STATE OF NEVADA RESEARCH

SATURATED ZONE & INFILTRATION

Presented By

LINDA LEHMAN
T-REG, INC.

PRESENTATION OUTLINE

CONCEPTUAL MODEL SATURATED ZONE FLOW AND TRANSPORT

- **Introduction**
- **Structural Controls on the Flow Field**
- **Specific Orientations**
  - **North-South Trending Faults**
  - **Northwest trending shear zones.**
  - **Northeast - Southwest Trending Faults**
- **Temperature as a flow path indicator**
- **Numerical Model Results**

CONCEPTUAL MODEL OF THE UNSATURATED ZONE INFILTRATION

- **Introduction**
- **Unsaturated Zone Model of Infiltration**
  - **Focused Flow**
  - **Lateral, Non-equilibrium Unsaturated Flow and Hysteresis**
  - **Structural Geology**

ANALYSIS OF REPRESENTATIVENESS

- **Saturated zone**
- **Infiltration**

DISCUSSION OF SENSITIVE VARIABLES

CONCLUSIONS

SATURATED ZONE DATA BASE

TEMPERATURE
HYDRAULIC HEAD
STRUCTURAL GEOLOGY
A FEW HYDROGEOLOGIC PARAMETERS

Saturated Zone Conceptual Flow Model

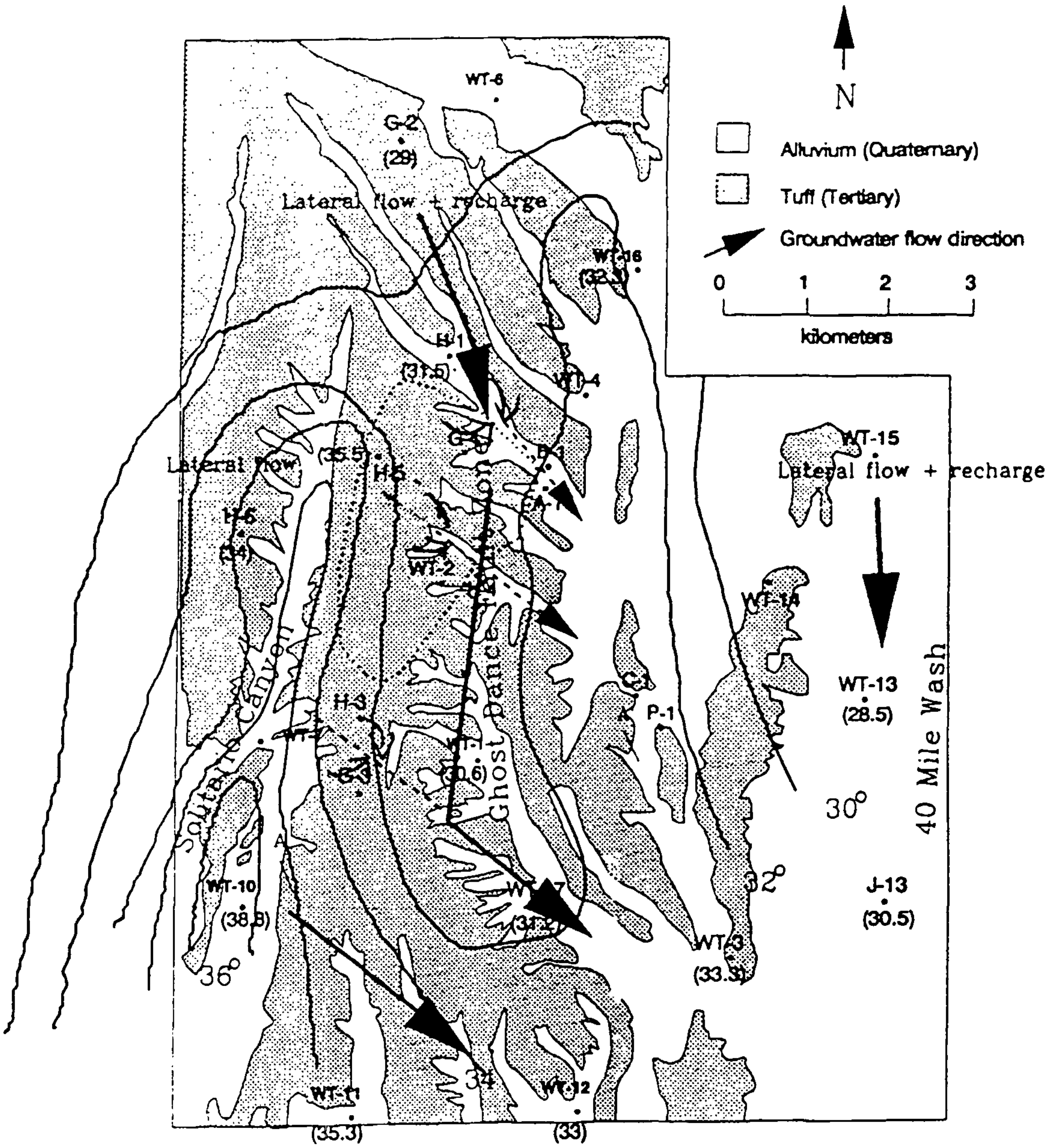


Figure 1. Saturated Zone Water Table Isotherms.

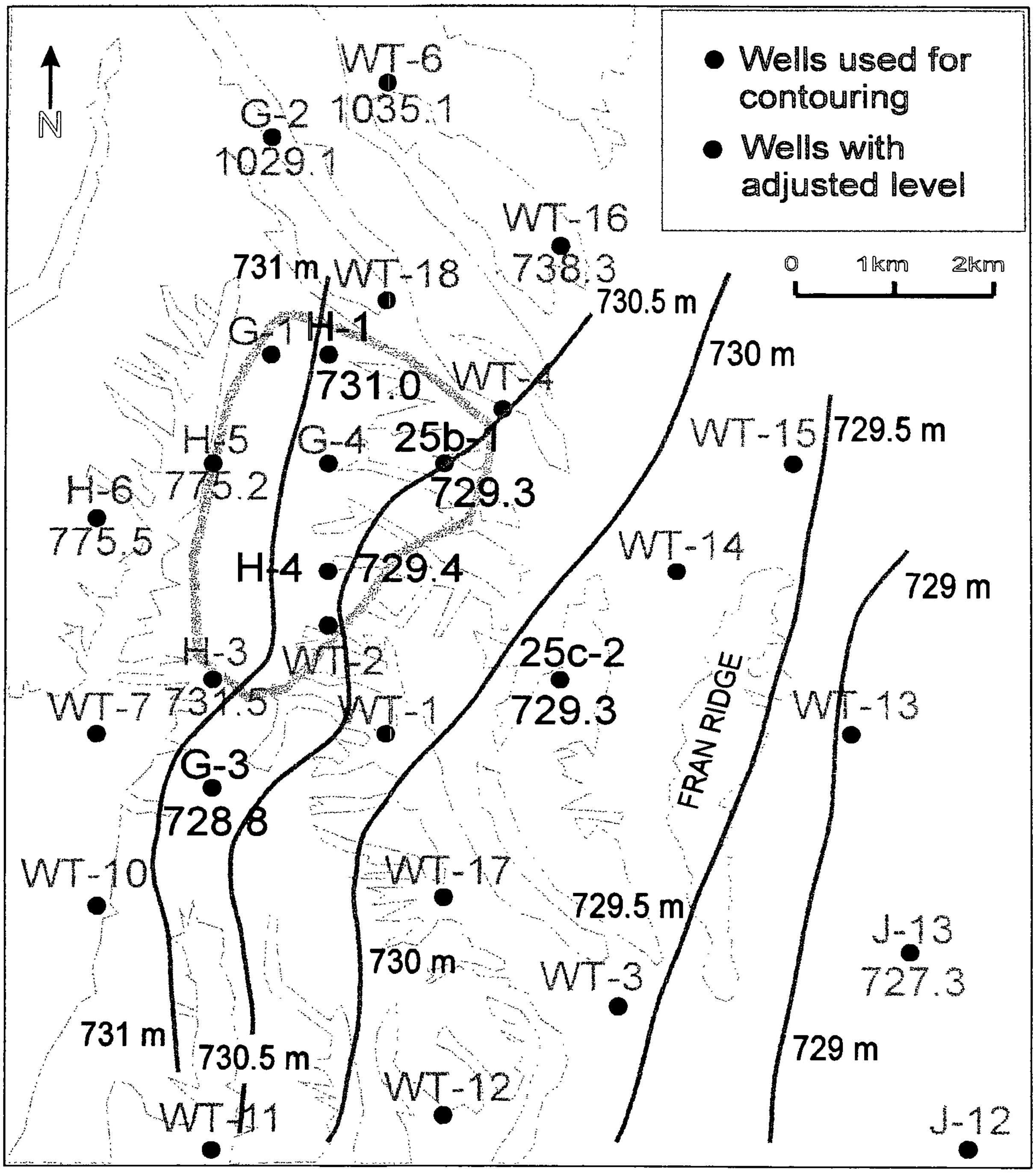


Figure 3. USGS Revised saturated zone potentiometric surface (Ervin, Luckey and Burkhardt, 1994). Red labels indicate adjusted data inconsistant with surface.

