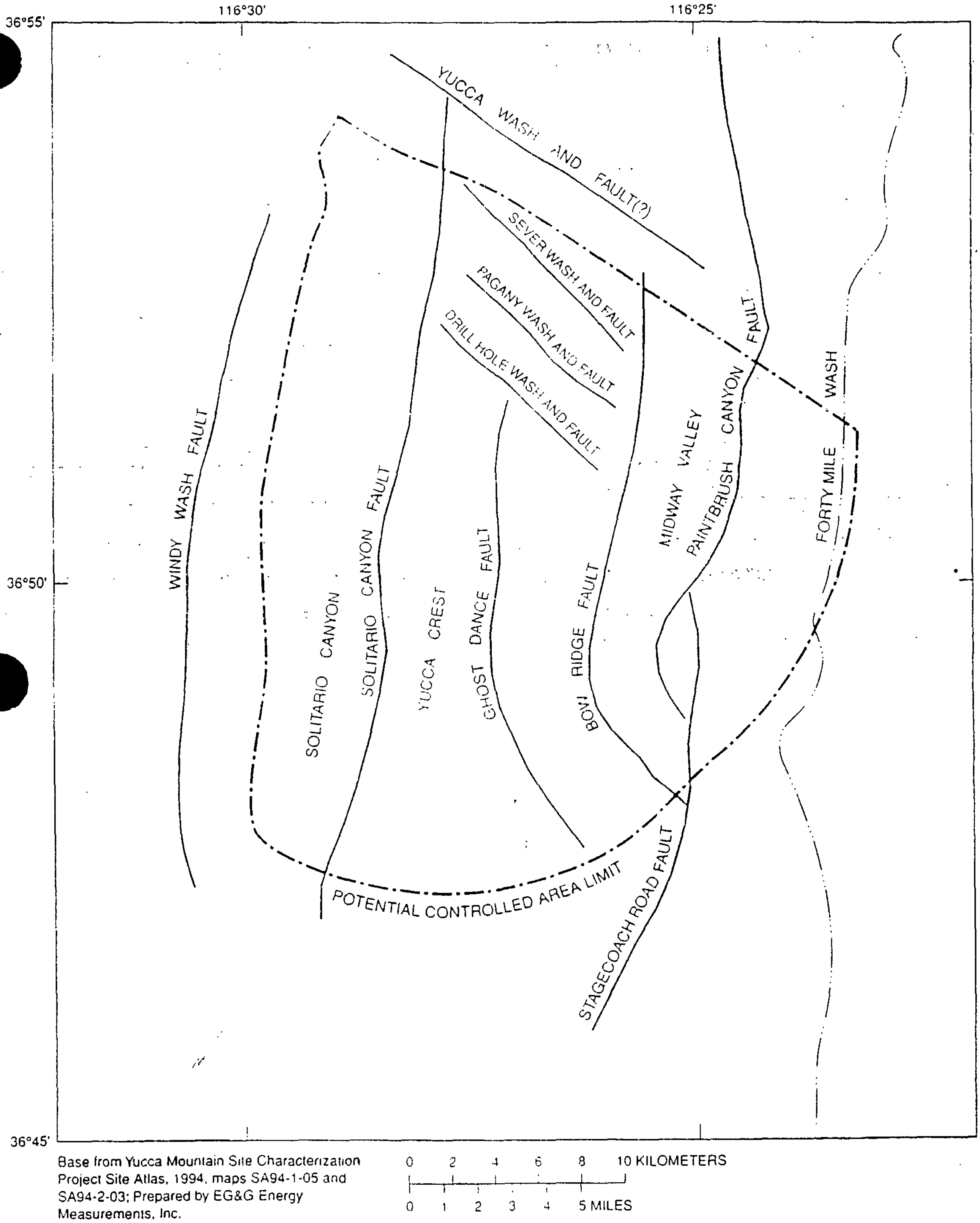
Note: Faults at all scales may exhibit high-K/low-K layering parallel to the fault plane within the tabular fault "zone".





Drill Hole Wash
Bow Ridge Fault
Potential Repository Site
200 m
Ghost Dance Fault
Solitario Canyon Fault
200 m
Modeled Region
~ 8 km
~ 8 km

After Barr



Base from Yucca Mountain Site Characterization Project Site Atlas, 1994, maps SA94-1-05 and SA94-2-03; Prepared by EG&G Energy Measurements, Inc.

Figure 3. Locations of major geographic features and selected faults in the Yucca Mountain area.

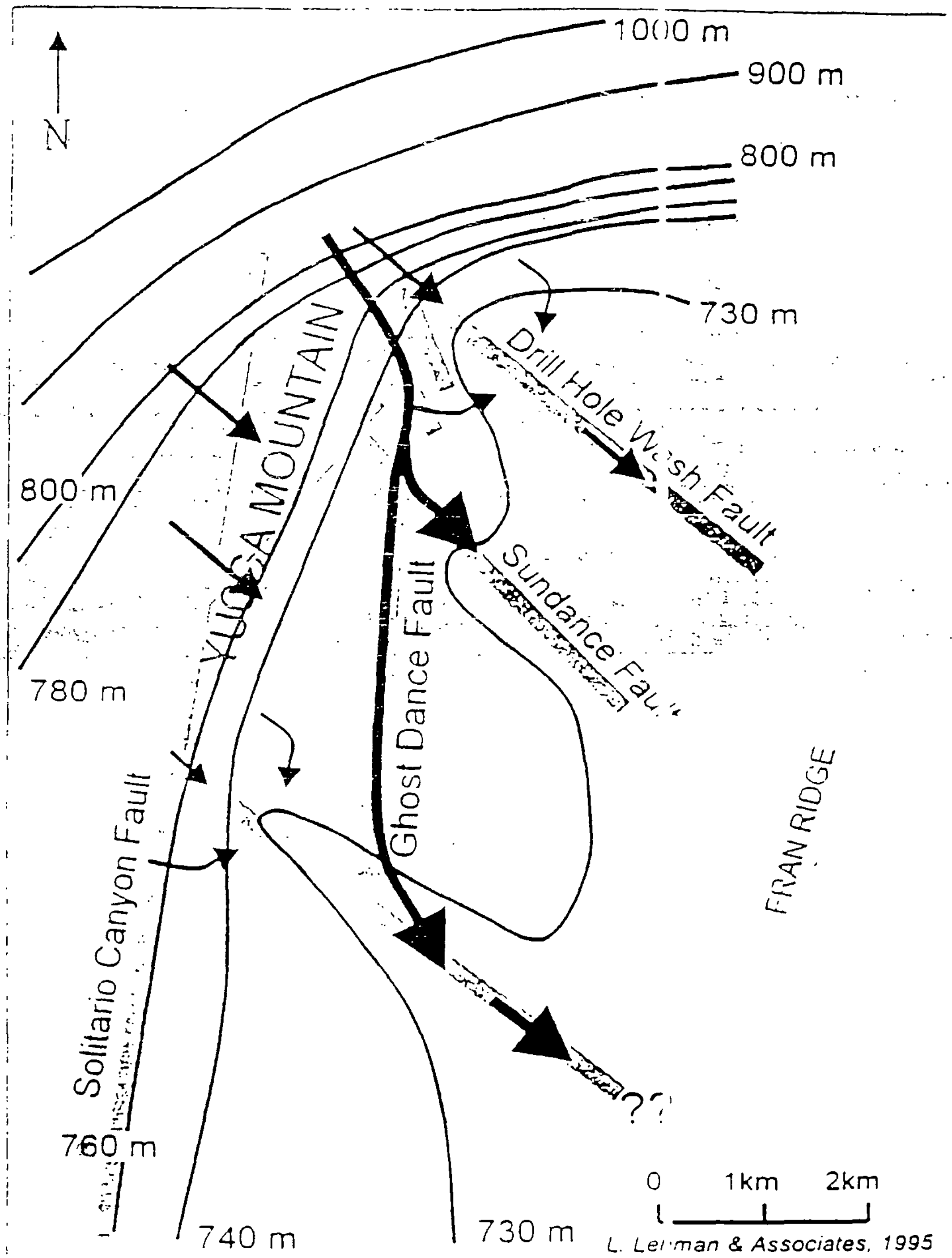


Figure 17. Saturated zone flow conceptual model compared with potentiometric surface (Ervin et al, 1994) and fault locations.

