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**STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE**

**NWPO-TR-011-89
THE RELATIONSHIP OF THE YUCCA MOUNTAIN
REPOSITORY BLOCK TO THE REGIONAL
GROUND-WATER SYSTEM:
A GEOCHEMICAL MODEL**

by

Nancy A. Matuska
John W. Hess
Water Resources Center
Desert Research Institute
University of Nevada System
Las Vegas and Reno, Nevada

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The Nevada Agency for Nuclear Projects/Nuclear Waste Project Office was created by the Nevada Legislature to oversee federal high-level nuclear waste activities in the state. Since 1985, it has dealt largely with the U.S. Department of Energy's siting of a high-level nuclear waste repository at Yucca Mountain in southern Nevada. As part of its oversight role, NWPO has contracted for studies of various technical questions at Yucca Mountain.

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ABSTRACT

Yucca Mountain, in southern Nevada, is being studied by the Department of Energy and the State of Nevada as the site of a high-level nuclear waste repository. Geochemical and isotopic modeling were used in this study to define the relationship of the volcanic tuff aquifers and aquitards to the underlying regional carbonate ground-water system. The chemical evolution of a ground water as it passes through a hypothetical tuffaceous aquifer was developed using computer models PHREEQE, WATEQDR and BALANCE. The tuffaceous system was divided into five parts, with specific mineralogies, reaction steps and temperatures. The initial solution was an analysis of a soil water from Rainier Mesa. The ending solution in each part became the initial solution in the next part. Minerals consisted of zeolites, smectites, authigenic feldspars and quartz polymorphs from described diagenetic mineral zones. Reaction steps were ion exchange with zeolites. The solution from the final zone, Part V, was chosen as most representative, in terms of pH, element molalities and mineral solubilities, of tuffaceous water. This hypothetical volcanic water from Part V was mixed with water from the regional carbonate aquifer, and the results compared to analyses of Yucca Mountain wells. Mixing and modeling attempts were conducted on wells in which studies indicated upward flow. These attempts suggest that volcanic water from well UE-25 p[#]1 may be represented as 68% modeled tuffaceous water and 32% carbonate aquifer water. The hypothetical tuffaceous water of Part V appears to most represent well samples with high pH values, such as USW H-3 and USW WT-10. Wells with near-neutral pH values are not well represented by this model, and appear to show great influxes of water from the carbonate aquifer. This may be an erroneous result, caused by problems with the model involving kinetics, thermodynamic data, and mineral equilibrium. Isotope analyses of the Yucca Mountain wells suggest no upward flow from the carbonate aquifer, except in well USW p[#]1, and suggest that Forty Mile Wash might be a local zone of recharge.

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INTRODUCTION

Yucca Mountain, Nevada, was selected as one of three possible sites for a high-level nuclear waste repository as part of the Nuclear Waste Policy Act of 1982, and targeted for further intensive study with the Nuclear Waste Policy Act Amendment of 1987. Yucca Mountain is located in southern Nevada, 105 km northwest of Las Vegas. The proposed repository site is on the east flank of Yucca Mountain on the southwest side of the Nevada Test Site (NTS) on three adjacent sections of Federal lands under the jurisdiction of the Department of Energy (DOE), the Air Force and the Bureau of Land Management (Figure 1).

The DOE's 1986 Environmental Assessment of Yucca Mountain required that a favorable condition which should be present at the proposed nuclear waste repository was a geohydrological system (which) can be readily characterized and modeled with reasonable certainty (DOE, 1986, p. 6-133). Due to a lack of available data, the DOE did not find this condition to be present at Yucca Mountain, although this area has been extensively studied by the DOE, U.S. Geological Survey (USGS), various national and local laboratories, and other agencies.

Hydrologic studies at Yucca Mountain indicate the ground-water flow to be controlled by both the Tertiary volcanic tuff aquifers and aquitards, and the underlying Paleozoic carbonate aquifer. Geochemical and isotopic modeling of the ground water, as presented in this study, is used to help define the vertical ground-water movement between the two units.

Figure 1: Location of Yucca Mountain and vicinity in southern Nevada.

Purpose

The purpose of this study is to further define the possibility of upward flow of groundwater from the regional carbonate aquifer into the Tertiary volcanic tuffs. This is accomplished by incorporating a variety of hydrologic, geochemical and isotopic techniques which resulted in a flow path model for Yucca Mountain, which is compared to the DOE analysis of the area. The following steps are taken to reach this goal:

1. compilation of an extensive data base consisting of hydraulic, physical, chemical and isotopic data for water from wells and springs at Yucca Mountain and elsewhere in southern Nevada, collected from published literature;
2. collection of ground-water samples from the USGS water-table wells surrounding Yucca Mountain to augment the data base;
3. delineation of well waters into geochemical groups and determination of mineral equilibrium (what is potentially precipitating or dissolving) in each well;
4. geochemical modeling of the ground-water, which is assumed to move from a volcanic terrane into a carbonate terrane, and vice versa, using the computer models BALANCE, WATEQDR and PHREEQE, and analysis of the resultant water chemistries;
5. comparison of these hypothetical waters to the data base water chemistries;
6. use of graphical and analytical methods to differentiate water groups on the basis of isotopic analysis, and comparison of these groups to the results of the geochemical flow path modeling.

Background

Yucca Mountain was selected for further study by the DOE as a potential high-level nuclear waste repository in part because hydrologic and geologic conditions seem to indicate a low potential for radionuclide transport. The rock type under consideration at the repository site is ash-flow and nonwelded to welded Tertiary volcanic tuff. Thick zeolitic layers are present within the tuffs. These may exchange cations and therefore may retard the movement of radionuclides.

The position of the potential repository horizon, within the Topopah Spring member of the Paintbrush Tuff, is 250 to 350 meters below land surface and 200 to 450 meters above the water table. Direct recharge from precipitation is estimated to be less than five millimeters per year. In the saturated zone, downward flow through the tuffs is believed to be of low quantity, less than 10 centimeters per year (Montazer and Wilson, 1984). There is evidence for possible upward flow from the carbonate aquifer occurring in one well, UE-25 p#1, and temperature gradients in other wells suggest upward flow, but not necessarily from the carbonate aquifer. Upward flow from the regional carbonate aquifer to the tuffs is viewed as a favorable condition for a nuclear waste repository, as this would limit the transport of radionuclides into the regional carbonate aquifer ground-water system.

Ground-water chemistry in a tuffaceous aquifer is believed to be controlled by the dissolution of volcanic glass, the removal of ions from solution through secondary mineralization of smectites, and cation exchange within zeolites. Water chemistry in a carbonate aquifer is a function of P_{CO_2} , calcite, dolomite and smectites. This results in a unique water chemistry in each type of aquifer.

Geochemical modeling is a process of simulating conditions expected to be present in a system and predicting what happens to such parameters as mineral equilibria, pH or P_{CO_2} . To model the geochemistry of ground-water at Yucca

Mountain, a flow path through a tuffaceous aquifer was constructed using published lithologies of volcanic tuff. The volcanic tuffs are divided into a series of mineral zones designed to reflect the reaction (ion exchange or dissolution of volcanic glass) between various volcanic minerals and ground water.

The objectives of the geochemical modeling of this study are presented in the following questions:

- 1) Can the geochemistry of the ground water traveling through Yucca Mountain be modeled?
- 2) What happens to various minerals along the flow path through the tuffs?
- 3) What is happening to theoretical partial pressure of CO_2 along the flow path, i.e., is this an open or closed system to atmospheric influence?
- 4) If modeled tuffaceous ground water is mixed with water from the regional carbonate aquifer, what happens with respect to mineral precipitation and dissolution?
- 5) How well do water samples from Yucca Mountain wells compare to the modeled tuffaceous ground water?
- 6) How does the ground water of Yucca Mountain and the model compare to ground waters in the study area of Pahute Mesa, Oasis Valley or the Amargosa Desert?
- 7) How do the results of this study compare to the DOE's assessment of the vertical ground-water flow between the tuffaceous and carbonate aquifers at Yucca Mountain?

The following report is divided into four sections: (1) the geologic history and previous hydrologic studies of Yucca Mountain; (2) the collection of data used in the study; (3) the controls and steps taken in constructing the

geochemical computer model; and (4) a comparison of the results of the computer and isotopic models and their applicability to Yucca Mountain wells.

PREVIOUS INVESTIGATIONS

The climate, geology, hydrology and chemistry of Yucca Mountain have been extensively studied by many agencies. A review of these studies provides a basis for understand how the modeling problem is set up, and how the results compare with those of previous investigations.

Climate

Yucca Mountain and vicinity have been classified as a low latitude desert, which is primarily the result of physiography. The Sierra Nevada Mountains to the west impede the movement of moisture-bearing Pacific air masses, causing a "rainshadow" effect. Precipitation averages 15 cm per year, 7-15 cm in the valleys and less than 25 cm on the ridges (Houghton *et al.*, 1975; Winograd and Thordarson, 1975). The amount of annual recharge at Yucca Mountain by precipitation is estimated at 0.5 to 4.5 mm/yr (Montazer and Wilson, 1984), and is a function of the amount, type and distribution of precipitation, conditions at time of snowmelt, moisture content of the soil, type of vegetation and topography (Waddell *et al.*, 1984). The annual potential evapotranspiration is estimated to be 5 to 25 times greater than precipitation (Winograd and Thordarson, 1975).

.PP The primary sources of precipitation in southern Nevada are the Pacific frontal systems, which generally occur from October to May, and the Great Basin lows, which occur from April to June. (Houghton *et al.*, 1975). These low pressure systems bring strong winds and moisture from the Pacific; but while the

Pacific fronts are more frequent, the Great Basin lows are the chief source of winter precipitation because they generally remain stationary for several days at a time (Spaulding, 1985).

Summer precipitation, which accounts for 25 percent of annual NTS precipitation (Spaulding, 1985), occurs as localized thunderstorms. These high intensity, short duration storms are the result of convection heating of air over the valleys and subsequent cooling of this air as it moves over mountain ranges. The sources of moisture for these storms are subtropical highs which push moist air masses up from the Gulf of Mexico and Gulf of California.

The distribution of precipitation over southern Nevada may be divided into two zones of relative moisture quantity (French, 1983). The western side of southern Nevada falls within the moisture deficit zone defined by a lack of winter precipitation due to the rainshadow effect. The eastern side of southern Nevada has a moisture excess relative to the western side, receiving both summer and winter precipitation. The NTS lies within the transition zone between the two. Parts of the NTS, particularly the western highlands, may be considered as part of the excess zone, whereas the lower elevations may be considered deficit. Yucca Mountain is considered part of the deficit zone (French, personal communications, 1988).

Geologic Studies

Ground-water flow directions and chemistry are in part a function of structure and rock lithologies present along the flow path. The stratigraphy of Yucca Mountain consists of Paleozoic sediments unconformably overlain by Tertiary volcanic sequences. Quaternary alluvium blankets the intermontane valleys. Table 1 gives the stratigraphic sequence and lithology of the units present beneath the Yucca Mountain area.

TABLE 1
STRATIGRAPHIC UNITS UNDERLYING YUCCA MOUNTAIN, NEVADA

AGE (m.y.) ¹	FORMATION	MEMBER	LITHOLOGY
Quaternary - Tertiary (0-3)	VALLEY FILL		Alluvial fan, fanglomerate, lakebed and fluvial deposits.
Tertiary Miocene (12)	PAINTBRUSH TUFF	Tiva Canyon	Compound cooling units of ash-flow tuff; nonwelded vitric base, welded, devitrified interior.
		Yucca Mountain	Ash-flow tuff; nonwelded vitric edges, partially welded devitrified interior.
		Pah Canyon	Nonwelded and vitric ash-flow tuff.
(13)		Topopah Spring	Compound cooling units of ash-flow tuff. Nonwelded to vitrophyric at top and base, welded, devitrified interiors. Zeolites present in basal units.
(13.4)	TUFF OF CALICO HILLS	(informal)	Nonwelded to partially welded ash-flow tuff; highly zeolitic, except for vitric southern region.
	CRATER FLAT TUFF	Prow Pass	Ash-flow tuff with nonwelded top and base and devitrified interior. Nonwelded zones are generally zeolitic.
(13.5)		Bullfrog	Compound cooling units of ash-flow tuffs. Nonwelded top and base, non- to -densely welded interior. Nonwelded zones are zeolitic.
(15)		Tram	Compound cooling units of ash-flow tuff; degree of welding is variable. Zeolitic in nonwelded zones, devitrified in welded zones.
	DACITE FLOW BRECCIA		Flow breccia, lava and tuffs with zeolitic zones.
	LITHIC RIDGE TUFF		Non- to -moderately welded devitrified ash-flow tuff with zeolitic horizons.
	OLDER TUFF UNITS (UNNAMED)		Dacitic to rhyolitic ash-flow tuffs, lavas, and reworked volcanic sediments. Some zeolitic horizons present.
Cretaceous to Permian (67)	GRANITIC STOCKS		Granodiorite and quartz monzonite stocks, dikes and sills.

TABLE 1 continued...
STRATIGRAPHIC UNITS UNDERLYING YUCCA MOUNTAIN, NEVADA

AGE (m.y.) ¹	FORMATION	MEMBER	LITHOLOGY
Permian - Pennsyl- vanian	TIPPIPAH LIMESTONE		Limestone
Mississippian - Devonian	ELEANA FORMATION		Argillite, quartzite, limestone and conglomerate.
Devonian	DEVILS GATE LIMESTONE		Limestone, dolomite, and minor quartzite.
	NEVADA FORMATION		Dolomite
Devonian - Silurian	LONE MOUNTAIN DOLOMITE		Dolomite
	ROBERTS MOUNTAIN FM		Limestone and limey dolomite.
Ordovician	ELY SPRINGS DOLOMITE		Dolomite
	EUREKA QUARTZITE		Quartzite with minor lime- stone.
	POGONIP GROUP	Antelope Valley Ls	Limestone and silty limestone.
		Ninemile Formation	Interbedded claystone and limestone.
		Goodwin Limestone	Limestone
Cambrian	NOPAH FORMATION	Smokey	Dolomite, limestone
		Halfpint	Limestone, dolomite and silty limestone.
		Dunderberg Shale	Shale, Limestone
	BONANZA KING	Banded Mountain	Dolomite, limestone and minor siltstone.
		Papoose Lake	Limestone, dolomite and minor siltstone.
	CARRARA FORMATION		Interbedded siltstone and limestones. Upper half is pri- marily limestone.
	ZABRISKIE QUARTZITE		Quartzite
Precambrian	WOOD CANYON		Quartzite, siltstone, shale, and minor dolomite.
	STIRLING QUARTZITE		Quartzite, siltstone.
	JOHNNIE FORMATION		Quartzite, sandstone, siltstone,

Modified From: Robinson, 1985; Broxton *et al*, 1986.

¹ Million Years Ago

Pre-Cenozoic Tectonism and Geology

Based on extrapolation of outcrops and aeromagnetic studies, a thick sequence of paleosediments is believed to be present beneath Yucca Mountain (Robinson, 1985). These sediments consist of Silurian to Mississippian sedimentary rocks which become younger to the south, and are folded into a large-scale, north-plunging syncline. Yucca Mountain is located over a small, northeast-plunging subordinent syncline on the western limb of this larger fold (Sinnock, 1982, Robinson, 1985).

The Paleozoic carbonates encountered in drillhole UE-25 p[#]1, which is located on the eastern flank of Yucca Mountain, are the Silurian Lone Mountain Dolomite and the Roberts Mountain Formation. These formations are finely crystalline bedded dolomite with calcite and chert stringers (Carr *et al.*, 1986) and are part of the lower carbonate aquifer which controls regional ground-water flow. Within the carbonate rocks, interstitial porosity is low, thus permeability is along secondary fractures.

Sediments of this aquifer are part of the miogeosynclinal strata of the Cordilleran geosyncline deposited during late Precambrian and early Paleozoic eras. They consist of up to 11,300 m of dolomites, limestones and siltstones, with calcite, dolomite, chert, fluorite, pyrite and iron-magnesium oxides present in the fractures (Winograd and Thordarson, 1975).

During Mississippian time, the Antler Orogeny thrust marine sediments eastward, creating a highland from which detritus is shed into a marine foreland basin (USGS, 1984). These sediments form the Paleozoic aquitard strata of argillites, conglomerates, and quartzites of the Eleana Formation. Further deposition of marine shelf carbonate rocks occurred during Pennsylvanian and early Permian time (USGS, 1984).

The next major orogenic event to influence the rocks of the study area is the Cordilleran Orogeny 195 to 80 m.y. (Robinson, 1985). During this time, the paleosediments were gently folded, and in some instances, thrust faulted. Segments of the CP thrust, a mid-Cretaceous age thrust which moved older rocks east-southeast over the younger Mississippian Eleana Formation (Carr, 1984), are exposed along the west side of Yucca Flat, in the Spotted Range, Bare Mountain, the Calico Hills and Death Valley.

During the Late Jurassic to early Late Cretaceous, the Sevier Arch, extending from southeast Nevada to western Utah, prevented any deposition of Mesozoic sedimentary rocks in the study area (Winograd and Thordarson, 1975). Mesozoic rocks present are mid-Cretaceous granite intrusives beneath Bare Mountain, Bullfrog Hills, Yucca Flat and, based on geophysical surveys, possibly the Calico Hills and Yucca Mountain (Winograd and Thordarson, 1975; Carr, 1984; USGS, 1984). Conjecture exists as to whether or not the granitic stocks under Yucca Mountain might actually be metamorphosed Eleana Formation (USGS, 1984).

Cenozoic Tectonism and Volcanism

The geology of the Yucca Mountain repository block itself is a result of the great amount of volcanic and tectonic activity which occurred during the Cenozoic era. During the late Mesozoic to mid-Cenozoic (100 - 10 m.y.), the Walker Lane Tectonic Belt was active. This is a northwest-trending, 100-km- wide zone of right-lateral shear extending from Texas to Oregon (Carr, 1984). Yucca Mountain and vicinity are located within this belt; a younger extension is the Las Vegas Valley Shear Zone. Total displacement along this zone may be 130 to 190 km (USGS, 1984). Proximal to Yucca Mountain, the Walker Lane Belt is expressed as right lateral shear, and is one of the least tectonically active zones

in the Great Basin.

The Walker Lane Belt is the source of middle and late Miocene silicic volcanism in southwestern Nevada (Carr, 1984). This may be due to "leaky" transform faulting where volcanic centers are located on northeast trending zones of Tertiary crustal spreading (Weaver and Hill, 1979). The silicic volcanic activity appears to be concentrated where large right-lateral faults die out or split into branches or en-echelon arrangements (USGS, 1984).

Cenozoic volcanism began in central Nevada about late Eocene time and spread southward, erupting within the Yucca Mountain area 16 to 7.5 m.y. (Carr, 1984; USGS, 1984). This volcanic activity deposited thick sequences of ash-fall tuffs, rhyolites, rhyodacites and lavas up to 4500 m thick beneath Pahute Mesa; less to the south (Winograd and Thordarson, 1975).

Five large calderas resulting from middle Miocene volcanic activity are located in the study area: Crater Flat-Prospector Pass, Silent Canyon, Claim Canyon, Timber Mountain and Oasis Valley calderas. There is evidence for an older caldera beneath Yucca Mountain (Carr, 1984). Approximately 11 to 8.5 m.y., volcanism changed from predominantly silicic to basaltic along rift-like structures localized in the Death Valley-Pancake Range Basalt Belt. This is a relatively youthful zone of slightly higher than regional tectonic activity (Carr, 1984; USGS, 1984). The basaltic cinder cones of Crater Flat are part of this zone and were erupted one million years ago (Carr *et al.*, 1983) or more recently. There is speculation that the basaltic cinder cone of Lathrop Wells may be late Pleistocene or Holocene in age (Wells, 1988).

The Miocene volcanics, in which the Yucca Mountain repository block is located, are high silica rhyolites and quartz latites that are 3 km thick at the northern end of Yucca Mountain and pinch out approximately 22 km to the south (Robinson, 1985). They were deposited predominantly as multiple ash-

flow sheets that constitute one compound cooling unit. Generally the top and base of the flows are nonwelded, vitric, and may contain pumice, glass shards and lithic fragments. The interiors of the flows are generally welded and devitrified, and may have vapor-phase crystallization. Vitrophyric zones are often present between the welded and nonwelded zones. Compositional variations within each ash-flow sheet are thought to record, in inverse order, the compositional sequences that were established in the magma chamber prior to eruption (Lipman *et al.*, 1966).

The lithology of a "typical" unaltered rhyolite from Yucca Mountain consists of 1 to 20 percent phenocrysts of sanidine, oligoclase, quartz, biotite, minor clinopyroxene and oxides, plus lithic fragments, pumice and glass shards in a fine-grained groundmass of alkali feldspar - plagioclase - quartz - perlite (Bish *et al.*, 1982). A description of each volcanic unit may be found in Table 1 and a thorough discussion of the lithology of Yucca Mountain volcanics may be found in Bish *et al.*, 1982 and Broxton *et al.*, 1986.

Diagenetic alteration has affected most of the volcanic rocks, especially those below the water table. Paleowater tables and/or zones of perched water may be inferred from secondary mineralization zones. The principal alteration products present in the volcanic rocks are zeolites, smectites and authigenic feldspars which replace volcanic glasses, pumice, and primary feldspars. Diagenetic alteration is best developed in the groundmass and phenocrysts of the nonwelded sections of the cooling units (Broxton *et al.*, 1986), and as fracture coatings in the welded tuffs (Carlos, 1985).

Approximately 17 m.y., Basin and Range extensional tectonism began, resulting in the formation of the long, linear, north-striking horst and graben topography prevalent today. These high-angle normal faults often occur along reactivation of caldera ring fractures and tend to flatten with depth. Nearly all

extensional faulting has occurred by reactivation of existing faults. The present-day topography of the study area was influenced by both Cenozoic volcanism and Basin and Range faulting.

The Yucca Mountain repository block has typical Basin and Range topography of tilted mountain blocks bounded by antithetic normal faults. To the north of Yucca Mountain is a highly faulted and eroded volcanic plateau. Yucca Mountain is on the southern boundary of this plateau and is bounded on three sides by faults. The geomorphology of Yucca Mountain is controlled by two sets of faults. The first set consists of Basin and Range-type, high-angle, normal faults striking north-northeast. Ghost Dance, Solitario Canyon, Dune Wash, Bow Ridge, Paintbrush Canyon, Fatigue Wash and Abandoned Wash faults (Scott and Bonk, 1984) are the larger faults of this set. The second set consists of faults which are at the northern end of Yucca Mountain and are a series of northwest-trending, right-lateral, strike-slip faults. Yucca Wash, Pagany Wash, Sever Wash and Drill Hole Wash faults are examples, and may be from reactivation of the Walker Lane Belt. Figure 2 shows the location of the major faults of these sets. Some minor late Pleistocene movement has occurred in the vicinity of Yucca Mountain; however, no unequivocal displacement of Holocene deposits has been discovered (USGS, 1984). Knowledge concerning fault locations is important in ground-water modeling, as the faults may be either conduits or barriers to ground-water flow.

The Quaternary alluvial deposits in the study area are fanglomerate, alluvial fan, lakebed and fluvial detritus shed from the mountain ranges, and may attain thicknesses greater than 2000 m in the centers of valleys (Winograd and Thordarson, 1975). The composition of the alluvium is a function of the lithology of the source rock and distance of transport.

Figure 2: Location of strike-slip and normal faults around Yucca Mountain, Nevada (USGS, 1984).

Hydrologic Studies

Yucca Mountain is located in the Great Basin subprovince of the Basin and Range physiographic province. Our current understanding of the spatial and temporary characteristics of recharge in this region is limited. It appears that the major recharge sources to ground water are long duration winter storms, with minor input from summer thundershowers. A generalized ground-water system in the Great Basin is conceptualized as a local flow system consisting of precipitation recharge on the mountain flanks that moves downward through bedrock into valley fill in the basin, where it is discharged through evapotranspiration (Schoff and Moore, 1964). The local system of mountain recharge - valley discharge may be underlain by a larger, more regional ground-water basin consisting of several interconnected local systems, which may or may not coincide with the topographic surface watersheds (Naff *et al.*, 1974).

The three prevalent rock types of the study area, valley-fill alluvium, Tertiary volcanic rocks, and Paleozoic carbonate rocks, are general aquifer classifications that have been further divided into 12 formal aquifers and aquitards for the NTS area by Winograd and Thordarson (1975) (Table 2). The aquifers with the largest areal distribution are the lower carbonate and the valley-fill aquifers. The tuff aquifers and aquitards are the location of the potential nuclear waste repository horizons at Yucca Mountain.

Lower Carbonate Aquifer

The lower carbonate aquifer, also known as the regional carbonate aquifer, generally underlies most of the study area and transmits much of the interbasin flow. This aquifer is alternately confined and unconfined (Winograd and Pearson, 1976). Its saturated thickness is a few hundred to a thousand meters and is a function of geology, structure, erosion and elevation of the water table.

TABLE 2
HYDROLOGIC UNITS OF THE NEVADA TEST SITE

Hydrologic Unit	Maximum Thickness (m)	Stratigraphic Unit ¹
Valley Fill Aquifer	1100	
Lava Flow Aquifer	75 600 75	Basalt of Kiwi Mesa Rhyolite of Shoshone Mesa Basalt of Skull Mountain
Welded Tuff Aquifer	230 250 375	Thirsty Canyon Tuff Timber Mountain Tuff Paintbrush Tuff
Bedded Tuff Aquifer	300	Paintbrush Tuff
Lava Flow Aquitard	1200	Wahmonie Formation
Tuff Aquitard	500 600 150 600	Wahmonie Formation Salzer Formation Belted Range Tuff Local Informal Units
Tuff Aquifer / Aquitard	600 600	Tuff of Calico Hills Crater Flat Tuff
Tuff Aquitard	300 ? 425 300 ?	Lithic Ridge Tuff Older Tuff Units (Unnamed) Rocks of Pavits Springs Horse Springs Formation Granitic Stocks
Upper Carbonate Aquifer	1100	Tippipah Limestone
Upper Clastic Aquitard	2400	Eleana Formation
Lower Carbonate Aquifer	425 460 430 90 100 650 615 1400 610	Devils Gate Formation Nevada Formation undifferentiated Ely Springs Dolomite Eureka Quartzite Pogonip Group Nopah Formation Bonanza King Carrara Formation
Lower Clastic Aquitard	70 700 1025 975	Zabriskie Quartzite Wood Canyon Formation Stirling Quartzite Johnnie Formation

Modified From Winograd and Thordarson, 1975.

¹ See Table 1 For Explanation of Stratigraphic Units

The stratigraphy of this aquifer is Devonian Devils Gate Formation through the Cambrian Carrara limestones and dolomites. Intercrystalline porosity is low, but secondary permeability is high and water moves primarily along fractures. The greatest fracture density occurs in fine-grained rocks. Often fractures are partially or completely filled with secondary calcite, calcareous clay, or iron oxides (Winograd and Thordarson, 1975).