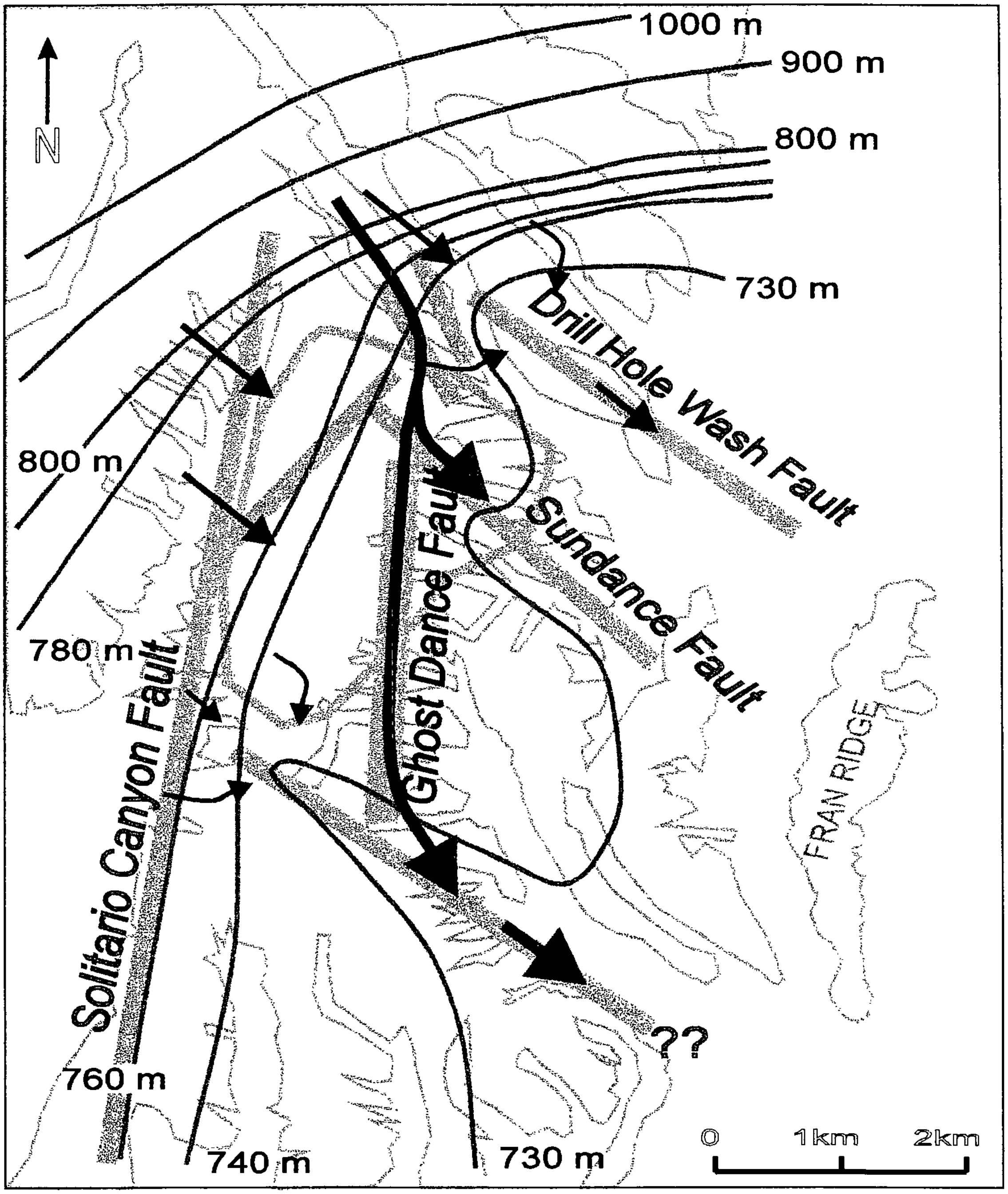


Figure 4. Alternative potentiometric surface with fault locartions and resulting flow pathways.

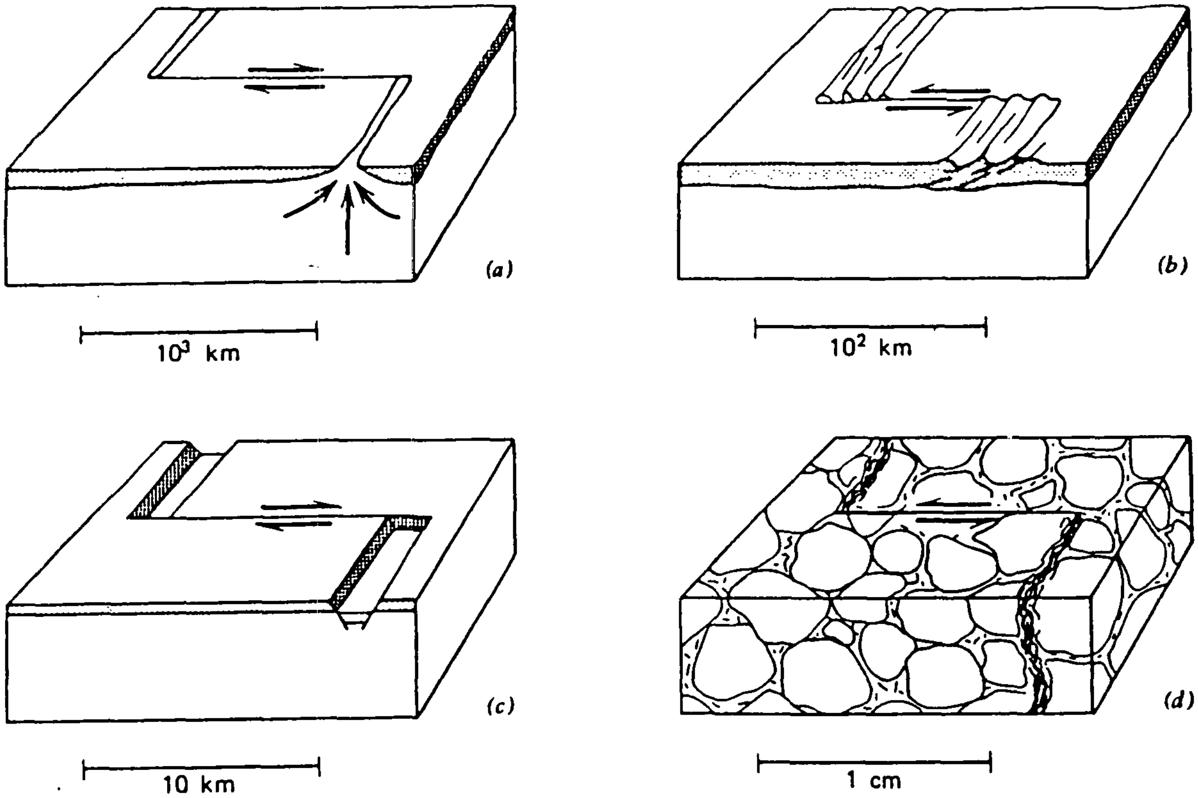


Figure 8. FIGURE 7.19 Faults associated with transverse structures at their termini. (*a*) Ridge-ridge transform fault. (*b*) Fault terminating in shallow fold and thrust belts (cf. *tear faults* of the Jura and elsewhere). (*c*) Fault terminating in block-faulted regions [cf. the Garlock fault in California as interpreted by Davis and Burchfiel (1973)]. (*d*) Microfault terminating in stylolitic seams, from which coarse white grains are removed in solution.