After Lehman

HYDRAULIC CONDUCTIVITY: GENERAL COMMENTS

- Regional patterns:
  - volcanic rocks thin to south
  - Calico Hills thins to south within volcanic rocks
  - Carbonate aquifer shallower to south
  - valley fill alluvium

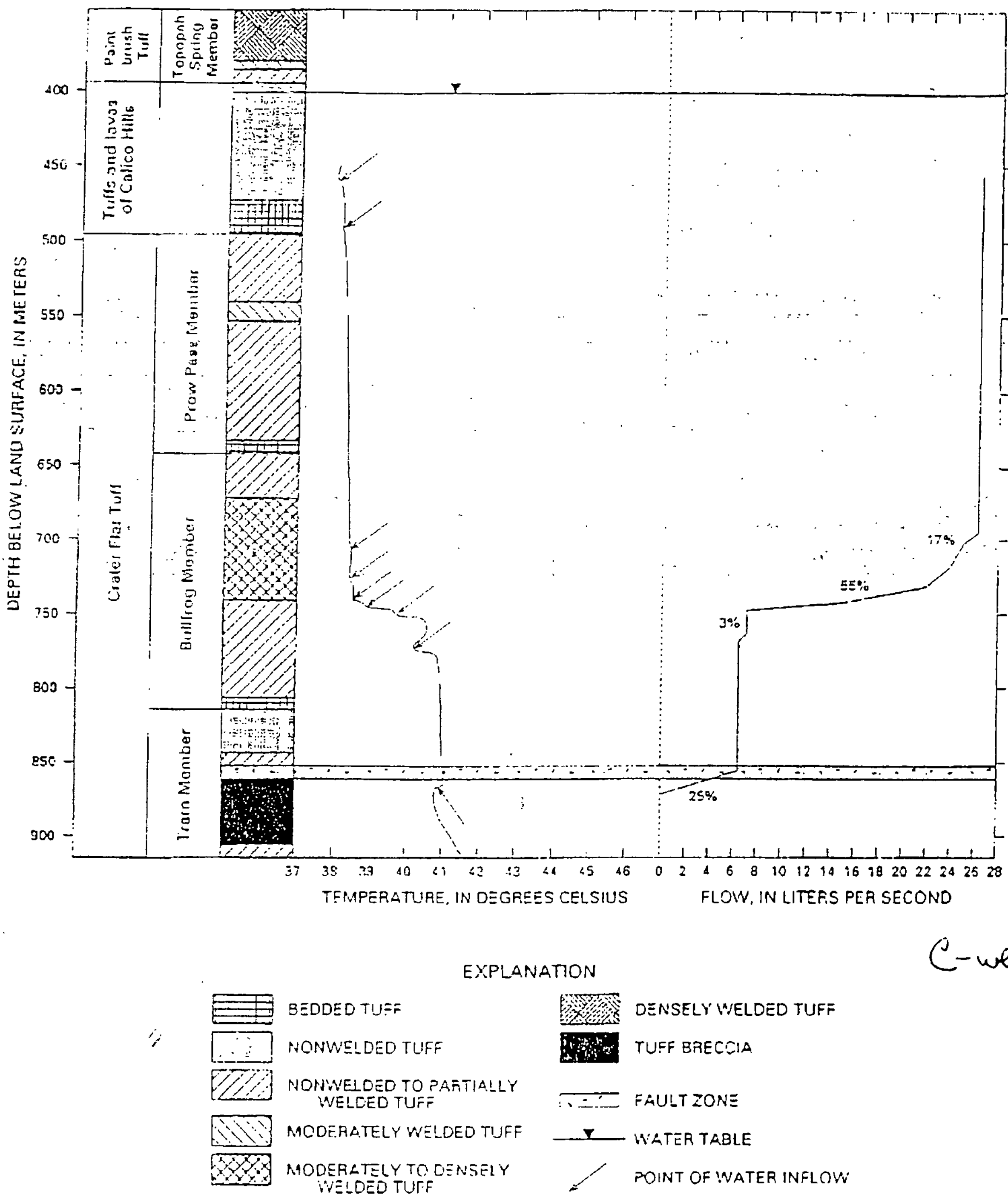
- Trends within volcanic rocks:
  - K decreases with depth due to lithostatic loading
  - K increases to south due to increase in tectonic fracturing and decrease in extent of alteration

- Existence of high-K pathways
  - flow surveys in wells
  - groundwater temperature anomalies

- Continuity of high-K pathways
  - major faults throughgoing
  - hydrostratigraphic units offset
  - within-unit stratigraphic continuity between offsets

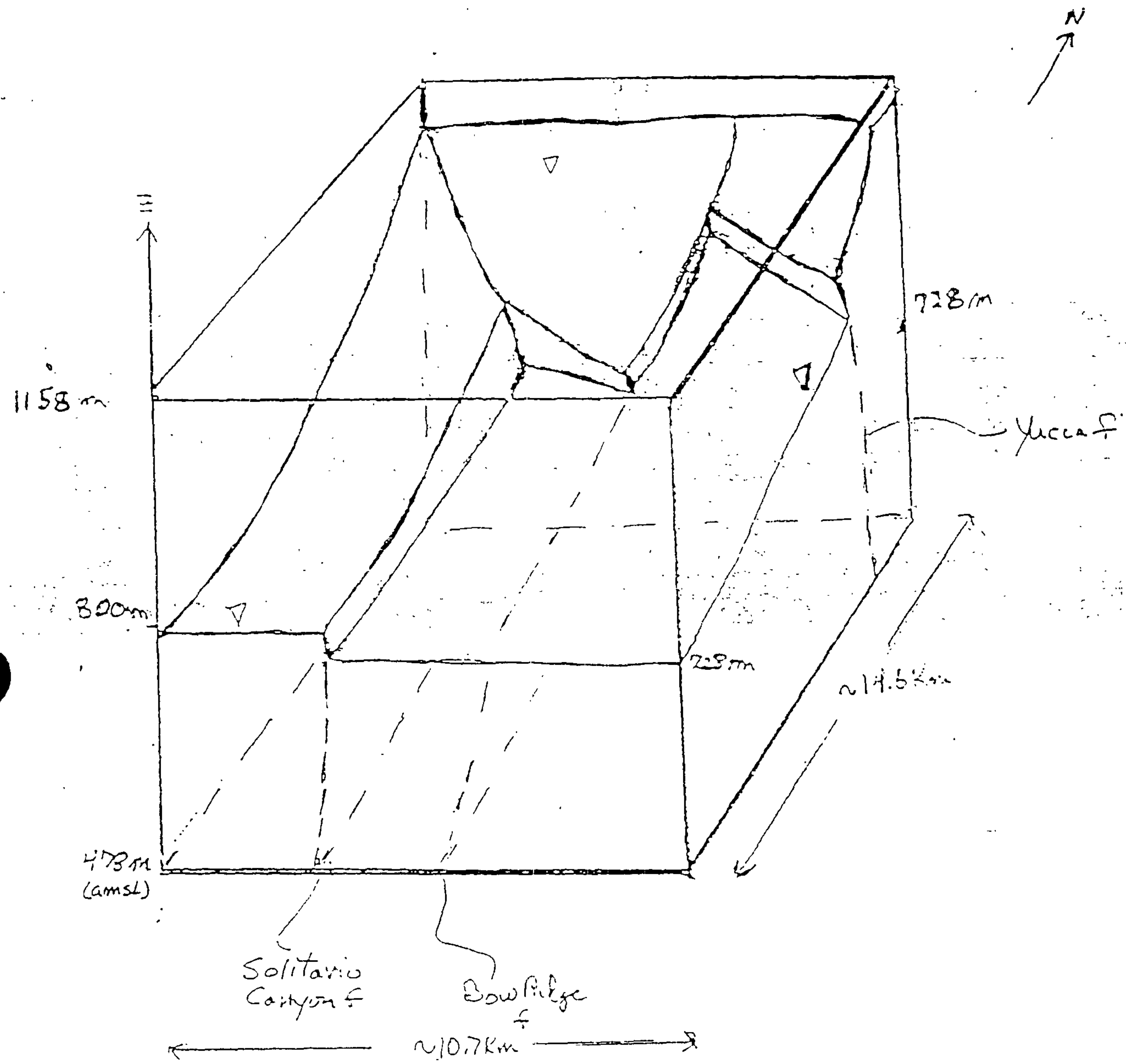
- Large-scale horizontal-to-vertical anisotropy expected due to stratigraphic layering; small-scale vertical-to-horizontal anisotropy possible due to columnar jointing in welded units

