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ALTERNATE CONCEPTUAL MODEL OF GROUND WATER FLOW AT YUCCA MOUNTAIN

BY

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OF GROUND WATER FLOW AT YUCCA MOUNTAIN

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ABSTRACT

Attempts to predict the performance of a high-level nuclear waste repository in the United States have lead to the development of "alternative conceptual models" of the ground water flow field in which the repository will be located. This step has come about because of the large uncertainties involved in predicting the movement of water and radionuclides through an unsaturated fractured rock. Alternative concepts necessitates the use of simplifying assumptions. In this paper we examine an alternative conceptual model which utilizes more realistic assumptions of focused recharge in concert with a fractured matrix and non-equilibrium view of ground water flow.

INTRODUCTION

Attempts to predict the performance of a high-level nuclear waste repository in the United States have lead to the development of "alternative conceptual models" of the ground water flow field in which the repository will be located. This step has come about because of the large uncertainties involved in predicting the movement of water and radionuclides through an unsaturated fractured rock. Further, one of the standards to which we are comparing performance is probabilistic, so we are forced to try to conceive of all credible scenarios by which ground water may intersect the repository horizon and perhaps transport radionuclides to a given compliance boundary. To simplify this task, the DOE set about identifying alternative conceptual models of ground water flow which are consistent with existing data. The DOE and its contractors, among them the USGS, have identified a number of conceptual models.

Modeling these concepts necessitates the use of simplifying assumptions regarding the configuration of the physical system of the water movement, sources and amounts of recharge, the chemical or thermal characteristics of the system, and coupled interactions. Among the modeling assumptions commonly utilized by analysts of the Yucca Mountain site are those of uniformly distributed, small volumes of recharge and matrix or porous media flow. Most scientists would agree that recharge at Yucca Mountain does not occur in this ideal and simplified fashion, yet modeling endeavors continue to commonly utilize this approach.

Likewise matrix flow, while certainly operating at the site, is not the only flow mechanism thought important. Validation of unsaturated fracture flow processes for

Performance Assessment modeling has not been emphasized by DOE project researchers. Rather the focus to date has been on matrix properties such as imbibition. In this paper, we examine the potential effects of focused recharge on the flow field at Yucca Mountain in concert with a fractured matrix and non-equilibrium view of ground water flow.

FOCUSED RECHARGE

Freeze and Banner (1970) in discussing mechanisms of natural ground water recharge, used the word "focused" to describe how surface runoff was directed to concentrated recharge locations. Other workers such as Labaugh, et al, 1987, Lissey, 1971, and Meyboom, 1966 and 1967 have noted the importance of this phenomena in understanding recharge mechanisms. Though much previous work has been done in the East and Midwest, nothing suggests that this recharge mechanism is constrained to areas with humid climates.

With respect to Yucca Mountain, focused recharge is the most likely method by which precipitation makes its way through the subsurface. While this concept has been widely discussed with respect to recharge in the Forty Mile Wash area, it has not been explored in other areas near Yucca Mountain.

Figure 1 is a topographic map of Yucca Mountain from U.S. DOE Site Characterization Plan, (U.S. DOE, 1988). The mountain is a fault block with a much steeper slope on the west than on the east. The rock strata, composed of a series of welded and non-welded vitric and zeolitic tuffs dips to the east at a 6-8 degree slope. The surface area on top of the mountain, through which recharge can occur is small. There is a thin natural soil cover, and much of it has been removed by road construction. In some areas, large fractures and joints are open to the surface. Personal observation indicates some focused recharge may be occurring on the top of the mountain; however, the majority of the estimated 102-203 mm of annual rainfall[a] are directed into steep channels along the flanks of the mountain. These steep channels direct the runoff toward the permeable talus at the base of the mountain. Along these lower flanks, if soil conditions are right, focused recharge likely occurs especially if normal fault zones underlie the talus and alluvium.

While many such areas of focused recharge may exist around the flanks of Yucca Mountain, an obvious area where this focusing may occur is the northern extension of the Solitario Canyon Fault which bounds Yucca Mountain on the west. This area is outlined on Figure 2. The potential to concentrate or focus precipitation from a relatively large area exists and may result in recharge several orders of magnitude greater than that assumed by the uniformly distributed analyses.

STRUCTURAL GEOLOGY

Figures 3-5 are also from the U.S. DOE Site Characterization Plan, (U.S. DOE, 1988). They show the positions of known and possible major faults which bound and intersect Yucca Mountain. Figure 3 shows the locations of faults interpreted from low-altitude aeromagnetic data, while Figure 4 illustrates those interpreted from geologic mapping. Figure 5 depicts faults and/or fractures interpreted from electrical resistivity data.

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[a]Data obtained from NOAA regional stations.

These interpretations indicate one or more faults or fractures exist in the area proposed for waste disposal which may provide potential pathways for focused recharge. It has also been theorized that since the area is undergoing tensile stress, the north-south trending structures are generally considered conduits while east-west or oblique striking features may act as barriers to saturated ground water flow. It should also be noted that features which act as barriers in a horizontal sense may act as conduits to flow in a vertical sense. These relationships are not easily analyzed with respect to unsaturated flow, but the existence of these faults and their potential to focus recharge must be recognized and analyzed during site characterization.