Volcanic Tuff Aquifers and Aquitards

The Tertiary volcanic tuffs form a system of interlayered aquifers and aquitards. The tuffs induration ranges from nonwelded to densely welded. Nonwelded tuffs may have interstitial porosities as high as 35-40% (Winograd and Thordarson, 1975), however, secondary mineralization within void spaces decreases permeability; therefore, it has been suggested that the amount of secondary permeability defines whether a tuff unit is either an aquifer or an aquitard. Tuff aquifer transmissivity is a function of degree of fracturing and interconnectiveness of fracture systems. Fracture permeability may be related to the vertical position within a cooling unit, distance from the eruptive source, proximity to faults, secondary mineralization, and lithology (Waddell *et al.*, 1984), and the tectonically controlled stress field. In the tuff aquitards, with less fracture density and/or interconnectiveness, interstitial porosity probably controls ground-water movement (Winograd and Thordarson 1975). The tuff aquitards are the principal hydrologic units in which perched water occurs at the NTS (Winograd and Thordarson, 1975). In the eastern part of the NTS, volcanic rocks commonly transmit water downward to the underlying carbonates; in the western part of the NTS, volcanic rocks act as regional aquifers and move water laterally (Rush, 1970).

Valley-Fill Aquifer

This widespread aquifer is composed of Quaternary and Tertiary alluvial fan, lakebed and fluvial deposits, and typically is saturated only beneath the structurally deepest parts of the intermontane basins and near the discharge areas in the Amargosa Desert (Waddell *et al.*, 1984). Because of the interlayered nature of the conglomerates and alluvium, horizontal permeability in this unit is generally much greater than vertical permeability.

Regional Ground-Water Flow Directions

The regional ground-water flow direction in the lower carbonate aquifer underlying the NTS and vicinity is generally from the north to the southwest, and is thought to eventually discharge into Death Valley, California. Discharge is primarily through evapotranspiration and has been estimated at 25-30 million m³/year (Miller, 1977). This system is believed to be under steady-state conditions with respect to recharge, storage and discharge for hundreds of years, with some water in transit longer than 10,000 years (Miller, 1977). Smaller local flow systems may be developed within the Tertiary volcanic tuffs, which may or may not be hydrologically connected to the underlying lower carbonate aquifer. Geologic structure and lithology may influence these local ground-water flow directions.

The Death Valley regional ground-water system has been divided into two subbasins, the Ash Meadows subbasin and the Alkali Flat-Furnace Creek Ranch subbasin (Figure 3). Because of the scarcity of data from the lower carbonate aquifer, boundaries of these subbasins are not definite. Figure 3 represents an intermediate location of suggested subbasin boundaries. Yucca Mountain is located within the Alkali Flat-Furnace Creek Ranch subbasin and is probably a

Figure 3: Ground-water flow directions within subbasins of the Death Valley Ground Water Basin in southern Nevada.

local flow system within the Miocene tuffs overlying the regional flow system of the lower carbonate aquifer.

Ash Meadows Subbasin

The Ash Meadows ground-water basin is located on the eastern side of the NTS (Figure 3). Regional ground-water movement is strongly influenced by the late Mesozoic and early Tertiary deformation of Precambrian and Paleozoic miogeosynclinal rocks (Rush, 1970; Naff *et al.*, 1974) and is to the south-southwest. Semi-perched ground water in Frenchman and Yucca Flats moves from the valley fill to the underlying regional carbonate aquifer (Rush, 1970; Naff *et al.*, 1974; Winograd and Thordarson, 1975; French *et al.*, 1984; Waddell, 1984). This downward flow has been estimated at 120,000 m³/year per valley (Rush, 1970). Ground water moves laterally from these valleys to the Amargosa Desert.

The discharge point of this subbasin is an alignment of 15 springs located along a fault-induced barrier in Ash Meadows of the Amargosa Desert where Paleozoic carbonate terrain is juxtapositioned next to Quaternary and Tertiary alluvium. There may be appreciable leakage across this barrier (Rush, 1970). The Ash Meadows ground-water system discharge, temperature and water chemistry have changed little over the past few decades, indicating a steady-state hydraulic condition of a time frame of decades, and possibly since the turn of the century (Winograd and Pearson, 1976).

Alkali Flat - Furnace Creek Ranch Subbasin

This ground-water subbasin has been alternately described as the Pahute Mesa subbasin (Rush, 1970; French *et al.*, 1984) and the Oasis Valley - Forty Mile Canyon subbasin (Winograd and Thordarson, 1975) (Figure 3). It extends

from Pahute Mesa in the north to the western one-third of the NTS (including Yucca Mountain), Oasis Valley, and the Amargosa Desert. The actual boundary on the eastern side of this subbasin is still uncertain. Because Tertiary volcanism obliterated most of the carbonate rock directly around Pahute Mesa, the Tertiary volcanic rock aquifer is the principal aquifer, moving water from the recharge areas of Pahute Mesa in the northeast section southward into Oasis Valley, Crater Flat, and western Jackass Flats, then into the Amargosa Desert (Blankennagel and Weir, 1973; Winograd and Thordarson, 1975; Waddell, 1982). Other authors (White, 1979; White and Chuma, 1987) believe that ground water in Forty Mile Wash is from recent recharge and that no underflow from Pahute Mesa occurs.

Ground-water flow direction is generally to the south. Figure 3 indicates flow directions in the Tertiary tuffs, as suggested by Feeney (1987), based upon his Discrete State Compartment (DSC) model using deuterium as a tracer. These flow directions suggest local flow across boundaries, possibly indicating connection between the volcanic flow system and the underlying carbonate system. Feeney's (1987) flow model suggests that the caldera structure in Pahute Mesa may be locally influencing the flow directions.

About one-half of the ground water in Oasis Valley is lost through evapotranspiration, with the rest continuing as underflow to the Amargosa Desert (White, 1979). Some recent isotopic evidence is interpreted by Claassen (1985) to indicate that ground water in the Amargosa Desert was recharged to the valley-fill aquifer primarily by overland flow in stream channels from snowmelt at the end of the Pleistocene, rather than by underflow from the north, and that none of the water is older than 17,000 years B.P.

Waddell (1982), Waddell *et al.* (1984), and Sinton (1987) suggest that the large Alkali Flat - Furnace Creek Ranch subbasin be further divided into two

subbasins, with a smaller Oasis Valley subbasin receiving underflow from Pahute Mesa. Waddell (1982) proposes that a flow barrier exists between the southern edge of Pahute Mesa and northern Jackass Flats, perhaps caused by the Timber Mountain Caldera complex, which prohibits underflow from Pahute Mesa to Yucca Mountain.

Discharge from the Amargosa Desert is believed to be through evapotranspiration and underflow to Death Valley (Naff *et al.*, 1974). There is an upward potentiometric head potential in the alluvium in the southern part of Amargosa Desert which may or may not be connected to the underlying carbonates (Waddell *et al.*, 1984).

Ground-Water Flow Around Yucca Mountain

Some of the sources of the ground water in the tuffaceous aquifer at Yucca Mountain have been suggested as subsurface flow from other tuffaceous recharge areas, direct recharge from local precipitation or runoff, and upward flow from the regional carbonate aquifer (Kerrisk, 1987). The direction and pathways of ground-water flow surrounding Yucca Mountain are of great interest in characterizing the area for the proposed nuclear waste repository. The regional ground-water flow direction in the underlying lower carbonate aquifer is to the south-southwest, as part of the Alkali Flat-Furnace Creek Ranch ground-water subbasin (Waddell *et al.*, 1984). The direction of vertical ground-water flow between the Tertiary volcanic tuff aquifers and the underlying lower carbonate aquifer at Yucca Mountain could directly affect the travel time of radionuclides to the accessible environment

Yucca Mountain is in an arid region and recharge is considered to be fairly low. Waddell *et al.*, (1984) propose two hypotheses of recharge to Yucca

Mountain. One is that runoff recharges the alluvium in the washes; however, evapotranspiration may remove this water before it reaches the water table. Another hypothesis suggests that open fractures in surficial bedrock transmit water very quickly below the depth of evaporation. This water then passes through the unsaturated zone to recharge the ground water. Waddell *et al.*, (1984) suggest that recharge will occur as pulses rather than as a steady condition over long periods of time.

Due to the interbedded and fractured nature of the welded and ash-fall tuffs of Yucca Mountain, hydraulic conductivity could be highly anisotropic. Highly fractured welded tuff units might allow for either isotropic or anisotropic flow conditions; in the bedded, nonwelded ash-fall tuffs, vertical conductivity is likely to be smaller than horizontal conductivity. Major fault or fracture zones locally may penetrate both types of lithologies to establish zones of greater vertical hydraulic conductivities. These probable conditions create uncertainty in location and importance of vertical ground-water flow in the Yucca Mountain region.

Temperature measurements in wells USW H-1, USW H-4, UE-25 b#1 and USW G-2 indicate downward flow in the upper part of the saturated zone, while also indicating a very low upward gradient in the deepest parts of the wells (Waddell *et al.*, 1984). Hydraulic head potentials also increase with depth in wells USW H-1 and UE-25 p#1. Based upon potentiometric head data in wells surrounding Yucca Mountain, the hydraulic head gradient is apparently very low in the volcanics on the eastern side of Yucca Mountain, and much steeper in the volcanic rocks in the northern part of Yucca Mountain (Robison, 1985). Waddell *et al.* (1984) consider Yucca Mountain to be located within the transitional zone of the regional ground-water flow; therefore, it is considered neither a significant recharge nor discharge area. They suggested that vertical flow, as related to the regional ground-water system, may be in either direction

(Waddell *et al.*, 1984, p. 61).

Sinton (1987) numerically modeled the ground-water flow in the region of Yucca Mountain by dividing the area into a two-layer model. The upper layer is composed of volcanic and alluvium aquifers and aquitards, and the lower layer represents the lower carbonate aquifer. The amount of vertical leakage is controlled by recharge and discharge, and the difference between the upper and lower layer transmissivities. From this model, Sinton (1987) proposed an upward flux of 44 m³/year for the Yucca Mountain repository area, and also proposed upward fluxes in Crater Flat, Amargosa Desert, Ash Meadows and Oasis Valley. In contrast, there were downward fluxes in Forty Mile Wash, Pahute Mesa and Timber Mountain.

Ground-Water Chemistry

Ground-Water Chemistry of the Study Area

Schoff and Moore (1964) studied the ground-water chemistry at the NTS and came up with three divisions of ground water: a (Na+K)HCO₃ type found in the volcanic tuffs and tuffaceous valley-fill alluvium; a (Ca+Mg)HCO₃ type found in the Paleozoic carbonate aquifers and carbonate detritus; and a mixed type from the interaction of ground water traveling between these two. Water from the regional carbonate aquifer, the (Ca+Mg)HCO₃ type, is found to be relatively uniform in terms of total dissolved solids (TDS) to depths of several thousand meters (Winograd and Thordarson, 1975).

Pahute Mesa, which has been suggested as a source area for Yucca Mountain ground water, has a similar volcanic terrain and diagenetic minerals. The ground water of Pahute Mesa is a sodium-bicarbonate type, with Na⁺ + K⁺ comprising 90 % cations (Blankennagel and Weir, 1973). Pahute Mesa may be

divided hydrologically into two regimes: a nonzeolitized eastern section with decreasing head potential with depth, and a zeolitized western section with increasing head potential with depth. The ground water in the eastern section is primarily a NaHCO_3 type, with accessory Ca^{2+} and SO_4^{2-} (Blankennagel and Weir, 1973). In the western section, sodium, sulfate and chloride contents increase, while calcium decreases, relative to the eastern section (Blankennagel and Weir, 1973). This may be due to longer flow paths in the western section which allow more water/rock interaction and hydrothermal alteration of older volcanic rocks. Secondary mineralization is believed to have formed under closed conditions (Moncure *et al.*, 1981).

Oasis Valley, to the west of the NTS, might be viewed as a small-scale analog of the regional ground-water flow system containing Yucca Mountain, with underflow and recent recharge in Tertiary volcanics and carbonate aquifers. The ground water in Oasis Valley was characterized as NaHCO_3 type by Malmberg and Eakin (1962) and $(\text{Na}+\text{K})\text{HCO}_3$ by Winograd and Thordarson (1975). Along a flow path down the valley, modeled as a system open to atmospheric CO_2 , White (1979, p.17) found that evapotranspiration causes TDS increases, calcium increases due to CaCO_3 input from carbonate rocks of Bare Mountain, and potassium and fluoride are removed by clay minerals and fluorite, respectively. White (1979) also found that in water containing moderate amounts of Mg^{2+} , the principal alteration product is montmorillonite, while if Mg^{2+} is deficient, but Na^+ and K^+ were present, zeolites such as clinoptilolite, mordenite, analcime and chabasite would form. Using environmental isotopes, White and Chuma (1987) suggested underflow from Pahute Meas as a recharge source, and that local recharge occurs in Bullfrog Hills. There is a 5 ‰ deuterium depletion in older ground water. White and Chuma (1987) modeled the ground water in

Oasis Valley as an open system, a decision based upon the shallow depth (< 10 m) to ground water. They supported this by noting that P_{CO_2} and $\delta^{13}C$ increases and $\delta^{14}C$ decreases along a flow path. Calcium carbonate saturation is maintained by the dissolution of caliche.

Southern Amargosa Desert is suggested as a possible discharge area for the ground water from Yucca Mountain. Winograd and Thordarson (1975) described the ground water as a mixed type which graded into a (Na+K)HCO₃/mixed type to the west. Claassen (1985) divides the water chemistry into three groups: volcanic, carbonate and mixed ground waters, similar to Schoff and Moore's 1964 work on the NTS, that are controlled by the alluvium lithology. Claassen (1985) found that the north-central part of Amargosa Desert has the lowest values of Na⁺, Ca²⁺, HCO₃⁻ and SO₄²⁻, with ion concentrations increasing sharply to the east and west. This coincides with the presence of highly permeable sands and gravels within the center of the Amargosa Desert. Claassen (1985) suggests that, with respect to cation composition, Amargosa Desert ground water is more similar to the NTS spring water compositions derived from perched systems, rather than the regional ground-water table. Amargosa Desert has been modeled as a system that is closed to atmospheric CO₂ (Claassen, 1985; White and Chuma, 1987) because P_{CO_2} decreases along the flow path. Assuming cooler recharge conditions during Pleistocene time, Claassen (1985) used $\delta^{13}C$, δD and $\delta^{18}O$ to support his hypothesis that water was recharged to the valley fill primarily through runoff infiltration and overland flow from Pleistocene snowmelt.

Ground water near Forty Mile Wash, which is located to the east of Yucca Mountain (Figure 4), is thought to be either a mixture of underflow from Yucca

Mountain and recent recharge (Waddell *et al.*, 1984; White and Chuma, 1987), or derived purely from recent recharge (Claassen, 1985). Three wells are completed in the Tertiary volcanics underlying Forty Mile Wash. Well UE-29 a#2, located the farthest upgradient, has a lower ion concentration (except for Cl^-) and is isotopically lighter than Yucca Mountain wells (Benson *et al.*, 1983). Wells J-12 and J-13 are higher in ions (except for Na^+) and isotopically lighter than Yucca Mountain wells (Benson *et al.*, 1983). Based upon carbon-14 data, uncorrected ground-water ages of these wells are 4,000, 9,100 and 9,900 years B.P. for UE-29 a#2, J-12 and J-13, respectively (Benson and Mickinley, 1985). Ogard and Kerrisk (1984) consider well J-13 to be typical of wells surrounding Yucca Mountain, although this well is used for water supply and as such has undergone extensive pumping, thus likely disturbing the local flow field. White (1981) and White and Chuma (1987) have modeled Forty Mile Wash as a closed system, after a total carbon balance showed decreases of P_{CO_2} and increases of $\delta^{13}\text{C}$ downgradient. An increase in CO_3^{2-} could result from increased CaCO_3 saturation from the dissolution of calcite (perhaps caliche?) by ground water.

Yucca Mountain Ground-Water Chemistry

Composite ground-water samples have been collected from 20 wells on and surrounding Yucca Mountain (Table 3) which were completed in Tertiary volcanics. The screened interval in each well is generally quite large, up to several hundred meters, thus the sample collected probably represents a mixture of several geologic units and flow paths. Well UE-25 p#1 is sampled from two separate packed intervals in the volcanics and the lower carbonate aquifer in the Paleozoic carbonates. Figure 4 shows the locations of these wells on Yucca Mountain. While no data have been published about the unsaturated zone water, Ogard and Kerrisk (1984) estimated the chemistry of pore water to be in

TABLE 3
HYDROGEOLOGY OF WELLS SURROUNDING YUCCA MOUNTAIN, NEVADA

Well	Depth (m)	Hydraulic Head (m) ¹	Sampled Interval (m)	Producing Unit ²
J-12	347	953.2	214-264	Topopah Spring
J-13	1063	727.1	207-450	Topopah Spring-Tram
UE-29 a#2	422	1188.0	87-213 247-354	Tuff of Calico Hills
UE-25 b#1	1220	730.3	863-875	Bullfrog
UE-25 c#1	914	728.4	-	Bullfrog-Tram
UE-25 c#2	913	-	-	Bullfrog
UE-25 c#3	913	-	-	Bullfrog-Tram
UE-25 p#1(vol)	1805	729.9	381-1197	Tuff of Calico Hills - Crater Flat Tuff - Lithic Ridge Tuff
UE-25 p#1(carb)	1805	751.0	1297-1805	Lone Mountain Dolomite - Roberts Mountain Formation
USW G-4	915	730.1	549-915	Tram
USW H-1	1829	730.7	572-687 687-1829	Prow Pass
USW H-3	1220	732.4	822-1220	Tram-Lithic Ridge Tuff
USW H-4	1220	730.7	569-1219	Bullfrog-Tram
USW H-5	1220	774.7	-	Bullfrog-Tram
USW H-6	1220	775.6	608-646 753-835	Bullfrog-Tram
USW VH-1	762	779.3	-	Bullfrog
UE-25 WT-4	482	728.2	474-477	Tuff of Calico Hills
USW WT-7	491	775.9	477-481	Topopah Spring
USW WT-10	430	728.0	399-403	Topopah Spring
UE-25 WT-12	399	729.2	382-388	Tuff of Calico Hills
UE-25 WT-14	399	729.9	393-397	Tuff of Calico Hills
UE-25 WT-15	415	728.6	403-407	Topopah Spring

¹ Meters Above Mean Sea Level

² See Table 1 for Explanation of Stratigraphic Units.

equilibrium with the rock with which it is in contact. Vadose water in the fractures of the crystalline tuff would likely be higher in Ca^{2+} and lower in Na^+ relative to saturated zone water, whereas water in the pores of zeolitized tuff should be similar to saturated zone water because of glass dissolution (Ogard and Kerrisk, 1984). In general, unsaturated zone water should show a higher concentration of ions due to higher evaporation rates than saturated zone water (Kerrisk, 1987).

Kerrisk (1987) described six active processes that may control ground-water chemistry at Yucca Mountain: 1) physical transport of dissolved species with water; 2) rock-water interactions; 3) ion exchange; 4) gas dissolutions; 5) mixing of different water compositions; and 6) evaporation. The last, evaporation, Kerrisk did not consider likely at Yucca Mountain. The ground water in the tuffs is primarily a NaHCO_3 type: $\text{Na}^+ = 65\text{-}95\%$ of cations and $\text{HCO}_3^- = 80\%$ of anions with subequal Cl^- and SO_4^{2-} (Ogard and Kerrisk, 1984).

The ground-water chemistry may be divided into two groups based upon $\text{Ca}^{2+}:\text{Na}^+$ ratios. The sodic western side of Yucca Mountain, consisting of wells USW H-3, USW H-5 and USW H-6, has higher Na^+ content, while the calcic eastern side, wells USW H-1, USW H-4, USW G-4 and UE-25 b#1, has higher relative Ca^{2+} (Ogard and Kerrisk, 1984; Kerrisk, 1987). Ghost Dance Fault may be an approximate dividing line between the two. Well USW H-3 is considered as the representative well for Yucca Mountain by Ogard and Kerrisk (1984). These wells may be correlated chemically to Pahute Mesa wells UE-19e (sodic) and U-20a2 (calcic) (Ogard and Kerrisk, 1984). Kerrisk (1987) modeled the ground-water chemistry at Yucca Mountain based upon a system that is open to P_{CO_2} transfer at the water table surface, and which becomes closed at depth. Most wells at Yucca Mountain were oxidizing with dissolved oxygen (D.O.) values of 2-6 mg/l; only UE-25 b#1 and USW H-3 had D.O. values less

than 0.1 mg/l (Kerrisk, 1987). Calcium content is controlled by calcite solubility, ion exchange and precipitation of smectites. Because of the relatively low Ca^{2+} concentrations, carbonate above 2 mmole/l was thought to come from soil zone CO_2 , rather than from dissolution of carbonate minerals (Kerrisk, 1987).

The ground water from well UE-25 p#1(carbonate) is the only sample from the Paleozoic carbonate aquifer beneath Yucca Mountain, and thus serves to represent the water chemistry of this aquifer. The amounts of chemical constituents are more concentrated in water from the carbonate aquifers than in the water from the tuffaceous aquifers, with greater Ca^{2+} , Mg^{2+} , Cl^- and SO_4^{2-} concentrations (Benson and McKinley, 1985).

METHODOLOGY

Geochemical data for this study are from the collection of ground-water samples from six wells surrounding Yucca Mountain and a review of current literature for well and spring data from 17 sources. The data are assembled in a Unix data base (Appendix A), which is a computer data management system developed by the Unify Corporation that is useful for storage, organization and retrieval of large amounts of data.

Literature Review

A literature review on published data on wells and springs in southern Nevada resulted in the collection of information on 135 wells and springs located within the NTS, Amargosa Desert, Oasis Valley and Yucca Mountain. Figure 5 indicates the general location of these data points. The extensive collection of data from areas other than Yucca Mountain was used to 1) compare Yucca Mountain to areas of similar terrain, such as Pahute Mesa, Rainier Mesa and Oasis Valley, which have been extensively studied and modeled; and 2) include recharge (Pahute Mesa) and discharge (Amargosa Desert) areas in the study.

Ground-Water Sampling

The USGS, as part of the Nevada Nuclear Waste Storage Investigation (NNWSI) study of the water table in the vicinity of Yucca Mountain, completed 16 test wells on the NTS and Bureau of Land Management-administered lands surrounding Yucca Mountain. These 16 wells have been monitored by the USGS

Figure 5: Location of Yucca Mountain and data points in southern Nevada. Hatched box is Figure 2.

for water-level data; however, the wells were not sampled for ground-water chemistry or isotopic analyses. As part of this current study, samples were collected from six of these wells and analyzed for major and minor element chemistries and isotopic analyses. A complete discussion of the sampling program can be found in Matuska, 1989.

The NNWSI water table (WT) wells are located to the east and south of Yucca Mountain in the surrounding basins. The wells were drilled in 1983 to depths between 348 and 628 meters using conventional rotary methods, with a LiBr tracer added to the air foam. The boreholes are 22.2 cm in diameter at depth and have 6.2 cm steel tubing, which is screened over its last four meters, suspended in the open borehole.

Water-level monitoring transducers, which prevented sample collection, are installed in six of the water table wells, and four other WT wells were deemed unsuitable for sampling because they are either dry or too deep. The WT wells which were sampled are listed in Table 3.

Prior to sampling, a quality assurance sampling program, "Technical Procedure for Ground-Water Sampling and Hydrogeologic Data Acquisition", DTP-03.5, was written using sample collection methods suggested by Brown *et al.* (1970) and Wood (1976), of the USGS. This document contains instructions on collecting ground-water samples, the preparation of the samples for laboratory analysis, as well as field analysis of unstable parameters.

The wells were first logged with the DRI chemical sonde, which consists of an Omega temperature resistance cell and a Yellow Springs Instrument flow-through fluid conductivity cell that are connected to 1160 meters of four conductor cable. The electronic signal is transmitted to the surface and recorded by a YSI S-C-T meter and Tandy RS-80 portable computer. The initial logging served several purposes: 1) to insure that the well bores were open and free of

obstructions; 2) to determine water levels; and 3) to record temperature and electrical conductivity profiles of the wells.

After logging, the pump was lowered to within the screened interval and well purging began. The wells were sampled using an air-driven, double-piston pump manufactured by the Robert Bennett Company, which can lift water samples from a depth of 500 m in a six cm I.D. well. Samples were collected, within an hour after purging began, from the initial waters for tritium, LiBr and methylene blue active (MBA) to determine relative amounts of natural purging in the wells since their installation. Purging the wells generally required several days of pumping, during which field parameters such as pH, temperature, electrical conductivity, alkalinity and flow rate were measured at four- to six-hour intervals.

Once three well volumes had been purged, and the field parameters had stabilized for three successive readings taken 15 to 20 minutes apart, samples for chemical and isotopic analysis were collected. Chemical analysis is performed for major ion chemistry, alkalinity, SiO_2 , MBA and LiBr. Isotopic samples were collected for tritium, deuterium, oxygen-18, carbon-13 and carbon-14 analysis. The chemical and isotopic samples were randomly split with the USGS representative onsite. Quality assurance requirements were met during the sampling procedure by the collection of blanks, duplicates, standards and the required chain-of-custody.

The WT well data from this sampling program were added to the data base (Appendix A) compiled from the literature review. This data base contains information about the location, static water level, lithology, well depths and producing intervals of the wells, in addition to chemical and isotopic analyses. This data base is the source of the data which is used in the following geochemical modeling and isotope analyses sections.

CONTROLS ON GEOCHEMISTRY

Influence Of Volcanic Tuffs

Extensive flow path geochemical modeling has been conducted on Rainier Mesa, 50 km northeast of Yucca Mountain, by Claassen and White (1979), White *et al.* (1980), and Kerrisk (1983). Rainier Mesa is geologically similar to Yucca Mountain. Claassen and White (1979) and White *et al.* (1980) studied the ground-water flow of Rainier Mesa, using fracture and interstitial water from devitrified, welded crystalline tuffs and nonwelded vitric tuffs, respectively. The glass samples were initially higher in silica and monovalent Na^+ and K^+ , while the crystalline rocks were higher in aluminum and bivalent cations Ca^{2+} and Mg^{2+} (White *et al.*, 1980). Claassen and White (1979) presented the following model of flow path evolution of a ground water in a volcanic tuff:

1. Aerobic biological activity and recharging water dissolves soil zone atmospheric CO_2 in the reaction:

In a simple silicate rock dissolution, all the carbonate species would result from the reaction of this H_2CO_3 with the rock.