- "Plaid" conceptual model appropriate



C-wells

from Geldon (1993)


N
728m
1158m
Yucca f
800m
728m
~14.5Km
478m
(amsl)
Solitario
Canyon f
Bow Ridge
f
~10.7Km

After Barr

WATER TABLE CONFIGURATION

- Large hydraulic gradient to N
  - regionally ubiquitous
  - controlled by topography and geology
  - possibly fully or partially perched

- Steps across major faults
  - 45 m step across Solitario Canyon fault
  - smaller steps (?) across other faults on Yucca Mountain

- Locally, apparently less affected by:
  - local-scale faulting
  - hydrostratigraphic offsets
  - heterogeneity of hydrostratigraphic units

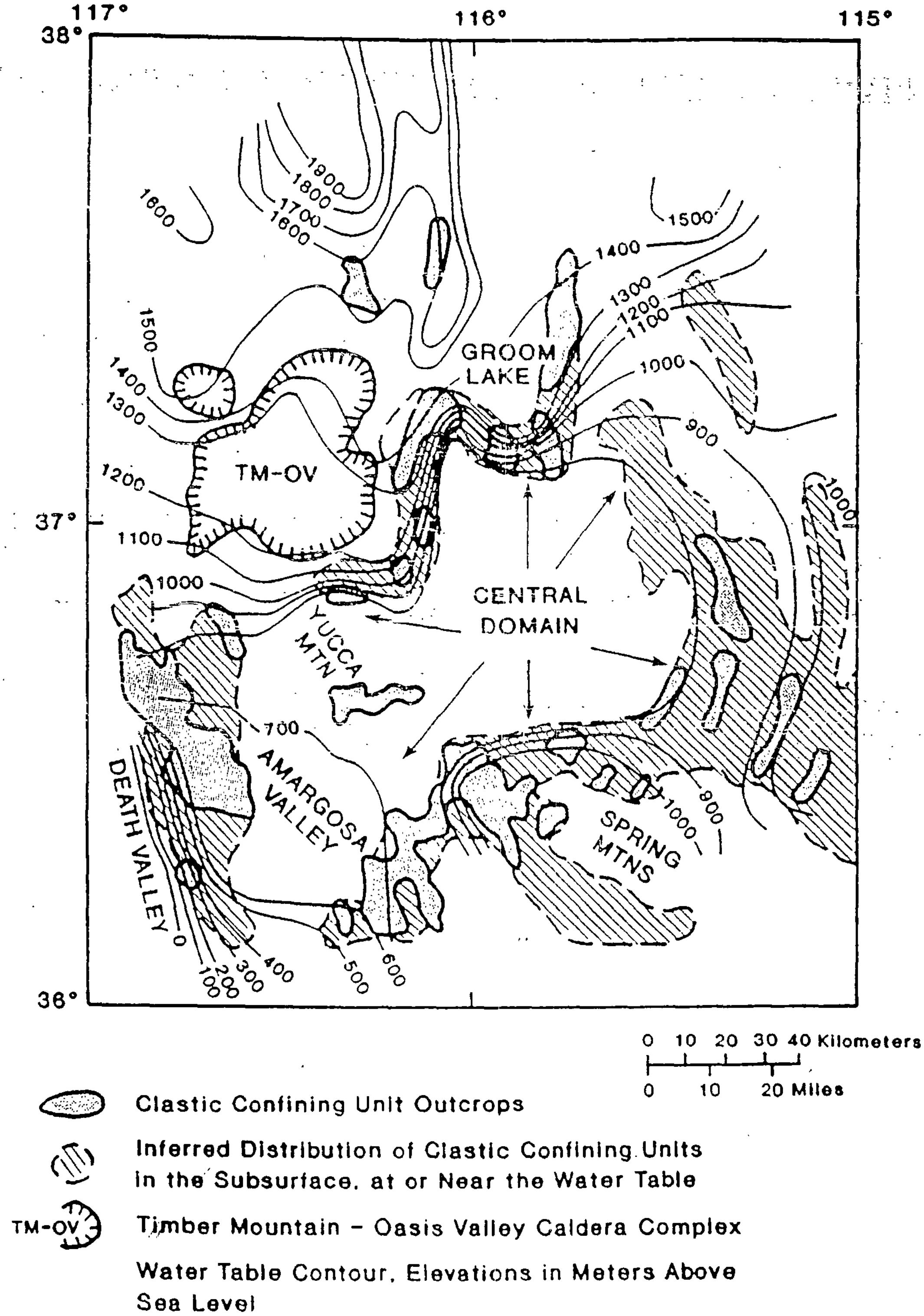


Fig. 2. Regional water-table configuration in the Death Valley NE ground-water system, reproduced from Waddell et al. (1984), with overlain interpretation of the distribution of the clastic confining units of Paleozoic and youngest Precambrian age, constructed using data from Longwell et al. (1965), Cornwall (1972), Stewart and Carlson (1978), Robinson (1985) and Frizzell and Shulters (1990). Labeled features include the Timber Mountain–Oasis Valley caldera complex (TM–OV) and the central domain of very small hydraulic gradient.