Figure 6 is a cross-section of Yucca Mountain (U.S. DOE, 1988) showing the location of the repository horizon within the mountain. As can be seen, the repository is located at an elevation of approximately 1067m ASL on the west, sloping to approximately 975m ASL on the east. The topographic map (Figure 1) shows the surface elevation where the steep western slope of Yucca Mountain breaks is at an elevation of 4200-4400 feet ASL in the area of the repository. This elevation coincides with talus deposits. The floor of Crater Flat is about 4000 feet ASL. This structural relationship leaves the Topopah Springs welded units #1 and #2 very near the valley floor of Crater Flat. The Solitario Canyon Fault intersects these units (Figure 7). These units dip to the east as do units just to the west of the Solitario Canyon Fault. It is therefore possible that if recharge occurs in localized regions of the Solitario Canyon Fault, the movement of water into Yucca Mountain from the west via the Paint Brush non-welded or lower units could take place. Potential flow mechanisms are matrix imbibition and localized fracture flow.

EVIDENCE FOR LATERAL AND NON-EQUILIBRIUM UNSATURATED FLOW

Most model studies conducted at Yucca Mountain to date show limited penetration of infiltration from the top of Yucca Mountain. Most models also assume uniformly distributed recharge flux on the order of .1 mm/year to .5 mm/year. Chemistry data obtained by the USGS indicate that tritium is present at depths of 46m in Borehole UZ-4 but not above this depth. This fact has lead some researchers to hypothesize that perhaps this tritium could have moved laterally into the system rather than vertically through the tuff units. (Al Yang, Nuclear Waste Technical Review Board Meeting, June 1991.)

To date, the concept of lateral unsaturated flow has not been fully explored, especially under conditions of focused recharge. Until recently, many researchers did not fully accept the notion of extensive lateral flow in the unsaturated zone, preferring instead a system more strongly influenced by gravity. Therefore, most early models utilized a predominately vertical flow field. Certainly most transport models only considered one-dimensional movement.

Much previous modeling utilized continuum approaches and as such the matrix and fractures were often assumed to be in equilibrium. One such approach is the composite porous media model which combines fracture and matrix conductivity curves. The system then responds as an equivalent porous media. The portion of this combined conductivity curve utilized for flow analyses is determined by the pressure head or level of saturation.

Other approaches utilized only matrix flow or discrete fracture networks. Dudley, et al (1988) utilized a dual continuum approach. In this approach, the fractures and matrix are assumed to behave as a continuum and obey Darcy's Law. The fracture continuum and

matrix continuum are generally coupled by a mass exchange or transfer term. In most cases, this transfer function is a linear function of water pressure difference between the two continua multiplied by a transfer coefficient. In unsaturated media, this transfer coefficient is proportional to permeability and therefore a function of the degree of saturation.

One issue currently being debated is regarding the initiation of fracture flow. In several modeling studies, initiation of flow in the fracture appears dependent upon matrix saturations reaching 100%. Non-equilibrium flow, as discussed here, is defined as the initiation of flow in a fracture without the matrix reaching 100% saturation in its entirety. Rather, matrix saturations approach 100% very near to the fracture, but the rest of the matrix (within some distance of the fracture) remains relatively drier. Recent work funded by the U.S. DOE and the U.S. NRC has given us a clearer picture of the type of flow regime we might envision operating at Yucca Mountain.

Tom Buscheck in June, 1991 presented data at a Nuclear Waste Technical Review Board Meeting which indicated the possibility of significant lateral flow in the Calico Hills non-welded vitric unit. His modeling study, using V-TOUGH, concluded that non-equilibrium fracture flow was a possibility, involving significant distances and depths, depending on fracture apertures, saturations and fracture configurations. Buscheck's work notes that relatively high saturations need not be achieved before this non-equilibrium fracture flow can be sustained. Buscheck (personal conversation) indicates that given the existing Yucca Mountain site data base, lateral flow is most likely to occur in the Paint Brush and Calico Hills vitric units (above and below the repository horizon). He also believes the distance from the fracture where increased saturation occurs is controlled in part by the sorptivity of the matrix. For example, the increased saturations into the matrix may be tens of meters in vitric non-welded units, but in welded units, these distances can be extremely small. Buscheck (personal conversation) indicates that the high saturations observed in the vitric Calico Hills units may imply either non-equilibrium flow or a lateral movement of moisture, or both. For further detailed discussions of non-equilibrium flow, refer to Buscheck and Nitao, 1991 and Nitao, 1991.

Kay Birdsell and others (1991) produced innovative results in a continuum modeling of unsaturated flow and transport by utilizing a 3-Dimensional geometry. These results were similar in appearance to the unstable fingering encountered in the fluids problem of immiscible flow. This three-dimensional geometry utilized tilted beds and homogeneous hydraulic properties within each hydrogeologic unit. Faults were represented as offsets, i.e. no specific fault properties were assigned. Lateral flow was induced because of the tilted geometry. Birdsell's report indicated increased saturations occurred along the Ghost Dance Fault and along other interfaces.

Birdsell believes that the "fingering" is a function of the three-dimensional geometry which accounts for dipping beds, offsets along fault zones, thinning of beds, and lateral flow.