2. The recharged water leaves the soil zone and reacts with the rock (either vitric or crystalline) in a closed (with respect to atmospheric CO_2) system. The H_2CO_3 contributes H^+ , which attacks silicate minerals resulting in the release of cations (M^+) and the formation of bicarbonate by the reaction:

As the dissolution proceeds, the aqueous phase becomes saturated and subsequently precipitates zeolites, smectites and feldspar minerals. Differences in fracture and interstitial waters at Rainier Mesa were distinguishable because the fracture water becomes enriched in Ca^{2+} and Mg^{2+} and deficient in K^+ relative to the interstitial waters. White *et al.* (1980) found that the source of Ca^{2+} is clinopyroxene, rather than plagioclase feldspar. Interstitial waters, influenced by glass dissolution, are dominated by Na^+ (White *et al.*, 1980). Both fracture waters and interstitial waters in Rainier Mesa were found to be deficient in K^+ , which is preferentially retained by glass and minerals. As dissolution proceeds, crystallization of montmorillonite and zeolites provide a sink for the bivalent cations Ca^{2+} and Mg^{2+} .

Claassen and White (1979) and White *et al.* (1980) found that incongruent dissolution of the volcanic glass was the primary influence on ground-water chemistry evolution at Rainier Mesa; because of the porous nature of the nonwelded tuff, flow paths and travel times were longer than in the fractures of the crystalline rock, thus allowing more mineral/water interaction.

Minerals Which Influence Chemistry

Ground-water chemistry in a volcanic rock is controlled by primary glass, pumice fragments and the diagenetic minerals (smectites, zeolites, feldspars) (Claassen and White, 1978). Because of the importance these play in defining ground-water chemistry, a brief discussion about each of these follows. Table 4 gives the mineralogy of diagenetic minerals present at Yucca Mountain.

Volcanic Glass

Volcanic glass (perlite) is present at Yucca Mountain as part of the fine-grained groundmass, as shards and pumice fragments, and as insets in the vitrophyres. Glass is mostly found in the nonwelded horizons above the water table;

TABLE 4
DIAGENETIC MINERALS OF YUCCA MOUNTAIN

Zeolite	analcime	$\text{Na (Al Si}_2\text{ O}_6\text{)}\cdot\text{H}_2\text{O}$
	clinoptilolite	$(\text{Na}_2, \text{K}_2, \text{Ca})(\text{Al}_2 \text{Si}_{10} \text{O}_{24})\cdot 8\text{H}_2\text{O}$
	heulandite	$\text{Ca (Al}_2 \text{Si}_7 \text{O}_{18})\cdot 6\text{H}_2\text{O}$
	mordenite	$\text{Na K (Al Si}_5 \text{O}_{12})\cdot 3\text{H}_2\text{O}$
Feldspar	albite	$\text{Na Al Si}_3 \text{O}_8$
	adularia	$\text{K Al Si}_3 \text{O}_8$
Clay	montmorillonite	$(\text{Na}_2, \text{K}_2, \text{Ca, Mg}) \text{Al}_{14} \text{Si}_2 \text{O}_{60} (\text{OH})_{12}$
	illite	$\text{K}_{0.6} \text{Mg}_{0.25} \text{Al}_{2.3} \text{Si}_{3.5} \text{O}_{10} (\text{OH})_2 \cdot 4(\text{H}_2\text{O})$
	chlorite	$(\text{Mg, Fe})_3 (\text{Si, Al})_4 \text{O}_{10} (\text{OH})_2, \text{Fe})_3 (\text{OH})_6$

Clay mineral formulas from Hurlbut and Klein, 1977.

Zeolite formulas from Kerrisk, 1983.

however, some glass has been preserved below the water table in dense vitrophyres and lavas (Bish and Vaniman, 1985). The composition of perlite is that of a hydrated high-silica rhyolite with subequal Na_2O and K_2O , plus CaO and H_2O and a silica-to-aluminum ratio of 4.8 - 5.6 (Broxton *et al.*, 1986, Broxton *et al.*, 1987). It is the composition of glass which largely controls the chemistry of the pore water during diagenesis, and hence the secondary mineralization. The most common alteration products of volcanic glass dissolution are cristobalite, which is a metastable, low-temperature polymorph of quartz, and zeolites. The silica concentration in the ground water is thought to be controlled by cristobalite rather than quartz when both phases are present (Bish and Vaniman, 1985).

Zeolites

Zeolites present at Yucca Mountain are clinoptilolite, heulandite, mordenite and analcime. The zeolites form as replacements of glass in the groundmass of

the nonwelded tuff, and as fracture fillings in the welded tuff. They are rarely present above the water table, except in zones of perched water or paleowater tables. Zeolites are probably the most common alteration product in the tuffs of Yucca Mountain and in places may constitute more than 90 % of the rock body (Bish *et al.*, 1982; Broxton *et al.*, 1986). There is a lateral and vertical stratification of mineralogy across Yucca Mountain. For example, clinoptilolite is Ca^{2+} -rich at the top of the zeolitized zones, and Na^+ -rich at greatest depth, while heulandite occurs only locally (Bish, 1984). Lateral zeolite zonation is also present, whereby the zeolites grade from more sodic on the western side of Yucca Mountain to more calcic on the eastern side and potassic in the northern end. Variation of Ca^{2+} content may have been caused during initial zeolite formation by water from the carbonate aquifer mixing with the tuffaceous water; this does not appear to be occurring at present (Kerrisk, 1987). The abundance of zeolites increases with depth.

Smectites

Smectites are alteration products of volcanic glasses and feldspars, and are ubiquitous, although in small amounts, throughout Yucca Mountain. Dominant smectites are dioctahedral montmorillonite - beidellites with variable exchangeable Na^+ , K^+ and Ca^{2+} . Sodium is the dominant alkaline exchangeable cation in the shallow smectites, whereas deeper smectites contain subequal Na^+ , K^+ and Ca^{2+} (Bish, 1988). Interstratified illite/montmorillonite layers become common at depths greater than 1500 m, especially in the northern section of Yucca Mountain (Bish, 1988). Bish (1988) noted that chloritic interlayers are also present in the northern sections. Smectites are the major fracture filling minerals above the water table (Carlos, 1985) and have a tendency to be concentrated along structures such as major strike-slip faults (Bish and Vaniman, 1985).

Diagenetic Mineral Zones

Distribution of the diagenetic minerals falls into four zones similar to those proposed by Iijama (1980) for zeolite zonation. Broxton *et al.* (1986) applied this distribution of diagenetic minerals to Yucca Mountain, and from shallowest downward the zones are:

ZONE I : Found above the water table, this zone has substantial amounts of unaltered volcanic glass with minor heulandite and calcic clinoptilolite present locally in fractures, and incipient alteration of glass to smectite and opal in the groundmass. Some calcite is present as fillings in pumice fragments. Clinoptilolite occurs at the base of this zone in the Topopah Spring member of the Paintbrush Tuff.

ZONE II : This zone is vertically discontinuous, generally forming within the nonwelded tops and bases of the Tuff of the Calico Hills through the Crater Flat Tuff formations. Zone II is found both above and below the water table, and is postulated to be the major geologic sorptive barrier to radionuclide transport. Clinoptilolite completely replaces volcanic glass, and makes up 50-75% of the rock in the upper portions of this zone, whereas mordenite increases in abundance in the lower sections of the zone. Minor cristobalite, feldspar (Or_{99-100}) and smectite are present.

ZONE III : This zone is entirely below the water table and occurs as a continuous unit within dacite lavas and flow breccias and the Lithic Ridge Tuff. This zone is discontinuous at the tops and basal layers of members of the Crater Flat Tuff in well J-13. In Zone III, analcime progressively replaces clinoptilolite and mordenite. Some quartz and calcite are present in vugs, and smectites increase in the groundmass.

ZONE IV : This zone occurs in the lower tuff layers of the unnamed older tuff sequence. Most of the hydrologic wells of Yucca Mountain do not

penetrate to this depth. In this zone, analcime is replaced by authigenic albite. The groundmass consists of cryptocrystalline quartz and feldspar; plagioclase phenocrysts are altered to albite, calcite and illite, and sanidine phenocrysts are either unaltered or altered to orthoclase. Calcite and chlorite minerals are minor, but ubiquitous.

Figures 6 and 7 show the distribution of these zones at Yucca Mountain. Reactions occurring in Zones I and II are hydration processes, while those in Zones III and IV are dehydration processes (Moncure *et al.*, 1981).

Diagenesis is accompanied by widespread mobilization and redistribution of elements, especially the alkaline earths. Therefore, despite very similar starting compositions of the tuffs, this has resulted in a broad division of the diagenetic minerals laterally and vertically. Sodium and potassium are generally depleted in the zeolitized tuff (as compared to the non-zeolitized tuff) and enriched in calcium. The eastern side of Yucca Mountain is considered a calcic-rich suite, and the western side an alkalic-rich suite, with a potassic-rich suite in the northern end (Broxton *et al.*, 1986, and Broxton *et al.*, 1987).

Figure 6: Diagenetic mineral zones of Yucca Mountain wells UE-25 b#1 and J-13. Modified from Bish et al., 1982.

Figure 7: Diagenetic mineral zones of Yucca Mountain, Nevada. Cross section is from Scott and Bonk (1984), along Yucca Mountain crest. See Figure 6 for explanation of zones and lithology. Well data modified from Bish et al., 1982, and Vaniman et al., 1984.

GEOCHEMICAL COMPUTER MODELS

The objective of this study is to determine if there is evidence of upward ground-water flow from the Paleozoic carbonate aquifer to the volcanic tuffs through the use of geochemical models. The approach is to trace a hypothetical flow path and subsequent changes in chemistry of a ground-water solution as it passes through a tuffaceous aquifer. This hypothetical tuffaceous water is then mixed with a water sample from the carbonate aquifer, and the results compared to water samples collected from Yucca Mountain wells. The computer programs used to achieve these goals are BALANCE, WATEQDR and PHREEQE.

BALANCE (Parkhurst *et al.*, 1982) was developed to define and quantify chemical reactions between water and minerals through simultaneously solving a set of linear equations specified by the user. BALANCE is used as a check on the solutions developed after modeling the reaction path with PHREEQE. This is accomplished by mass balancing the phases precipitating or dissolving between two water samples and comparing the results to the PHREEQE mass balance. BALANCE is also used as an indicator of mixing amounts (percentages) of two waters to form a third.

The DRI uses WATEQDR (Bohm and Jacobson, 1981), which is an updated version of WATEQF (Plummer *et al.*, 1976). WATEQDR, which is short for WATER Equilibrium (DRI version), thermodynamically models the equilibrium distribution of aqueous species and ions of a given water sample. From this, states of equilibrium of the water with respect to solid phases (minerals) are calculated. These include activity coefficients, ionic activity products, saturation

indices and partial pressure of gases. WQPLOT, a subprogram of WATEQDR, constructs graphs of these parameters that describe the solution. Because the thermodynamic database of WATEQDR cannot be easily modified to include zeolites and smectites, WATEQDR is used for an initial well-by-well study of water-mineral equilibria at Yucca Mountain prior to modeling the flow path in PHREEQE, and for graphical comparisons of the modeled flow path to the well samples.

PHREEQE (Parkhurst *et al.*, 1980), which is an acronym for pH-Redox-Equilibrium-EQuations, predicts geochemical reactions based on an ion-pairing aqueous model with a thermodynamic data base that can be extensively modified by the user. This program combines the qualities of both BALANCE and WATEQDR by mass balancing solutions to minerals phases and solving the solution for various parameters. PHREEQE can be used to simulate a flow path through a tuffaceous aquifer by computing reactions involving the addition of reactants to a solution and mineral suite, and solving for mineral equilibria of the resulting solution. PHREEQE is also used to mix carbonate aquifer water with the modeled tuffaceous water in set ratios and in proportions suggested from BALANCE output. The resultant solutions from the flow path modeling and mixing are compared to the chemistry analyses from Yucca Mountain wells. A listing of the input, thermodynamic data and a sample of the output used to model the flow path and mix the resulting solution with carbonate water using PHREEQE are given in Appendix B.

WATEQDR ANALYSIS

An initial analysis of the Yucca Mountain well-water analyses was completed using WATEQDR to solve for equilibrium distribution of the species and mineral phases present. The ground water was found to be supersaturated with respect to montmorillonite, adularia, albite, cristobalite, chalcedony and quartz, and undersaturated with zeolites and calcite.

Mineral stability diagrams were first constructed for minerals likely to be present. The phase boundaries were determined using thermodynamic data from Robie and Waldbaum (1968), Helgeson (1969) and Naumov et al. (1974) (Table 5); these are the sources used in the WATEQDR thermodynamic data base.

The temperature of the Yucca Mountain ground water ranges from 22.7 °C in well UE-29 a#2 to 56.0 °C in the carbonate aquifer of well UE-25 p#1, (Benson and McKinley, 1985) (Figure 8) and may be roughly divided into two sets of data with averages of 25 °C and 37 °C, respectively. In general, wells from Forty Mile Wash are lower in water temperature than wells on Yucca Mountain. Wells USW H-3, UE-25 WT-14 and UE-25 WT-15 are exceptions to the higher temperature Yucca Mountain wells, and are grouped with the lower temperature wells. Because of the two temperature groups, the mineral stability diagrams were constructed for 25 °C and 37 °C. The temperature of 32 °C was chosen as the dividing point. Figure 8 also shows the range of $\log [\text{H}_4\text{SiO}_4]$, determined by WATEQDR, to be from -3.3 to -3.0. Because of this low range, a value of $\log [\text{H}_4\text{SiO}_4] = -3.1$ was chosen for the calculations of the phase boundaries in the mineral stability diagrams.

TABLE 5
THERMODYNAMIC DATA USED IN GROUND-WATER MODELING
AT 25 °C and 1 BAR

Formula	Mineral	ΔH_f kcal/mol	ΔG_f kcal/mol	ΔS_f cal/°K	Source
Al^{3+}	-	-127.00	-116.00	-	1
Ca^{2+}	-	-129.71	-132.18	-13.19	1
K^+	-	-60.30	-67.70	24.19	1
Mg^{2+}	-	-110.35	-108.90	-28.62	1
Na^+	-	-57.43	-62.54	14.10	1
$Al(OH)_4^-$	-	-356.19	-312.00	34.49	1
H_2O	-	-68.32	-56.69	16.71	1
H_4SiO_4	-	-348.95	-312.62	42.90	1
$Al_2Si_2O_5(OH)_4$	kaolinite	-979.46	-902.86	48.53	2
SiO_2	chalcedony	-217.28	-204.28	9.87	3
SiO_2	cristobalite	-216.93	-204.07	10.37	2
SiO_2	quartz	-217.65	-204.64	9.87	2
$CaAl_2Si_2O_8$	anorthite	-1109.30	-955.63	48.45	2
$KAlSi_3O_8$	adularia	-945.00	-892.60	63.43	2
$NaAlSi_3O_8$	albite	-934.51	-882.89	54.66	2
$CaAl_2Si_7O_{18} \cdot H_2O$	heulandite	-2527.50	-2331.43	-	3
$NaAlSi_2O_6 \cdot H_2O$	analcime	-786.34	-734.26	56.03	2
$Ca_{0.167}Al_{2.33}Si_{3.67}O_{10}(OH)_2$	Ca-montmorillonite	-1367.98	-1279.24	61.21	4
$K_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2$	K-montmorillonite	-1369.60	-1280.20	63.41	4
$Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2$	Na-montmorillonite	-1366.83	-1277.75	62.81	4
$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2 \cdot 4(H_2O)$	illite	-1391.46	-1300.98	66.44	4
$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2$	chlorite	-2127.53	-1973.54	115.44	5

Sources: 1) Naumov *et al.*, 1974
 2) Robie and Waldbaum, 1968.
 3) Helgeson *et al.*, 1978.
 4) Helgeson, 1969.
 5) Karpov *et al.*, 1971.

Figure 8: Log activity of H_4SiO_4 and temperature of Yucca Mountain, Nevada, wells. Log activity H_4SiO_4 computed by WATEQDR.

Figures 9 and 10 show the changes in mineral stability boundaries for the $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{CaO}-\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ systems, respectively, at 1 bar pressure and 25 °C and 37 °C. As the temperature increases, the stability fields of kaolinite and adularia increase, and that of K-montmorillonite decreases. There are only slight changes to the stability boundaries of Na-montmorillonite, Ca-montmorillonite and albite with the increase in temperature.

Mineral equilibria of the study area, except for Yucca Mountain, are plotted in Figures 11 and 12. Figure 11 shows the stability fields of Na-K minerals for the entire study area. At 25 °C, data lie within smectite and feldspar stability fields. Pahute Mesa (P) data (Blankennagel and Weir, 1973) have the highest Na^+/K^+ log activity ratios and thus generally plot within the Na-montmorillonite phase. Data from Amargosa Desert (A) (Claassen, 1985) are more K^+ enriched and lie within the K-montmorillonite and adularia fields. Oasis Valley (O) data (Malmberg and Eakin, 1962; White, 1979) lie between the two, are subequal in Na^+ and K^+ clays, and, assuming that the adularia field represents a more evolved flow path than do the smectite fields, are slightly more evolved along the flow path than their Pahute Mesa source.

At 37 °C, the data are stable only within the adularia mineral field. This suggests that the water samples with warmer temperatures are more evolved along the flow path than those with lower temperatures. If a flow path from Pahute Mesa to Oasis Valley to the Amargosa Desert is traced, as proposed by Winograd and Thordarson (1975), it appears that the K^+ to Na^+ log activity ratio increases along the flow path.

Mineral stability relationships of the Ca-Na diagenetic minerals (Figure 12) show that all the data plot within the Ca-montmorillonite field at both 25 °C and 37 °C. Again following a Pahute Mesa to Amargosa Desert flow path, a

Figure 9: Mineral stability relationships of $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$ system at 1 bar pressure and 25 °C and 37 °C. Thermodynamic data used to plot phase boundaries are from Robie and Waldbaum, 1968; Helgeson, 1969; and Naumov *et al.*, 1974. $\text{Log H}_4\text{SiO}_4$ is set at -3.1, computed from WATEQDR analyses.

Figure 10: Mineral stability relationships of $\text{CaO-Na}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ system at 1 bar pressure and 25 °C and 37 °C. Thermodynamic data used to plot phase boundaries are from Robie and Waldbaum, 1968; Helgeson, 1969; and Naumov *et al.*, 1974. $\text{Log H}_4\text{SiO}_4$ is set at -3.1, computed from WATEQDR analyses.

Figure 11: Sodium-potassium mineral stability relationships of wells and springs at 1 bar pressure and 25 °C and 37 °C, of study area in southern Nevada.

Location

A = Amargosa
(Clausen, 1988)

O = Oasis Valley
(Malmberg and Eskin,
1982; White, 1979)

P = Pahute Mesa
(Blankenhorn and Weir, 1975)

Figure 12: Calcium-sodium mineral stability relationships of wells and springs at 1 bar pressure and 25°C and 37°C, of study area in southern Nevada.

tendency for increasing Ca-montmorillonite stability may be seen. This may be caused by two factors: either Ca-montmorillonite is thermodynamically the most stable and kinetically the most reactive mineral, and thus Ca^{2+} is being selectively removed from solution by Ca^{2+} ion exchange into montmorillonite; or there is another source of Ca^{2+} to the ground water which would increase Ca^{2+} dominance in the minerals. These sources include the weathering of carbonate detritus, underflow of carbonate water from Bare Mountain in Oasis Valley or the regional carbonate aquifer in the Amargosa Desert.

When these Na-K-Ca mineral stability diagrams are compared to similar diagrams of Yucca Mountain well samples, it may be seen that Forty Mile Wash well samples, which are lower temperature, appear to be less evolved along a flow path, with respect to feldspar development than Oasis Valley, Amargosa Desert or other Yucca Mountain wells (Figure 13). These well data, from J-12, J-13, UE-29 a#2, UE-25 WT-14, and UE-25 WT-15, are stable within the smectite fields. One sample from well J-12 does plot in the adularia stability field; this was the first sample collected from the well, shortly after its completion. The other two J-12 samples were collected after long pumping periods. Another lower temperature well, USW H-3, is also more stable within the adularia field. At a higher temperature, 37°C (Figure 13), the Yucca Mountain wells all lie within the adularia stability field. Wells on the eastern flank of Yucca Mountain and the adjoining valley have higher $\text{K}^{+}/\text{Na}^{+}$ ratios than the wells on the ridge crest and western side. This is probably caused by the selective removal of K^{+} through the precipitation of K-minerals and/or ion exchange along the flow path.

The relationship of Na^{+} to Ca^{2+} mineral stability of Yucca Mountain water is shown in Figure 14. It may be seen that the well data at both 25°C

Figure 13: Sodium-potassium mineral stability relationships of wells at 1 bar pressure and 25 °C and 37 °C, Yucca Mountain, Nevada.

Figure 14: Calcium-sodium mineral stability relationships of wells at 1 bar pressure and 25 °C and 37 °C, Yucca Mountain, Nevada.

and 37 °C are located within the Ca-montmorillonite stability field. Again, this may be caused either by selective removal of Ca^{2+} by ion exchange in montmorillonite, or an increase in the Ca^{2+} content from input of carbonate aquifer ground water. Figure 15 suggests that the source of the Ca-montmorillonite is selective removal of Ca^{2+} , and not the addition of carbonate ground water.

Figure 15 shows the relationship of the saturation index of Ca-montmorillonite to the partial pressure of CO_2 . Along a northwest-southeast flow path in the volcanic tuffs, which is indicated by the hydraulic gradient (Robison, 1984), there is a tendency for an *increase* of Ca-montmorillonite saturation with a slight increase in P_{CO_2} . In contrast, well UE-25 p#1, which has an upward hydraulic gradient from the carbonate aquifer, shows a *decrease* in Ca-montmorillonite saturation with an increase in P_{CO_2} . Therefore, the apparent dominance of K^+ and Ca^{2+} removal by ion exchange in the montmorillonites, which in turn releases Na^+ , at Yucca Mountain agrees with the flow path evolution given by Claassen and White (1979) and White *et al.* (1980) when they proposed that montmorillonites were providing a sink for K^+ and Ca^{2+} cations within Rainier Mesa.

From the initial analysis of Yucca Mountain wells using WATEQDR, the following four points may be made:

1. Yucca Mountain ground water is supersaturated with respect to montmorillonites, illites, feldspars and quartz polymorphs.
2. The ground water is undersaturated with respect to analcime and calcite.
3. Water samples from wells in Forty Mile Wash are of low temperature and are generally stable with respect to smectites. This suggests that the water in this area is less evolved than is the water from Yucca Mountain, Oasis Valley or Amargosa Desert, and that this area may be a recharge zone.

Figure 15: Saturation index of Ca-montmorillonite compared to the partial pressure of CO_2 along a flow path at Yucca Mountain, Nevada.

4. The dominance of Na^+ in solution is from the selective removal of K^+ and Ca^{2+} through precipitation of K-feldspars and (K,Ca) ion exchange with montmorillonites.

PHREEQE GEOCHEMICAL MODEL

Geochemical Model Input

The hypothetical geochemical flow path developed in PHREEQE consisted of six zones which correlate to initial recharge through the soil and a downward travel path through the diagenetic mineral zones discussed previously. In each zone a reaction step releases ions into the initial solution to form a new solution. This new solution then interacts with specified minerals, which undergo congruent dissolution, until equilibrium is attained with the first mineral phase listed.

The ground-water flow path model of Yucca Mountain was divided into five parts that are based upon the four diagenetic mineral zones described by Broxton *et al.* (1986). Each part is characterized by a specific mineral assemblage, temperature, initial solution and reaction step that produce the final solution. The diagenetic mineral Zone II was divided into two regions in this model.

The initial solution is the chemical analysis of the starting solution from a well, soil or previous zone. Included in the solution input are chemical analyses of major ions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , SO_4^{2-} , SiO_2 , Cl^-) in mg/l, and pH, pe and temperature. In the data from Yucca Mountain wells (Benson and McKinley, 1985), no aluminum values are reported. Because aluminum is an important cation for aluminosilicate reactions, such as those involving zeolites and smectites, an Al^{3+} value of 0.047 mg/l was set for the Yucca Mountain well initial solutions. This value is derived from previous Al^{3+} analyses of wells J-11 and J-12, reported by Moore (1961). The aluminum values used in the modeled

tuffaceous flow path come entirely from the dissolution of the aluminosilicate-rich volcanic glass.

The reaction step is an ion suite or phase that was reacted with the solution and subsequent mineral phases. This phase is either the most chemically reactive phase present, such as a volcanic glass, or else composed the largest volume percentage of the rock unit, as in the case of the zeolites. In the first part of the flow path model, the reaction step is the complete dissolution of a volcanic glass, whereas in subsequent parts the reaction step is an ion exchange within zeolites and consists of ions (Na^+ , K^+ , Ca^{2+}) that are released into solution. The resultant solution formed from reactions and mineral dissolutions and precipitations in each part is used as the starting solution in the next region.

Temperature is increased with each subsequent zone, based on the assumption of increasing temperature with depth. In the initial part of the model, temperature is 25 °C, and increases to 40 °C by Part V.

The mineral assemblages used in each section are those defined by the diagenetic mineral zones of Broxton *et al.* (1986), and consists of zeolites, smectites, feldspars and quartz polymorphs. Because of limitations of the thermodynamic data base, the zeolites and smectites used are end-members, such as Na-montmorillonite, rather than mixed-cation minerals (i.e. Na-K), which would be more representative of minerals present. This results in differences between the flow path model and the actual tuffaceous system. Unfortunately, there are no mixed-cation thermodynamic data to resolve this problem and determine the amount of differences these end-members may make in the model. No sources or sinks for the anions Cl^- or SO_4^{2-} were included in the flow path model because the necessary mineral phases were either not identified in the formations or were not discussed in the literature.

In each part of the model PHREEQE, calculations are run until the first mineral in the given list reaches equilibrium. The minerals which are assumed to be at equilibrium are various polymorphs of quartz because WATEQDR analysis showed these minerals to be ubiquitous and near equilibrium in most of the Yucca Mountain wells. Formulas and thermodynamic properties of the mineral phases used by PHREEQE in the model are listed in Table 5. These data were taken from an uncritical summary published by Woods and Garrels (1987), and selected for their similarity to thermodynamic data used in WATEQ, as published by Truesdell and Jones (1974).

Geochemical Flow Path Model

The following hypothetical flow path was assumed to be the most representative model of ground-water flow through the volcanic tuffs of Yucca Mountain. Table 6 lists the properties of each modeled zone.

Part I: This domain coincides with the diagenetic mineral Zone I, as described by Broxton *et al.* (1986). This is the uppermost zone, entirely above the water table, and thus is modeled as an open system, with CO₂ exchanging freely with the atmosphere. The initial solution, considered to be from recharging soil water, is an analysis of a sample collected by Henne (1982) with a suction lysimeter on Rainier Mesa, and is considered similar to recharge at Yucca Mountain. The initial solution is sodium/calcium-rich. This solution reacts with the dissolution of volcanic glass, as described by Broxton *et al.* (1986), and the minerals cristobalite, Na-montmorillonite and heulandite. The model runs until cristobalite reaches equilibrium. At this point, Na-montmorillonite is dissolving into solution and heulandite is precipitating.