(1)

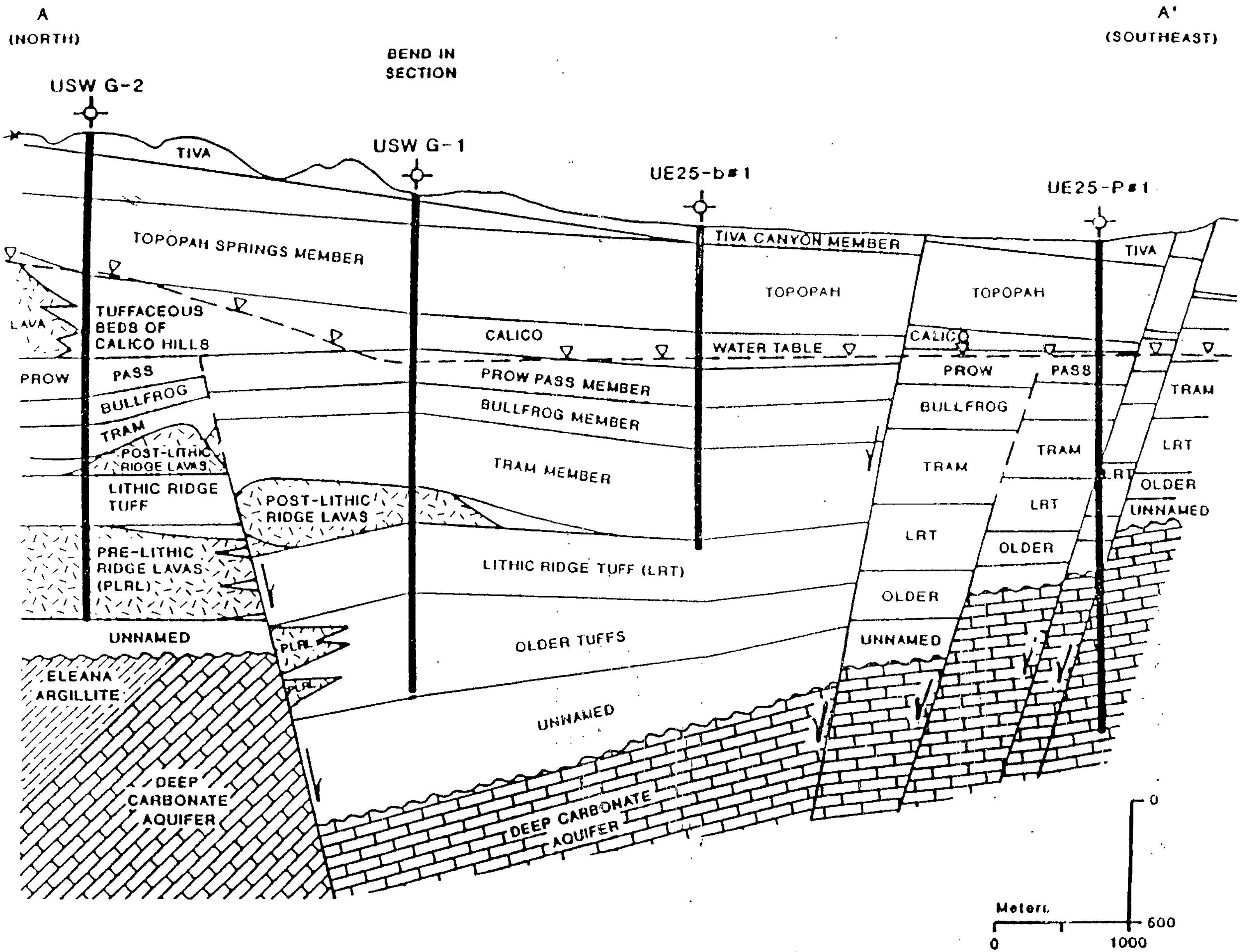


Fig. 11. North-to- southeast geologic section across Yucca Mountain showing the interpreted buried graben. Line of section shown in Fig. 5. Constructed using data from the full suite of lithology logs, cited in the caption of Fig. 4.

TWO POSSIBLE INTERPRETATIONS

Saturated Flow System

- Large hydraulic gradients (LHGs) are a common feature in the region, and it is likely that they share a common cause.
- The "large hydraulic gradient" is actually a steep water table slope. The 3D distribution of hydraulic head in the vicinity of the LHG north of YM is poorly known. The hydraulic gradients in the 3D flow system likely have both lateral and vertical components and may be quite complex.
- The configuration of the water table beneath the land surface is a function of:
    - topography
    - recharge patterns
    - geology:
        - hydrostratigraphic units
        - structural features
- Topography steepens to the north in the vicinity of the LHG.
- Recharge increases to the north of the LHG.
- Water table offsets are thought to be common in the area associated with faults (eg. Solitario Canyon fault).

Perched Flow System

- Perched flow systems are a common feature in the region.
- They usually develop on hillsides in horizontally stratified systems with large K-differences between units.
- They usually manifest themselves in springs and seepage areas at elevations well above the regional water table.

Hydraulic Gradients

- Amargosa valley 0.002
- Small hydraulic gradient SE of YM 0.0003
- Large hydraulic gradient N of YM 0.13

Topographic Gradients

- Alkali Flats to Lathrop Wells 0.004
- Lathrop Wells to Forty Mile Wash by YM 0.016
- Forty Mile Wash at YM to Timber Mountain .. 0.037

Depth to Water Table

- Alkali Flats to Lathrop Wells .... 0 - 100 m
- Lathrop Wells to Forty Mile Wash by YM ...... 100 - 300 m
- Forty Mile Wash by YM to Timber Mountain .. > 300 m

Mean Annual Precipitation

- Amargosa Desert .... 75 - 100 mm/y
- Yucca Mountain .... 125 - 175 mm/y
- Timber Mountain .... 200 - 250 mm/y

Recharge (Calibrated Regional Model)

- Amargosa Desert .... 0 mm/y
- Yucca Mountain, Timber Mountain .... 1 - 10 mm/y

FEATURES AND OBSERVATIONS

Favoring Saturated Flow System

- Large water-table slopes apparently associated with saturated-zone low-K features elsewhere in the region (Eleana formation NE of YM, Solitario Canyon fault). Some LHGs very unlikely to be perched (eg. Amargosa desert to Death Valley through Funeral Mountains).
- Even higher heads to north of LHG (1187 m in Upper Forty Mile Wash, 1400 m on Paiute Mesa).
- Upward flows from Carbonate aquifer into volcanics south of LHG. Higher heads at depth imply saturated connection with high heads N of LHG.
- No regional springs associated with LHG.
- Base of Calico Hills Upper Volcanic Confining Unit is at 730 m which coincides with water table elevation S of LHG.
- Data sparse, but two wells above LHG: USW-G2 (1020 m), UE-25 WT#6 (1034 m)

Favoring Perched Flow System

- Water levels in USW UZ-14 (967 m during drilling and pump testing, 778 m after casing off higher zone and completion in Bullfrog tuff).
- Draining of USW-G2 (from 1029 to 1020 m since 1982).
- Apparent partial saturation in Calico Hills formation in USW-G2 on basis of borehole geophysical logging.
- Decrease of thermal gradient profiles over time in USW-G2.