This fingering or channeling has been mentioned by others as well. The University of Arizona has conducted laboratory analyses of flow and solute transport through a fractured porous tuff. Haldeman, et al, 1991 report simulated travel times of streamlines become increasingly unstable because of convergence of flow in certain regions of the flow field. Further, they report results of three fracture transport tests. They state that the

breakthrough curves and temporal moments analyses show channeling of flow in the fracture segment probably occurred with one or more preferential flow paths.

Todd Rasmussen, 1991 simulated air-water interfaces in partially saturated fractures using the boundary integral method. He summarizes that his "simulations indicate the presence of zones of water under both positive and negative pressure head, as well as regions of air-filled voids. The implications of water being present under both positive and negative pressure heads are twofold: (1) equivalent continuum models which assume uniform pressure heads within an individual fracture may provide inaccurate predictions of flow velocities; and (2) regions of saturation will be present in vertical fractures at pressure heads greater than the critical capillary suction of the fractures, and also in the lowermost part of fractures under a wide range of pressure heads, perhaps leading to the enhanced movement of water from the fracture to the rock matrix and reducing fracture flow."

ALTERNATIVE CONCEPT

Figure 7 is a graphic depiction of focused recharge which would move vertically and down-dip laterally until discontinuities are encountered which would force the downward movement of water. This figure is for illustrative purposes only and simulations must be undertaken to determine if the quantities of flow derived from a focusing mechanism are sufficient to support flow into or through the repository horizon. The assumption is that flow can reach repository depths, but the volumes are currently unknown.

This alternative is of concern because of the short flow paths and the potential for significant volumes of transient recharge. The frequency of significant focused recharge is currently unknown. However, one possibility is that it may coincide with observed long-term periodicity of the water table in Solitario Canyon. Keen, et al, 1989 show these oscillations to have about a 2-3 year period. If this is the recurrence interval then channels of higher saturation may persist and consequently provide a faster flow path along these wetter routes. The flow paths to the repository itself may be less than 152m, due to the proximity of the repository to the valley floor and the Solitario Canyon Fault.

SUMMARY

In summary, the focused recharge of runoff from the Yucca Mountain region may provide a significant quantity of water over a small area and induce fracture flow movements in both horizontal and vertical directions with the potential of intersecting the repository horizon. It is recommended this alternative concept be explored further by the U.S. DOE and the USGS in computer simulations as well as in their Site Characterization studies at Yucca Mountain. DOE validation efforts should focus on fracture flow and non-equilibrium processes.

Recommendations for Future Research

The Apache Leap Tuff site currently funded by the U.S. NRC research provides an excellent opportunity to examine these effects. Two tunnels, one of intermediate depth and another of a deeper depth exist below a structurally controlled creek. The deep tunnel (mine) experiences increased inflow within months of flow initiation in the creek, and an immediate increase in pumping rates. The opportunity exists to further our understanding

of recharge mechanisms and scale effects. The DOE is encouraged to examine these effects both at the Apache Leap site and during Site Characterization at Yucca Mountain.

Additional analog sites were identified by Rasmussen (September, 1991) which may be useful in studying focused recharge. He lists the Huantla Cave System in southern Mexico and the Lechugilla and Carlsbad Cave System in New Mexico as potential study areas.

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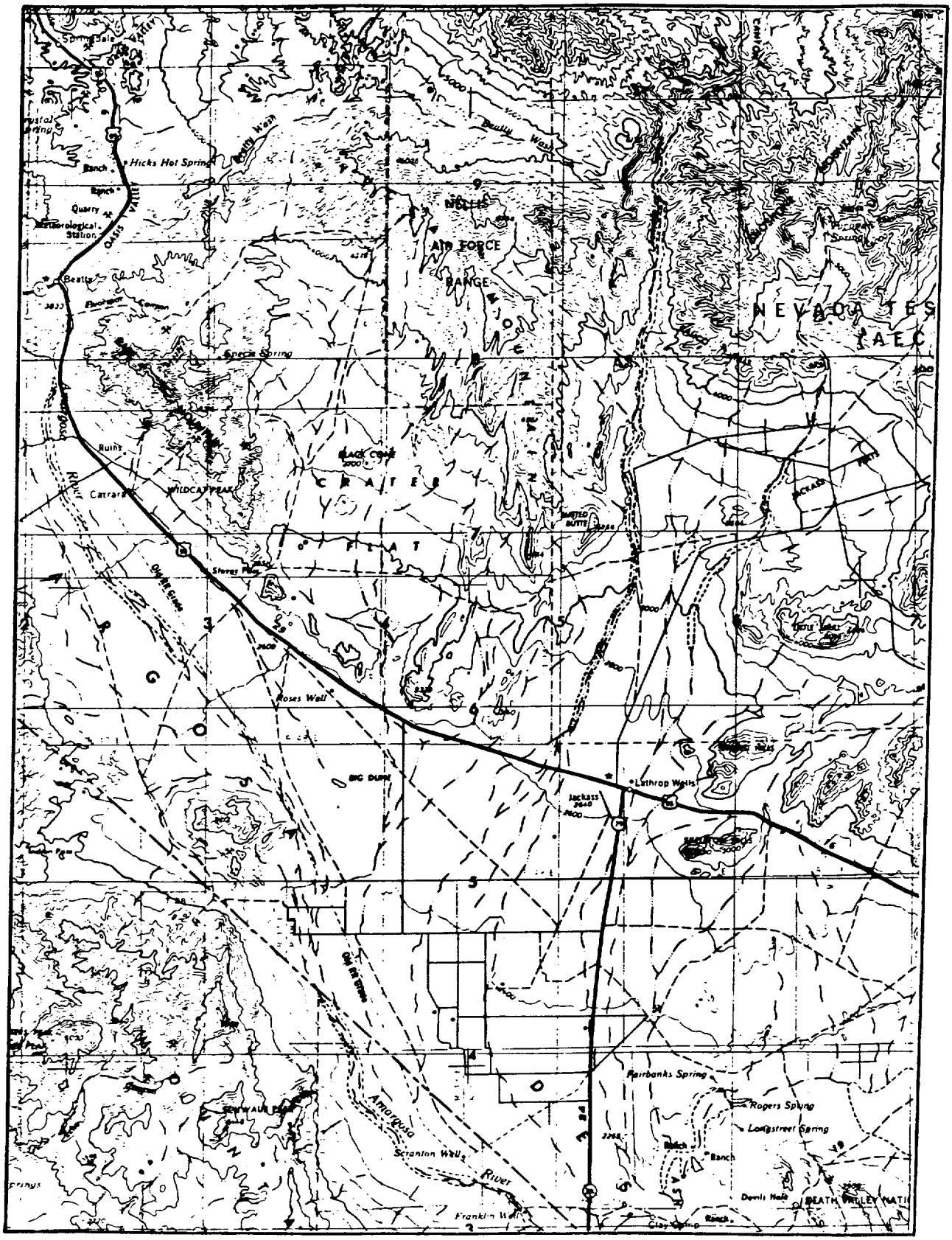