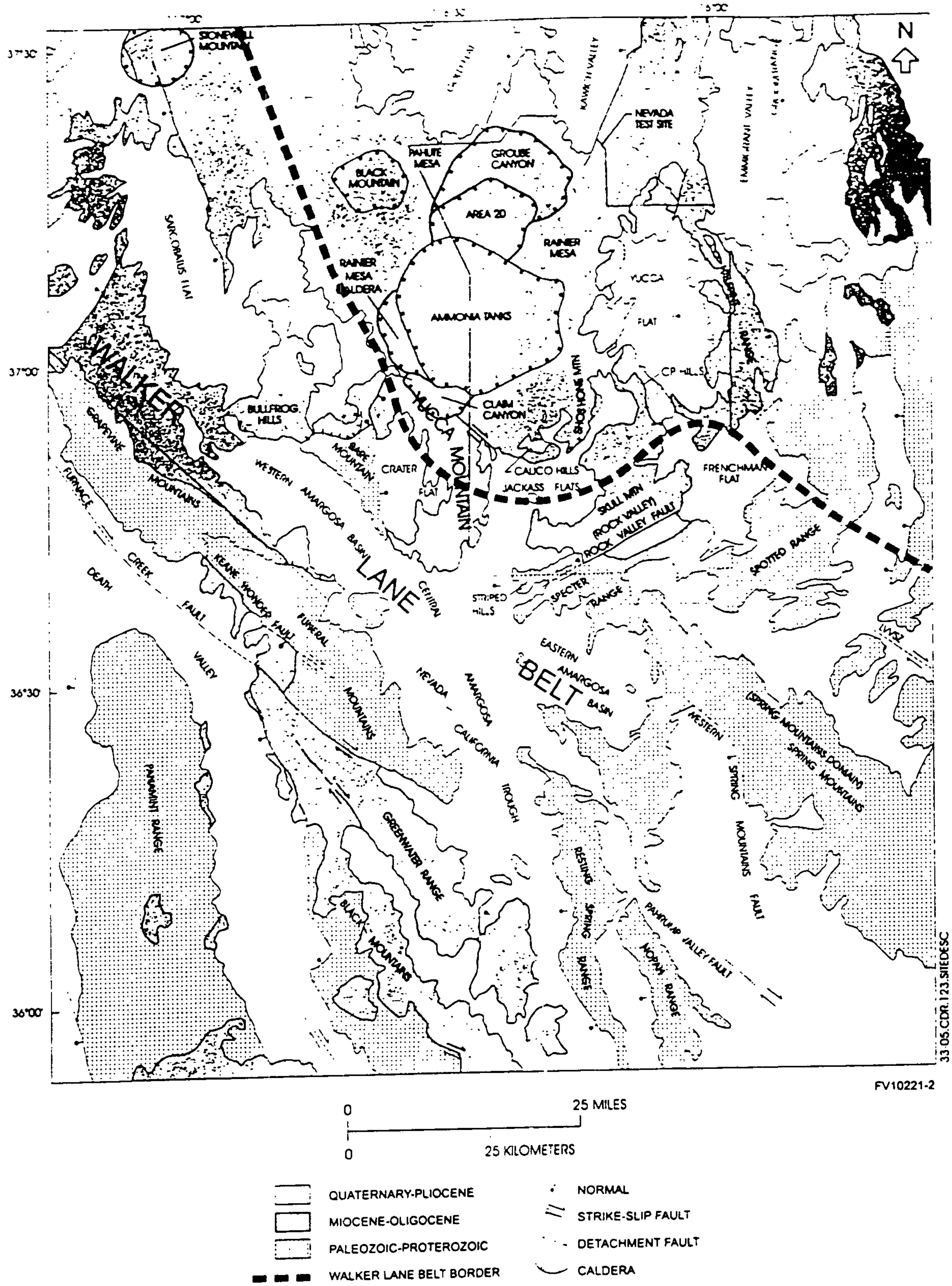


Figure 9. Generalized Geologic Map of the Yucca Mountain Region (Source: CRWMS M&O 1998d)

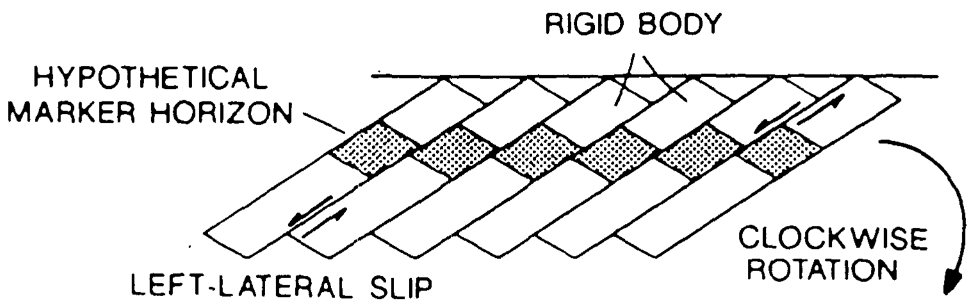


Figure 13. -Block model showing clockwise block rotation and left-lateral strike-slip faulting during rigid body deformation (modified from Nur and others, 1986).

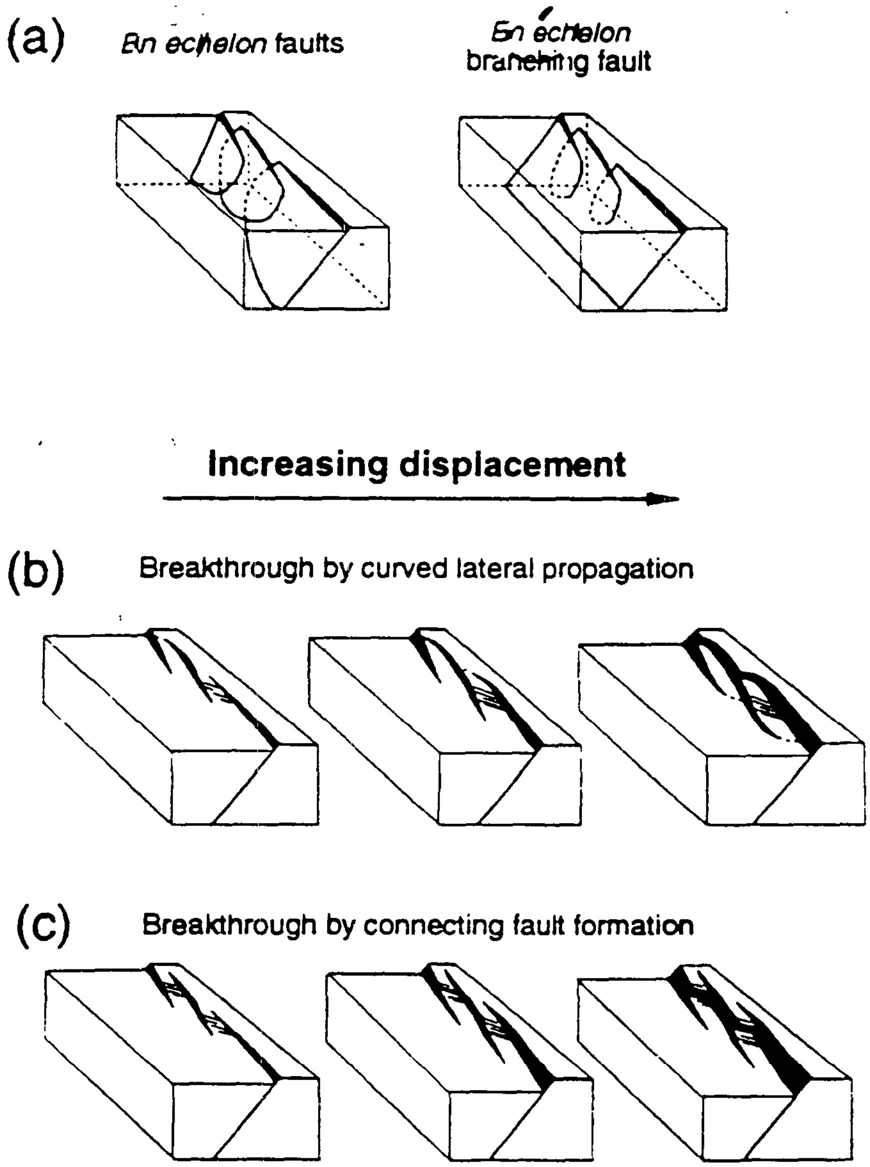
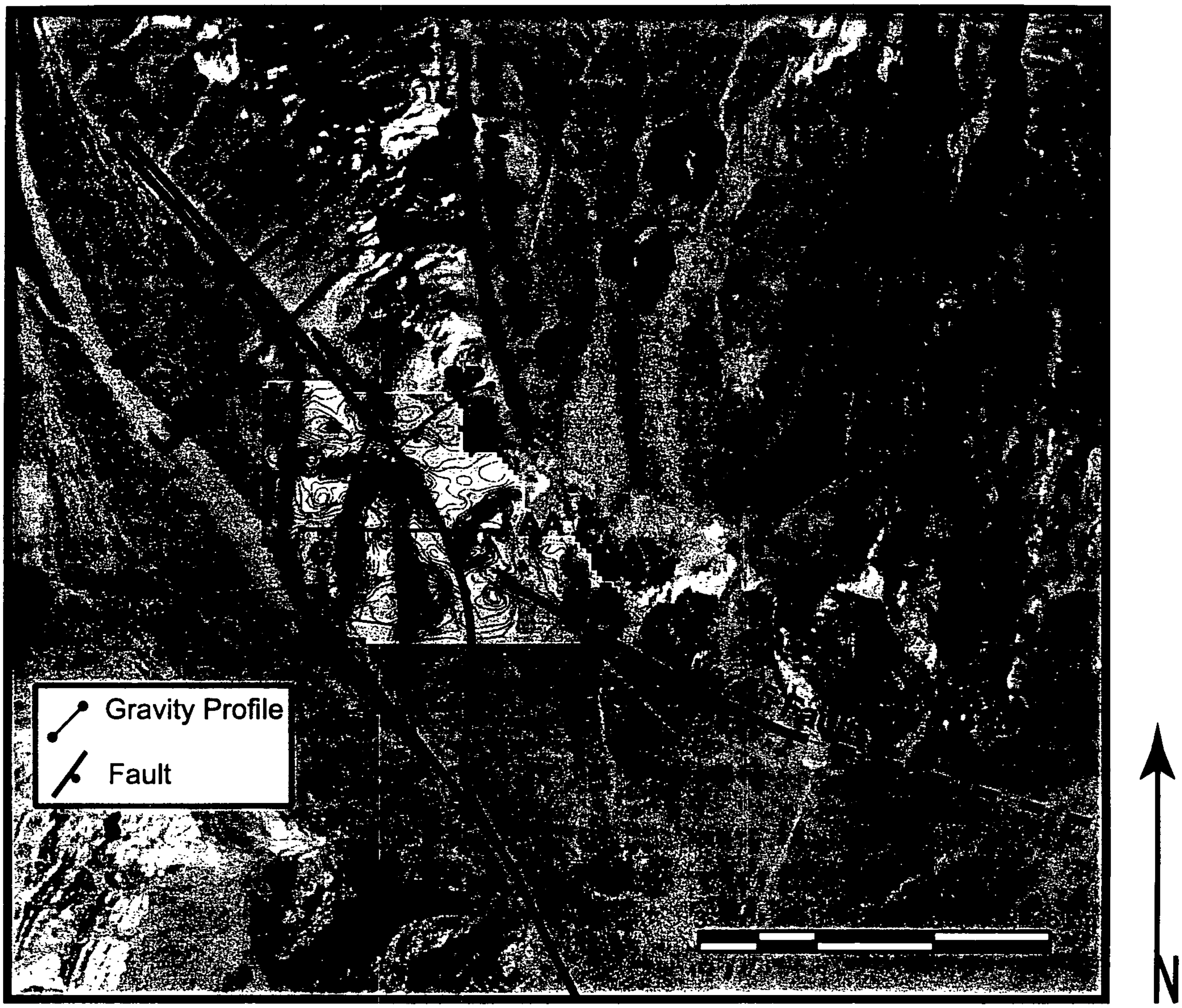
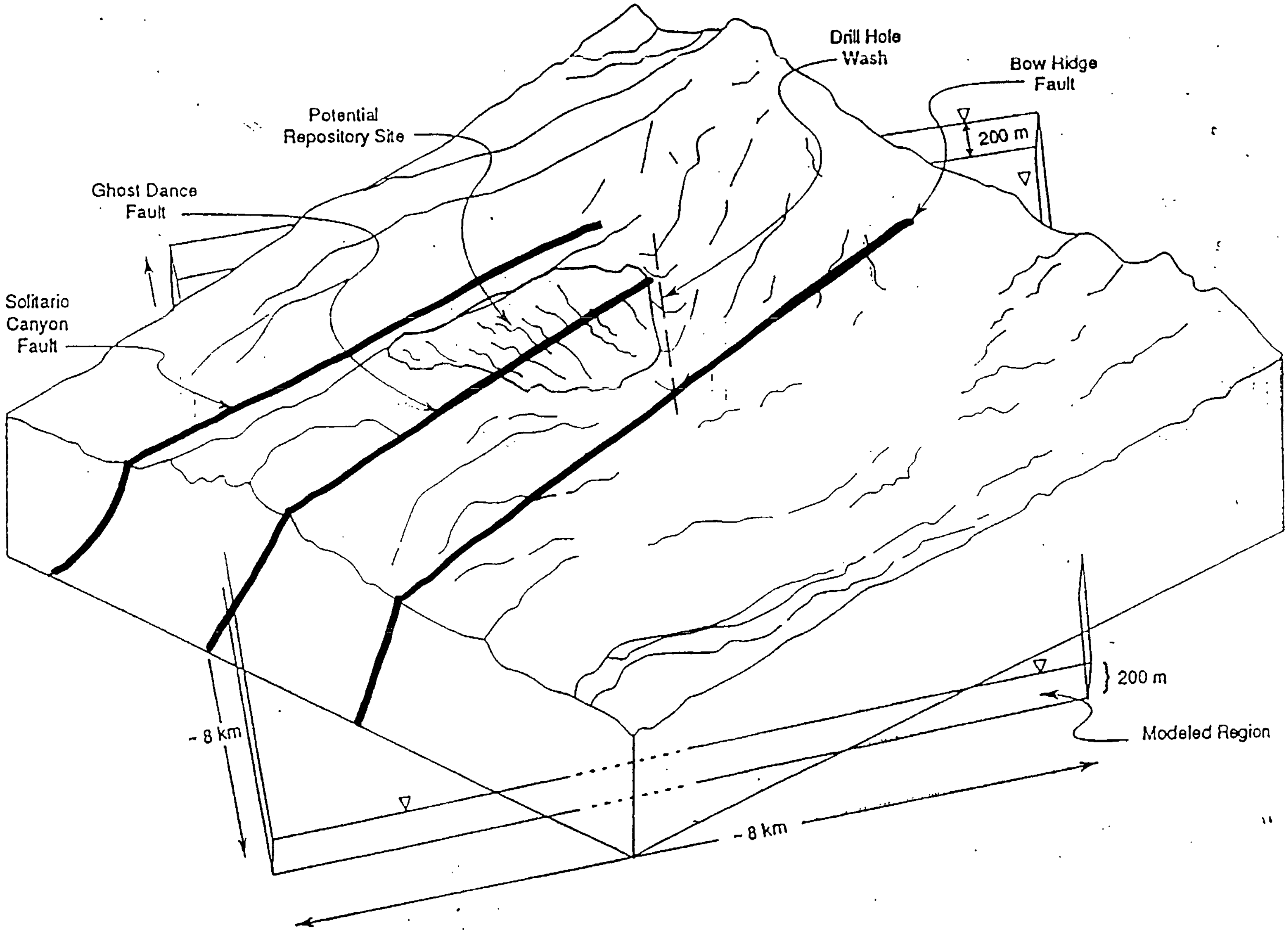