TABLE 6
TUFFACEOUS WATER CHEMISTRY ZONES MODELED IN PHREEQE

Part	Reaction	Phases	Molality	pH; log P _{CO₂} ; T
Initial Solution	Soil	Soil	Ca = 1.84×10^{-4} Mg = 8.88×10^{-5} Na = 1.37×10^{-3} K = 8.03×10^{-5} C = 1.72×10^{-3} Si = 3.99×10^{-4}	pH: 7.2 log P _{CO₂} : -2.17 T: 25 ° C
I	Dissolution of Volcanic Glass	cristobalite Na-montmorillonite heulandite log P _{CO₂}	Ca = 2.17×10^{-5} Mg = 8.88×10^{-5} Na = 1.47×10^{-3} K = 8.03×10^{-5} C = 3.57×10^{-2} Si = 2.05×10^{-4}	pH: 5.0 log P _{CO₂} : 0.00 T: 25 ° C
II	Clinoptilolite Ion Exchange 2Na:2K:1Ca (moles)	cristobalite Na-montmorillonite adularia	Ca = 5.29×10^{-3} Mg = 8.88×10^{-5} Na = 1.20×10^{-2} K = 1.06×10^{-2} C = 3.57×10^{-2} Si = 2.38×10^{-4}	pH: 7.3 log P _{CO₂} : -1.04 T: 30 ° C
III	Mordenite Ion Exchange 2Na:2K (moles)	cristobalite Na-montmorillonite K-montmorillonite adularia	Ca = 5.28×10^{-3} Mg = 8.88×10^{-5} Na = 2.97×10^{-2} K = 5.43×10^{-4} C = 3.57×10^{-2} Si = 2.90×10^{-4}	pH: 8.9 log P _{CO₂} : -2.16 T: 32 ° C
IV	Analcime Ion Exchange 6Na:2K (moles)	quartz Na-montmorillonite K-montmorillonite Ca-montmorillonite	Ca = 3.35×10^{-2} Mg = 8.88×10^{-5} Na = 1.51×10^{-5} K = 2.86×10^{-7} C = 3.57×10^{-2} Si = 5.62×10^{-4}	pH: 10.1 log P _{CO₂} : -4.56 T: 35 ° C
V	No Reaction Step	chalcedony illite chlorite adularia albite calcite	Ca = 1.57×10^{-6} Mg = 8.53×10^{-8} Na = 3.46×10^{-3} K = 1.37×10^{-5} C = 2.23×10^{-3} Si = 8.28×10^{-4}	pH: 9.5 log P _{CO₂} : -4.39 T: 40 ° C
UE-25 p#1	Lower Carbonate Aquifer	dolomite calcite chalcedony iron oxides	Ca = 2.48×10^{-3} Mg = 1.61×10^{-3} Na = 6.32×10^{-3} K = 3.07×10^{-4} C = 9.36×10^{-3} Si = 6.84×10^{-4}	pH: 6.6 log P _{CO₂} : -0.62 T: 56 ° C

* UE-25 p#1 data from Benson and McKinley, 1985.

This results in the removal of calcium from the solution, and addition of sodium. Because the system is modeled as open, the subsequent addition of CO_2 and carbonic acid lowers the pH from 7.2 to 5.0. Temperature is held constant at 25 °C.

Part II: The upper region of the diagenetic mineral Zone II is modeled as Part II of the flow path model. This zone is found both above and below the water table, therefore very little volcanic glass is present. The system is modeled as closed to atmospheric CO_2 addition, as suggested by White and Chuma (1987), because of the several hundred meter depth to the water table. The resultant solution of Part I interacts with clinoptilolite as an ion-exchange which releases one mole Ca^{2+} and two moles each Na^+ and K^+ . The reaction proceeds until equilibrium with cristobalite, Na-montmorillonite and adularia is attained, and the temperature reaches 30 °C. After reacting with these minerals, the resulting solution is enriched in Na^+ and K^+ , which are released from the clinoptilolite. Molality of Ca^{2+} increases from the previous zone, but the solution chemistry is still dominated by the monovalent cations. Adularia is dissolving at approximately twice the rate that Na-montmorillonite is precipitating. Because carbonic acid is decreasing, the pH increased to 7.3.

Part III: The lower portion of diagenetic mineral Zone II is modeled as Part III and lies entirely below the water table in all wells on Yucca Mountain. Mordenite reacts as an ion exchange by releasing two moles of Na^+ and K^+ . Other minerals present are cristobalite, Na-montmorillonite, K-montmorillonite and adularia. Temperature is increased to 32 °C. The reaction proceeds until cristobalite equilibrium is reached, at which point Na-montmorillonite is dissolving (releasing Na^+) at about the same rate

that K-montmorillonite is precipitating (removing K^+). This apparent end-member dissolution and precipitation is probably a simple ion exchange of K^+ for Na^+ , rather than complete mineral formation. The resultant solution is greatly enriched in Na^+ and Ca^{2+} , and depleted in K^+ . The pH increases to 8.9.

Part IV: This part contains quartz, analcime and the (Na,Ca,K) end-member montmorillonites found in the diagenetic mineral Zone III. Analcime releases six moles Na^+ and two moles K^+ into the final solution from Part III. Ca is exchanging for Na in montmorillonite in subequal quantities: subsequently, the resulting solution becomes Ca^{2+} -rich, and depleted in Na^+ and K^+ . The pH increases to 10.1.

Part V: The solution in this part reacts equally with all minerals present, because the diagenetic mineral Zone IV as described by Broxton *et al.* (1986) has few zeolites, compared to other minerals. The final section is modeled instead with no specific reaction step, such as ion exchange, occurring. The original volcanic mineralogy of Zone IV has been replaced by secondary chalcedony, illite, chlorite, adularia, albite and calcite. After interaction with this mineral suite, the temperature increases to $40^\circ C$, the resulting solution becomes Na^+ -rich, with K^+ and Ca^{2+} subequal, and depleted in Mg^{2+} . Chalcedony, illite and calcite are precipitating, and chlorite and the feldspars are dissolving. The pH decreases to 9.5, and the partial pressure of CO_2 is -4.4.

Geochemical Modeling Results

The objective of the geochemical modeling is to construct a theoretical flow path that will describe the chemical changes in a ground water solution as it traveled through a tuffaceous aquifer.

The initial soil water input into the model is an Na^+ - Ca^{2+} -rich solution with a pH of 7.2. Along the flow path, the solution reacted with the dissolution of volcanic glass, and ion exchange of Na^+ - K^+ - Ca^{2+} with zeolites and smectites. Because of the great depth to the water table, except for the first zone, the system is modeled as closed to atmospheric exchange; subsequently, the P_{CO_2} decreases and pH increases along the flow path. In the final zone, Part V, the reaction with calcite adds a minor amount of CO_2 to the system. The most reactive minerals are the smectites, zeolites and feldspars, and the solution becomes alternately either Na^+ - or Ca^{2+} -rich, dependent upon the mineral stabilities. By the final zone, Part V, the solution is Na^+ -rich, with subequal amounts of Ca^{2+} - K^+ , and is depleted in Mg^{2+} . Chalcedony, illite and calcite are precipitating, and chlorite and feldspars are dissolving.

Graphical analyses of the data show the differences between the modeled zones and the samples from the Yucca Mountain wells (Figures 16 and 17). The initial input, from the Rainer Mesa soil (Henne, 1982) is very similar in chemical composition to the Yucca Mountain wells. In the next four zones, the ionic concentration increases in the solution, especially Ca^{2+} , are the greatest difference between the model and Yucca Mountain well samples. The large amount of mineral reactions, coupled with no reaction step, removes the majority of the ions from the solution in Part V. The concentration of the ions in solution decreases from nearly 40 equivalents per million (EPM) to less than 6 EPM, which is similar to the Yucca Mountain samples (Figures 16 and 17).

Figure 16: Chemical analyses of geochemical flow path modeled zones in volcanic aquifers at Yucca Mountain, Nevada. Scale is to 60 EPM.

Figure 17: Chemical analyses of Yucca Mountain wells, Part V modeled zone and carbonate wells surrounding Yucca Mountain, Nevada. Scale is to 12 EPM.

The STIFF diagrams of Figure 17 show differences between the Yucca Mountain wells and some of the carbonate wells of the NTS. The carbonate wells show a distinct pattern of $\text{Ca}^{2+} + \text{Mg}^{2+} > \text{Na}^+ + \text{K}^+$. The opposite is true of the Yucca Mountain wells; Part V of the modeled zone follows the latter pattern. Because of this pattern, and low ionic concentration, Part V was selected as the most representative of a volcanic water at Yucca Mountain.

When the results of the modeled Part II - Part V are plotted on mineral stability diagrams (points 2-5, Figures 18 and 19), the increase in the cation concentration along the modeled flow path is again visible. The large input of calcium and subsequent decrease in sodium concentration in Part IV is the result of Na^+ ions substituting into the montmorillonite molecule for Ca^{2+} ions. This release of extra Ca^{2+} ions makes the solution very calcium rich, and the data for Part IV plot off the scale in Figure 19. With no ion-exchange cation input occurring in Part V, the resultant mineral reactions tend to remove the excess Ca^{2+} and bring the cation concentrations to a more reasonable level. Overall, the solution modeled in Part V is most similar to well USW H-3 (point H, Figures 18 and 19). Part V is also similar to another high pH well, USW WT-10, with respect to pH and saturation indices of minerals (Table 7).

When pH, constituent molalities, ionic log activity and saturation indices of minerals from the five zones are compared, Part V again is most similar to Yucca mountain samples (Tables 6 and 8). While the other modeled zones may be similar to the Yucca Mountain wells in one parameter (i.e., pH or SI of a mineral phase), differences arise when all the parameters are compared. The greatest difference appears to be in pH and calcite saturation. Most of the Yucca Mountain well analyses are lower in pH and calcite saturation than what the modeled zones predict. This is a problem with the proposed flow path model which is probably caused by the way the ion-exchanged elements, CO_2 , and

Figure 18: Sodium-potassium mineral stability relationships of flow path model compared to Yucca Mountain, Nevada, wells at 1 bar pressure and 25 °C and 37 °C.

Figure 19: Calcium-sodium mineral stability relationships of flow path model compared to Yucca Mountain, Nevada, wells at 1 bar pressure and 25 °C and 37 °C. Part IV (symbol 4) plots off scale at $\log \text{Ca}/\text{H}^2 = 22.2$ and $\log \text{Na}/\text{H} = 5.17$.

TABLE 7
ANALYSES OF WATER TABLE WELLS ON
YUCCA MOUNTAIN, NEVADA

	USW WT-7	USW WT-10	UE25 WT-12	UE25 WT-14	UE25 WT-15
pH	8.7	8.4	7.6	7.3	7.5
T (°C)	34	40	34	31	28
(molality)					
Ca	6.5×10^{-5}	6.8×10^{-5}	3.5×10^{-4}	3.5×10^{-4}	2.9×10^{-4}
Mg	7.4×10^{-6}	2.9×10^{-6}	1.6×10^{-6}	3.2×10^{-6}	7.0×10^{-6}
Na	4.2×10^{-3}	4.1×10^{-3}	2.8×10^{-3}	1.8×10^{-3}	2.9×10^{-3}
K	5.3×10^{-6}	2.9×10^{-6}	5.9×10^{-6}	1.4×10^{-4}	1.2×10^{-4}
Log P _{CO2}	-3.27	-3.01	-2.31	-2.18	-2.08
SI calcite	0.15	-0.13	-0.31	-0.77	-0.41
SI quartz	0.35	0.66	0.39	0.89	0.89
SI Na mont.	-0.46	3.15	1.78	4.32	4.19
SI analcime	-3.30	-1.78	-3.41	-2.58	-2.38

TABLE 8
COMPARISON OF YUCCA MOUNTAIN WELL ANALYSES TO
PHREEQE FLOW PATH MODEL: HYDROCHEMICAL
PART V ANALYSIS

	Part V	USW H-3	USW H-3*	USW H-1	USW H-4	UE-25 b#1
pH	9.5	9.2	7.1	7.7	7.4	7.1
T (°C)	40	26	45	33	35	37
(molality)						
Ca	1.5×10^{-5}	1.9×10^{-5}	7.9×10^{-4}	1.1×10^{-4}	4.2×10^{-4}	4.5×10^{-4}
Mg	8.0×10^{-6}	-	5.1×10^{-4}	4.1×10^{-6}	1.2×10^{-5}	2.9×10^{-5}
Na	3.4×10^{-3}	5.2×10^{-3}	4.4×10^{-3}	6.6×10^{-3}	3.2×10^{-3}	2.0×10^{-3}
K	1.4×10^{-5}	2.8×10^{-5}	1.1×10^{-4}	1.7×10^{-6}	6.6×10^{-5}	7.2×10^{-5}
Log P _{CO2}	-4.60	-3.85	-1.49	-0.89	-2.10	-1.87
SI calcite	-0.14	-0.08	-0.19	-2.59	-0.42	-0.73
SI quartz	0.43	0.75	0.61	0.77	0.74	0.75
SI Na mont.	1.49	1.50	6.32	4.08	4.25	4.65
SI analcime	-1.67	-1.94	-1.48	-1.89	-2.32	-2.52

* Modeled USW H-3 as suggested in BALANCE: 51% Part V and 49% carbonate aquifer.

Yucca Mountain well data from Benson and McKinley, 1985.

mineral suites were interacting. Further modifications on these zones would be necessary to overcome these problems. The solution modeled in Part V appears most similar to wells with high pH, and is most similar in terms of molality to Yucca Mountain well analyses than are the other zones. Therefore, the solution modeled in Part V is used as the representative solution of tuffaceous water when mixing carbonate water with the tuffaceous water.

MIXING MODELED VOLCANIC AND CARBONATE WATERS

After the geochemical evolution of the water along the hypothetical flow path through the tuffaceous aquifer has been established, the resultant solution is computationally mixed with water from the 1297 to 1805-meter interval of well UE-25 p#1, which is assumed to be representative of water from the Paleozoic carbonate aquifer in the Yucca Mountain area. This is to determine if the Yucca Mountain wells could be a mixture of tuffaceous and carbonate waters. The mixing problem is approached through two methods: 1) modeling specific Yucca Mountain wells using both BALANCE and PHREEQE; and 2) a general comparison of all Yucca Mountain wells to solutions modeled in PHREEQE from the mixing of the hypothetical tuffaceous water together with the carbonate aquifer water in set ratios.

Modeling Specific Wells

Ten Yucca Mountain wells were chosen for more intensive studies to determine the possibility of mixing between the carbonate and tuffaceous aquifers.

To find approximate mixing ratios between the hypothetical volcanic water and the carbonate water needed to produce a solution similar to an actual well on Yucca Mountain, the waters are first mixed using the computer program BALANCE. In this program, a sample analysis from a Yucca Mountain well is entered along with the analyses of carbonate water, a solution from one of the modeled zones and a mineral suite which is expected to be present. From these

analyses, BALANCE suggests a mixing ratio between the carbonate and modeled volcanic water necessary to produce the given well sample analysis and saturation indices of the minerals present. During this BALANCE modeling, a potential problem arose which affected the outcome of the BALANCE model. Because several different mineral phases could be used as sources or sinks for ions, the specific mineral suite used made a great difference in the final mixing ratio between the two input waters. When the mineral suite used is similar to the diagenetic minerals present around the screened interval of the well, the resultant mixed solution is similar to the well sample. However, when the specified mineral suite used was composed of minerals found in a different zone than that near the screened interval, BALANCE would suggest a mixing ratio that did not match the actual well sample. Therefore, care had to be taken during the literature review of the published well logs to determine the minerals most likely to be present.

Because BALANCE runs through a mass balance of molalities, and thus might suggest solutions which are thermodynamically impossible, the modeled volcanic zone solution and carbonate water are next mixed together using PHREEQE. Using the ratios suggested by BALANCE, the hypothetical tuffaceous and carbonate aquifer waters are titrated together and the resulting solution solved by PHREEQE for mineral equilibria and molality. The actual sample from the well is also solved in PHREEQE for mineral equilibria, and compared to the results of the mixing model.

Modeling Specific Wells Results

The Yucca Mountain wells listed below were chosen for individual modeling attempts. They are the water table (WT) wells sampled during this study, and the wells in which previous studies have indicated an upward flow gradient.

UE-25 p#1	UE-25 b#1	USW WT-10	UE-25 WT-15
USW H-3	USW H-4	UE-25 WT-12	
USW H-1	USW WT-7	UE-25 WT-14	

Results from Well UE-25 p#1

For the first modeling effort, the well UE-25 p#1 was chosen because the upward gradient in this well has been documented hydrologically and geochemically by previous authors (Craig and Robison, 1984). To find the approximate mixing ratios between the carbonate aquifer and hypothetical tuffaceous waters, volcanic aquifer and carbonate aquifer sample analyses from well UE-25 p#1 (Benson and McKinley, 1985) were entered into a BALANCE program along with the analysis of Part V water, and a mineral suite consisting of albite, adularia, illite, quartz and calcite. Through a mass balance of these analyses, BALANCE suggested that the volcanic water sample from UE-25 p#1 was a mixture of 68% Part V water and 32% water from the carbonate aquifer. This agrees fairly closely to the 28.6 % carbonate water influence suggested by Craig and Robison (1984, p.49) from a borehole flow study.

The next step was to mix the hypothetical tuffaceous water and the carbonate aquifer water to determine if the ratio suggested in BALANCE was thermodynamically correct with respect to the actual volcanic water sample from UE-25 p#1. The two water types were titrated together using PHREEQE, and the resulting solution, 68% Part V and 32% carbonate aquifer water, solved for mineral equilibria. This modeled mixed solution was compared to the volcanic sample from UE-25 p#1, and the results given in Table 9.

The modeled UE-25 p#1 volcanic water and the actual UE-25 p#1 volcanic waters were similar in pH, P_{CO_2} , molalities of their elements and saturation indices. The waters were both supersaturated with respect to montmorillonites, heulandite and illite, and undersaturated with respect to

TABLE 9

COMPARISON OF UE-25 p#1 SAMPLE ANALYSIS TO UE-25 p#1
FROM FLOW PATH MIXING MODEL USING PHREEQE

Mineral	UE-25 p#1 (modeled) ¹ Log Saturation Index	UE-25 p#1 (sampled) ²	Element	UE-25 p#1 (modeled) ¹ Molality	UE-25 p#1 (sampled) ²
calcite	-0.191	-0.381	pH	7.1	6.8
Log P _{CO₂}	-1.490	-1.218	T ° C	45.1	44.3
chalcedony	0.202	0.229	Ca	7.99 x 10 ⁻⁴	9.23 x 10 ⁻⁴
cristobalite	0.325	0.353	Mg	5.11 x 10 ⁻⁴	4.12 x 10 ⁻⁴
quartz	0.611	0.640	Na	4.37 x 10 ⁻³	4.00 x 10 ⁻³
chlorite	0.322	-5.114	K	1.07 x 10 ⁻⁴	1.43 x 10 ⁻⁴
illite	4.293	1.563	Fe	5.66 x 10 ⁻⁶	1.74 x 10 ⁻⁶
Na-mont.	6.322	3.703	Al	2.24 x 10 ⁻⁶	-
K-mont.	6.307	3.745	Si	7.83 x 10 ⁻⁴	8.16 x 10 ⁻⁴
Ca-mont.	5.300	2.707	Cl	3.47 x 10 ⁻⁴	3.67 x 10 ⁻⁴
analcime	-1.458	-2.846	C	5.11 x 10 ⁻³	4.62 x 10 ⁻³
heulandite	11.906	9.379	S	5.42 x 10 ⁻⁴	3.96 x 10 ⁻⁴
adularia	1.108	-0.072	F	7.87 x 10 ⁻⁶	1.79 x 10 ⁻⁶
albite	0.379	-0.976	Li	2.71 x 10 ⁻⁶	3.31 x 10 ⁻⁶

¹ UE-25 p#1 modeled: 68% Part V solution and 32% carbonate aquifer water.

² UE-25 p#1 sample: From Benson and McKinley, 1985.

analcime, calcite and CO_2 . There was a difference between the two analyses in the saturation indices of chlorite and the feldspars, which was probably a function of Mg^{2+} concentration, and the manner in which the minerals were equilibrated in PHREEQE. When plotted on mineral stability diagrams (Figures 18 and 19), the modeled volcanic UE-25 p#1 (X) plotted very close to the actual UE-25 p#1 volcanic sample (P). Therefore, this modeled volcanic UE-25 p#1 solution may be considered fairly representative of processes occurring in the well UE-25 p#1.

Results From Wells USW H-3 and USW H-4

The next modeling attempts were with two other wells in which temperature and isotopic data have indicated upward flow gradients. The anomalously enriched $\delta^{13}\text{C}$ values of -4.9 ‰ (Benson and McKinley, 1985) from well USW H-3 indicated the possibility of upward flow from the carbonate aquifer. The problem in BALANCE of using the correct mineral suite, discussed previously, appeared in this model. When the mineral suite was from diagenetic mineral Zone IV, (feldspars, illite, quartz and calcite), the suggested ratio of Part V to carbonate water necessary to produce the USW H-3 water sample was 51 % to 49 %, respectively. However, when this ratio was mixed using PHREEQE, the resulting solution was very dissimilar to the USW H-3 sample (Table 8). In Figures 18 and 19 it may be seen that the log activity ratios of the 51/49 mixture flow model (O) lies far from the log activity of USW H-3 (H). In both Figures, the actual data from USW H-3 has greater log activities of Na^+ , K^+ and Ca^{2+} than the 51/49 mix model did. As stated previously, in terms of pH, molalities and saturation indices of mineral phases, USW H-3 more resembled the Part V solution.

Well USW H-4, when modeled in BALANCE with a suite of minerals from Zone IV, indicated a possibility of being 3.4% water from the carbonate aquifer, and 96.6% from modeled Part V. However, when this mixture was equilibrated with PHREEQE, the pH, molalities and SI of the minerals did not match those for the USW H-4 well water sample. The low percentage of carbonate water is within the range of standard deviation error of the BALANCE computations, and may not actually show a carbonate water component.

Mixing Tuffaceous and Carbonate Waters in Set Ratios

The next approach to the mixing problem is to titrate a set percentage of carbonate aquifer water into the hypothetical tuffaceous water from one of the modeled zones, using PHREEQE, and solve the resulting solution for mineral equilibria and solution composition.

The geochemical solution modeled in Part V, was chosen as being most representative of ground water found in a tuffaceous environment. This water is mixed with carbonate aquifer water from well UE-25 p#1 in the following ratios: 100-0; 95-5; 90-10; 80-20; 70-30; and 60-40 percent modeled tuffaceous to percent carbonate water, respectively.

The results from these mixtures were compared to the Yucca Mountain wells through comparison of molalities and saturation indices calculated by PHREEQE (Tables 7, 8, and 10). In addition, the log activity of major cations were plotted on mineral stability diagrams using WQPLOT for graphical comparisons in Figures 18 and 19.

TABLE 10
PHREEQE ANALYSES OF MIXING PART V TUFFACEOUS
SOLUTION WITH CARBONATE AQUIFER WATER

Mix Ratio*:	95/5	90/10	80/20	70/30	60/40
pH	9.2	8.8	7.6	7.1	6.9
T (°C)	40	41	43	45	46
(molality)					
Ca	1.4×10^{-4}	2.6×10^{-4}	5.1×10^{-4}	7.5×10^{-4}	1.0×10^{-3}
Mg	8.0×10^{-5}	1.6×10^{-4}	3.2×10^{-4}	4.8×10^{-4}	6.4×10^{-4}
Na	3.6×10^{-3}	3.8×10^{-3}	4.0×10^{-3}	4.3×10^{-3}	4.6×10^{-3}
K	2.8×10^{-5}	4.3×10^{-5}	7.2×10^{-5}	1.0×10^{-4}	1.3×10^{-4}
Log P _{CO₂}	-4.08	-3.57	-2.17	-1.55	-1.28
SI calcite	0.71	0.79	0.09	-0.18	-0.18
SI quartz	0.53	0.60	0.64	0.61	0.59
SI Na mont.	2.42	3.27	5.61	6.30	6.25
SI analcime	-1.46	-1.35	-1.32	-1.43	-1.58

* Mixing Ratio: Part V/Carbonate

Mixing In Set Ratio Results

The remaining Yucca Mountain wells which were compared to the theoretical flow path and mixing model were generally near-neutral pH wells. In this respect they did not resemble the higher pH modeled Part V water (Tables 7 and 8). However, when comparing the models of mixed carbonate/tuffaceous waters to these Yucca Mountain wells, there was a similarity (A-E, Figures 18 and 19), especially with the mixing ratios from 80/20 to 60/40 (C,D,E). This would seem to indicate either:

- 1) a great volume of upward flow from the carbonate aquifer into the volcanic tuffs;

or that

2) the geochemical model is not representative of all the volcanic wells on Yucca Mountain, thus giving erroneous results. This is an inherent problem of taking a relatively complex system such as that found at Yucca Mountain and over-simplifying it in the geochemical model.

Based upon the literature, the WATEQDR analyses discussed previously, and isotope analyses in the next section, it is believed that the similarity of volcanic/carbonate water mixtures to the Yucca Mountain well analyses is due to the initial Part V water not being representative of all the wells completed in volcanic terrain on Yucca Mountain. When these mixing models were analyzed for element molalities and saturation index of calcite, it was seen that they were higher in calcium and magnesium than the actual well samples, and supersaturated with calcite (Table 10), which was not likely to occur in the Yucca Mountain wells. Based upon the WATEQDR results, which show definite differences in montmorillonite saturation with increasing P_{CO_2} between carbonate and volcanic wells (Figure 15), and $\delta^{13}C$ isotope analyses in the following section, (p. 91 and Figure 22) which indicate no marine carbonate influence, it appears unlikely that large volumes of carbonate-type ground water are entering the tuffaceous zones. The mixed zones may resemble the Yucca Mountain wells, especially those with nearly neutral pH, because the initial Part V solution may have too high a pH to accurately represent the ground water in the volcanic rocks. The solution from Part V does appear to model higher pH wells, such as USW H-3 and USW WT-10. Therefore, rather than assume that the wells are greatly influenced by the carbonate aquifer, it would be desirable to further refine the modeled flow path through the tuffaceous aquifer to represent lower pH wells.

ENVIRONMENTAL ISOTOPES

Environmental isotopes are a means of fingerprinting and tracing waters in the hydrologic cycle. Some of their uses include determining the origin (location, age, recharge process) and history (mixing, discharge process) of the water. The environmental isotopes collected in this study were the isotopes of oxygen, hydrogen and carbon.

Environmental isotope values are expressed in δ as units "per mil" ($^{\circ}/\infty$) units. The δ value is a ratio of the isotope value to the international Standard Mean Ocean Water (SMOW) and is found by the formula:

$$\delta = \left(\frac{R_x - R_{std}}{R_{std}} \right) \times 10^3$$

where R_x = isotope ratios of heavy over light;

and R_{std} = corresponding ratio in the standard (SMOW)

(Fritz and Fontes, 1980).