FIGURE 1: Study Area at Yucca Mountain, Nevada.

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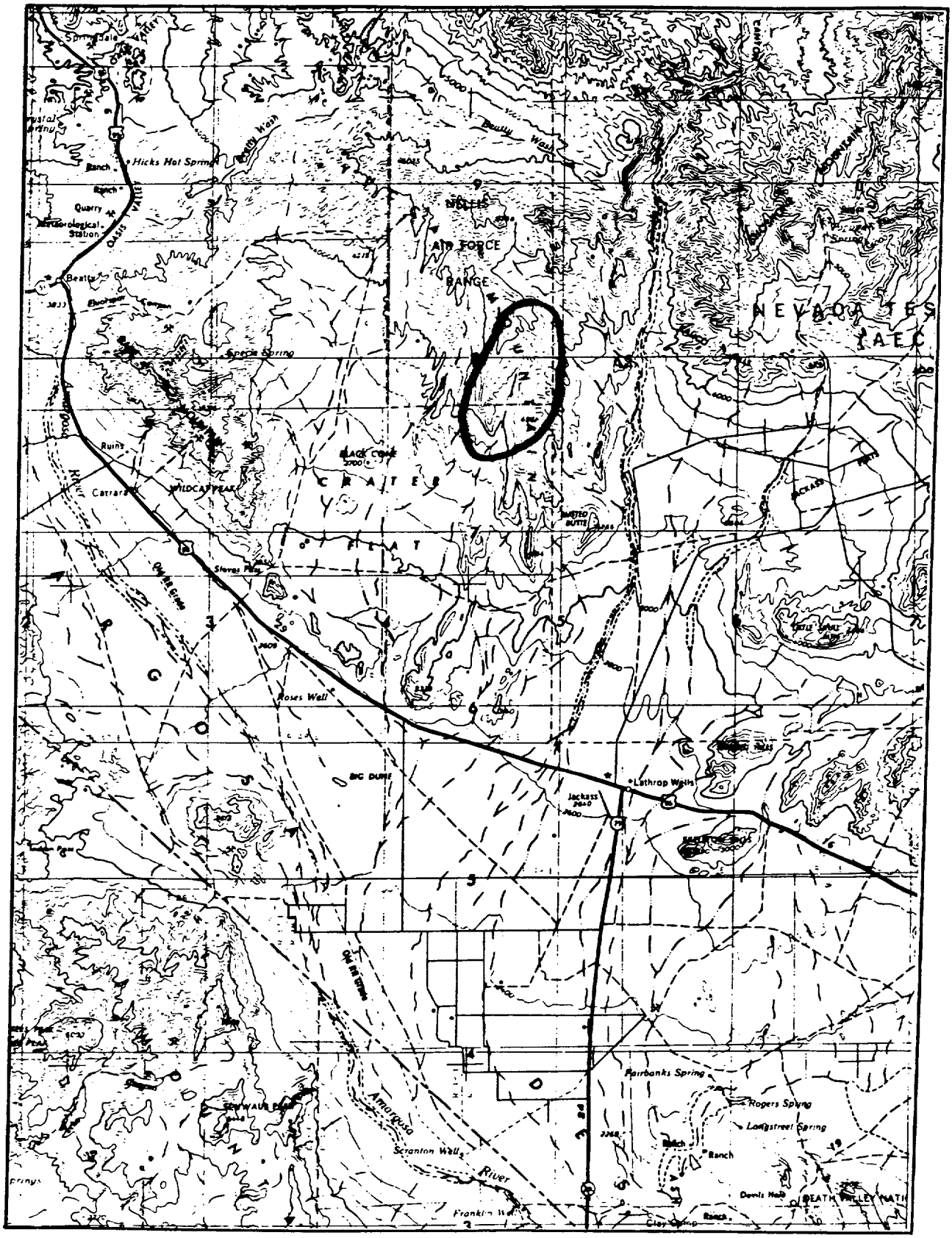