RAF Bayesian Prior

- Saturated: 80%   Perched: 20%

POSSIBLE GEOLOGIC CONTROLS ON SATURATED FLOW SYSTEM

South to North Permeability Reduction Trend	
⊙ Reduced fracturing to N due to lithologic trends	R
⊙ Reduced fracturing to N due to changes in stress field	U to MV
⊙ Increased alteration toward caldera complex to N	MV
Near-Vertical Low-K Structural Feature	
⊙ Buried Fault - Low-K barrier - Offset of hydrostratigraphic units	MV
Near-Horizontal Low-K Stratigraphic Unit	
⊙ Calico Hills Upper Volcanic Confining Unit ("Semi-Perched")	MP
⊙ Eleana formation Upper Clastic Aquitard	R
Deep Drains South of LHG	MP
⊙ Carbonate aquifer	
⊙ NW-SE trending faults	

Note: Dudley Classification:
R = rejected
U = unlikely
MV = marginally viable
MP = more probable

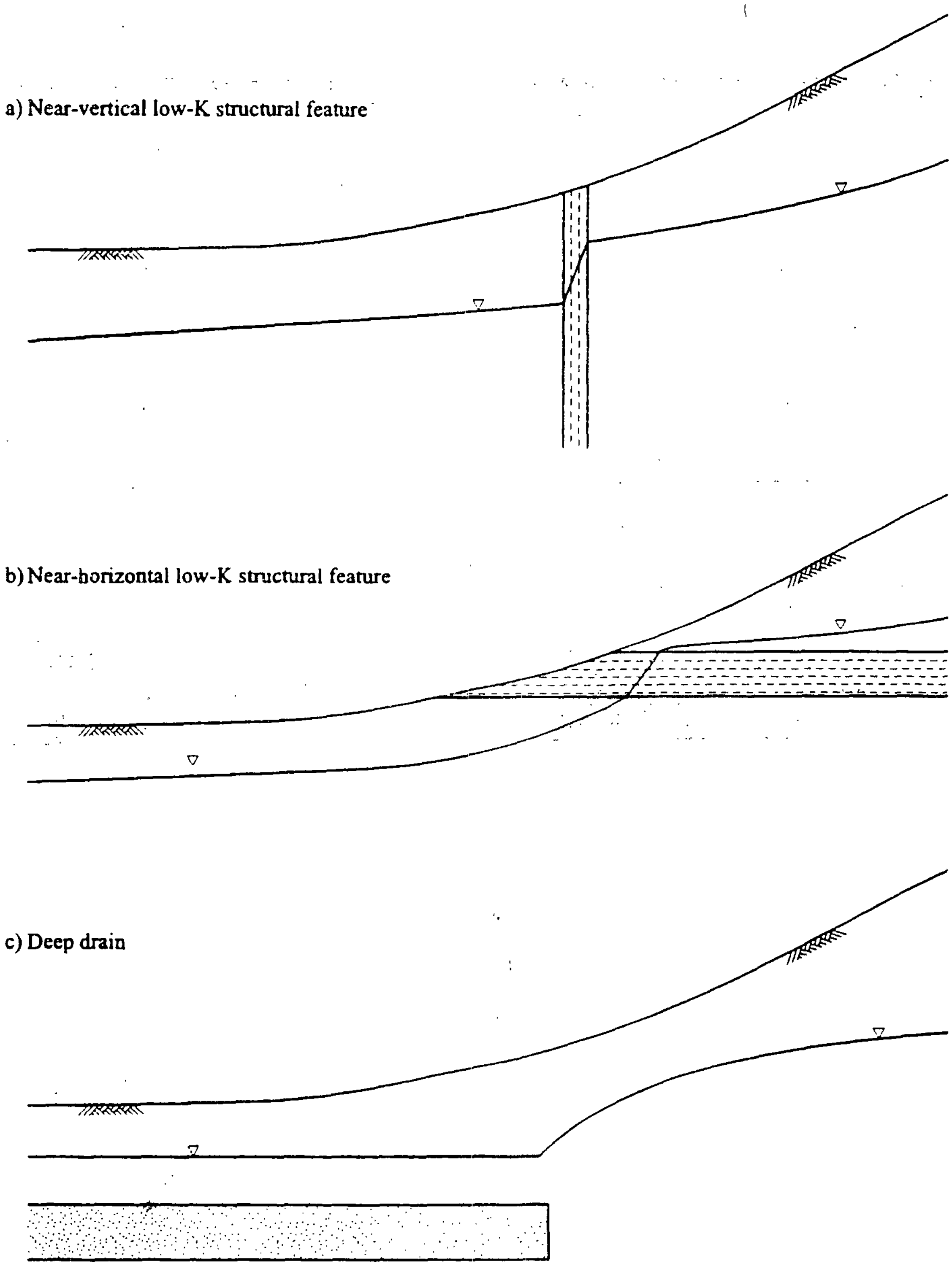


Figure AF-1 Alternative possible causes for the large hydraulic gradient (LHG), assuming a saturated flow system model rather than a perched flow system model.

FLOW-NET ANALYSIS

- No evidence of significant natural transients near Yucca Mountain. Steady-state analysis appropriate. Seasonal pumping demands and long-term increases in pumping in Amargosa Desert may create transients, but response in high-K units there ought to be rapid.

- Upward flow from Carbonate aquifer to Volcanic aquifers
  - measured at UE-25p#1, USW H-1, USW H-3
  - groundwater temperature anomalies

- Regional flow tubes from YM to SE in volcanics, then into alluvium along eastern boundary of Alkali Flats - Furnace Creek Ranch groundwater subbasin.

- Local flow tubes beneath repository erratic, due to:
  - stratigraphic unit at water table
  - proximity to fault zone

- Potential for focussed flow:
  - natural flow system geometry (Schwartz)
  - NW-SE faults act as drains (Lehman)
  - Line of intersection of major tectonic fracture zones and strata most easily fractured and brecciated create "gently dipping drainage pipes" (Fridrich)
  - High-K channel under Forty-Mile Wash (Wittmeyer)
  - Pumping-well capture zones in Amargosa Valley

- Flow tubes splay in and out of high-K features. Infiltration from UZ likely to enter and remain in flow tube. Mixing zone at water table not a good conceptual model.