Fig. 1. Block diagrams illustrating (a) topology of en échelon fault systems and en échelon branching faults, (b) sequence of evolution of en échelon normal fault array or en échelon branching normal fault involving linkage and breakthrough by lateral propagation of curved fault-tips, and (c) sequence of evolution of en échelon normal fault array or en échelon branching fault system involving linkage and breakthrough by connecting fault formation.

Carrara Fault




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

After Barr

GHOST DANCE

To the south, the Ghost Dance fault trends toward a complex zone of north-to northwest-trending faults and fault segments that converge northward. These segments, which were in part mapped and named by Scott and Bonk (1984) are from west to east.

1. An unnamed, previously mapped fault along the west side of Middle Crest (Carr, 1984; Maldonado, 1985; Frizzell and Shulters, 1990; Reheis and Noller, 1990), marked in the south and central parts by small scarps and in the north by topographic and tonal-contrast lineaments.

2. The Abandoned Wash fault that down drops yucca Crest against Middle Crest and is marked by pronounced topographic lineaments. The extension of this fault to the south is tenuous; it appears to curve southwestward into a topographic gap in Middle Crest and may join the previously described fault that bounds the west side of Middle Crest.

3. An unnamed, previously mapped fault that bounds the west side of East Crest and separates Middle Crest from East Crest. The fault is marked by small west-facing scarps on the south and collinear fractures in bedrock on the north where it crosses East Crest.

4. Two parallel zones of unnamed, closely paced north- to northwest-trending faults along the east flank of East Crest, marked by topographic and tonal-contrast lineaments, minor fractures, and offset of bedrock.

Flow moving south from Ghost Dance fault could go into any one or more of these structures. The flow may be distributed along several of these pathways, and could resemble Figure 7.18 d