FIGURE 2: Area of Potential Focused Recharge

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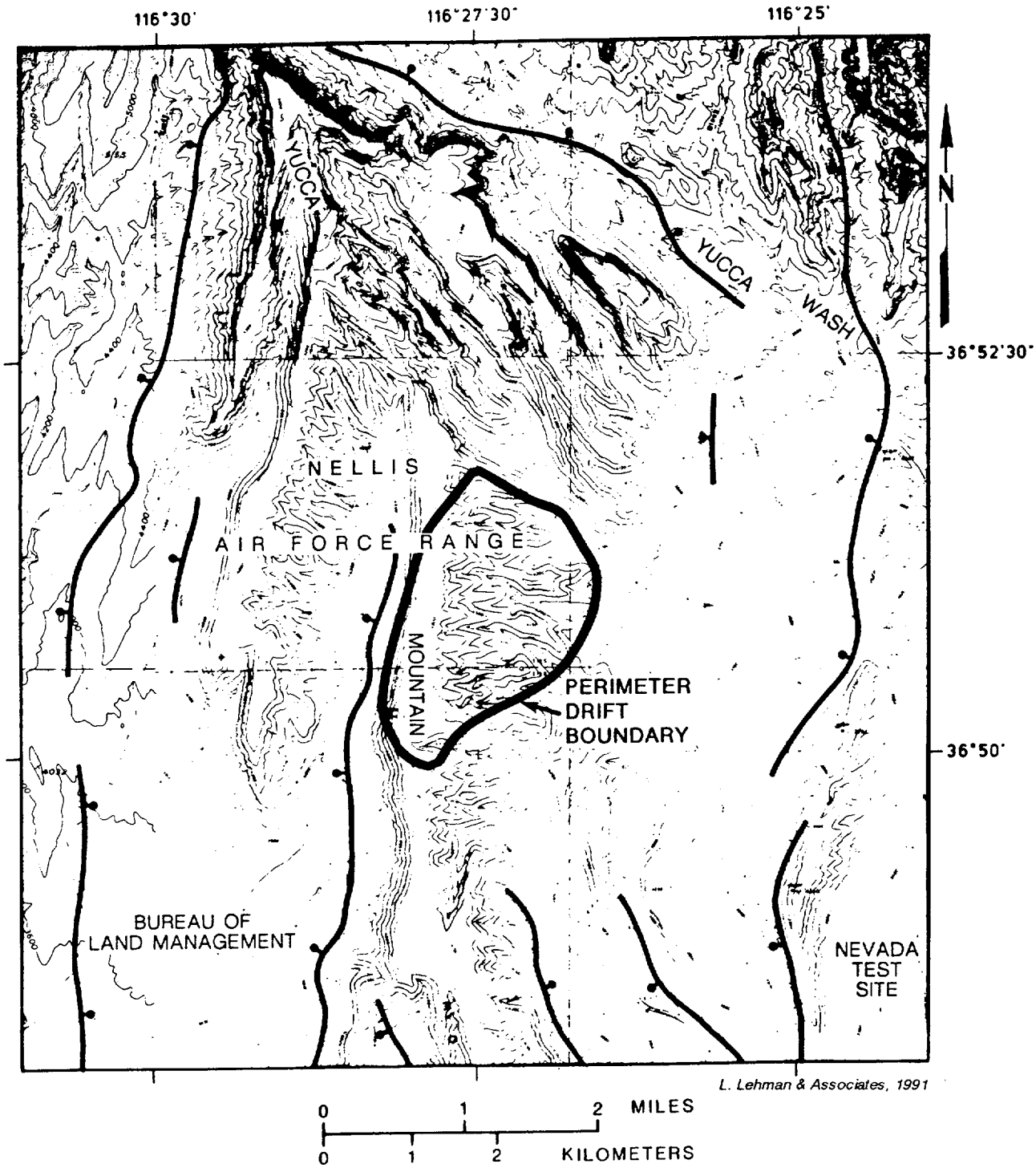


FIGURE 3: Faults At Yucca Mountain Interpreted From Low Altitude Aeromagnetic Data. Modified From DOE (1988).