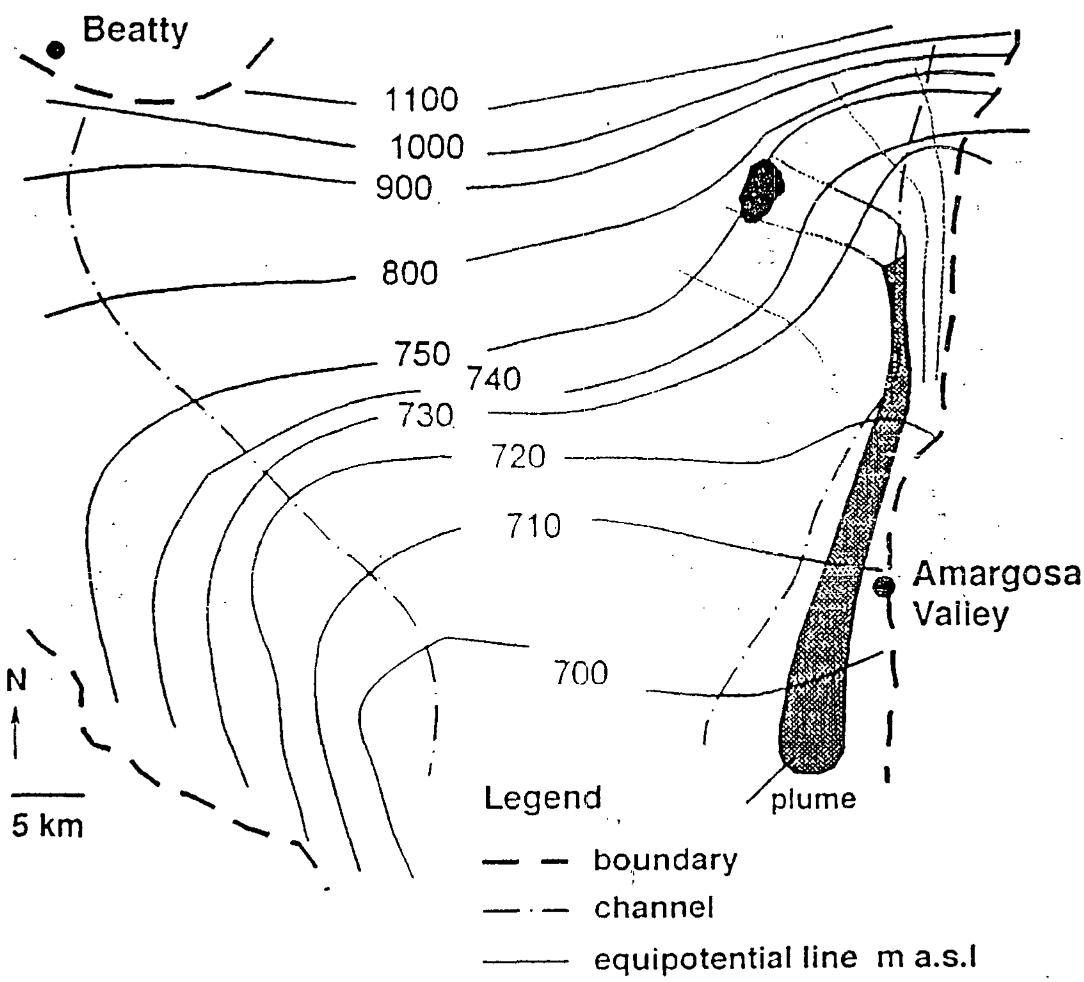
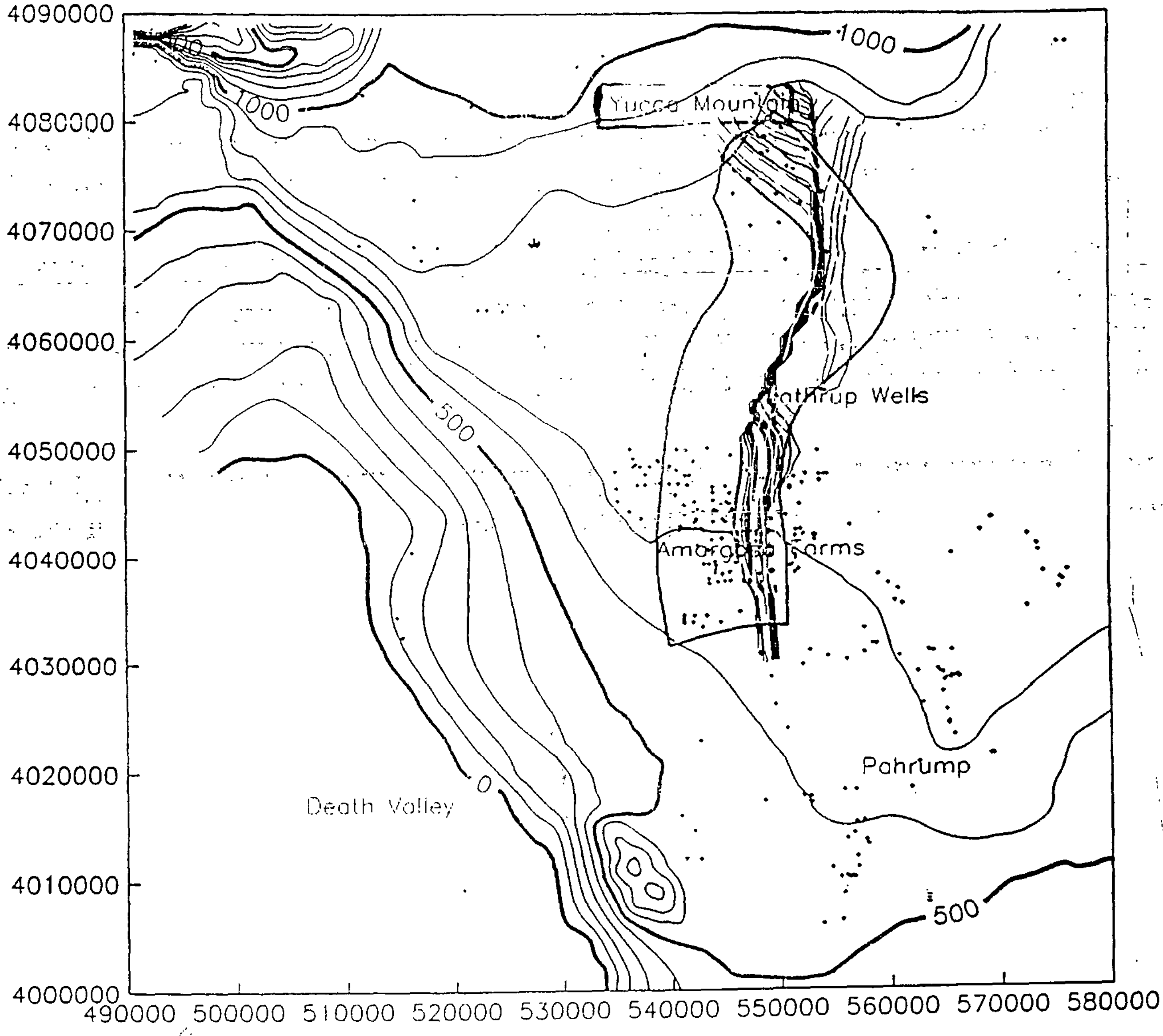


Figure 8-10 Map illustrating the likely size and location of a contaminant plume moving south toward the Amargosa Desert.