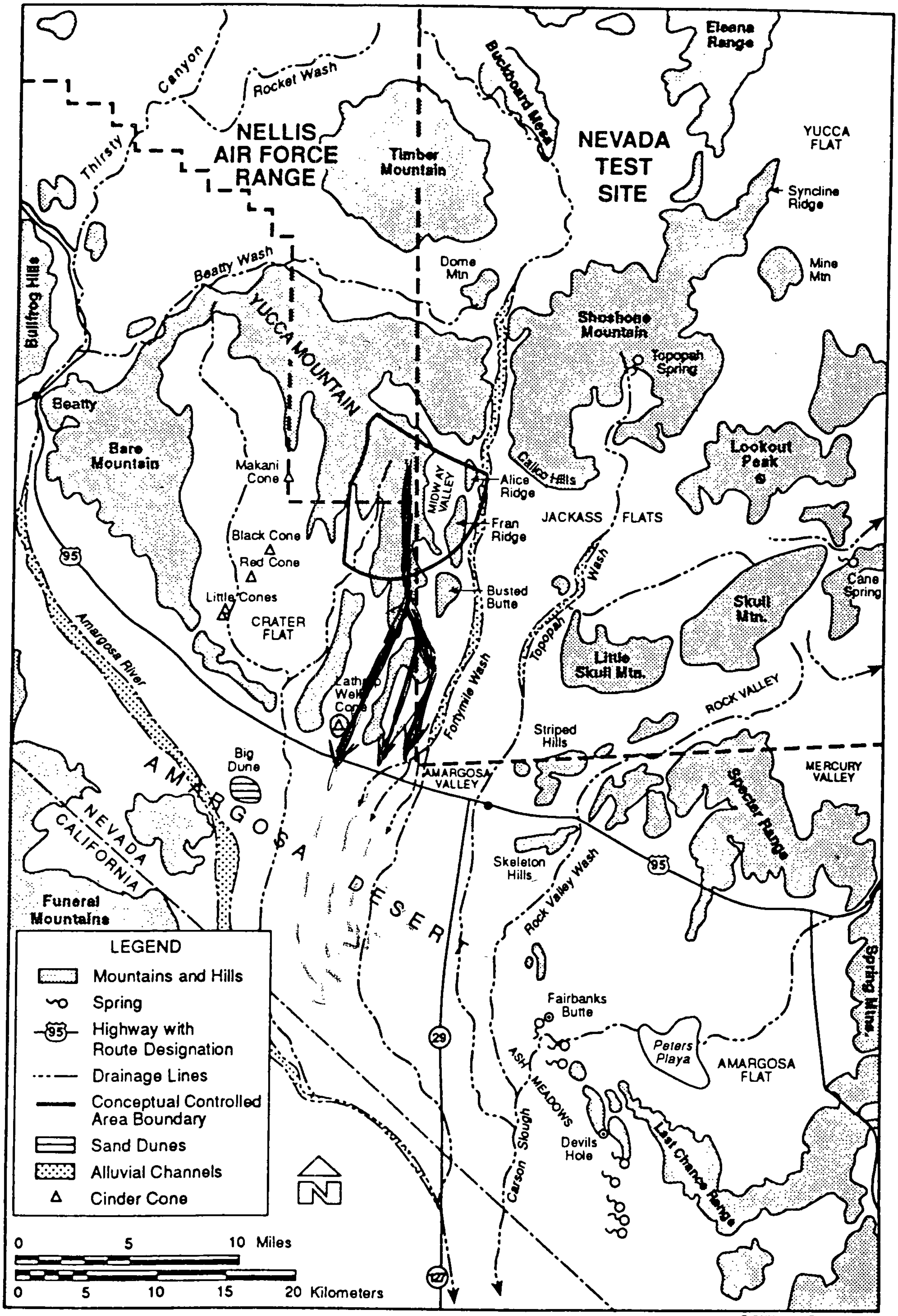
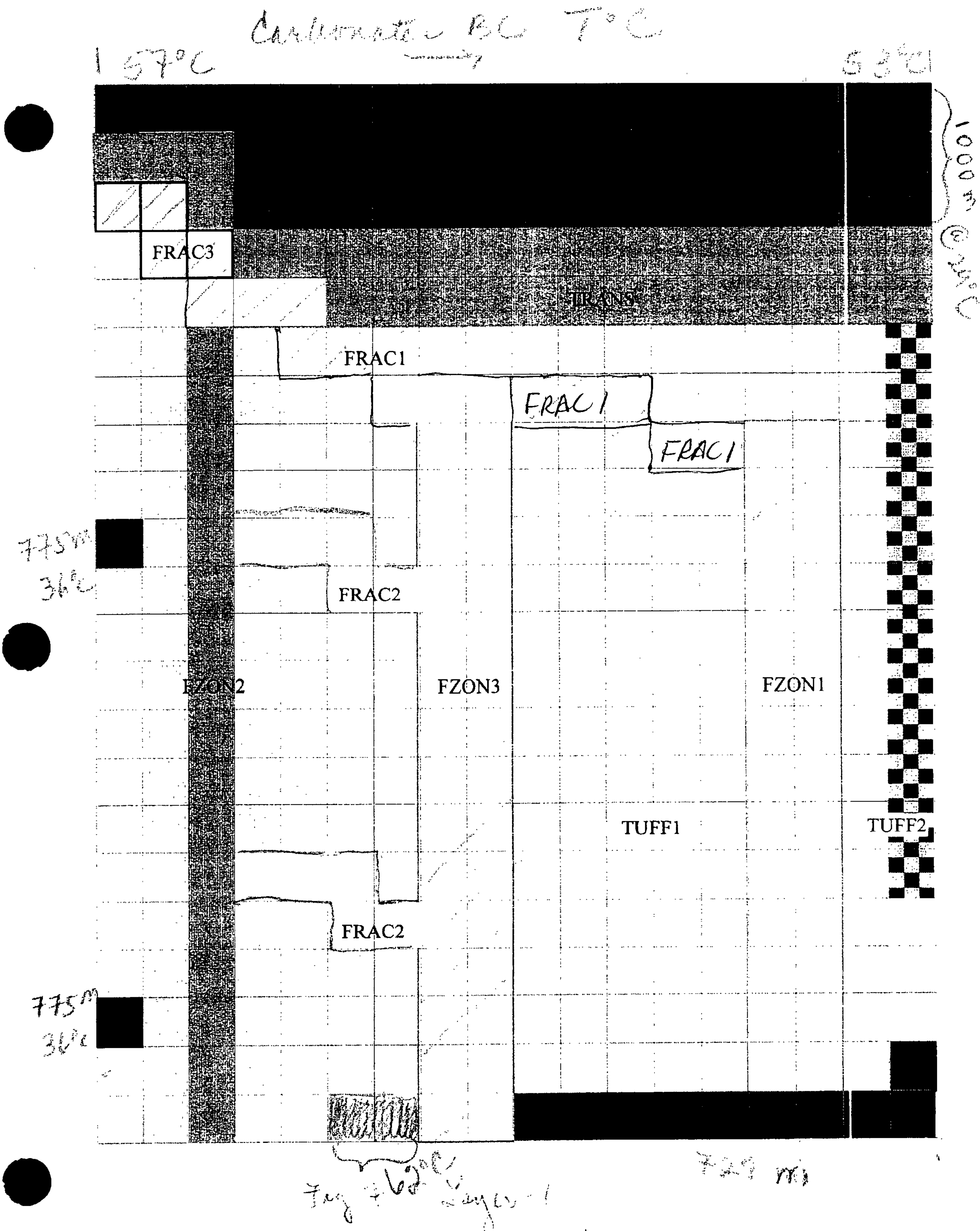
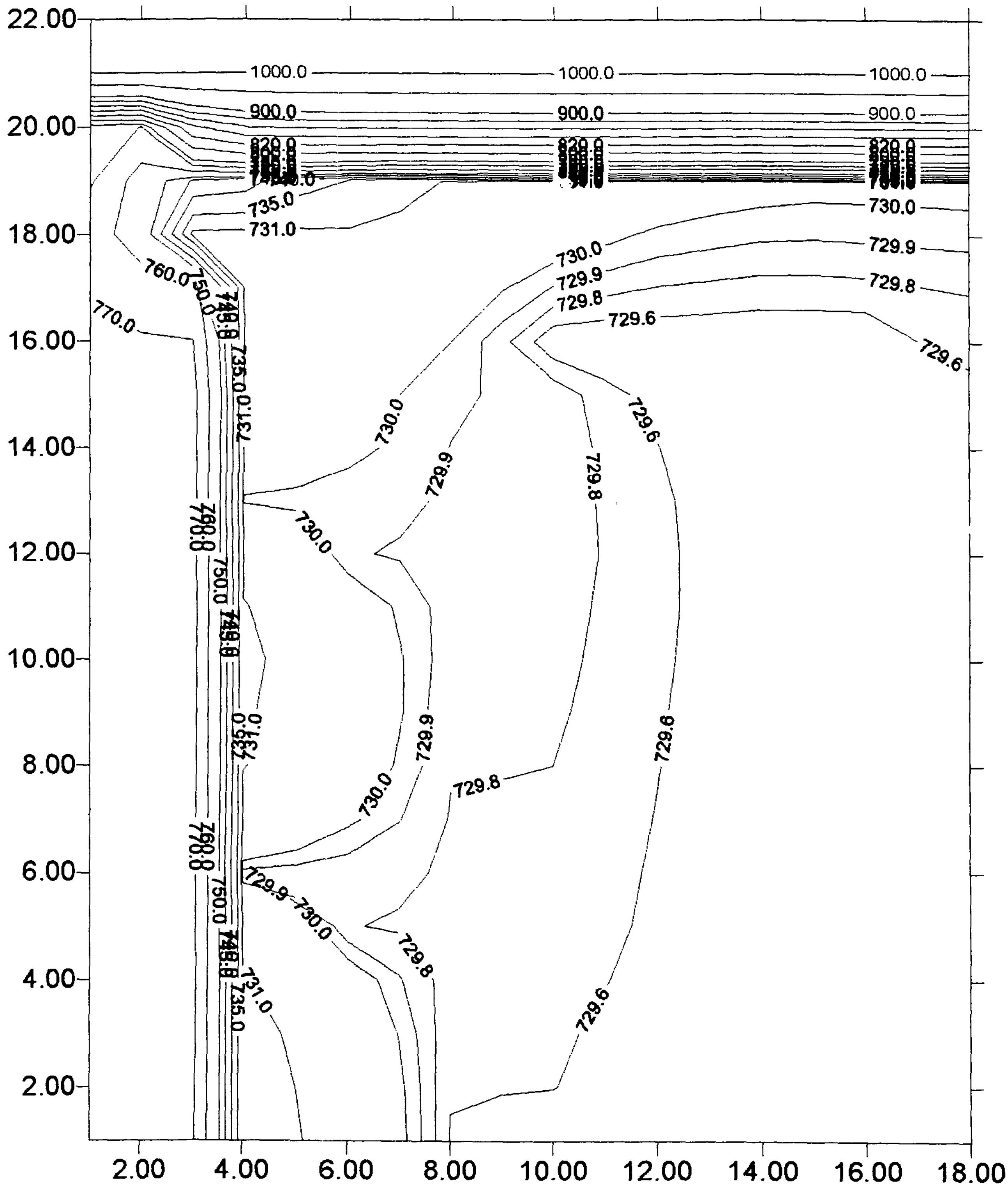