Deuterium and ^{18}O Oxygen

The three stable isotopes of oxygen (^{16}O , ^{17}O , ^{18}O) were discovered in 1929 by Giaugue and Johnson (Gat, 1980); ^{18}O makes up 0.1 % of these (Fritz and Fontes, 1980). Deuterium (D), a stable isotope of hydrogen, was discovered by Urey in 1932 (Gat, 1980) and composes just 0.015 % of the hydrogen isotopes (^1H , D, ^3H) (Fritz and Fontes, 1980).

The initial source of water vapor is the ocean, where $\delta^{18}\text{O}$ and δD values are, by definition, 0.0 $^{\circ}/\infty$. As the water vapor is transported away from the

ocean source, the δ value of the isotopes is controlled by fractionation, a temperature dependent process whereby either lighter or heavier isotopes are selectively removed from a liquid or vapor. This process occurs through equilibrium fractionation (Rayleigh distillation), and nonequilibrium fractionation through molecular kinetic processes (the 'raindrop effect') during phase changes such as evaporation and condensation.

Once below the evaporation zone, recharging ground waters generally do not undergo phase changes. Therefore, oxygen and hydrogen isotopes do not experience further fractionation and may be considered to be conservative in the flow system. Exceptions to this may occur during diagenetic mineral formation or within limestone aquifers where exchange with calcite may cause a shift towards heavier $\delta^{18}\text{O}$ values (Clayton *et al.*, 1966). During alteration of volcanic rocks to smectites, feldspars and zeolites, mineral precipitation may remove the heavier isotopes of oxygen, causing a slight depletion of $\delta^{18}\text{O}$ values (Lawrence and Taylor, 1971; Lawrence *et al.*, 1979). A significant $\delta^{18}\text{O}$ depletion requires very slow ground-water movement and a low water/rock ratio (Drever, 1982), a condition which is not found in most aquifers. However, due to the thick unsaturated zone present at Yucca Mountain, very slow matrix flow may provide these conditions. Because of a lack of data on this subject at Yucca Mountain, the quality of conservativeness of the isotopes was assumed. It is a combination of this conservativeness and the relative scarceness of these isotopes that makes them so useful as ground-water tracers.

Previous authors have discussed the deuterium and oxygen isotopic compositions of the waters surrounding Yucca Mountain. Claassen (1985) found the δD and $\delta^{18}\text{O}$ values of Amargosa Desert ground water to be depleted compared to Yucca Mountain; this he attributed to colder climate conditions

during recharge 10,000 to 15,000 years B.P. Using environmental isotopes, White and Chuma (1987) concluded that Oasis Valley ground water is a mixture of underflow from Pahute Mesa and recharge in the nearby Bullfrog Hills.

Ingraham *et al.* (1989) studied five years of precipitation and spring $\delta^{18}\text{O}$ and δD data from the NTS and suggested that the local meteoric water line was $\delta\text{D} = 6.87 \delta^{18}\text{O} - 6.5$, which was slightly $\delta^{18}\text{O}$ enriched from the Craig (1961) global meteoric water line. From this study, they suggested that White Rock and Cane Springs, two NTS springs which issue from perched water in volcanic rock, had recharge travel paths of less than one year. Summer recharge from high intensity thundershowers was hypothesized to be the fastest recharge, occurring along fractures. Winter precipitation was thought to contribute a larger, more steady recharge by both fracture and matrix flow. An enrichment of $\delta^{18}\text{O}$ isotopes in the spring samples was thought to have been caused through fractionation brought about by evaporation.

In Figure 20, the $\delta^{18}\text{O}$ and δD analyses from the water table (WT) wells sampled for this study are plotted along with Yucca Mountain samples (McKinley and Benson, 1985). Kerrisk (1987) and Matuska (1989) found that Yucca Mountain well waters (except for USW H-3) were slightly δD depleted from the proposed local meteoric water line (Ingraham *et al.*, 1989), and the Craig (1961) global meteoric water line, which is indicative of closed basins (Drever, 1982). Kerrisk also found that water samples in Forty Mile Wash (J-12, J-13, UE-29 a#2) were slightly more enriched in terms of $\delta^{18}\text{O}$ and δD , which he proposed were waters originating as precipitation at higher temperatures or lower elevations. Most of the Forty Mile Wash wells lie on or very near to the proposed local meteoric water line (Ingraham *et al.*, 1989), and at a more enriched position than the other Yucca Mountain wells, which might suggest relatively recent recharge which has undergone evaporation, similar to the

Figure 20: Delta deuterium and delta ¹⁸Oxygen values of Yucca Mountain, Nevada, wells.

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scenario they proposed for White Rock and Cane Springs.

Water table wells UE-25 WT-14 and UE-25 WT-15, located a few kilometers to the west of Forty Mile Wash, show isotopic signatures similar to Forty Mile Wash wells. UE-25 WT-15 appears almost identical in terms of $\delta^{18}\text{O}$ and δD , to J-12 and J-13, while UE-25 WT-14 shows an even greater $\delta^{18}\text{O}$ enrichment. Wells UE-25 b#1 and USW H-3 also show slight enrichment, suggesting different recharge sources than the other Yucca Mountain wells. The isotope enrichment may be due to $\delta^{18}\text{O}$ and δD shifts in precipitation, as Kerrisk suggests, or evaporation, as Ingraham *et al.* suggest, or perhaps the isotopic signature of the ground water is being affected through exchange with CaCO_3 of the caliche layers as suggested by Clayton *et al.* (1966). During the length of time required for CaCO_3 exchange to significantly change $\delta^{18}\text{O}$, it appears the soil water would be removed through evapotranspiration rather than recharging the ground water. Another possibility is water is recharged quickly to the subsurface along fractures, as suggested by Waddell *et al.* (1984), and encounters calcite coatings on the fracture walls or caliche layers in the thick vadose zone.

Carbon Isotopes

The stable carbon isotope, ^{13}C , is useful in ground-water studies as an indicator of the path of the carbon cycle. Carbon-13 makes up about 1.11% of carbon isotopes, and the varying $\delta^{13}\text{C}$ values reflect changes CO_2 undergoes along the flow path. Each CO_2 source has a distinctive $\delta^{13}\text{C}$ value, from vegetation $\delta^{13}\text{C}$ being most depleted, to marine limestone $\delta^{13}\text{C}$ being most enriched (Table 11). Sources of $\delta^{13}\text{C}$ in ground water are (Salomons and Mook, 1980; Drever, 1982):

TABLE 11
 $\delta^{13}\text{C}$ SIGNATURES OF CO_2 SOURCES

CO_2 Source ¹	$\delta^{13}\text{C}$ (‰)
Carbonate Rock	-2 to +2
Caliche ²	-7.9 to -4.6
Atmosphere CO_2	-9 to -7
Soil Water ³	-13.1 to -11.1
CAM vegetation ⁴	-25 to -14

¹ $\delta^{13}\text{C}$ values from Fritz and Fontes, 1980.

² Nevada Test Site caliche values from Boughton, 1986.

³ Oasis Valley soil water from White and Chuma, 1987.

⁴ Crassulaceae Acid Metabolism vegetation; i.e., drought resistant plants, see note 1.

- 1) introduction of CO_2 gas from the atmosphere ($\delta^{13}\text{C}$ light).
- 2) dissolution of carbonates by action of CO_2 ($\delta^{13}\text{C}$ heavy);
- 3) dissolution of organic matter ($\delta^{13}\text{C}$ light);
- 4) weathering of silicate minerals ($\delta^{13}\text{C}$ light);

Carbon-14, the radioactive isotope of carbon, has a half-life of 5,730 years and is used in age-dating ground waters. Percent modern carbon (PMC) is a measure of the ^{14}C content expressed as a percentage of the standard ^{14}C from an 1890 wood grown in an environment free of fossil fuel CO_2 (Fritz and Fontes, 1980) and can be used to determine apparent relative ages of ground waters. Carbon, which is in equilibrium with the atmosphere, will have PMC values of 100% (or greater, due to contamination by atomic testing); carbon, which is

isolated from the atmosphere for long periods of time, will have PMC values near zero (Fritz and Fontes, 1980).

Recently recharged ground water will have relatively depleted $\delta^{13}\text{C}$ values due to the input from the atmosphere, soil water, vegetation and caliche. Correspondingly, the PMC of these waters should be high. Water that has had contact with a limestone formation will show enrichment of $\delta^{13}\text{C}$ values along a flow path, and may have either high or low values of PMC, depending upon the length of the flow path. Water from the regional carbonate aquifer underlying the Yucca Mountain study area should generally show enriched $\delta^{13}\text{C}$ values and very low PMC.

Figures 21 and 22 show the relationship of PMC to $\delta^{13}\text{C}$ values for the study area and Yucca Mountain, respectively. In Figure 21, Pahute Mesa (P) wells (Boughton, 1986; White and Chuma, 1987) show low values of PMC combined with very light $\delta^{13}\text{C}$ values, similar to CAM vegetation values. This could indicate either mixing of older ground water with more recent recharge, or simply be a ground water that has been removed from the atmosphere for a long time. There is no isotopic evidence for influence from carbonate aquifer waters at Pahute Mesa.

Oasis Valley (O) ground waters (White and Chuma, 1987) show a wide range of PMC values, from less than 10% to fully modern, and $\delta^{13}\text{C}$ are values very close to atmospheric. This indicates a system open to CO_2 exchange with the atmosphere, in which older ground waters are mixing with more recent recharge. Based upon $\delta^{13}\text{C}$ values, Amargosa Desert (A) ground waters (Claassen, 1985) are probably open to atmospheric CO_2 , however, they generally appear to be older (PMC < 30%) than the Oasis Valley waters. Both Oasis Valley and Amargosa Desert waters show a trend of increasing $\delta^{13}\text{C}$ with decreasing PMC, indicating the influence of older water, most likely from the

Figure 21: Delta ¹³Carbon as a function of percent modern carbon of study area wells and springs in southern Nevada.

regional carbonate aquifer.

In Figure 22, the Yucca Mountain wells (Benson and McKinley, 1985) show two trends in PMC relationships: a flow path with high PMC, present in Forty Mile Wash; and a flow path with lower PMC, found in the other Yucca Mountain wells. Wells in Forty Mile Wash (J-12, J-13, UE-29 a#2) have higher PMC values and depleted $\delta^{13}\text{C}$, which correlates well with $\delta^{18}\text{O}$ and δD data which indicated a more recent recharge (Kerrisk, 1987). However, wells UE-25 WT-14 and UE-25 WT-15, which were similar in $\delta^{18}\text{O}$ and δD to J-12, J-13 and UE-29 a#2, show much lower PMC values, which indicates an older ground water than in Forty Mile Wash.

Along a flow path based upon hydraulic gradients (Robison, 1984), there is a general trend for increasing $\delta^{13}\text{C}$ with decreasing PMC. This could be due to mixing of older waters with more recent recharge. USW H-6, which is upgradient of the majority of the Yucca Mountain wells shows a low PMC value and $\delta^{13}\text{C}$ values close to atmospheric values. This could indicate mixing between older water and more recent waters, perhaps along the Solitario Canyon fault. The relatively depleted $\delta^{13}\text{C}$ values of wells UE-25 WT-14, UE-25 WT-15, USW H-1 and, to a lesser extent, UE-25 b#1 and USW H-5, which place the data outside the general trend of the flow path, fall within the $\delta^{13}\text{C}$ range of soil water and CAM vegetation given in Table 11. Of these five wells, three are proximate to major faults: UE-25 b#1 and USW H-1 along Drill Hole Wash fault; and UE-25 WT-14 near Paintbrush Canyon Fault (Figure 2). This indicates that these faults may be conduits for recharge, which agrees with Waddell *et al.* (1984) suggestion of pulse recharge through open fractures. This also agrees with the $\delta^{18}\text{O}$ and δD analyses.

Three samples (USW H-3, UE-25 p#1 volcanic and carbonate), show $\delta^{13}\text{C}$ signatures similar to carbonate waters ($\delta^{13}\text{C}$ near $-2^\circ/\infty$). An upward gradient

Figure 22: Delta ^{13}C Carbon as a function of percent modern carbon of Yucca Mountain, Nevada, wells. Flow paths from potentiometric data of Robison, 1985.

from the carbonate aquifer to the tuffaceous aquifers has been documented hydrologically in well UE-25 p#1, therefore enriched $\delta^{13}\text{C}$ values might be expected. However, USW H-3, a well completed in the tuffs on the crest of Yucca Mountain, is anomalously enriched compared to the other Yucca Mountain wells. From these data it may appear that there is some influence of carbonate ground water in this well. However, geochemical analysis of this well, discussed in the previous geochemical modeling sections, shows no influence from the carbonate aquifer. This anomalous $\delta^{13}\text{C}$ value could be caused by more recent recharge waters, perhaps along fractures, which have passed through an enriched $\delta^{13}\text{C}$ caliche zone. In studies of caliche zones in soil on the NTS, Boughton (1986) found that waters had heavier $\delta^{13}\text{C}$ than the soil-gas samples, indicating the influence of another factor such as caliche. In addition, well USW H-3 has $\delta^{18}\text{O}$ and δD values which are very similar to modern precipitation (Figure 20), a further indication of more recent recharge.

SUMMARY AND CONCLUSIONS

The purpose of this study was to further define the possibility of upward flow from the regional carbonate aquifer into the overlying Tertiary volcanic tuff aquifer, using a variety of isotopes and geochemical modeling techniques.

Conclusions From WATEQDR Analysis

Initial computer modeling of the study area wells was conducted using WATEQDR to construct mineral stability diagrams of Na-K and Ca-Na minerals at 25 °C and 37 °C. Data from the wells lie within smectite stability fields at lower temperatures, while those at higher temperatures lie within the K-feldspar fields. A flow path from Pahute Mesa to Oasis Valley to Amargosa Desert, as first suggested by Winograd and Thordarson (1975), shows an increase of K-montmorillonite, K-feldspar and Ca-montmorillonite precipitation along the flow path. This could be caused by either the thermodynamics of the system being most conducive for K^+ and Ca^{2+} ion exchange within the montmorillonites, or an increase in Ca^{2+} to the system through weathering of carbonate detritus or inflow from a carbonate aquifer. For the area of Oasis Valley and Amargosa Desert, both of these are likely to be factors in controlling the dominance of K and Ca minerals.

Yucca Mountain well chemistries appear to be supersaturated with respect to montmorillonites, illites, feldspars and quartz polymorphs, and undersaturated with respect to analcime, based on mineral stability diagrams.

There is a tendency for Ca^{2+} and K^{+} mineral stability to increase along a flow path. Wells in Forty Mile Wash are less evolved with respect to feldspar development than are Yucca Mountain wells. This suggests that Forty Mile Wash may be acting as a local recharge area. The resulting dominance of Na^{+} in solution is probably from the selective removal of K^{+} and Ca^{2+} by mineral precipitation. This agrees with White *et al.* (1980) findings for Rainier Mesa.

Conclusions From PHREEQE Model

Summary of Results

A hypothetical flow path through a tuffaceous aquifer was modeled using PHREEQE, based upon formation lithologies presented in previous literature. The geochemical model was divided into five parts based upon diagenetic mineral zones, and water/rock interactions within each zone were controlled by reactions with diagenetic smectite, zeolites and feldspars. Part V, the final reaction zone, appears to be the most analogous in terms of pH, molality, log activity of ions and saturation indices of minerals, to a high pH tuffaceous water.

The flow system, except for Part I, was modeled as one which is closed to CO_2 input from the atmosphere for two reasons: studies by White and Chuma (1987) suggested that deep ground-water systems were closed, and, in addition, when this system is modeled with P_{CO_2} at equilibrium, the pH of the water quickly decreased to less than 4.00; and, the partial pressure of CO_2 generally decreases from Part I to Part V, indicating that the system is closed, rather than open, as Kerrisk (1987) suggests.

When these modeled zones were compared to Yucca Mountain well samples, the solution of Part V was most similar to tuffaceous waters with high pH, such as USW H-3, or USW WT-10. Wells displaying water with lower pH did not

appear to be well represented by this flow model.

The attempts to model well UE-25 p[#]1 were successful; BALANCE models predicted a mixture of 68% volcanic water (from Part V) to 32% carbonate aquifer water. When these ratios were mixed using PHREEQE, the resultant solution was similar to the volcanic water analysis from well UE-25 p[#]1. These ratios also corresponded well with mixing values of 28.6% carbonate water reported by Craig and Robison (1984).

Similar attempts were made to model waters from other Yucca Mountain wells, with less success. Because water from most of these wells has lower pH than the tuffaceous water modeled in Part V, they superficially resemble mixtures of volcanic water (Part V) to carbonate water, in ratios of 80:20 through 60:40. This would indicate a great influx of carbonate waters to these wells. However, from the WATEQDR and $\delta^{13}\text{C}$ analyses, this does not appear likely. The initial resemblance may be more a factor of the Part V solution not being truly representative of lower pH tuffaceous waters, rather than any influence from the carbonate water.

Discussion of Errors in Modeling

Problems with geochemical modeling arise when the extremely complicated system present at Yucca Mountain is simplified.

The greatest source of error in the PHREEQE flow path model is ignoring the kinetics of the system, such as the rate and path of ground-water flow. The actual pathway of a ground water through the interlayered Tertiary volcanic aquifers and aquitards is probably tortuous, rather than the steady, smooth flow path assumed in the model. Ground-water flow is likely to be rapid through the fractured welded tuff zones, and slower through zones of bedded tuff moving as

matrix flow. Therefore, it is likely that water samples from the fractured welded tuffs might have different chemistries than those from the bedded tuff zones, as was found in Rainier Mesa by White *et al.* (1980).

Time is a factor which is also ignored by PHREEQE. This may cause problems in mineral equilibrium, because PHREEQE assumes all mineral reactions go to equilibrium. There are no data to support this assumption at Yucca Mountain. The kinetics involved in reaching equilibrium are dependent upon the flow path, rate of ground-water velocity, nature of mineral surfaces and the amount of impurities within the mineral. The diagenetic minerals employed in the model may be coated with silicates, calcite, and aluminum and iron oxides; therefore, mineral precipitation, dissolution, or ion exchange may not be approaching equilibrium.

The use of end-member zeolites and smectites may also influence the results. The limitations imposed upon the model by the lack of mixed-cation thermodynamic data resulted in the model being set up with end-member minerals which are not representative of the true mineralogy that is controlling ion-exchange and mineral equilibria. A topic for further research would be to determine the thermodynamic properties of these minerals, which would allow the PHREEQE model to become more site specific.

Mixing the modeled tuffaceous zone water with the carbonate water relied on one analysis of carbonate water in the vicinity of Yucca Mountain, a sample from well UE-25 p#1. This may be a factor in the success in modeling the mix of Part V water with carbonate water to form the volcanic water of UE-25 p#1. The carbonate sample from UE-25 p#1 may not be representative of all the carbonate ground water beneath Yucca Mountain, which could be a cause of the misleading results of the mixed model attempts.

Other sources of error in the model may arise from using incorrect assumptions concerning temperature, Al^{3+} concentrations, mineralogy and P_{CO_2} . Further refinements of these assumptions may improve the geochemical model.

Conclusions From Isotope Analyses

Environmental isotopes used in this study were $\delta^{18}\text{O}$, δD , $\delta^{13}\text{C}$ and ^{14}C . Yucca Mountain ground water has a deuterium depletion from the meteoric water line, which suggests recharge during conditions different than those at present. Wells in and near Forty Mile Wash are more enriched in terms of $\delta^{18}\text{O}$ than the other Yucca Mountain wells and lie within or near the local meteoric water line, suggesting $\delta^{18}\text{O}$ enrichment. This indicates recharge from lower elevations and/or warmer temperatures than the other Yucca Mountain wells, and that Forty Mile Wash is acting as a local recharge zone.

Carbon isotope data show a general trend of increasing $\delta^{13}\text{C}$ with increasing age of the ground water along a flow path. Two flow paths are apparent: one with high percent modern carbon in Forty Mile Wash, and a flow path(s) with low percent modern carbon indicated by Yucca Mountain WT wells. The $\delta^{13}\text{C}$ data from Forty Mile Wash wells correlate well with the $\delta^{18}\text{O}/\delta\text{D}$ data; i.e., more recent recharge. Three wells with very depleted $\delta^{13}\text{C}$ values, which are similar to $\delta^{13}\text{C}$ fractionation by desert vegetation, are close to two faults in the area. This suggests that Drill Hole Wash and Paintbrush Canyon faults serve as conduits for more recent recharge in the areas near US-25 WT-14, UE-25 b#1 and USW H-1.

Two well analyses show relatively enriched $\delta^{13}\text{C}$ values, indicating carbonate rock influence. In well UE-25 p#1, this might be expected, since an upward gradient has been previously documented; however, well USW H-3, completed in

the tuffaceous aquifer, is anomalously enriched compared to other tuffaceous wells. Delta ^{18}O and δD data from this well indicate recharge similar to present day. The enriched $\delta^{13}\text{C}$ values, therefore, may be a result of more recent recharge passing through a caliche zone, which would enrich the $\delta^{13}\text{C}$, rather than any influence from the carbonate aquifer.

Summary

From the geochemical and isotopic modeling analyses of this study, the influx of ground water from the lower carbonate aquifer into the tuffaceous aquifers appears to be minimal. The upward flow gradient present in UE-25 p#1 may be a local phenomenon caused by a confining layer between the two aquifers. There appears to be more recent recharge to several wells which are proximal to major faults, thus supporting the pulse-recharge hypothesis. The enriched $\delta^{13}\text{C}$ values from USW H-3 appear to be from caliche, rather than the tuffaceous aquifer, also suggesting more recent recharge. Forty Mile Wash appears to be a region of local recharge, extending as far as UE-25 WT-15. The geochemical model shows decreasing P_{CO_2} conditions, suggesting that the system is closed to P_{CO_2} input. The summary of the modeling attempts suggested the model was partially successful in terms of modeling high pH well waters and the mixed waters of UE-25 p#1, and was not as successful in modeling wells with near-neutral pH. Further refinement of the geochemical flow path model is desirable to increase confidence in the model of ground-water flow for Yucca Mountain. However, the results of the model may prove to be a useful start for future studies.

Additional Studies

Additional modeling of the geochemical flow path through the tuffaceous aquifers at Yucca Mountain is currently under investigation at the Desert Research Institute, Water Resources Center, in Las Vegas. The flow path is being refined for more control over the pH of the solution, better ion-exchange within each zone and a more realistic value of $\log P_{\text{CO}_2} = -2.5$ in the uppermost zones. In addition, the initial input soil water was changed from the analysis of Rainier Mesa data (Henne, 1986) to an analysis of data from Shoshone Mountain (Spencer, 1989), which was thought to be more representative of the conditions found at Yucca Mountain. The preliminary results are being compared to the other carbonate aquifer wells on the NTS, in addition to Yucca Mountain well UE-25 p#1.

These modifications to the flow path model should help to remove many of the errors of the model as it now exists. The results of this additional work are beyond the scope of this report and will be published under a separate report.