After Schwartz

Streamline Capture (in red) with 8660000 cu m/year Pumping



After Wittmeyer

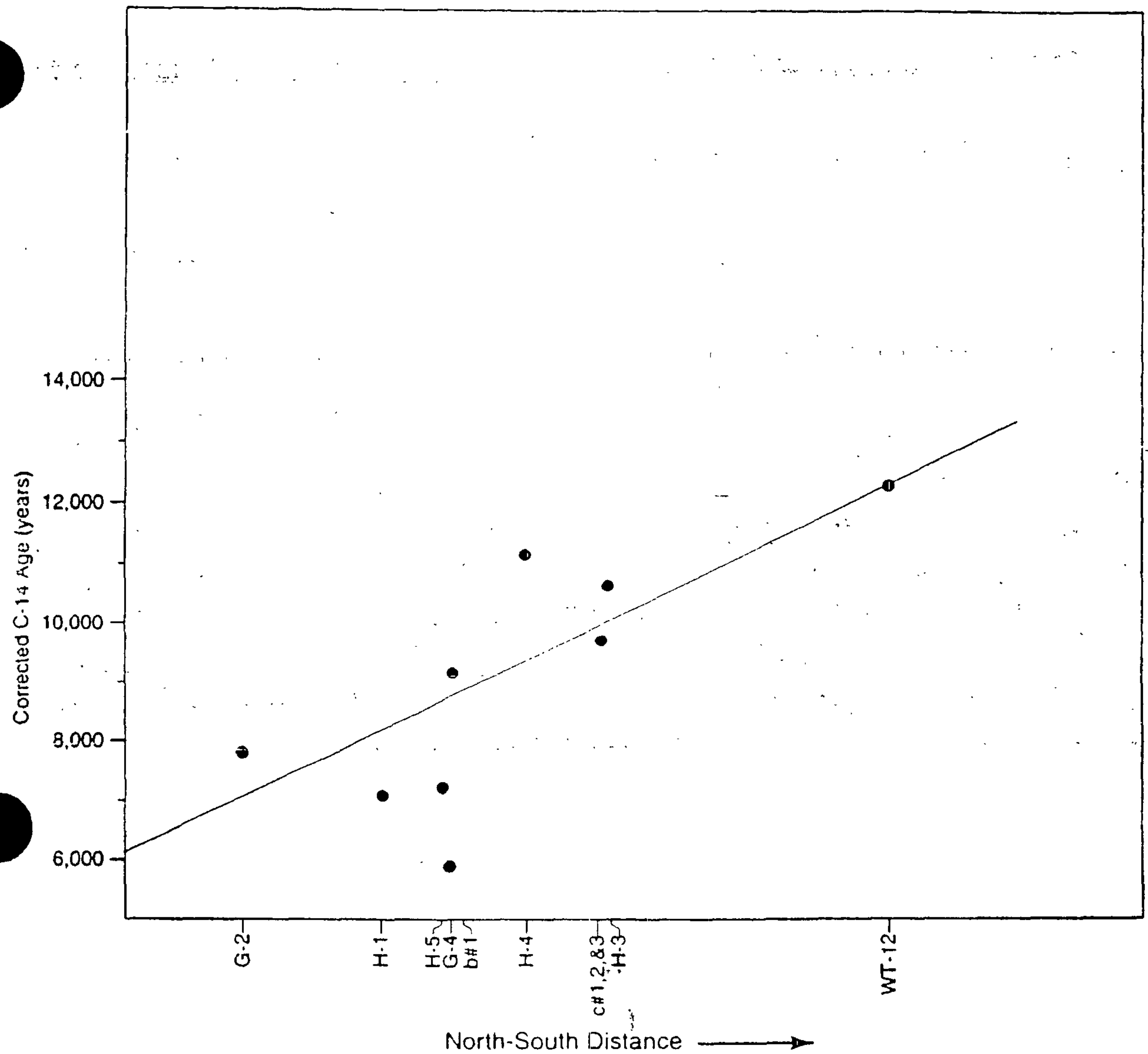


Figure DL-3 Average corrected $\delta^{14}C$ ages of groundwaters in the Tertiary volcanics under Yucca Mountain east of Solitario Canyon fault, plotted against the north to south distances of the wells. The line drawn has no statistical significance.

ADVECTIVE FLOW RATES FROM SITE

STEPS

- 3D hydrogeologic framework
- flow-net analysis to identify flow tubes and gradients, i:
  - scoping
  - model output
- estimate hydraulic conductivity, K, and porosity, n
- Darcy's law to calculate:
  - specific discharge, q = Ki
  - average linear velocity, v = q/n

FOR FLOW TUBES IN LVA + FAULT ZONES

- K (LVA) : $3x10^{-5}$ to $3x10^{-3}$ cm/s, median: $3x10^{-4}$ cm/s
- K (FZ) : 10 x K (LVA)

- q : 0.01 to 1 m/y, median 0.1 m/y
- v : 0.3 to 30 m/y, median 3 m/y

For local to regional scale. Site scale ranges larger.

ADVECTIVE FLUX ESTIMATES

Other Published Estimates

- Winograd and Thorardson: Carbonate aquifer beneath Yucca Flats: 1.8 - 180 m/y
- Schwartz: Alluvium in Amargosa Desert: 55 m/y
- TSPA '93: YM volcanics: 2 - 22 m/y
- TSPA '95: YM volcanics: lognormal distribution
  - mean = 2.0 m/y
  - median = 1.07 m/y
  - std dev = 0.49
- Arnold overheads: YM volcanics: 0.1 - 10 m/y (?)
- Site-scale model: ???

Isotopic Age Dates

- W and S of YM: 11000 - 12000 y
- N and within YM: 6000 - 8000 y
- E and SE of YM: 4000 - 7000 y (probably affected by recharge to Forty-Mile Wash)

  - implication: 1000s of m in 1000s of y 1 m/y

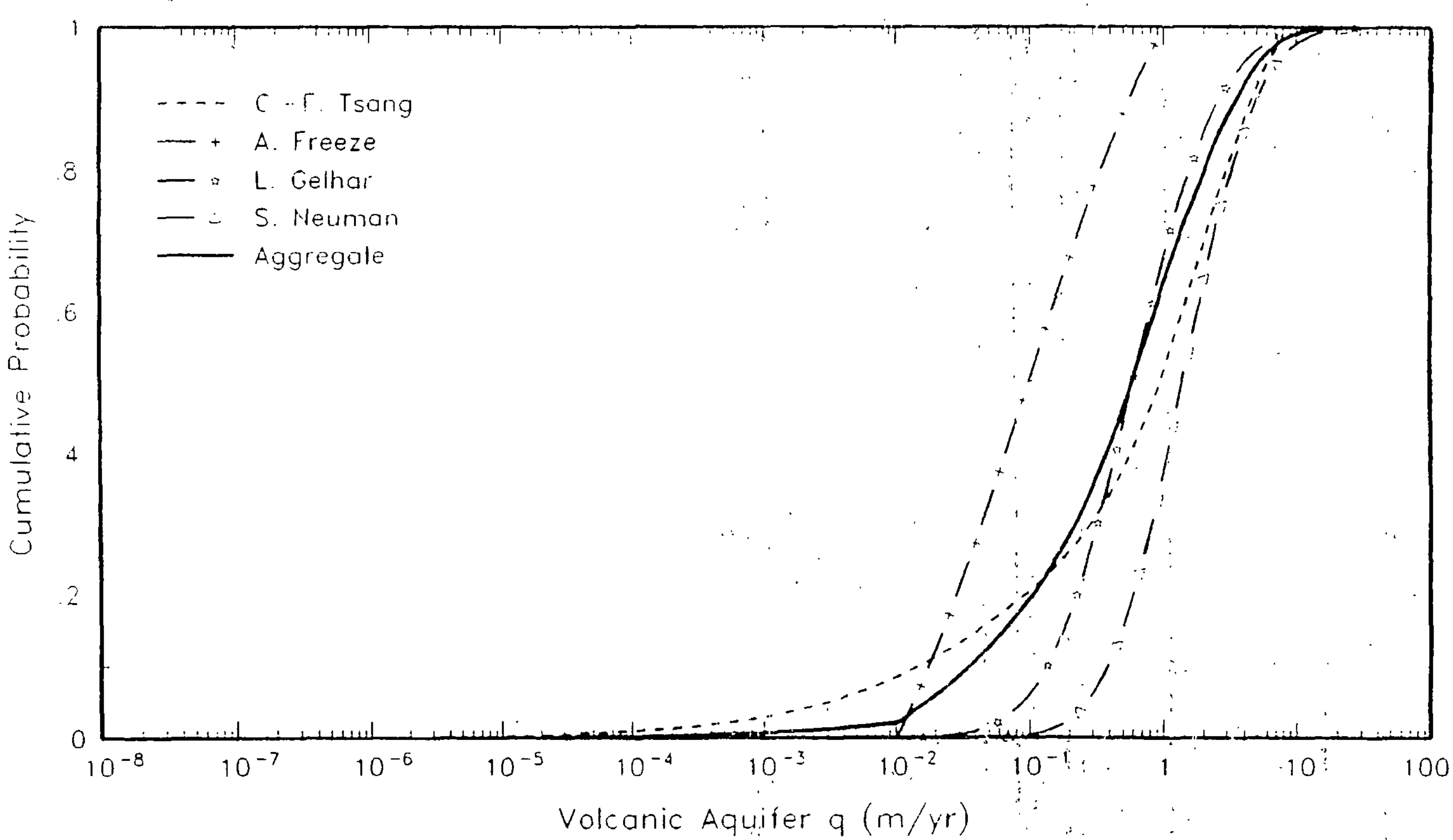


Figure 3-2e Individual and aggregate cumulative distributions for volcanic aquifer specific discharge

DILUTION

- Defined as contaminant concentration at release point divided by highest concentration at potential receptor locations.