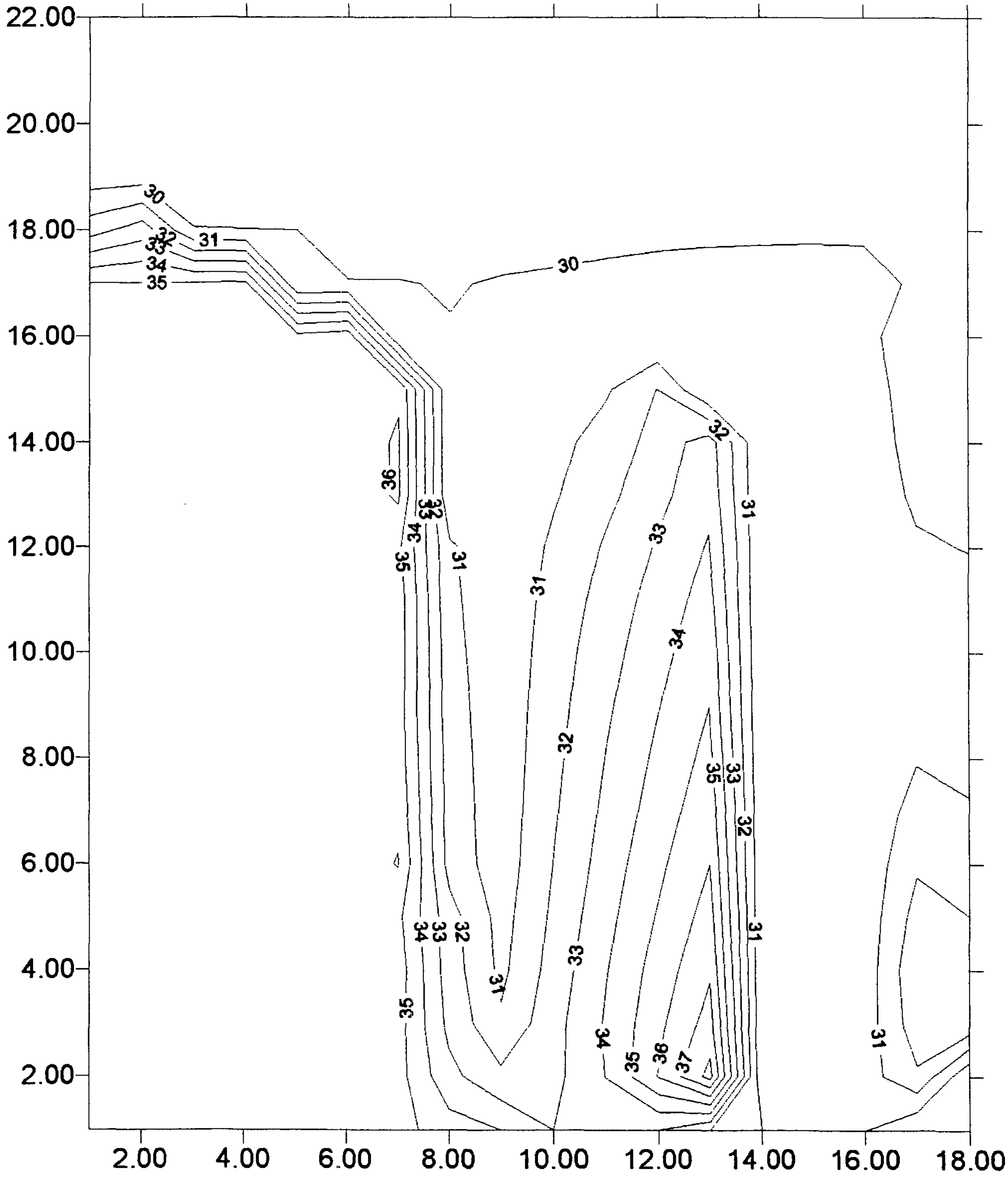
Figure 1 Location map


Carbonate BC T°C
1 57°C
53°C
1000 m @ 24°C
FRAC3
TRANS
FRAC1
FRAC1
FRAC1
775m 36°C
FRAC2
FZON2
FZON3
FZON1
TUFF1
TUFF2
FRAC2
775m 36°C
729 m

RUN **99026** -INITIAL PERMEABILITIES, 10mm/yr INFILTRATION AT FAULT and FRACTURE



RUN **99026** -INITIAL PERMEABILITIES, 10mm/yr INFILTRATION AT FAULT and FRACTURE

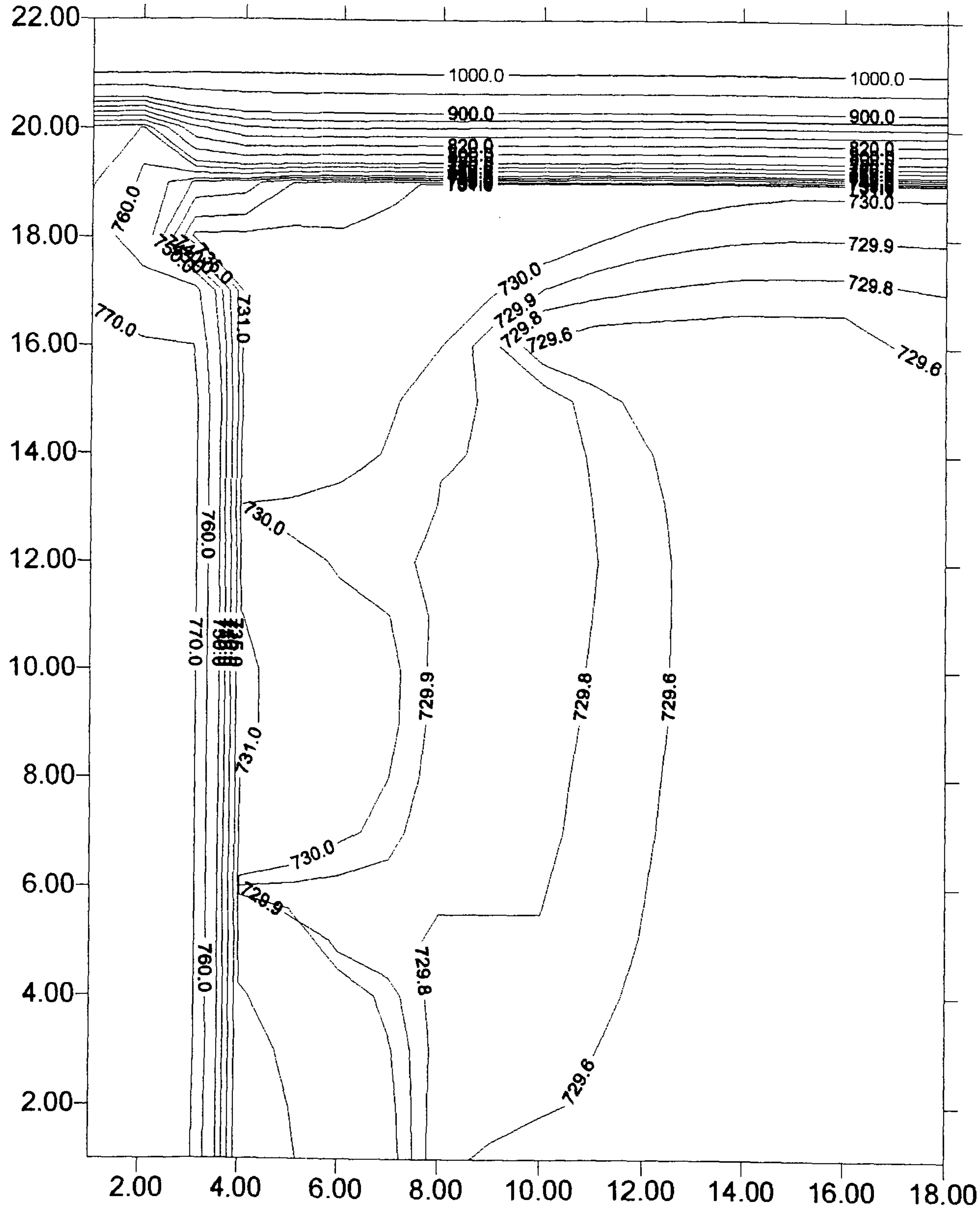


RUN 99026							
ELEM1	ELEM2	Velocity (M/S)		East	South	Magnitude (M/S)	Degrees south of due east
tu102	**tu103**	1.26E-02					
tu103	tu104	1.26E-02		0.0126			
tuf85	**tu103**	-5.28E-05				**0.0126**	**0.099**
tu103	tu121	9.04E-06			2.19E-05		
tu133	**tu134**	6.63E-06					
tu134	tu135	1.36E-05		1.01E-05			
tu116	**tu134**	1.15E-05				**1.28E-05**	**-37.70**
tu134	tu152	4.20E-06			-7.8E-06		
tu219	**tu220**	3.25E-05					
tu220	tu221	3.45E-05		3.35E-05			
tu202	**tu220**	-7.63E-03				**0.00763**	**89.75**
tu220	tu238	-7.64E-03			0.00763		
tu244	**tu245**	1.06E-05					
tu245	tu246	2.06E-05		1.56E-05			
tu227	**tu245**	-8.08E-04				**0.000812**	**88.90**
tu245	tu263	-8.15E-04			0.000812		

- Velocities are for element interfaces. Elements in **bold** are the elements of interest.
- Output velocities are positive when direction is right-to-left and negative when left-to-right.
- Velocity vectors have been summed and resultant magnitudes given along with resultant direction.

GW TT range = 18 days to 96 yrs.

RUN **99027** ***-LOW PERMEABILITIES/10^5***, 10mm/yr INFILTRATION AT FAULT and FRACTURE



RUN 99027							
ELEM1	ELEM2	Velocity (M/S)		East	South	Magnitude (M/S)	Degrees south of due east
tu102	**tu103**	1.28E-07					
tu103	tu104	1.28E-07		1.28E-07			
tuf85	**tu103**	-5.80E-10				**1.28E-07**	**0.11**
tu103	tu121	1.05E-10			2.37E-10		
tu133	**tu134**	8.12E-11					
tu134	tu135	1.65E-10		1.23E-10			
tu116	**tu134**	1.44E-10				**1.59E-10**	**-39.45**
tu134	tu152	5.83E-11			-1E-10		
tu219	**tu220**	3.96E-10					
tu220	tu221	3.13E-10		3.55E-10			
tu202	**tu220**	-8.75E-08				**8.75E-08**	**89.77**
tu220	tu238	-8.75E-08			8.75E-08		
tu244	**tu245**	1.41E-10					
tu245	tu246	2.55E-10		1.98E-10			
tu227	**tu245**	-8.15E-09				**8.45E-09**	**88.66**
tu245	tu263	-8.74E-09			8.45E-09		

- Velocities are for element interfaces. Elements in **bold** are the elements of interest.
- Output velocities are positive when direction is right-to-left and negative when left-to-right.
- Velocity vectors have been summed and resultant magnitudes given along with resultant direction.

GWTT ranges from 4,980 yrs to 7.8×10^6 yrs.