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APPENDIX A

DATA BASE OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Table I: Lithology and Hydrology

Table II: Water Chemistry Analyses

Table III: Isotopic Analyses

TABLE 1
WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Longitude (dms)	Latitude (dms)	Elevation (m)	Total Depth (m)	Producing Unit	Screened Interval (m)	Hydraulic Head (m)	Date (m/d/y)	Source
AMARCOSE DESERT									
AM 101 Amargosa	1162445	363715	786.3		Q alluvium: mixed	composite		03/10/73	4
Ash Tree Spg	1162445	362538	664.0		Q alluvium: mixed	-	664.0	03/06/74	1
15S/49E-22dc	1162633	363722	784.0	150	QT alluvium: volcanic	composite	706.0	11/20/72	1
16S/49E-5acc	1162842	363528	746.0	90	QT alluvium: volcanic	composite	726.0	03/03/74	1
16S/49E-8abb	1162841	363456	739.0	60	QT alluvium: volcanic	composite	695.0	11/17/72	1
16S/49E-8acc	1162840	363435	737.0	90	Q alluvium: volcanic	composite	692.0	04/01/71	1
16S/49E-9cda	1162742	363418	741.0	90	Q alluvium: volcanic	composite	694.0	11/18/72	1
16S/49E-9dce	1162735	363410	740.0	60	QT alluvium: volcanic	composite	691.0	03/01/74	1
16S/49E-18dc	1162944	363323	722.0	110	QT alluvium: volcanic	composite	689.0	03/01/74	1
16S/49E-16ccc	1162809	363311	727.0		QT alluvium: volcanic	composite		06/26/79	1
16S/49E-19daa	1162919	363249	720.0	90	QT alluvium: volcanic	composite	690.0	03/05/74	1
16S/48E-24aaa	1163025	363313	722.0	150	Q alluvium: volcanic	composite	692.0	11/17/72	1
16S/48E-25aaa	1163024	363219	715.0	50	QT alluvium: volcanic	composite	689.0	03/05/74	1
16S/48E-36aaa	1163024	363128	701.0	50	QT alluvium: volcanic	composite	687.0	03/04/74	1
17S/48E-1ab	1163025	363028	702.0	60	QT alluvium: volcanic	composite	686.0	03/05/74	1
17S/49E-7bb	1163001	362938	698.0	150	QT alluvium: carbonate	composite	686.0	03/01/74	1
17S/49E-9aa	1162758	362940	695.0		QT alluvium: carbonate	composite		03/01/74	1
17S/49E-8ddb	1162808	362904	693.0	100	QT alluvium: volcanic	composite	678.0	03/06/74	1
17S/49E-15bdd	1162637	362839	689.0	110	QT alluvium: carbonate	composite	672.0	03/06/74	1
16S/49E-23add	1162510	363310	732.0		QT alluvium: volcanic	composite		06/25/79	1
16S/48E15dda	1163235	363325	719.0		Q alluvium: volcanic	composite		06/26/79	1
16S/48E-15aaa	1163231	363403	724.0	50	QT alluvium: volcanic	composite	695.0	03/31/71	1
16S/48E-23bdb	1163210	363300	716.0	100	Q alluvium: volcanic	composite	687.0	08/19/62	1
16S/48E-10cba	1163320	363425	725.0		QT alluvium: volcanic	composite		03/31/71	1
16S/48E-36dcc	1163050	363035	701.0	120	Q alluvium: volcanic	composite	689.0	04/05/76	1
16S/50E-7bcd	1162350	363425	756.0	60	QT alluvium: carbonate	composite	713.0	08/18/62	1
16S/49E-12ddd	1162450	363420	748.0		Q alluvium: mixed	composite		06/26/79	1
16S/49E-15aaa	1162600	363400	743.0	120	QT alluvium: volcanic	composite	692.0	03/31/71	1
16S/49E-36aaa	1162409	363126	713.0		QT alluvium: carbonate	composite		06/24/79	1
16S/49E-36aba	1162420	363120	712.0		Q alluvium: mixed	composite		06/24/79	1
16S/49E-35aaa	1162510	363110	708.0		Q alluvium: mixed	composite		06/24/79	1
16S/49E-35baa	1162537	363127	714.0	100	Q alluvium: mixed	composite	687.0	06/24/79	1
15S/50E-18cdc	1162348	363832	812.0		Q alluvium: mixed	composite		12/15/68	1
15S/50E-18ccc	1162357	363836	812.0		Q alluvium: mixed	composite		11/17/72	1
17S/49E-11ba	1162515	362936	693.0		Q alluvium: mixed	composite		03/07/74	1
16S/48E-15ba	1163318	363358	722.0	50	QT alluvium: mixed	composite	692.0	06/24/71	1
17S/49E-15bc	1162643	362832	689.0		Q alluvium: mixed	composite		02/17/66	1
17S/49E-28bcd	1162603	363650	689.0		Q alluvium: volcanic	composite		06/23/79	1
16S/49E-1aba	1162330	362520	664.0		Q alluvium: mixed	composite	664.0	04/06/71	1
16S/49E-2cdc	1162541	362451	658.0	160	Q alluvium: mixed	composite	636.0	11/18/72	1

TABLE 1
WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Longitude (dms.)	Latitude (dms.)	Elevation (m)	Total Depth (m)	Producing Unit	Screened Interval (m)	Hydraulic Head (m)	Date (m/d/y)	Source
18S/49E-11bbb	1162514	362435	661.0		Q alluvium: mixed	composite		06/23/79	1
18S/50E-6dac	1162237	362454	660.0		Q alluvium: mixed	composite		02/12/72	1
17S/49E-29acc	1162817	362650	686.0		Q alluvium: mixed	composite		06/23/79	1
16S/48E-8ba	1163530	363450	727.0	80	Q alluvium: mixed	composite	692.0	06/24/71	1
16S/48E-7ba	1163640	363455	725.0		Q alluvium: mixed	composite		03/30/71	1
16S/48E-7cbc	1163650	363425	722.0		QT alluvium: carbonate	composite		01/31/71	1
16S/48E-18bcc	1163520	363400	720.0		Q alluvium: mixed	composite		06/24/79	1
16S/48E-17ccc	1163546	363309	718.0		Q alluvium: mixed	composite		06/25/79	1
16S/48E-18dad	1163549	363332	718.0		QT alluvium: volcanic	composite		06/25/79	1
16S/48E-8cda	1163520	363415	722.0		Q alluvium: mixed	composite		03/31/71	1
16S/48E-17abb	1163510	363400	722.0	30	Q alluvium: mixed	composite	691.0	08/18/62	1
16S/48E-21da	1163135	363244	715.0	140	Q alluvium: volcanic	composite	691.0	02/17/66	1
27S/4E-27bbb	1163215	362700	686.0	90	Q alluvium: mixed	composite	672.0	08/18/62	1
17S/59E-19aab	1162230	362800	664.0		Q alluvium: mixed	composite		12/27/71	1
18S/50E-7aa	1161608	362403	658.0		Q alluvium: mixed	composite		12/28/71	1
N.E.C. Well 1	1164011		835.0	180	Tv	composite	749.0	12/16/68	1
Cane Spring	1160530	364750	1286.0		Tv	-	1286.0	09/19/57	3
Cane Spring	1160530	364750	1286.0		Tv	-	1286.0	03/24/58	3
Captain Jack Spg	1160950	371030	1673.0		tunnel beds	-	1673.0	05/01/59	3
Copeland	1162658	362940	696.0		QT alluvium: mixed	composite		03/01/74	4
Devils Hole	116127	362532	737.6		Bonanza King	-	719.6	10/21/64	12
Fairbanks Spg	1162032	362925	649.9		Q alluvium: mixed	-	694.9	10/27/64	12
Grapevine Spg	1160135	362727	1356.0		Q alluvium: mixed	-	1356.0	06/28/85	4
Jacobs East	1163024	363219	3000.0		Q alluvium: mixed	composite		03/05/74	4
King Spg	1161614	362405	707.0		Q alluvium: mixed	-	709.0	03/09/81	4
Longstreet Spg	1161930	362804	701.6		Undiff Paleo	-	701.6	10/28/64	12
Ray Van Horn 1	1161312	363158	729.0	75	Q alluvium: mixed	composite	719.1	01/10/61	3
Ray Van Horn 2	1161315	363155	729.0		Q alluvium: mixed	composite	719.0	01/10/61	3
Riess	1160048	363437	1050.0	382	quartzite	352-374	735.9	01/27/60	3
Supply	1162639	363740	784.0					03/04/74	4
Yucca Club	1162515	362936	695.0		QT alluvium: mixed	composite		03/07/74	4
----- NEVADA TEST SITE -----									
Army-1	1160214	363536	961.3	593	Nopah, Bonanza King	244-320	722.3	11/16/67	8
Butte Spg	1160400	371450	1582.0		Tunnel beds	-	1582.0	04/30/59	3
Camp Desert Rock	1160059	363720	329.4	372		-	695.2	10/15/51	3
Indian Spg	1160610	372640	2036.0			-	2036.0	05/01/58	3
Marble 3	1160405	371348	1620.0	298	Pogonip-Ordovician	composite	1474.9	07/11/59	3

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
ANARGOSA DESERT												
AM 101 Anargosa	42.0	7.80		19.0	22.0	1.6	48.0	2.9	151.0		7.3	36.0
Ash Tree Spg	18.0	8.00	7.90	80.7	15.2	4.6	50.6	8.0		157.0	6.6	40.3
15S/49E-22dc		7.78	6.70	49.2	27.0	1.9	43.0	4.7		148.0	8.3	32.6
16S/49E-5acc	23.0	8.15	7.80	61.8	29.0	2.2	34.9	5.1		135.0	5.9	25.9
16S/49E-8abb		7.47	7.00	54.0	30.1	2.7	37.0	5.5		152.0	7.6	29.7
16S/49E-8acc	25.8	7.90	7.50		22.8	2.4	37.0	6.7		138.0	5.9	28.8
16S/49E-9cda	24.0	7.61	7.40	65.4	30.4	3.4	51.1	8.6		143.0	11.7	64.3
16S/49E-9dcc	23.3	8.16	7.60	72.0	22.8	2.7	56.1	9.0		141.0	9.7	67.2
16S/49E-18dc		8.12	8.00	58.8	20.0	2.7	42.1	9.0		150.0	7.2	27.8
16S/49E-16ccc		7.87		76.8	30.1	1.9	39.8	4.3		132.0	7.9	50.9
16S/49E-19daa	26.4	8.20	7.90	75.0	24.1	1.2	36.1	8.2		134.0	6.6	12.6
16S/48E-24aaa	27.0	8.09	7.00	78.6	18.0	0.7	54.1	7.0		147.0	7.6	29.7
16S/48E-25aa	26.5	8.06	7.90	72.0	18.8	0.7	43.0	7.4		133.0	9.0	27.8
16S/48E-36aaa		8.40	7.90	78.6	16.8	1.9	40.0	6.3		133.0	6.6	24.9
17S/48E-1ab		8.15	8.00	78.6	18.8	1.5	40.0	7.0		134.0	6.2	24.9
17S/49E-7bb		8.30	8.00	79.8	24.1	1.7	48.1	7.4		153.0	9.3	30.7
17S/49E-9aa		8.02	7.90	70.2	24.8	3.7	48.1	9.8		131.0	9.7	69.1
17S/49E-8ddb	24.0	8.35	8.00	81.0	20.8	2.7	36.1	7.4		123.0	6.2	26.9
17S/49E-15bbd	22.5	8.12	8.10	72.6	20.8	3.9	31.3	8.2		120.0	9.7	34.6
16S/49E-23add		8.19		76.2	16.1	1.7	55.9	6.5		127.0	8.6	34.6
16S/48E-15kda		7.97		71.4	20.0	5.8	70.8	7.4		176.0	16.9	25.1
16S/48E-15aaa	25.5	8.10	7.90	67.8	9.6	3.2	58.2	5.9		153.0	7.2	27.8
16S/48E-23bdb	24.0		7.30	73.8	9.2	1.0	66.0	6.7		156.0	8.6	26.9
16S/48E-10cba	24.5	8.30	7.80	64.2	9.2	3.9	60.9	5.4		166.0	7.9	32.6
16S/48E-36dcc	26.0	7.20	7.90	70.2	55.0	9.7	100.0	12.9		300.0	32.1	110.4
16S/50E-7bcd	30.6	7.62	8.00	28.8	44.0	17.5	111.5	12.9		291.0	28.3	151.6
16S/49E-12ddd		7.64		20.4	45.7	17.0	120.0	4.3		288.0	23.5	160.3
16S/49E-15aaa	23.8	7.70	7.90	46.2	41.0	7.5	80.0	9.8		195.0	22.4	129.6
16S/49E-36aaa		7.76		37.8	52.1	22.0	120.0	18.0		314.0	26.2	168.0
16S/49E-36aba		7.65		42.6	45.0	20.0	110.2	16.8		293.0	23.5	155.5
16S/49E-35aaa		7.65		36.6	49.1	16.0	120.0	16.0		271.0	28.3	147.8
16S/49E-35baa	24.0	7.41		37.8	53.3	18.0	113.2	13.3		302.0	30.4	170.0
15S/50E-18cdc	25.1	8.00		37.8	13.0	0.7	93.2	3.9		153.0	16.6	77.7
15S/50E-18ccc		8.37	7.50	34.2	16.8	0.5	93.2	3.9		157.0	12.7	99.8
17S/49E-11ba	22.0		8.10	52.8	40.1	14.1	97.1	14.1		210.0	27.3	160.0
16S/48E-15ba	25.0	8.00		37.2	60.1	7.8	147.2	9.8		268.0	63.8	198.7
17S/49E-15bc	24.0	8.20		21.6	21.6	1.0	39.1	6.6		122.0	10.4	27.8
17S/49E-28bcd		7.56		70.2	43.0	9.9	100.0	12.1		295.0	23.4	89.2
18S/49E-1aba	17.5	8.60		72.6	24.1	11.9	94.9	19.2		263.0	17.6	99.8
18S/49E-2cbc	23.8	7.82	7.40	58.8	28.9	11.9	120.0	9.8		352.0	19.3	73.9

TABLE 1
WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Longitude (dms)	Latitude (dms)	Elevation (m)	Total Depth (m)	Producing Unit	Screened Interval (m)	Hydraulic Head (m)	Date (m/d/y)	Source
11S/47E-9acl (spg)	1164322	365945	1106.0		Q alluvium: mixed,	-	1106.0	03/14/62	6
11S/47E-10abl (spg)	1164222	365941	1164.0		undiff. tuffs	-	1164.0	03/14/62	6
11S/47E-16dcl (spg)	1164317	365921	1097.0		undiff. tuff	-	1097.0	07/03/67	7
11S/47E-18aal (spg)	1164530	365910	1208.0			-	1208.0	07/03/67	7
11S/47E-21acl (spg)	1164301	365803	1085.0		Q alluvium: mixed	-	1085.0	07/03/67	7
11S/47E-28aal (spg)	1164315	365727	1073.0		Q alluvium: mixed	-	1073.0	03/14/62	6
11S/47E-33bal (spg)	1164343	365631	1061.0			-	1061.0	07/03/67	7
12S/47E-5cal (spg)	1164437	365507	1027.0		undiff. welded tuff	-	1027.0	07/03/67	7
12S/47E-20bbi (spg)	1164500	365306	975.0		Q alluvium: mixed	-	975.0	07/03/67	7
10S/47E-bab (spg)	1164124	370427	1216.0		Q alluvium: mixed	-	1216.0	07/03/67	7
10S/47E-27cba	1164819	365705	1164.0	2	Q alluvium: mixed	composite		07/03/67	7
10S/47E-31aab (spg)	1164517	370151	1268.0		Q alluvium: mixed	-		07/03/67	7
10S/47E-32dda (spg)	1164400	370110	1134.0		Q alluvium: mixed	-	1134.0	07/03/67	7
10S/47E-33aab (spg)	1164307	370149	1182.0		Q alluvium: mixed	-	1182.0	07/03/67	7
10S/47E-30dte	1164530	370200	1183.0	37	Q alluvium: mixed	composite		07/03/67	7
11S/47E-3cda (spg)	1164230	370020	1170.0			-	1170.0	07/03/67	7
11S/47E-4cad (spg)	1164330	370030	1134.0		Q alluvium: mixed	-	1134.0	07/03/67	7
11S/47E-10bcc (spg)	1164251	365945	1122.0		undiff. tuff	-	1122.0	07/03/67	7
11S/47E-21ddb	1164320	365756	1079.0		Q alluvium: mixed	composite		07/03/67	7
11S/47E-21aba (spg)	1164315	365825	1094.0		Q alluvium: mixed	-	1094.0	07/03/67	7
11S/47E-21aba (spg)	1164310	365821	1097.0		undiff. tuff	-	1097.0	07/03/67	7
11S/47E-27cba	1164246	365658	1061.0	17	undiff. tuff	composite		07/03/67	7
11S/47E-28aac	1164310	365718	1073.0	8	Q alluvium: mixed	composite		07/03/67	7
11S/47E-10ccb (spg)	1164253	365924	1113.0		undiff. tuff	-	1113.0	07/03/67	7
12S/47E-6cdd	1164540	365455	1030.0	55	Q alluvium: mixed	composite		07/03/67	7
12S/47E-7dbd	1164530	365420	1000.0	91	Q alluvium: mixed	composite		07/03/67	7
12S/47E-19adc	1164518	365245	969.0		Q alluvium: mixed	composite		07/03/67	7
White	1162537	362452	732.0	30	Q alluvium: mixed	15-30	636.0	11/08/60	3
PAIUTE MESA									
Uel8r	1162640	370806	1662.0	1525	undiff tuff, rhyolite	496-1525	1107.0	01/29/68	9
U19as	1162208	371636	2078.0		ash/rhy- Dead Horse Flat	974		06/07/65	9
Uel9b-1	1161804	371855	2073.0	1371	Rhy of Dead Horse Flat	677-1371	1428.0	06/21/64	9
Uel9c	1161910	371608	2144.0	2587	Ptbrsh-Dead Horse-Bldg	702-1382	1429.3	03/09/66	9
Uel9d	1161920	372054	2091.0	2343	Rhy of Dead Horse Flat	785-2344	1427.5	06/27/64	9
Uel9e	1162002	371653	2109.0	1830	Rhy/tuff- Dead Horse Flat	759-1830	1426.3	08/01/66	9
Uel9fs	1162203	371328	2053.0	2118	Rhy/tuff-Dead Horse Flat	782-1456	1350.5	08/18/65	9
Uel9gs	1162153	371833	2048.0	2286	Rhy of Dead Horse Flat	807-1374	1424.7	03/27/65	9
Uel9gs	1162153	371833	2048.0	2286	Belted Range/Dead Horse F	807-2286	1424.7	08/02/66	9
Uel9i	1162048	371458	2085.0	2438	Pahute Mesa	883-2438	1396.8	09/02/65	9

TABLE 1
WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Longitude (dms)	Latitude (dms)	Elevation (m)	Total Depth (m)	Producing Unit	Screened Interval (m)	Hydraulic Head (m)	Date (m/d/y)	Source
U20a-2	1162516	371434	1973.0	1371	Rhy of Dead Horse Flat	630-1371	1343.3	10/14/64	9
UE20d	1162848	371452	1906.0	1630	tuff/rhy of Area 20	975	1273.5	03/08/66	9
UE20d	1162848	371452	1906.0	1630	tuff/rhy of Area 20	745-1371	1273.5	07/28/66	9
UE20e-1	1162725	371901	1919.0	1949	tuff/rhy of Area 20	556-1949	1363.7	06/05/64	9
UE20e-1	1162725	371901	1919.0	1949	tuff/rhy of Area 20	792	1363.7	03/08/66	9
UE20f	1162917	371617	1864.0	4171	Belted Range/tuff Area 20	1358-4171	1268.5	08/11/64	9
U20f	1162918	371617	1864.0	1281	tuff/rhy of Area 20	1228	1354.0	05/21/66	9
UE20h	1162602	371618	1999.0	2197	Belted Range tuff	764-2196	1354.0	08/26/65	9
UE20j	1163201	371801	1798.0	1734	Belted Range tuff	530-1734	1410.9	10/21/64	9
----- YUCCA MOUNTAIN -----									
J-11	1161706	364706	1050.0	405	Topopah Spg-PtT/BsIt Kiwi	328-396	732.6	12/16/58	3
J-12	1162324	364555	953.5	347	Topopah Spg-PtT	214-264	953.5	03/26/71	2
J-12	1162324	364555	953.5	270	Topopah Spg-PtT	214-264	727.3	02/19/59	3
J-13	1162340	364828	1011.3	1063	Topopah S-PtT/Tram-CFT	207-450	728.1	03/26/71	2
UE-25bP1	1162623	365108	1700.6	1220	Tram/Bullfrog/ProwP-CFT	composite	730.3	09/01/81	2
UE-25bP1	1162623	365108	1200.6	1220	Bullfrog-CFT	863-875	730.3	01/20/82	2
UE-25cP1	1162542	364947	1130.4	914	Bullfrog/Tram-CFT		728.4	09/30/83	2
UE-25cP2	1162540	364944	1133.0	913	Bullfrog-CFT			03/13/84	2
UE-25cP3	1162545	364945	1133.0	913	Bullfrog/Tram-CFT			05/09/84	2
UE-25pP1 (v)	1162521	364938	1114.0	1805	Rhy-Calico H-CFT-LRT	381-1197	729.9	02/09/83	2
UE-25pP1 (c)	1162521	364938	1114.0	1805	Silurian-Lone Mtn-Rbt Mun	1297-1805	751.0	05/12/83	2
UE-25 WT#4	1162608	365150	1167.1	482	Tuff of Calico Hills	474-477	728.2	11/01/83	16
UE-25 WT#12	1162626	364700	1074.6	399	Tuff of Calico Hills	382-388	729.2	10/31/83	16
UE-25 WT#14	1162443	365029	1076.1	399	Tuff of Calico Hills	393-397	729.9	11/07/83	16
UE-25 WT#15	1162343	365120	1082.8	415	Topopah Spg-PBT	403-407	728.6	12/01/83	16
UE-25 WT#17	1162635	364820	1124.5	443		composite	729.9	11/07/83	16
UE-29aP2	1162226	365629	1215.2	422	Rhy of Calico Hills	247-354	1188.0	01/08/82	2
USW G-4	1162226	365629	1215.2	422	Rhy of Calico Hills	87-213	1188.0	01/15/82	2
USW H-1	1162700	365114	1269.6	915	Tram-CFT	549-915	730.1	12/09/82	2
USW H-1	1162712	365158	1302.8	1829	Prow Pass-CFT	572-687	730.7	10/20/80	2
USW H-1	1162712	365158	1302.8	1829	lava/brec-CFT+LRT-Bullfg	687-1829	730.7	12/08/80	2
USW H-3	1162801	364942	1483.3	1220	Tram/Bedded-CFT+LRT	922-1220	732.4	03/14/84	2
USW H-4	1162654	365032	1248.6	1220	Bullfrog/Tram-CFT	569-1219	730.7	05/17/82	2
USW H-5	1162755	365122	1478.5	1220	Bullfrog/Tram-CFT		774.7	01/26/82	2
USW H-6	1162855	365049	1301.7	1220	Bullfrog-Tram		775.6	10/16/82	2
USW H-6	1162855	365049	1301.7	1220	Bullfrog-CFT	753-835	775.6	06/20/84	2
USW H-6	1162855	365049	1301.7	1220	Bullfrog-CFT	608-646	775.6	07/06/84	2
USW WT-1	1163307	364732	963.5	762	Bullfrog-CFT		779.3	02/11/81	2
USW WT-1	1162710	364911	1201.7	515		504-507	730.7	10/31/83	16
USW WT-7	1162905	364947	1197.0	491	Topopah Spg-PBT/Calico H.	477-481	775.9	10/24/83	16
USW WT-10	1162909	364821	1123.2	430	Topopah Spg-PBT	399-403	775.5	10/24/83	16

Footnotes:

* Stratigraphic Units of Wells: Table 1,
and Winograd and Thordarson, 1975, p. 10-11.

** Sources 1-18, see list on page 128.

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
AMARGOSA DESERT												
AM 101 Amargosa	42.0	7.80		19.0	22.0	1.6	48.0	2.9	151.0		7.3	36.0
Ash Tree Spg	18.0	8.00	7.90	80.7	15.2	4.6	50.6	8.0		157.0	6.6	40.3
15S/49E-22dc		7.78	6.70	49.2	27.0	1.9	43.0	4.7		148.0	8.3	32.6
16S/49E-5acc		8.15	7.80	61.8	29.0	2.2	34.9	5.1		135.0	5.9	25.9
16S/49E-8abb	23.0	7.47	7.00	54.0	30.1	2.7	37.0	5.5		152.0	7.6	29.7
16S/49E-8acc	25.8	7.90	7.50	22.8		2.4	37.0	6.7		138.0	5.9	28.8
16S/49E-9cda	24.0	7.61	7.40	65.4	30.4	3.4	51.1	8.6		143.0	11.7	64.3
16S/49E-9dcc	23.3	8.16	7.60	72.0	22.8	2.7	56.1	9.0		141.0	9.7	67.2
16S/49E-18dc		8.12	8.00	58.8	20.0	2.7	42.1	9.0		150.0	7.2	27.8
16S/49E-16ccc		7.87		76.8	30.1	1.9	39.8	4.3		132.0	7.9	50.9
16S/49E-19daa	26.4	8.20	7.90	75.0	24.1	1.2	36.1	8.2		134.0	6.6	32.6
16S/48E-24aaa	27.0	8.09	7.00	78.6	18.0	0.7	54.1	7.0		147.0	7.6	29.7
16S/48E-25aa	26.5	8.06	7.90	72.0	18.8	0.7	43.0	7.4		133.0	9.0	27.8
16S/48E-36aaa		8.40	7.90	78.6	16.8	1.9	40.0	6.3		133.0	6.6	24.9
17S/48E-lab		8.15	8.00	78.6	18.8	1.5	40.0	7.0		134.0	6.2	24.9
17S/49E-7bb		8.30	8.00	79.8	24.1	1.7	48.1	7.4		153.0	9.3	30.7
17S/49E-9aa		8.02	7.90	70.2	24.8	3.7	48.1	9.8		131.0	9.7	69.1
17S/49E-8ddb	24.0	8.35	8.00	81.0	20.8	2.7	36.1	7.4		123.0	6.2	26.9
17S/49E-15bdd	22.5	8.12	8.10	72.6	20.8	3.9	31.3	8.2		120.0	9.7	34.6
16S/49E-23add		8.19		76.2	16.1	1.7	55.9	6.5		127.0	8.6	34.6
16S/48E-15dda		7.97		71.4	20.0	5.8	70.8	7.4		176.0	16.9	25.1
16S/48E-15aaa	25.5	8.10	7.90	67.8	9.6	3.2	58.2	5.9		153.0	7.2	27.8
16S/48E-23lxb	24.0		7.30	73.8	9.2	1.0	66.0	6.7		156.0	8.6	26.9
16S/48E-10cba	24.5	8.30	7.80	64.2	9.2	3.9	60.9	5.4		166.0	7.9	32.6
16S/48E-36dcc	26.0	7.20	7.90	70.2	55.0	9.7	100.0	12.9		300.0	32.1	110.4
16S/50E-7bcd	30.6	7.62	8.00	28.8	44.0	17.5	111.5	12.9		291.0	28.3	151.6
16S/49E-12ddd		7.64		20.4	45.7	17.0	120.0	4.3		288.0	23.5	160.3
16S/49E-15aaa	23.8	7.70	7.90	46.2	41.0	7.5	80.0	9.8		195.0	22.4	129.6
16S/49E-36aaa		7.76		37.8	52.1	22.0	120.0	18.0		314.0	26.2	168.0
16S/49E-36aba		7.65		42.6	45.0	20.0	110.2	16.8		293.0	23.5	155.5
16S/49E-35aaa		7.65		36.6	49.1	16.0	120.0	16.0		271.0	28.3	147.8
16S/49E-35baa	24.0	7.41		37.8	53.3	18.0	113.2	13.3		302.0	30.4	170.0
15S/50E-18cdc	25.1	8.00		37.8	13.0	0.7	93.2	3.9		153.0	16.6	77.7
15S/50E-18ccc		8.37	7.50	34.2	16.8	0.5	93.2	3.9		157.0	12.7	99.8
17S/49E-11ba	22.0		8.10	52.8	40.1	14.1	97.1	14.1		210.0	27.3	160.0
16S/48E-15ba	25.0	8.00		37.2	60.1	7.8	147.2	9.8		268.0	63.8	198.7
17S/49E-15bc	24.0	8.20		21.6	21.6	1.0	39.1	6.6		122.0	10.4	27.8
17S/49E-28bcd		7.56		70.2	43.0	9.9	100.0	12.1		295.0	23.4	89.2
18S/49E-1aba	17.5	8.60		72.6	24.1	11.9	94.9	19.2		263.0	17.6	99.8
18S/49E-2cbc	23.8	7.82	7.40	58.8	28.9	11.9	120.0	9.8		352.0	19.3	73.9