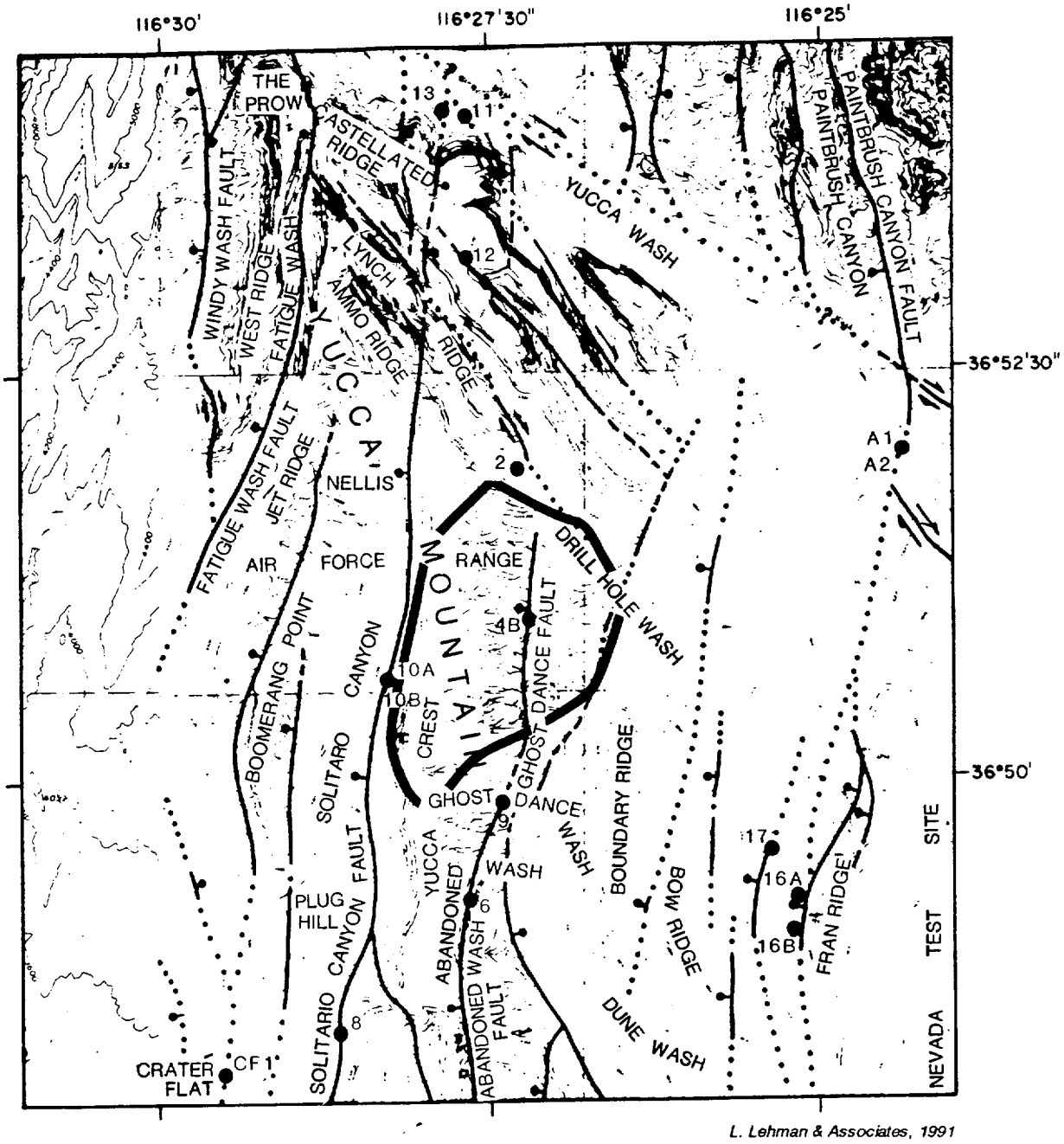


FIGURE 4: Faults At Yucca Mountain Interpreted From Geologic Mapping. Modified From DOE (1988).