RUN **99027** -***LOW PERMEABILITIES/10^5***, 10mm/yr INFILTRATION AT FAULT and FRACTURE

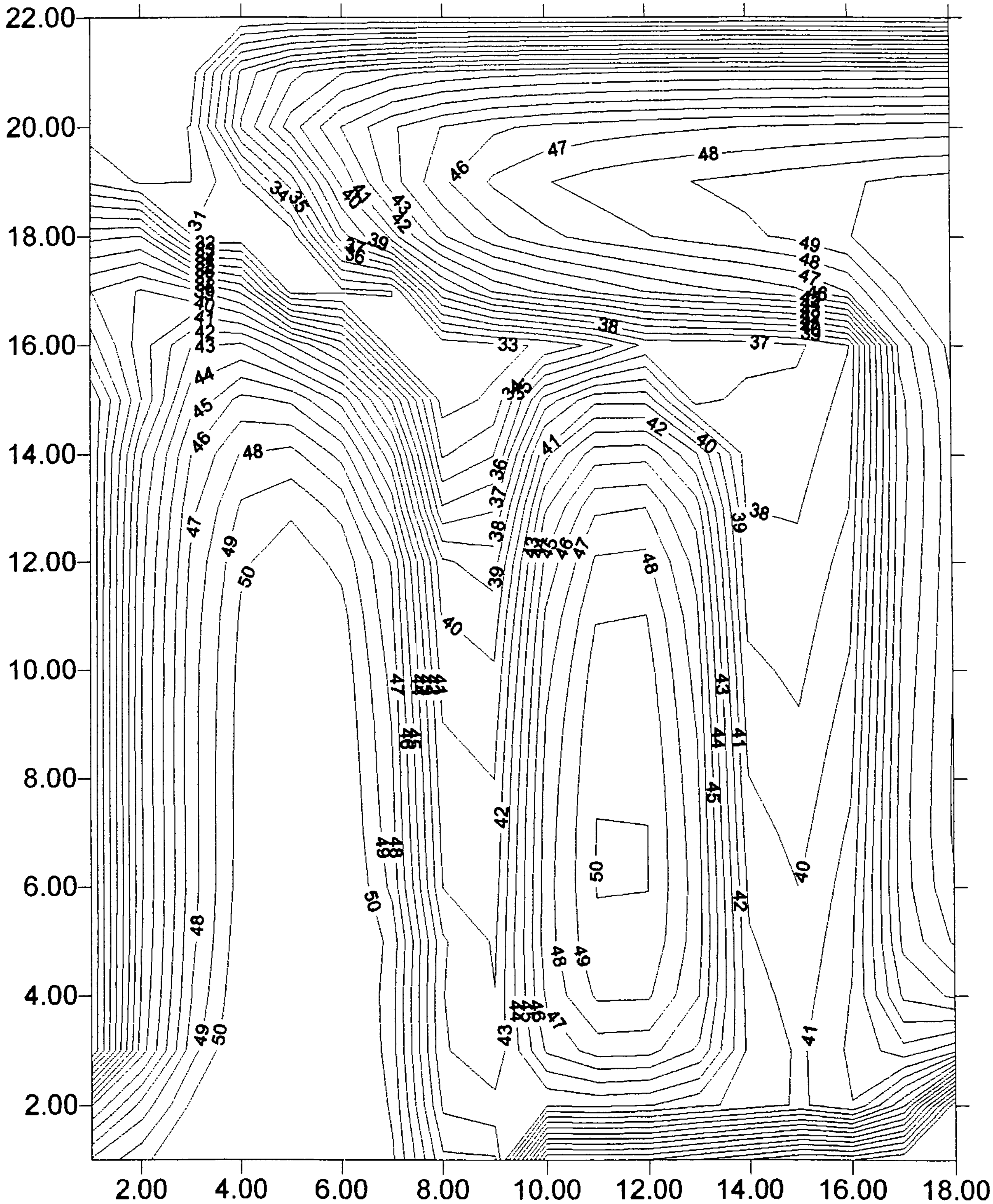
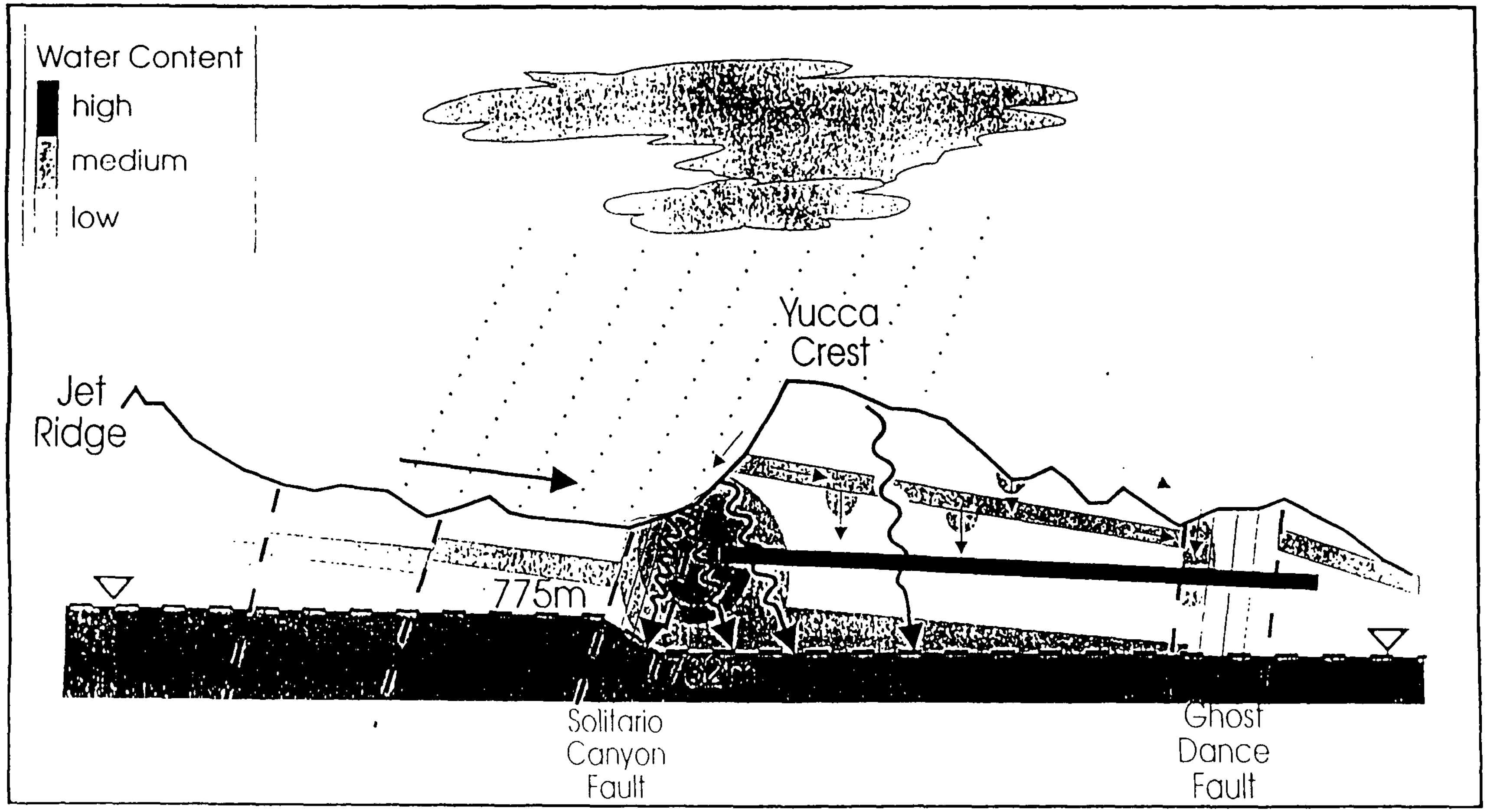