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
18S/49E-11bbb	25.0	7.56		78.0	34.1	8.5	99.1	11.7		224.0	30.0	90.2
18S/50E-6dac		8.22		80.4	23.6	11.9	102.5	13.7		169.0	20.0	106.5
17S/49E-29acc	21.0	7.60		72.0	54.1	15.1	160.1	19.9		276.0	68.0	186.2
16S/48E-8ba	25.0	7.90		37.8	58.5	6.3	180.5	12.9		296.0	77.6	202.6
16S/48E-7bba	24.7	7.40	7.90	69.0	53.0	9.5	140.1	10.1		251.0	61.4	179.5
16S/48E-7cbc	24.2	7.70	7.80	64.2	47.0	16.0	130.2	9.4		239.0	60.4	179.5
16S/48E-18bcc		7.98		64.2	55.0	10.9	150.7	11.7		239.0	59.3	190.1
16S/48E-17ccc		7.69	7.70	77.4	66.2	10.9	170.0	12.1		239.0	80.7	235.0
16S/48E-18dad		7.69		16.8	53.0	8.5	150.0	10.6		236.0	61.4	187.2
16S/48E-8cda	23.3	7.60	7.90	67.8	48.1	6.8	154.0	10.1		264.0	65.2	179.0
16S/48E-17abb	24.0		7.40	75.0	60.1	7.8	157.0	12.1		302.0	67.3	178.0
16S/48E-23da	24.0	8.20		22.0	22.0	2.2	69.0	6.6		134.0	25.9	67.0
27N/4E-27bbb	22.0		7.80	72.0	58.1	18.9	134.0	19.1		476.0	31.0	106.0
17S/50E-19aab	16.0	8.60		42.4	7.6	8.5	252.0	27.4		415.0	67.9	79.7
16S/50E-7aa	13.0	8.40		47.4	25.6	9.5	141.0	19.1		261.0	37.6	50.8
N.E.C. Well 1		7.60		70.2	55.0	14.1	170.0	10.1		328.0	76.9	190.0
Grapevine Spg	20.0	7.70	8.00	21.0	64.0	42.0	27.0	1.5	265.0		12.0	130.0
Copeland		7.90		70.0	25.0	3.6	48.0	9.7	131.0		10.0	69.0
Devils Hole	27.2	7.80	7.50	21.0	52.0	19.0	67.0	8.1	306.0	310.0	22.0	78.0
Fairbanks Spg	27.2	7.30	7.30	20.0	51.0	18.0	71.0	8.0	300.0	304.0	22.0	80.0
Jacobs East		7.90		75.0	24.0	1.1	36.0	8.2	134.0		6.6	31.0
King Spg	25.5	7.70	7.90	21.0	47.0	20.0	65.0	7.4	292.0	292.0	23.0	79.0
Longstreet Spg	27.2	7.40	7.30	22.0	51.0	17.0	68.0	7.9	303.0	302.0	22.0	78.0
Riess	24.4	8.00		9.3	24.0	16.0	222.0	11.0		406.0	23.0	169.0
Supply		7.80		49.0	28.0	2.1	39.0	4.9	146.0		6.7	33.0
Yucca Club		8.10		53.0	40.0	14.0	97.0	14.0	210.0		28.0	160.0
----- NEVADA TEST SITE -----												
Army-1	33.3	7.80		19.0	46.0	22.0	36.0	5.4		258.0	15.0	49.0
Butte Spg	11.1	7.10		64.0	16.0	3.9	31.0	4.0		118.0	11.0	14.0
Cane Spg.a	18.9	7.90		64.0	32.0	9.2	37.0	7.8		163.0	20.0	28.0
Cane Spg.b	17.8	8.00		63.0	30.0	9.2	36.0	7.6		152.0	19.0	30.0
Captain Jack Spg	13.3	6.90		43.0	3.2		47.0	2.2		95.0	4.0	25.0
Indian Spg	10.0	7.20		61.0	42.0	7.8	17.0	4.8		148.0	12.0	36.0
Marble 3	21.6	7.90		46.0	25.0	47.0	15.0	3.8		310.0	5.0	24.0
Oak Spg	12.8	7.50		57.0	18.0	4.9	22.0	6.4		116.0	9.0	14.0
Rainier Spg	16.1	8.30		65.0	7.2	1.0	66.0	4.0		158.0	14.0	18.0
Test Hole 7	20.5	7.30		1.4	1.0	.2	113.0	4.6		286.0	8.0	2.1
Test Well C	36.7	7.20	7.00	30.0	74.0	27.0	142.0	15.0		577.0	34.0	71.0
Test Well F	64.0	7.40		38.0	44.0	16.0	64.0	9.7		264.0	20.0	75.0
Tippipah Spg.a		7.70		53.0	4.8	.1	40.0	3.0		88.0	7.2	16.0
Tippipah Spg.b	12.2	7.40		50.0	4.8		37.0	3.2		81.0	6.0	19.0

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field) (umhos/cm)	EC (lab) (umhos/cm)	F	NO3	PO4 (mg / l)	Fe	Li	Sr	Source
18S/49E-11bbb	06/23/79							7.600		1
18S/50E-6dac	02/12/72									1
17S/49E-29acc	06/23/79									1
16S/48E-8ba	06/24/71			1.90	1.90			.180	.440	1
16S/48E-7bba	03/30/71			2.00	2.50			.160	.460	1
16S/48E-7cbc	03/31/71			1.80	2.90					1
16S/48E-18bcc	06/24/79			1.20	1.20			.200	.600	1
16S/48E-17ccc	06/24/79			3.60	.20			.140	.600	1
16S/48E-18dad	06/25/79			1.30	.10			.710	.070	1
16S/48E-8cda	03/31/71			1.20	1.20					1
16S/48E-17abb	08/18/62			3.60	.20			.140	.600	1
16S/18S/50E-7aa	02/17/66			1.30	.10			.710	.070	1
27N/48E-27bbb	08/18/62			1.20	1.20			.200	.600	1
17S/50E-19aab	12/27/71			1.20	1.20			.200	.600	1
18S/50E-7aa	12/28/71			1.20	1.20			.200	.600	1
N.E.C. Well 1	12/16/68			1.20	1.60		.080	.050		1
Copeland	03/01/74	422		1.40	.30			.090	.890	4
Devils Hole	10/21/64	686		2.20	9.99		.042	.100	.760	13
Fairbanks Spg	10/27/64	686		.20						13
Grapevine Spg	06/28/85	674								4
Jacobs East	03/05/71	324		1.00	1.60		.010	.040		4
King Spg	03/09/81	665		1.50	.30			.090		4
Longstreet Spg	10/28/64		681	1.60	.30		.023	.100	.830	13
Riess	04/27/58	1130		.80	4.10				.100	3
Supply	03/04/74	337		1.00	1.60		.030	.040		4
Yucca Club	03/07/74	798		2.90	.10		.170	.140		4
NEVADA TEST SITE										
Army-1	11/16/67	531		1.10	1.20		.030	.040	.760	8
Butte Spg	04/30/59	260		.40	.80		.130		.100	3
Cane Spg.a	09/19/57	425		.50	19.00		.100			3
Cane Spg.b	03/24/58	403		.70	18.00					3
Captain Jack Spg	05/01/59	188		.40	9.99		.950		.100	3
Indian Spg	05/01/58	358		.40	9.99		.080			3
Marble 3	07/11/59	522		.70	2.90		.600		.200	3
Oak Spg	04/28/58	241		.30			.100			3
Rainier Spg	09/18/57	346		.60	.60		.040		.200	3
Test Hole 7	11/15/89	466		2.40						3
Test Well C	09/01/61	1080		.90	1.00		1.000			10
Test Well F	03/12/80	625		3.00	.10		.023			4
Tippipah Spg.a	09/17/57	207		.30	4.60		.310			3
Tippipah Spg.b	03/24/58	192		.30	4.20		.230			3

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
Topopah Spg. a	21.1	6.90		71.0	20.0	3.9	19.0	18.0		147.0	6.0	11.0
Topopah Spg. b	11.7	6.90		50.0	7.2	1.0	14.0	6.4		48.0	3.0	15.0
Tw-8	26.1	6.80		45.0	8.8	.9	30.0	3.3		78.0	7.8	16.0
U12e.HI		8.60		22.0	7.2	.5	75.0	6.0		158.0	12.0	25.0
UE-16F	23.0	8.20		7.2	5.2	2.0	430.0	3.0	1000.0		18.0	110.0
USGS A	26.5	7.80		69.0	21.0	7.4	49.0	8.8		215.0	21.0	17.0
USGS D	25.5	7.80		18.0	17.0	10.0	107.0	14.0		274.0	20.0	71.0
USGS E	42.2	9.00		61.0	1.6		81.0	2.6		187.0	6.0	16.0
Well 3.a		7.80		74.0	22.0	12.0	40.0	7.4		192.0	8.0	22.0
Well 3.b	21.6	8.00		74.0	19.0	13.0	39.0	7.4		194.0	6.0	21.0
Well 3.c		8.10		66.0	21.0	12.0	40.0	7.4		196.0	5.0	22.0
Well 3.d		7.80		72.0	19.0	14.0	37.0	7.4		190.0	5.0	21.0
Well 5A.a		8.60		58.0	3.2		160.0	6.2		346.0	12.0	25.0
Well 5A.b	21.6	8.80		57.0	1.8	.5	158.0	5.8		341.0	9.0	25.0
Well 5A.c	23.5	8.90		67.0	1.6	1.0	165.0	6.6		336.0	9.0	30.0
Well 5A.d		8.60		58.0	2.4		158.0	6.0		344.0	9.0	24.0
Well 5B.a		8.40		64.0	8.0	1.5	96.0	11.0		168.0	25.0	55.0
Well 5B.b	27.2	9.00		16.0	5.6	1.0	102.0	10.0		155.0	24.0	59.0
Well 5B.c	25.0	8.40		61.0	8.0	1.9	96.0	11.0		166.0	21.0	60.0
Well 5C.a	26.6	8.80		55.0	1.8	0.7	128.0	5.6		263.0	9.0	24.0
Well 5C.b	23.8	8.80		58.0	2.5	0.5	130.0	68.0		262.0	8.0	26.0
Well 5C.c	22.2	8.50		59.0	1.6	1.0	126.0	5.8		265.0	10.0	24.0
Whiterock Spg. a		6.90		80.0	4.8		39.0	5.4		72.0	11.0	21.0
Whiterock Spg. b	15.0	7.10		52.0	4.0	0.2	42.0	5.4		78.0	8.0	29.0
Whiterock Spg. c	8.9	7.20		119.0	6.4		35.0	7.4		66.0	6.0	32.0
Whiterock Spg. d	19.4	8.80		48.0	4.8		39.0	4.0		50.0	9.0	23.0
OASIS VALLEY												
Ute Spg	21.0	8.20	8.40	46.0	8.4		249.0	2.3		310.0	26.2	70.1
7S/4E-28bcl		7.60			51.0	3.0	82.0	66.6		229.0	53.0	48.0
10S/47E-30dl	14.4	8.10			27.0	4.9	105.0	66.6		278.0	48.0	14.0
10S/47E-33al.a (spg)	23.8	8.00			24.0	0.1	127.0	66.6		275.0	65.0	14.0
10S/47E-33al.b (spg)	24.0	8.10		38.0	14.0	0.7	196.0	2.3		330.0	52.3	108.5
11S/45E-22bl (spg)		7.60			42.0	9.8	60.0	66.6		155.0	68.0	38.0
11S/46E-26cal.a (spg)	15.5	7.90		52.0	8.0	1.0	62.0	2.0		131.0	16.0	22.0
11S/46E-26cal.b (spg)	21.0	7.90		48.0	6.0			1.5		126.0	14.5	17.3
11S/46E-26cal.a (spg)	18.3	8.50			4.8	2.9	76.0	66.6		115.0	17.0	62.0
11S/46E-26cal.b (spg)	26.5	8.70		44.0		0.2	59.0	1.5		116.0	13.4	14.4

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field) ($\mu\text{mhos/cm}$)	EC (lab) ($\mu\text{mhos/cm}$)	F	NO ₃	PO ₄ (mg/l)	Fe	Li	Sr	Source
Topopah Spg. a	09/17/57	291		.70	.10		.080			3
Topopah Spg. b	03/25/58	114		.30	2.00		.440			3
TW-8	10/15/64	197		.70	3.60		.010			9
U12e.MI	11/04/59	351		.20	2.40		1.100		.065	3
UE-16F	09/25/77	1363		4.30	9.99		.140			4
USGS A	01/23/71	404		.60	6.90		.010	.020	.210	8
USGS D	01/09/60	486		1.60	4.20		.030			15
USGS E	07/31/60	358		.60	2.50		.130			3
Well 3. a	04/04/57	421		.90	7.10		.010		.200	3
Well 3. b	09/18/57		379	.90	6.90		.010			3
Well 3. c	03/24/58	368		.90	5.80		.010		.100	3
Well 3. d	12/02/58	386		.90	6.10		.030			3
Well 5A. a	04/04/57	677		2.20	4.80		.030			3
Well 5A. b	09/18/57	676		1.60	4.60		.030			3
Well 5A. c	04/24/58	682		1.80	3.20				.100	3
Well 5A. d	02/04/59	677		1.80	4.60		.200		.100	3
Well 5B. a	04/04/57	501		.80	11.00		.010			3
Well 5B. b	09/18/57	510		.90	2.60					3
Well 5B. c	03/24/58	512		.80	11.00		.080		.100	3
Well 5C. a	09/18/57	542		.70	6.90		.010		.200	3
Well 5C. b	03/24/58	557		.80	7.20		.110		.100	3
Well 5C. c	12/09/58	538		.60	5.00		.100		.400	3
Whiterock Spg. a	04/05/57	215		.40	4.90		.620			3
Whiterock Spg. b	09/18/57	222		.40	4.80		.030			3
Whiterock Spg. c	03/21/58	197		.60	4.80		.440			3
Whiterock Spg. d	05/19/59	219		.60	1.90		.300		.100	3
OASIS VALLEY										
Ute Spg	07/03/67			3.80						7
7S/44E-26bcl	03/07/62			2.70	6.00		.470	.240	.090	6
10S/47E-30d1	03/14/62	680		3.20	7.60					6
10S/47E-33al. a (spg)	03/14/62	760		1.90	4.00					6
10S/47E-33al. b (spg)	07/03/67			6.10		.20	.039	.220	.129	7
11S/45E-22bl (spg)	03/15/62			.40	12.00		.001			6
11S/46E-26cal. a (spg)	02/22/56		319	.50	6.70		.220			6
11S/46E-26cal. b (spg)	07/03/67			.40		4.50	.009	.040	.029	7
11S/46E-26cbl. a (spg)	03/15/62	280		.20	8.50		.080			6
11S/46E-26cbl. b (spg)	07/03/67			.40			.004			7

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	Sul
11S/46E-26dcl (spg)	18.3	8.20			8.0	3.9	64.0	66.6		139.0	18.0	24.0
11S/47E-4bbl (spg)	18.3	8.40			27.0	4.9	126.0	66.6		310.0	52.0	29.0
11S/47E-7dcl		7.70		55.0	21.0	2.9	58.0	3.0		147.0	27.0	27.0
11S/47E-9acl (spg)	15.0	8.00			24.0	5.8	177.0	66.6		383.0	78.0	34.0
11S/47E-10abl (spg)	21.7	8.30			19.0	1.0	90.0	48.0		188.0	48.0	24.0
7S/44E-28cbl	22.2	7.90			48.0	4.9	118.0	5.0		266.0	54.0	106.0
11S/47E-16dcl.a (spg)	37.8	7.90		65.0	18.0		167.0	7.4		256.0	45.0	121.0
11S/47E-16dcl.b (spg)	36.1	7.90			18.0	0.5	144.0	66.6		266.0	48.0	72.0
11S/47E-16dcl.c (spg)	36.5	7.80		60.0	18.0	0.5	173.0	7.8		267.0	45.8	126.7
11S/47E-18aal.a (spg)	20.5	8.10		22.0	22.0	3.9	57.0	66.6		151.0	27.0	14.0
11S/47E-18aal.b (spg)	24.0	7.70		45.0	22.0	3.6	50.0	3.5		142.0	20.3	22.1
11S/47E-21acl.a (spg)	36.1	7.90		27.0	27.0	3.9	181.0	66.6		393.0	75.0	48.0
11S/47E-21acl.b (spg)	31.5	7.70		60.0	23.2	2.9	232.0	8.6		372.0	65.1	158.4
11S/47E-28aal (spg)		8.10			40.0	4.9	226.0	66.6		532.0	108.0	19.0
11S/47E-33bal.a (spg)	31.1	8.40			4.8	0.5	96.0	66.6		176.0	31.0	34.0
11S/47E-33bal.b (spg)	34.0	8.30		50.0	12.0	0.7	112.0	4.7		173.0	43.7	81.6
12S/47E-3aal.a (spg)	24.4	8.20		68.0	14.0	1.9	106.0	5.8		194.0	27.0	69.0
12S/47E-3aal.b (spg)	24.0	7.90		54.0	32.1	4.4	106.0	7.4		196.0	36.8	93.1
12S/47E-20bbl.a (spg)	17.8	8.10			32.0	4.9	184.0	66.6		400.0	86.0	48.0
12S/47E-20bbl.b (spg)	18.5	7.80		67.0	27.3	3.6	254.0	10.1		389.0	70.9	130.6
8S/43E-23al		8.20		38.0		11.0	69.0	66.6		275.0	59.0	24.0
8S/44E-12bl		7.90		24.0		4.9	489.0	66.6		999.0	118.0	29.0
9S/46E-20al	22.2	8.20		18.0		2.0	149.0	66.6		212.0	87.0	67.0
9S/46E-35al	22.2	8.20		11.0		5.8	87.0	66.6		155.0	55.0	24.0
10S/47E-14bl (spg)	22.2	8.50		6.0		1.0	117.0	66.6		212.0	54.0	24.0
10S/47E-27al (spg)	14.4	8.00			24.0	2.0	136.0	66.6		288.0	66.0	34.0
10S/47E-30cl		7.90			29.0	4.9	110.0	66.6		266.0	49.0	34.0
10S/47E-14bab (spg)	29.0	8.10		57.0	7.2	0.2	143.0	8.2		207.0	49.6	82.6
11S/47E-4cad (spg)	21.0	7.70		62.0	26.1	4.4	223.0	8.6		380.0	77.8	129.6
12S/47E-10bcc (spg)	16.5	7.60		51.0	14.0	0.5	156.0	7.0		292.0	40.6	91.2
11S/47E-21dcb	29.0	7.70		55.0	24.8	3.1	243.0	8.2		390.0	69.9	167.1
11S/47E-21aba (spg)	26.0	7.90		54.0	26.1	3.1	246.0	8.2		394.0	69.3	167.1
11S/47E-21aba (spg)	41.0	7.60		54.0	12.8	0.5	150.0	7.8		223.0	34.1	116.1
10S/47E-14bab (spg)	19.0	7.70		62.0	22.0	1.5	171.0	8.6		279.0	63.0	101.8
11S/47E-27cba	21.5	8.00		59.0	36.1	5.1	115.0	10.9		185.0	90.2	217.9
11S/47E-28aac	18.0	9.10		45.0	10.0	4.6	315.0	9.0		512.0	66.1	169.0
11S/47E-10ccb (spg)	21.0	8.20		60.0	12.8	2.7	124.0	5.8		185.0	25.1	70.1
12S/47E-6cdd	21.5	7.90			27.3	3.1	105.0	10.1		211.0	70.9	178.6
12S/47E-7dbd	20.0	7.70		66.0	25.3	3.6	256.0	10.1		396.0	70.9	130.6
12S/47E-19adc	20.0	7.70		67.0	38.1	5.6	290.0	10.1		439.0	97.8	249.6

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field)	EC (lab)	F	NO ₃	PO ₄	Fe	Li	SR	Source
(mg / l)										
11S/46E-26dcl (spg)	03/15/62	330		.50	14.00					6
11S/47E-4bb1 (spg)	03/14/62	760		2.20	6.50					6
11S/47-7dcl	02/22/62		399	.70	12.00					6
11S/47E-9acl (spg)	03/14/62			3.80						6
11S/47E-10abl (spg)	03/14/62	590		2.90	.01					6
7S/44E-28cbl	03/13/62			2.70	3.00					6
11S/47E-16dcl.a (spg)	02/22/56	821		5.00	.30					6
11S/47E-16dcl.b (spg)	03/14/62	750		4.20			.024			6
11S/47E-16dcl.c (spg)	07/03/67			6.10	.78				.120	7
11S/47E-18aal.a (spg)	03/14/62	240		.40	23.00					6
11S/47E-18aal.b (spg)	07/03/67			.50			.014		.044	7
11S/47E-21acl.a (spg)	03/14/62	1100		4.50						6
11S/47E-21acl.b (spg)	07/03/67			6.10			.049	.270	.220	7
11S/47E-28aal (spg)	03/14/62	1500		3.00	3.00					6
11S/47E-33bal.a (spg)	03/14/62	470	330	4.10						6
11S/47E-33bal.b (spg)	07/03/67			2.60	.10		.011	.140	.020	7
12S/47E-5cal.a (spg)	02/22/56	552		4.00	.80					6
12S/47E-5cal.b (spg)	07/03/67			.40	.10		.010	.110	.075	7
12S/47E-20bbl.a (spg)	03/16/62	1200		.30	.30					6
12S/47E-20bbl.b (spg)	07/03/67	820		6.10			.009	.100	.009	7
8S/43E-23al	03/13/62	830		1.80	.01					6
8S/44E-12bl	03/07/62			3.40	.01		.001			6
9S/46E-20al	03/21/62	810		3.20	11.00					6
9S/46E-35al	03/21/62	610		4.50	12.00					6
10S/47E-14bl (spg)	03/14/62	550		3.80	.01					6
10S/47E-27al	03/14/62			3.70			.001			6
10S/47E-30cl	03/14/62	590		1.50	11.00					6
10S/47E-14bab (spg)	07/03/67			4.10	.10		.020	.170	.015	7
11S/47E-4cad (spg)	07/03/67			5.10	.40		.008	.150	.279	7
11S/47E-10bcc (spg)	07/03/67			4.50	.40		.045	.180	.040	7
11S/47E-21dbb	07/03/67			6.10			.060	.280	.251	7
11S/47E-21aba (spg)	07/03/67			6.10			.030	.250	.260	7
11S/47E-21aba (spg)	07/03/67			6.10	.10		.010	.190	.120	7
10S/47E-27cba	07/03/67			18.80	.10		.010	.150	.150	7
11S/47E-27cba	07/03/67			7.00			.060	.140	.020	7
11S/47E-28aac	07/03/67			6.40			.070	.360	.399	7
11S/47E-10ccb (spg)	07/03/67			3.80	1.40		.009	.160	.059	7
12S/47E-6cdd	07/03/67			6.10	2.00		.060	.080	.120	7
12S/47E-7dbd	07/03/67			6.10			.049	.210	.120	7
12S/47E-19adc	07/03/67			6.20	.48			.220	.200	7

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
PAIUTE MESA												
105/47E-31aab (spg)	19.5	7.60		71.0	23.2	4.4	100.0	7.8		228.0	40.6	52.8
105/47E-32dda (spg)	22.0	7.60		62.0	30.1	5.3	137.0			310.0	35.8	96.0
105/47E-33aab (spg)	22.0	7.80		54.0	30.1	4.6	169.0	9.0		296.0	66.1	102.7
105/47E-30dcc	22.5	7.80		72.0	24.0	4.6	100.0	7.8		231.0	38.9	56.6
PAIUTE MESA												
U19as		9.30		66.0	2.0	0.1	200.0	5.5		174.0	19.0	26.0
U20a-2	26.6	6.90		41.0	5.9	0.1	58.0	1.9		108.0	11.0	28.0
U20f	41.6	9.10		39.0	0.4	0.1	69.0	.8		98.0	7.0	23.0
Ue18r	32.2	8.00		45.0	26.0	1.0	81.0	3.1		252.0	7.8	24.0
Ue19b-1	31.6	6.70		47.0	20.0	1.7	43.0	2.9		130.0	13.0	24.0
Ue19c	31.1	7.90		30.0	13.0	0.1	141.0	.2		400.0	7.7	1
Ue19d.a	32.2	7.50		28.0	29.0	2.9	173.0	3.6		424.0	39.0	61.0
Ue19d.b	45.0	7.90		58.0	44.0	5.0	150.0	3.7		380.0	33.0	80.0
Ue19e	35.0	8.20		56.0	3.7		43.0	.8		80.0	3.7	16.0
Ue19fs	37.7	8.10		56.0	11.0	1.6	29.0	3.0		86.0	6.3	9.0
Ue19gs.a	41.6	8.20		46.0	12.0		68.0	.6		146.0	9.0	36.0
Ue19gs.b	41.6	8.20		50.0	2.8		84.0	1.5		123.0	22.0	41.0
Ue19i	47.2	7.70		39.0	5.0		75.0	.5		98.0	7.0	70.0
Ue20d.a	41.6	8.30		46.0	1.4		83.0	.1		120.0	24.0	42.0
Ue20d.b	40.0	8.40		52.0	21.0		68.0	.5		143.0	8.8	53.0
Ue20e-1.a	47.2	7.70		44.0	0.4		112.0	3.8		130.0	57.0	43.0
Ue20e-1.b	32.8	8.50		36.0	0.2		83.0	2.0		119.0	20.0	42.0
Ue20f	48.8	7.20		47.0	4.8		113.0	2.0		119.0	40.0	48.0
Ue20h	32.2	8.10		49.0	0.6		64.0	1.8		107.0	151.0	30.0
Ue20j	38.9	7.00		44.0	46.0	1.2	138.0	6.4		150.0	115.0	135.0
YUCCA MOUNTAIN												
J-11.a	33.3	7.80		67.0	85.0	14.0	157.0	16.0		102.0	20.0	484.0
J-11.b	35.5	8.00		67.0	84.0	13.0	154.0	16.0		104.0	18.0	479.0
J-11.c	35.5	7.60		68.0	82.0	13.0	143.0	15.0	102.0	102.0	18.0	449.0
J-12	27.0	7.10		54.0	14.0	2.1	38.0	5.1		119.0	7.3	22.0
J-12.a	25.5	8.20		26.0	9.6	1.9	46.0	5.2		121.0	7.0	24.0
J-12.b	25.5	7.40		49.0	14.0	1.5	42.0	4.4		118.0	8.0	24.0
J-13	31.0	7.20		57.0	12.0	2.1	42.0	5.0		124.0	7.1	17.0
UE-25b#1.a	36.0	7.10	6.80	53.0	19.0	0.7	53.0	3.7	173.0	158.0	13.0	22.0
UE-25b#1.b	36.0	7.50	7.50	52.0	17.0	0.6	46.0	3.5	139.0	134.0	8.5	22.0
UE-25b#1.c	37.2	7.10	7.70	51.0	18.0	0.7	46.0	2.8	133.0	138.0	7.5	21.0
UE-25c#1	41.5	7.60	7.70	56.0	11.0	0.3	56.0	2.0	151.0	140.0	7.4	23.0
UE-25c#2	40.5	7.70	7.80	54.0	12.0	0.4	54.0	2.1	139.0	143.0	7.1	22.0
UE-25c#3	40.8	7.70	7.80	53.0	11.0	0.4	55.0	1.9	137.0	143.0	7.2	22.0
UE-25p#1 (vol)	44.3	6.80	7.70	49.0	37.0	10.0	92.0	5.6	282.0	282.0	13.0	38.0
UE-25p#1 (carb)	56.0	6.60	7.20	41.0	100.0	39.0	150.0	12.0	569.0	569.0	28.0	160.0