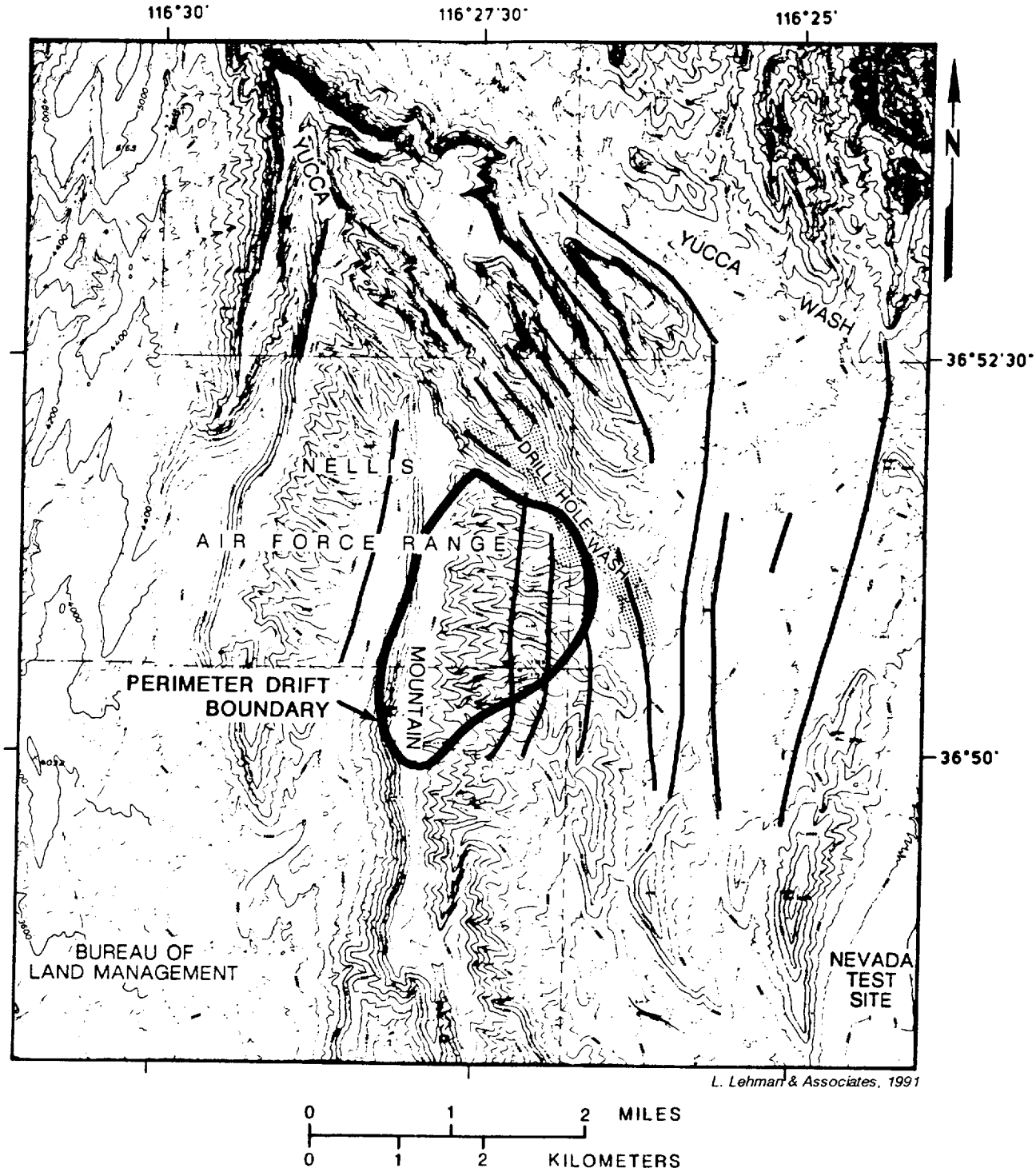


FIGURE 5: Faults And Fractures At Yucca Mountain Interpreted From Electrical Resistivity Data. Stippling shows Zone of Inferred Fracturing and Faulting Along Drill Hole Wash; Fault Trends Appear To Change Abruptly Across This Zone. Modified From DOE (1988).