Figure 14. 3-D Focused Infiltration Scenario



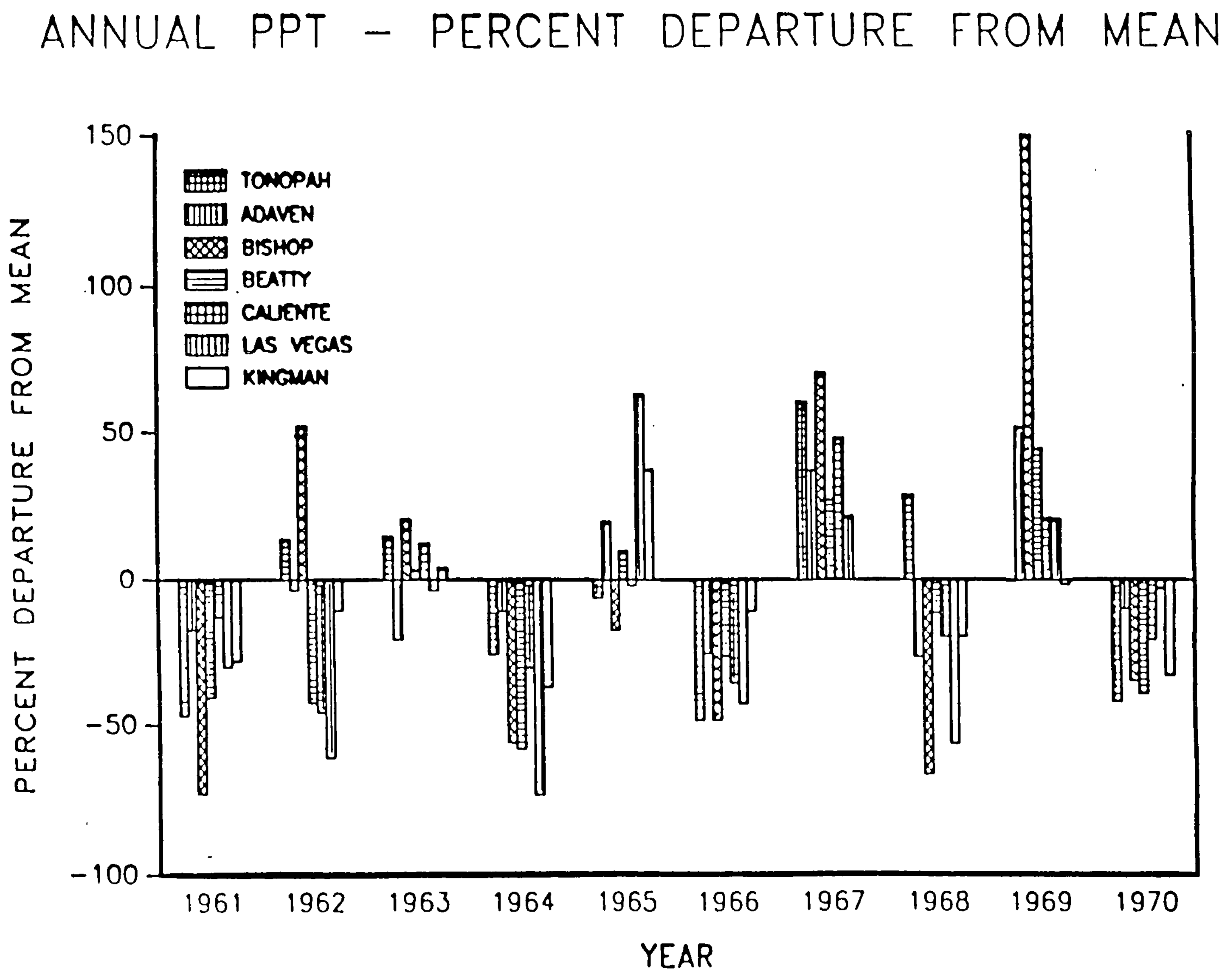


Fig. 5.
Annual Precipitation Totals During Years 1961-1970
From Cochran et al.

ANALYSIS OF REPRESENTATIVENESS OF THE TSPA

There are a number of items which were found incompatible, not well represented or non-representative for our structurally controlled conceptual flow field. Most of the non-representativeness occurs in the saturated zone, or in the areal distribution of recharge to the water table, via the unsaturated zone. Each of these items is discussed separately.

Saturated zone

1. The TSPA conceptual flow model allows particles of water to move orthogonal to the hydraulic gradient. Anisotropic effects due to structure are not considered. This causes the flow path for releases from the repository to move initially eastward and then southeastward to Forty Mile Wash, then curve back to the southwest to the Amargosa Farms area at a 20 km radius. Utilizing anisotropic transmissivities, we create flow paths which are directly south, then southeast and southwest, considerably shortening the flowpath to the receptors.

2. Flow path properties used in the "six flow tubes" are not representative of the southerly flow path. This is because the TSPA flow path would take the releases into alluvium at a shorter distance than our more southerly flow path. Thus out of the 20 km compliance distance, less distance is assigned tuff properties and more is assigned alluvial properties. (The TSPA flow path is actually longer than 20 km.) The alluvial properties are generally more favorable for retarding and dispersing the repository releases than the tuff properties and in fact now consititute the most important barrier in the saturated zone. We would also have a shorter flow path to the receptors as our path is on a more direct radial than is the TSPA path.

3. Alluvial properties assigned may not be representative of valley fill sediments. According to drilling results of Nye County, presented by Tom Buqo at the Devils Hole Workshop, the valley fill sediments south of Yucca Mountain are not primarily alluvium. Rather they consist of coarse gravels, tufa, basalts, tuffs and lake bed sediments. Sorption, retardation, dispersion and effective porosity assumptions used to describe transport through "alluvium" must be justified.

4. Fracture zone effective porosities or hydraulic apertures also need to be reconsidered or verified. Porosities ranging up to 10% or more are used currently. The TSPA sampled a distribution of porosities ranging from 10^{-5} to approximately 20% but the mean value centered near 2 - 3% Normally effective porosities for fractured aquifers range on the order of .01 to .001. These changes would work to increase the flow velocities inversely, making them higher than most base case scenarios.

5. Eastward expansion of the water table receptor area appears inconsistent with channelized flow through Ghost Dance fault zone. This eastward expansion could add up to about 25% more area over which to average repository releases from the unsaturated zone. It also appears inconsistent with results of Bodvarson, shown in the TSPA, where his center of mass calculations show eastward movement cut off by the presence of the Ghost Dance fault. (If waste is placed east of the Ghost Dance, then some areas of eastward expansion could be envisioned, but only at these positions, not uniformly across the length of the repository.)

6. The eastward flow path is not consistent with chemistry data of USGS, Zell Peterman Devils Hole Work Shop, April 1999, or his earlier work. These data do not indicate an eastward flow path, but rather a southerly one for numerous isotopes.

7. The eastward flow path may not be consistent with temperature data. Temperature calculations must be a part of this flow path analyses. Both data sets (temperature and pressure) must be matched before any flow paths can be believed.

8. NRC well bore dilution numbers and DOE dilutions are questioned based on the idea of rigid blocks separated by transmissive faults. Nye County drilling results indicate 3 boundaries in one of their pump tests. These boundaries were not distant and depict a situation where by smaller volumes of water would be available for dilution. Their drilling results also show that pumping rates are highly non-uniform ranging from a few gallons a minute to several hundred gallons per minute. To use huge well bore dilution volumes (10^8 gallons per day) at this point is not justified. The DOE flow path dilution numbers are much smaller than NRC's but still not based on channelized flow and therefore must be justified.

Infiltration

1. The map of infiltration based on Flint is partially inconsistent with our conceptual model of infiltration. While slope, depth of alluvium, evapotranspiration and elevation are definitely important, so may be some other factors. Flint assumes that where thick alluvium is present, little recharge occurs. This may not hold true on the steep western slope of Yucca Mountain, as discussed earlier. The VA infiltration model shows a dry area to the west of the crest of Yucca Mountain rather than a wetter one which our concept would predict..

It is possible for runoff to go under the alluvium and into fractures, thus being blanketed from potential evaporation. Given that the Ptn unit is not present to divert any infiltration in some areas to the west of the repository, then infiltration is possible directly or nearly so into the Topopah Springs unit, up gradient of the repository. As stated in our conceptual model previously (Lehman, 1992), the western side would be expected to be wetter than the eastern side.

Recent correspondence from Steve Brocum, DOE to the NRC (Sandra Wastler) dated 03-26-99 Monthly Progress Report, indicates that water potentials are higher in the East-West Cross Drift (ECRD) and indicate that the rock is wetter and the moisture is more uniformly distributed than expected. The structure here is probably important. Tensional north-south trending smaller structures across the mountain block may be channeling the movement of infiltrating water. By cutting across them in an east-west direction, the ECRD has intercepted more pathways than when they bored north-south in the main drift section, parallel to these features.

2. Flint et al. (1996) and the VA infiltration model indicate that the net infiltration is lower in the washes. We generally concur, except that we believe higher infiltration occurs in the upper reaches of most washes, not along the lower reaches.

3. The infiltration at the water table surface may also not be representative, nor consistent with our model. The VA infiltration map shows lower infiltration along the Ghost Dance fault area where we would assume higher infiltration based on the temperature distribution.

Zell Peterman, USGS has shown what appears to be a plume of younger water along the northwest side of the mountain block. We would expect that this plume would be infiltrating or recharging in that area. The water table map in the VA shows it to be relatively dry.

4. Breakthrough curves simulating the Dry (present day) climate conditions Figure 3-10 of the VA indicate less than 5% cumulative breakthrough for an unretarded tracer at the water table in less than 800 years with 95% breakthrough between 800-12,000 years. It seems reasonable that if in the north-south trending drifts, we see some ^{36}Cl within 50 years, that when sampled, the ECRD may also yield ^{36}Cl hits and perhaps more than in the north-south drift. These low percentages of groundwater breakthrough are not justified.

5. Drift scale seepage assumes a 99.5% reduction of net infiltration. While we would expect some diversion, we would expect that the infiltration rate of water into the drifts would be on the

order of that calculated for G Tunnel, i.e., about 3% of the annual average rainfall. This would allow for 4.5 mm/yr into the tunnel. Instead, VA values are orders of magnitude lower. These low values need to be supported.

6. Seepage Fraction, or number of canisters hit by drips is surprisingly low. Given our concept of fracture controlled drips and data from USDOE that the ECRD is wetter than expected, no confidence can be assigned to this number. Testing in Alcove 1, though shallow with high infiltration applied, is indicative of a potential for more wide spread dripping given that 45% of the roof area catchments had contacted drips.

7. Drips onto packages are assumed stationary during their flow history. This may also not be the case for many reasons, hydraulic, geochemical or tectonic. Moving them about over time would tend to wet a larger number of packages.

8. Sorption and matrix diffusion are assumed to always operate together on sorbing species. Is this a valid assumption? It allows for more retardation than may be justified if considering them separately.

9. Volumetric flux via the drift invert assumes 10% porosity, 99.8% saturation, sorption and diffusion. If the invert fails over time, or fractures develop due to tectonic activity, then flow would be focused and radionuclides less retarded. No provision for invert failure or degradation has been made in the TSPA

CONCLUSIONS

If the basic flow pathways and their characteristics are not correctly interpreted or represented, when they possess qualities which can be measured or tested in the field, then little confidence can be placed on analyses, interpretations or designs which have not been or cannot be tested or verified.

Need to calibrate against temperature or other independent variable in order to support flow paths selected.

Future TSPAs will have to modified their flow model to be representative of a structurally controlled flow field