- Assume:
  - Source of 10s to 100s m dimension
  - Steady, non-decaying source
  - Receptor location 25 km from source
  - Concentrations measured 1000s of years after release

- Most likely mechanisms:
  - hydraulic focussing
  - hydraulic defocussing
  - transient flow tube wandering
  - longitudinal dispersion
  - not much lateral dispersion
  - not much mixing
  - pumping well capture

- Estimated dilution factor: 1 - 100, median 10
  - Low end: site-wide source, little transient action
  - High end: point source, significant transients

- Mixing model used in current PA is inappropriate. Flow tubes are likely to remain fairly discrete.

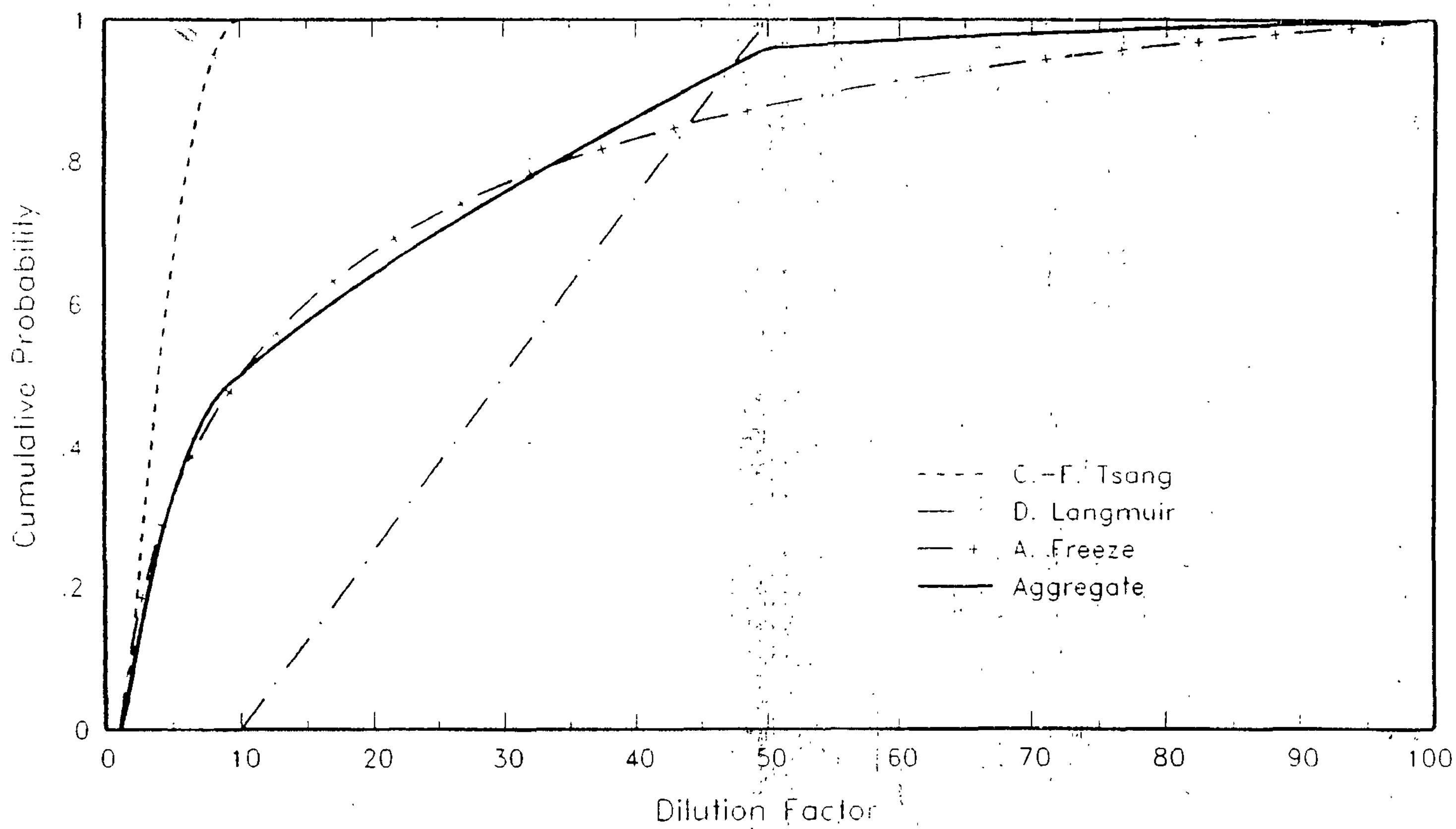


Figure 3-3d Individual and aggregate cumulative distributions for dilution factor

CHANGED CONDITIONS

Pluvial Climate

- Most likely future climate scenario: Anthropogenic greenhouse warming for 3 ky, then resumed global cooling toward next glacial epoch as predicted by Milankovitch orbital theory of climate.
- Under cooler, wetter climate with MAP 2-4 times current rates: increase in Death Valley water budget from 400,000 to 700,000 m^3/y, and rise in water table of 50-100 m.

Impact of Repository Heating

- Boiling, buoyant convection, redistribution and condensation of moisture in the UZ, leading to complex transient patterns of perched saturation. fracture drainage, and increased infiltration to the water table. Under some scenarios, ambient infiltration to the water table could increase 100-fold, and increased rates could persist for 1000 years.
- Temperature effects are predicted to extend into the SZ. They could potentially:
  - create convection cells in the SZ
  - produce mineralogic alteration that affects the permeability structure of the volcanic aquifers

SUMMARY OF CONCLUSIONS

- There is nothing about the YM saturated-zone flow system that precludes application of standard hydologic tools. It is complex and there are uncertainties, of course, but the basic flow and transport mechanisns are under suitable investigation, and there will be reductions in uncertainty over time. There is no fundamental difference between YM and other complex sites that have been successfully investigated.
- Faults are an important component of the flow system and their role is not yet sufficiently understood.
- The large hydraulic gradient is not a cause for alarm. It is not a particularly unusual hydrologic feature. It may be fully saturated or it may be perched, but settling this controversy is not critical to the project. The hydrologic impacts are similar in either case. A limited program of field work and modeling would put the issue to rest if need be.
- The carbonate aquifer exerts an important control on the overlying flow system, but it is not likely to be a pathway for contaminant transport from YM to AD.
- Flow tubes in the flow system between YM and AD are likely to remain fairly discrete with little mixing. Flow rates are on the order of a few m/y. Travel times are on the order of several thousands of years. There are some hydraulic processes operating in the flow system that will serve to focus flow and some that will serve to disperse flow. An overall dilution factor of 10 or more may be defensible. There is still considerable uncertainty over this value.

- **Water table changes under future climatic changes are likely to be in the same range as documented fluctuations under past climatic changes. Median anticipated rise: 75 m. Median anticipated increase in flow: 3X.**
- **Tectonic events are not likely to lead to large or long-lived changes in the hydrologic system at YM.**
- **Thermohydrologic impacts of repository heating will overwhelm the natural hydrologic conditions in the unsaturated zone at YM, and could have significant impact on the timing and extent of recharge to the saturated zone, and on near-site saturated flow systems.**

COMMENTS ON ELICITATION PROCESS

CONCERNS OF PANEL MEMBERS

- Stated purpose of elicitation is to inform PA. Will other PR uses be made of results?
- How will results be used in PA? Too much reliance relative to more-informed views of project teams?
- How will stochastic PA output be used and misused by various players in the "environmental game"?
- Does integration of uncertainties of panel members in report mask important individual uncertainties?

CONCERNS OF ELICITORS

- Are uncertainties overestimated? CYA syndrome.
- Are uncertainties underestimated? Expert overconfidence.
- Role of personalities: pessimists/optimists, supporters/critics, etc.