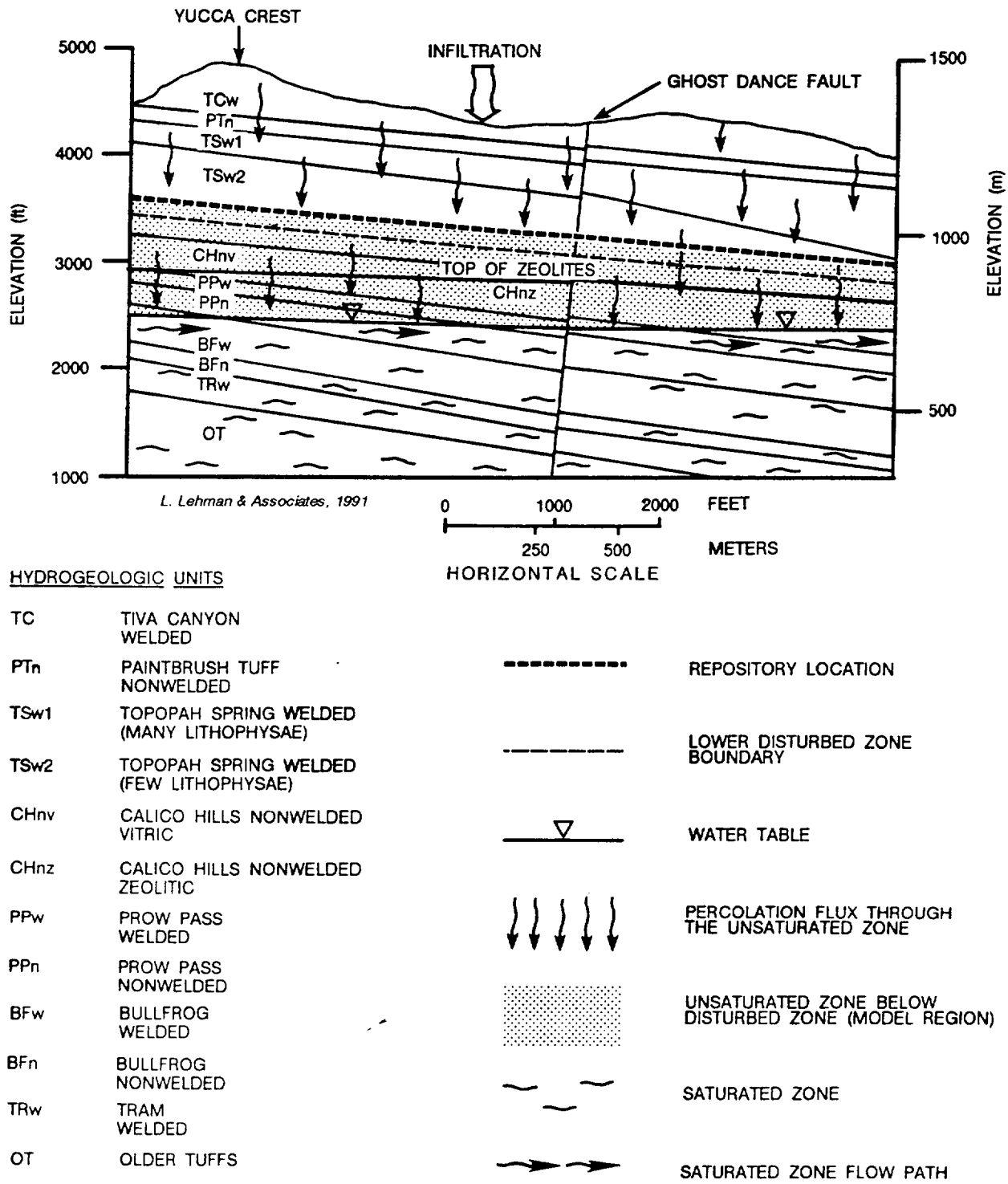
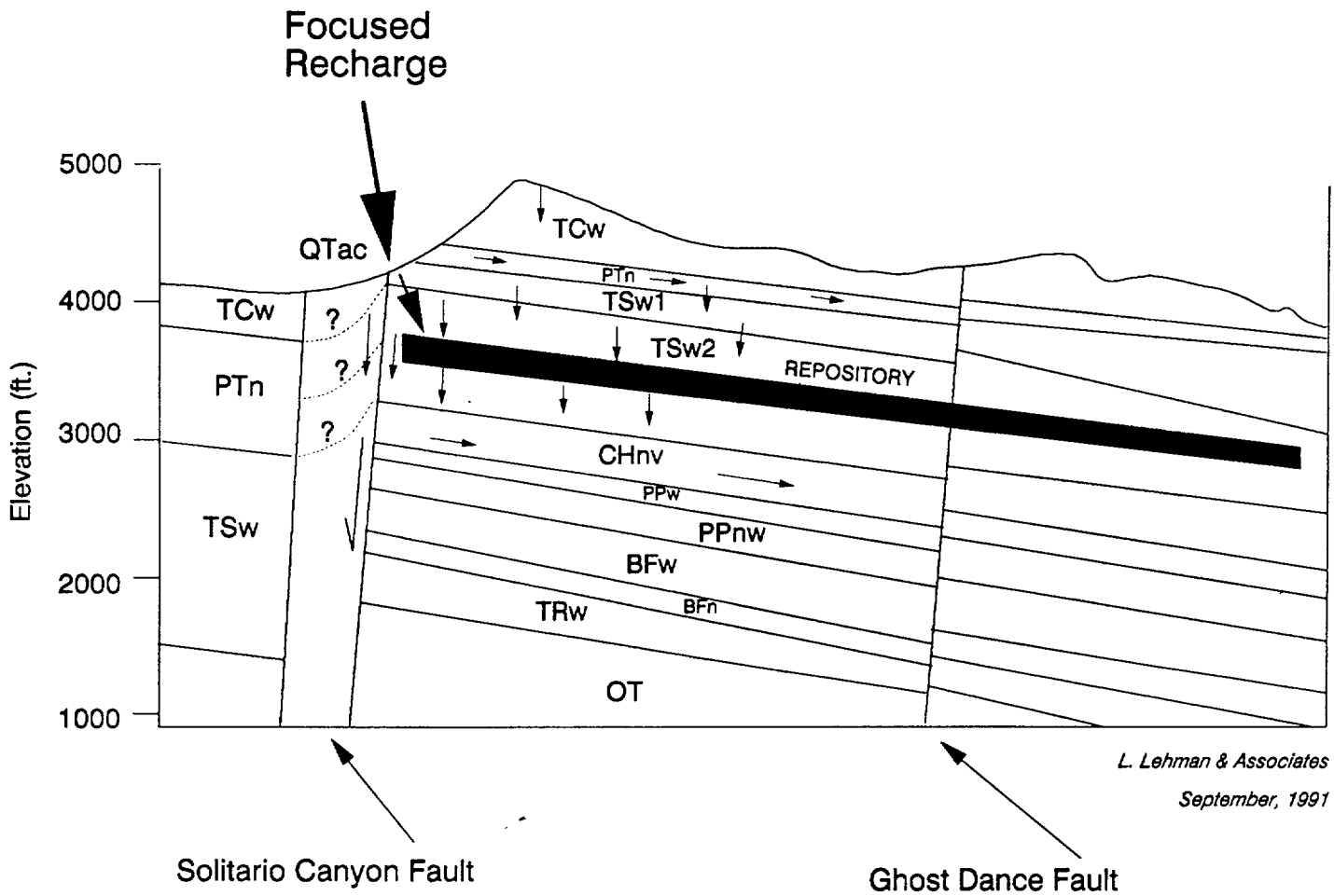


FIGURE 6: General Hydrogeologic Cross Section At Yucca Mountain. The Wavy Arrows Show The Flow Paths, Assumed By DOE, From A Potential Repository Through The Unsaturated Zone To The Water Table And Along The Upper Portion Of The Accessible Environment. Modified From DOE (1988).

Figure 7:
ALTERNATIVE CONCEPTUAL MODEL UTILIZING FOCUSED RECHARGE



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