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field)	EC (lab)	F	NO ₃	PO ₄	Fe	Li	Sr	Source
(mg / l)										
PARUTE MESA										
10S/47E-31aab (spg)	07/03/67			2.40	1.20		.011	.080	.179	7
10S/47E-32dda (spg)	07/03/67			2.30			.010	.110	.380	7
10S/47E-33aab (spg)	07/03/67			4.30	.20		.018	.110	.190	7
10S/47E-30dec	07/03/67			1.70			.018	.080	.190	7
U19as	06/07/65	889		80.00	1.00		.030	.610	.020	9
U20a-2	10/14/64	285		2.60	1.20		.130			9
U20f	05/27/66	297		3.70	.10		.560			9
Ue18r	01/29/68	449		2.90	.60			.100	.180	9
UE19b-1	06/21/64	316		3.20	.10	.01	.350			9
Ue19c	03/09/66	644		4.30	1.80		.040	.280	.070	9
UE19d.a	03/24/64	889		4.40	30.00		.590	.300	.290	9
UE19d.b	06/27/64	851		6.90	.10	.01	.060			9
UE19e	08/01/66	204		5.30	1.70		.020	.060	.020	9
UE19fs	08/18/65	202		3.60	2.20	.01	.010	.020	.020	9
UE19gs.a	03/27/65	345		2.00	1.30	.01	.070			9
UE19gs.b	08/02/66	388	270	3.00	.60		.010	.040	.020	9
UE19i	09/02/65	228		5.50	.20	.01	.010	.050	.040	9
UE20d.a	03/08/66	351		3.10	1.70		.070	.080	.030	9
UE20d.b	07/28/66	394		2.40	.30	.01	.020	.110	.110	9
UE20e-1.a	06/05/64	515		4.60	1.00		.170			9
UE20e-1.b	03/08/66	352		4.50	.50		.620	.070	.070	9
UE20f	08/11/64	519		5.00	.10	.02	.560			9
UE20h	08/26/65	301		3.70	1.30	.01	.010	.080	.020	9
UE20j	10/21/64	904		2.20	.90		.010			9
YUCCA MOUNTAIN										
J-11.a	09/18/57	1210		.90	7.40		.110			3
J-11.b	04/24/58	1200		1.00	5.80					3
J-11.c	12/16/58	1180		1.10	8.00		.130	.880	.200	3
J-12	03/26/71	285	252	2.10	285			.040	.010	2
J-12.a	04/25/58	266		1.80	9.99		.520			3
J-12.b	02/19/59	276		1.80	.70		.060		.200	3
J-13	03/26/71	285	252	2.40	7.20			.040	.020	2
UE-25b11.a	08/07/81	318	319	1.50	.91			.950	.044	2
UE-25b11.b	09/01/81	281	281	1.60				.220	.038	2
UE-25b11.c	07/20/82	291	297	1.60				.120	.047	2
UE-25c11	09/30/83	290	310	2.10	1.10			.120	.010	2
UE-25c12	03/13/84	295	303	2.10	2.10			.094	.045	2
UE-25c13	05/09/84	298	309	2.00	1.30			.110	.044	2
UE-25p11 (vol)	02/09/83	628	639	3.40				.230	.190	2
UE-25p11 (carb)	05/12/83	1120	1120	4.70				.590	.450	2

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Temp. C	pH (field)	pH (lab)	SiO ₂	Ca	Mg	Na	K (mg / l)	HCO ₃ (field)	HCO ₃ (lab)	Cl	SO ₄
UE-25 WT#4		7.61							140.0			
UE-25 WT#12	34.0	7.58	8.02	47.0	14.4		65.7	2.3	167.0	163.0	7.3	26.1
UE-25 WT#14	31.5	7.27	7.31	58.0	9.2	0.8	42.4	5.5	119.0	116.0	7.5	18.6
UE-25 WT#15	28.6	7.50	7.62	53.0	11.6	1.7	61.8	4.6	166.0	168.0	11.5	16.1
UE-29a#2.a	25.1	7.20	7.60	44.0	10.0	0.2	44.0	1.1	107.0	112.0	11.0	22.0
UE-29a#2.b	22.7	7.00	7.40	44.0	10.0	0.3	44.0	1.3	107.0	110.0	8.8	21.0
USW G-4	35.6	7.70	7.50	45.0	13.0	0.2	57.0	2.1	139.0	143.0	5.9	19.0
USW H-1.a	33.0	7.70	7.80	47.0	4.5	0.1	51.0	2.4		115.0	5.7	18.0
USW H-1.b	34.7	7.50	8.00	40.0	6.2	0.1	51.0	1.6		122.0	5.8	19.0
USW H-3	26.5	9.20	9.00	43.0	0.8		120.0	1.1		274.0	5.5	31.0
USW H-4	34.8	7.40	7.90	46.0	17.0	0.3	73.0	2.6	173.0	171.0	6.9	26.0
USW H-5.a	36.5	7.80	7.80	48.0	1.9		60.0	2.1	126.0	124.0	6.1	16.0
USW H-5.b	35.3	7.90	8.00	48.0	2.0		60.0	2.1	127.0	124.0	6.1	16.0
USW H-6.a	37.8	8.10	8.30	48.0	4.1	0.1	86.0	1.3	182.0	188.0	7.6	29.0
USW H-6.b	41.6	8.30	8.40	47.0	1.4		88.0	1.3	217.0	183.0	7.2	25.0
USW H-6.c	37.2	8.30	8.30	49.0	4.7	0.1	88.0	1.4	234.0	184.0	7.4	32.0
USW VH-1.a	35.2	7.90	8.00	50.0	11.0	0.6	79.0	1.9	167.0	158.0	11.0	44.0
USW VH-1.b	35.5	7.50	7.90	50.0	1.0	0.5	80.0	1.9	165.0	158.0	10.0	45.0
USW VH-1.c	35.5	7.50	8.00	49.0	9.9	0.5	78.0	1.8	162.0	158.0	10.0	44.0
USW WT-7		8.70	8.10	20.0	2.6	0.2	96.6	2.1	252.0	228.0	12.5	7.3
USW WT-10	31.5	8.28	8.42	47.0	2.7	0.1	93.8	1.1	202.0	181.0	7.8	33.6

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field) ($\mu\text{mhos/cm}$)	EC (lab) ($\mu\text{mhos/cm}$)	F	NO ₃	PO ₄ (mg / l)	Fe	Li	Sr	Source **
UE-25 WT14	04/13/88	346	0					.080		18
UE-25 WT12	04/28/88	365	347		4.56			.080		18
UE-25 WT14	03/26/88	256	251		1.86			.050		18
UE-25 WT15	04/23/88	347	344		.03			.550		18
UE-29a2.a	01/08/82	240	255	1.00				.100	.450	2
UE-29a2.b	01/15/82	258	317	.90	9.70			.110	.033	2
USM G-4	12/09/82	312	307	2.50				.067	.017	2
USM H-1.a	10/20/80	255	258	1.20	.10			.040	.005	2
USM H-1.b	12/08/80	247	266	1.00				.040	.020	2
USM H-3	03/14/84	523	535	5.50				.220	.001	2
USM H-4	05/17/82	340	381	4.60				.130	.027	2
USM H-5.a	07/03/82	275	273	1.40				.062	.009	2
USM H-5.b	07/26/82	278	276	1.40				.071	.004	2
USM H-6.a	10/16/82	372		4.70				.082	.008	2
USM H-6.b	06/20/84	360	392	3.90		.06		.071	.003	2
USM H-6.c	07/06/84	402	408	4.70		.18		.062	.008	2
USM VH-1.a	02/06/81	370	410	2.70				.090	.070	2
USM VH-1.b	02/08/81	395	397	2.70				.090	.070	2
USM VH-1.c	02/11/81	388	402	2.70				.090	.060	2
USM WT-7	06/04/88	422	413		0.04			.080		18
USM WT-10	05/16/88	416	407		4.25			.090		18

** Sources 1-18: See list on page 128.

TABLE III
ISOTOPES OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	Oxygen 18/16 (0/00)	Deuterium (0/00)	Tritium (TU)	Carbon 13/12 (0/00)	Carbon 14 (b.p.)	Percent Modern Carbon	Source
ANARGOOSA DESERT								
AM 101 Anargosa	03/30/73			200.0		15,900	13.8	4
Ash Tree Spg	03/06/74	-12.4	-102.0			15,900	13.8	1
15S/49E-22dc	11/20/72	-12.8	-102.0			14,900	15.6	1
16S/49E-5acc	03/03/74	-13.2	-103.0		-7.1	13,200	19.3	1
16S/49E-8abb	11/17/72	-13.2	-99.5		-6.8	12,400	21.4	1
16S/49E-9dcc	03/01/74	-13.4	-103.0		-7.3	12,200	21.9	1
16S/49E-18dc	03/01/74	-12.6	-102.0			10,100	28.4	1
16S/49E-16ccc	06/26/79	-13.2	-97.5		-5.2	11,200	24.8	1
16S/49E-19daa	03/05/74	-13.1	-101.0			12,600	20.8	1
16S/49E-25aa	03/05/74	-13.0	-102.0			13,200	19.3	1
16S/48E-16aaa	03/04/74	-12.6	-98.5			13,600	18.4	1
17S/48E-1ab	03/05/74	-13.0	-104.0			18,500	10.0	1
17S/49E-7bb	03/01/74	-12.7	-104.0			13,400	18.9	1
17S/49E-9aa	03/01/74	-12.8	-105.0			10,300	27.8	1
17S/49E-8ddb	03/06/74	-13.0	-102.0			7,300	40.3	1
17S/49E-15bbd	03/06/74				-8.4	10,400	27.4	1
16S/49E-23add	06/25/79	-13.2	-99.0			14,200	17.1	1
16S/48E-15dda	06/26/79	-13.4	-103.0		-7.1	14,900	15.6	1
16S/48E-15aaa	03/31/71	-13.4	-102.0		-5.6	21,400	7.0	1
16S/48E-10cba	03/31/71	-13.4	-102.0		-3.6	18,300	10.3	1
16S/50E-7bcd	08/18/62	-13.8	-105.0		-3.4	9,300	31.4	1
16S/49E-15aaa	03/31/71	-13.8	-105.0		-4.4			1
16S/49E-36aaa	06/24/79	-13.7	-104.0		-6.2			1
16S/48E-7cbc	03/31/71	-13.1	-102.0		-5.7			1
16S/48E-18dad	06/25/79	-13.6	-104.0		-5.9	10,000	28.8	1
N.E.C. Well 1	12/16/68		-112.0			17,300	11.6	4
Copeland	03/01/74		-102.0	23.1	-5.0	28,700	2.8	14
Crystal Pool	05/24/73	-13.7	-102.0	.6	-5.0	31,800	1.8	14
Devils Hole	12/14/74	-13.6	-103.0	.3	-4.9			14
Fairbanks Spg	05/23/73	-13.6	-103.0	.4				14
Jacobs East	03/01/74		-102.0	15.9	-4.1	24,500	1.7	4
King Spg	08/20/82	-13.6	-102.0	6.3	-4.8	29,000	2.7	4
Longstreet Spg	06/02/75		-103.0	16.9				14
Supply	03/04/74							4

NEVADA TEST SITE

Army-1	06/21/82	-13.1	-99.0			20,700		12
Test Hole 4	09/27/83	-12.6	-94.0	< 4.0	-10.9			12
Test Well C	06/22/82	-13.3	-108.0					12
Test Well F	03/12/80		-104.0	62.5				4
TW-8	03/24/71	-13.0	-104.0		-12.1	11,000	25.4	1

TABLE III
ISOTOPES OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	Oxygen 18/16 (0/00)	Deuterium (0/00)	Tritium (TU)	Carbon 13/12 (0/00)	Carbon 14 (b.p.)	Percent Carbon	Source
UE-16P	09/25/77	-14.9	-105.0	43.0	-8.9	23,823		12
USCS A	06/22/82	-13.0	-107.0	<2.0		14,800		12
Well 58.a			-110.0					17
Well 5C.a	06/21/82	-13.4	-108.0	.5				12
Whiterock Spg		-10.2	-82.0	34.0				12
OASIS VALLEY								
11S/47E-16del (spg)			-110.0		-4.5			5
11S/47E-21acl (spg)		-14.1	-109.0		-6.9			5
12S/47E-5cal (spg)		-14.1	-108.0		-6.3	4,100	34.2	5
12SA/47-20bbl (spg)		-13.6	-106.0		-8.0			5
10S/47E-14bab (spg)		-14.5	-112.0		-2.5	17,000	6.9	5
11S/47E-4cad (spg)		-14.0	-107.0		-5.0			5
11S/47E-21dbb		-14.0	-108.0		-4.5			5
10S/47E-cba		-14.3	-110.0		-5.3		38.9	5
11S/47E-27cba					-6.3	4,000	31.6	5
11S/47E-28aac		-14.9	-108.0		-7.1			5
12S/47E-6odd		-13.3	-102.0		-6.6			5
12S/47E-7dbd		-13.9	-107.0		-6.9		64.7	5
12S/47E-19adc		-13.3	-104.0		-8.0		28.4	5
10S/47E-11aab (spg)		-13.4	-102.0		-5.3		97.8	5
10S/47E-32dda (spg)		-13.4	-102.0		-6.0			5
10S/47E-11aab (spg)		-14.0	-108.0		-4.9		100.0	5
10S/47E-30dec (spg)		-13.4	-102.0		-5.2	3,900	35.0	5
PNIUTE MESA								
U20a-2		-14.7	-114.0		-13.5	15,100	15.3	5
UE19c	06/22/82	-14.1	-109.0	< 2.0	-11.6	21,757		12
UE19e	06/22/85	-14.0	-110.0					11
UE19gs		-14.5	-113.0					5
UE191		-14.1	-109.0					5
YUCCA MOUNTAIN								
J-12	03/26/71	-12.8	-97.5	< 68.7	-7.9	7,500	32.2	2
J-13	03/26/71	-13.0	-97.5	< 68.7	-7.3	8,100	29.2	2
UE-25b11.a	08/07/81	-13.4	-99.5		-10.7			2
UE-25b11.b	09/01/81	-13.4	-101.0	< 62.5	-10.4	14,100	16.7	3
UE-25b11.c	07/20/82	-13.5	-99.5	.6	-8.6		18.9	2

TABLE III
ISOTOPES OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	Oxygen 18/16 (0/00)	Deuterium (0/00)	Tritium (TU)	Carbon 13/12 (0/00)	Carbon 14 (b.p.)	Percent Modern Carbon	Source
UE-25c11	09/10/83	-13.5	-102.0	.3	-7.1		15.0	2
UE-25c12	03/13/84	-13.4	-100.0	.6	-7.0		16.6	2
UE-25c13	05/09/84	-13.5	-103.0	.6	-7.5		15.7	2
UE-25p11 (vol)	02/09/83	-13.5	-106.0	< 3.1	-4.2		3.5	2
UE-25p11 (carb)	05/12/83	-13.8	-106.0	3.1	-2.3		2.3	2
UE-25 WT12	04/28/88	-13.7	-101.0		-7.7		11.4	18
UE-25 WT14	03/26/88	-12.3	-96.0		-12.7		24.1	18
UE-25 WT15	04/23/88	-12.9	-97.0		-11.8		21.6	18
UE-29a12.a	01/08/82	-12.8	-93.5	11.6	-13.0	2,000	62.3	2
UE-29a12.b	01/15/82	-12.8	-93.0	11.6	-13.1	2,400	60.0	2
USW G-4	12/09/82	-13.8	-103.0		-9.1		22.0	2
USW H-1.a	10/20/80	-13.4	-103.0	< 6.3		13,000	19.9	2
USW H-1.b	12/08/80	-13.5	-101.0	< 6.3	-11.4		23.9	2
USW H-3	03/14/84	-13.9	-101.0	.6	-4.9		10.5	2
USW H-4	05/17/82	-14.0	-104.0	< 3.1	-7.4		11.8	2
USW H-5.a	07/03/82	-13.6	-102.0	< 62.5	-10.3		18.2	2
USW H-5.b	07/26/82	-13.6	-102.0	< 62.5	-10.3		21.4	2
USW H-6.a	10/16/82	-13.8	-106.0	< 3.1	-7.5		16.3	2
USW H-6.b	06/20/84	-14.0	-105.0	1.3	-7.3		10.0	2
USW H-6.c	07/06/84	-14.0	-107.0	.3	-7.1		12.4	2
USW VI-1.c	02/11/81	-14.2	-108.0	< 6.3	-8.5	17,000	12.2	2
USW WT-7	05/09/84	-13.7	-103.0					18
USW WT-10	05/09/84	-13.7	-103.0		-6.6			18

** Sources 1-18: See list on page 128.

*** Oasis Valley isotope data collected 1978, 1979 and 1984 by A.F. White (USGS), 1987.

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APPENDIX B

COMPUTER LISTING OF PHREEQE FLOW PATH AND MIXING MODELS

- 1: PHREEQE Input
- 2: Thermodynamic Data
- 3: Sample PHREEQE Output

PHREEQE INPUT OF
GEOCHEMICAL FLOW PATH

INITIAL, SOLUTION FROM SOIL WATER (HENNE, 1982)

100000100 0 6 0.0
ELEMENTS
C 15 61.0171

SOLUTION 1

Water from lysimeter 7, Rainier Mesa (Henne, 1982)

8 15 2	7.2	4.5	25.	71.2	47.4	52.16
1324.		631.5				
15105.		145.		161.6		
LOOK MIN						
CRISTOBA	2	0.0	-3.687	5.5	0	
13 1.0		3 -2.0				
PCO2	2	4.0	-1.466	-4.708	0	
35 1.0		3 -1.0				
NAMONT	5	0.	-46.24	57.09	0	0. 12.
3-12.		1532.33		133.67	60.33	
K-MONT	5	0.	-46.84	58.90	0	0. 12.
3-12.		1532.33		133.67	70.33	
CAMONT	5	0.	-45.03	58.37	0	0. 12.
3-12.		1532.33		133.67	40.165	
HEULANDI	4	0.	-49.26	62.60	0	0.
3-12.		41.		1532.	137.	
ADULARIA	4	0.	-20.57	30.82	0	0.
3-8.		71.		1531.	133.	
ALBITE	4	0.	-18.00	25.89	0	0.
3-8.		61.		1531.	133.	
ILLITE	6	0.	-40.267	54.68	0	0. 133.5
3-11.2		70.6		50.25	1532.3	
11.2						
ANALCIME	4	0.0	-12.70	18.21	0	0.
3-5.		61.		1531.	132.	

END

PART I: VOLCANIC GLASS DISSOLUTION

006010100 0 6 0.0

ELEMENTS

C 15 61.0171

MINERALS

CRISTOBA	2	0.0	-3.687	5.5	0	
13 1.0		3 -2.0				
NAMONT	5	0.	-46.24	57.09	0	0. 12.
3-12.		1532.33		133.67	60.33	
HEULANDI	4	0.	-49.26	62.60	0	0.
3-12.		41.		1532.	137.	
PCO2	2	4.	-1.47	-4.71	0	
351.		3-1.0				

REACTION

65.6	0.	74.2	0.	40.1	0.	80.7	2.
109.6	0.	1351.9	0.				

END

PART II: ION EXCHANGE IN CLINOPTILOLITE

006110100 0 3 0.0

ELEMENTS

C 15 61.0171

MINERALS

CRISTOBA	2	0.0	-3.687	5.5	0	
13 1.0		3 -2.0				
NAMONT	5	0.	-46.24	57.09	0	0. 12.
3-12.		1532.33		133.67	60.33	
ADULARIA	4	0.	-20.57	30.82	0	0.
3-8.		71.		1531.	133.	

TEMP

30.0

REACTION

41.	0.	62.	0.	72.	0.
-----	----	-----	----	-----	----

END

PART III: ION EXCHANGE IN MORDENITE

006110100 0 3 0.0

ELEMENTS

C 15 61.0171

MINERALS

CRISTOBA	2	0.0	-3.687	5.5	0	
13 1.0		3 -2.0				
NAMONT	5	0.	-46.24	57.09	0	0.
3-12.		1532.33	133.67		60.33	12.
K-MONT	5	0.	-46.84	58.90	0	0.
3-12.		1532.33	133.67		70.33	12.
ADULARIA	4	0.	-20.57	30.82	0	0.
3-8.		71.	1531.		133.	

TEMP

32.5

REACTION

41.	0.	66.	0.	72.	0.
END					

PART IV: ION EXCHANGE IN ANALCIME

006110100 0 2 0.0

ELEMENTS

C 15 61.0171

MINERALS

QUARTZ	2	0.0	-4.006	6.22	0	
13 1.0		3 -2.0				
NAMONT	5	0.	-46.24	57.09	0	0.
3-12.		1532.33	133.67		60.33	12.
K-MONT	5	0.	-46.84	58.90	0	0.
3-12.		1532.33	133.67		70.33	12.
CAMONT	5	0.	-45.03	58.37	0	0.
3-12.		1532.33	133.67		40.165	12.

REACTION 0. 72. 0.
 66.
 TEMP 35.0
 END

PART V: MINERALS REACT - NO ION EXCHANGE

005110100 0 3 0.0

ELEMENTS

C 15 61.0171

MINERALS

CHALCEDY	2	0.0	-3.523	4.615	0	
13 1.0		3 -2.0				
CHLORITE	5	0.0	-89.563	54.760	0	
3 -10.0		5 5.0	153 2.0		13 3.0	0.0
ADULARIA	4	0.	-20.57	30.82	0	31 8.0
3-8.		71.	1531.		133.	0.
ALBITE	4	0.	-18.00	25.89	0	
3-8.		61.	1531.		133.	0.
ILLITE	6	0.	-40.267	54.68	0	
3-11.2		70.6	50.25		1532.3	133.5
11.2						
CALCITE	2	4.0	-8.47	-2.58	1	
15 1.0		4 1.0				
13.543		-0.0401	-3000.0			

TEMP 40.0
 END

PHREEQE THERMODYNAMIC DATA

ELEMENTS
SPECIES
LOOK MIN

DATA: CARD IMAGES FROM DISK

ELEMENTS

4 40.08
5 24.305
6 22.9998
7 39.0983
8 55.847
9 54.9380
10 26.9815
11 137.33
12 87.62
13 60.0843
14 35.453
15 61.0171
16 96.06
17 62.0049
18 10.81
19 94.9714
20 18.9984
21 6.941
22 79.904

CA+2
MG+2
NA+
K+
FE+2
MN+2
AL+3
BA+2
SR+2
SIO2
CL-
HCO3-
SO4-2
NO3-
B
PO4-3
F-
LI+
BR-

SPECIES

1
H+ 100 1.0 0.0 0.0 9.0 0.0
0.0
1.1.0
2
E- 100 -1.0 0.0 0.0 0.0 0.0
0.0
4 1.0
3
H2O 100 0.0 0.0 0.0 0.0 0.0
0.0
3 1.0
4
CA+2 101 2.0 0.0 6.0 5.0 0.165
0.0
4 1.0
5
MG+2 101 2.0 0.0 8.0 5.5 0.20
0.0
5 1.0
6
NA+ 101 1.0 0.0 4.0 4.0 0.075
0.0
6 1.0
7
K+ 101 1.0 0.0 3.0 3.5 0.015
0.0

7 1.0
8
FE+2 100 2.0 2.0 6.0 2.0 0.0
0.0
8 1.0
9
MN+2 100 2.0 2.0 6.0 2.0 0.0
0.0
9 1.0
10
AL+3 100 3.0 0.0 9.0 0.0 0.0
0.0
10 1.0
11
BA+2 100 2.0 0.0 5.0 0.0 0.0
0.0
11 1.0
12
SR+2 100 2.0 0.0 5.0 0.0 0.0
0.0
12 1.0
13
H4SIO4 100 0.0 0.0 0.0 0.0 0.0
0.0
13 1.0
14
CL- 101 -1.0 0.0 3.0 3.5 0.015
0.0
14 1.0
15
CO3-2 101 -2.0 4.0 4.5 5.4 0.0 2.0
0.0
15 1.0
16
SO4-2 101 -2.0 6.0 4.0 5.0 -0.04 0.0
0.0
16 1.0
17
NO3- 100 -1.0 5.0 3.0 0.0 0.0
0.0
12 1.0
13
H4SIO4 100 0.0 0.0 0.0 0.0 0.0
0.0
13 1.0
14
CL- 101 -1.0 0.0 3.0 3.5 0.015 0.0
0.0
14 1.0
15
CO3-2 101 -2.0 4.0 4.5 5.4 0.0 2.0
0.0
15 1.0
16
SO4-2 101 -2.0 6.0 4.0 5.0 -0.04 0.0
0.0

	18 1.0	20 1.0			4 1.0	1 2.0	19 1.0		
59					H2				
HF2OH2-		400 -1.0	0.0	0.0	CAF+	200 1.0	0.0	0.0	0.0
7.628		1.635			0.940	3.798			
18 1.0		20 2.0	1 1.0	3 -1.0	4 1.0	20 1.0			
60					H5				
HF2OH-		400 -1.0	0.0	0.0	M2OH+	300 1.0	0.0	0.0	1.0
13.666		-1.38			-11.794	15.419			
18 1.0		1 2.0	20 3.0	3 -2.0	5 1.0	3 1.0	1 1.0		
61					H6				
BF4-		400 -1.0	0.0	0.0	M2CO3	210 0.0	4.0	0.0	2.0
20 2/4		-1.795			2.980	2.713	0.9910	0.00667	
18 1.0		1 3.0	20 4.0	3 -3.0	5 1.0	15 1.0			
65					H7				
HPO4-2		200 -2.0	0.0	4.0	M2HCO3+	310 1.0	4.0	0.0	1.0
12.346		-3.53			11.396	-2.527	-4.1790	0.01273	2.2981E 05
19 1.0		1 1.0			5 1.0	1 1.0	15 1.0		
66					H8				
H2PO4-		200 -1.0	0.0	4.5	M2SO4	200 0.0	6.0	0.0	0.0
19.553		-4.52			2.250	1.4			
19 1.0		1 2.0			5 1.0	16 1.0			
69					H9				
HF AQ		200 0.0	0.0	0.0	M2RO4-	200 -1.0	0.0	0.0	2.0
3.169		3.46			6.589	3.103			
1 1.0		20 1.0			5 1.0	19 1.0			
70					H9				
HF2-		200 -1.0	0.0	0.0	M2HPO4	300 0.0	0.0	0.0	1.0
3.749		4.55			15.216	-0.230			
1 1.0		20 2.0			5 1.0	1 1.0	19 1.0		
75					H1				
CAOH+		300 1.0	0.0	0.0	M2H2PO4+	300 1.0	0.0	0.0	0.0
-12.598		14.535			21.066	-1.120			
4 1.0		3 1.0	1 -1.0		5 1.0	1 2.0	19 1.0		
76					H2				
CACO3		210 0.0	4.0	0.0	M2F+	200 1.0	0.0	0.0	0.0
3.153		4.023	-27.393	0.05617	1.820	4.674			
4 1.0		15 1.0			5 1.0	20 1.0			
77					H5				
CAHCO3+		310 1.0	4.0	0.0	NACO3-	200 -1.0	4.0	0.0	2.0
11.345		1.806	-9.448	0.03709	1.268	8.911			
4 1.0		15 1.0	1 1.0		6 1.0	15 1.0			
78					H6				
CASO4		200 0.0	6.0	0.0	NAHCO3	300 0.0	4.0	0.0	1.0
2.309		1.470			10.080	-3.604			
4 1.0		16 1.0			6 1.0	1 1.0	15 1.0		
79					H7				
CAPO4-		200 -1.0	0.0	0.0	NASO4-	200 -1.0	6.0	0.0	0.0
6.459		3.100			0.700	1.120			
4 1.0		19 1.0			6 1.0	16 1.0			
80					H8				
CAHPO4		300 0.0	0.0	0.0	NAHPO4-	300 -1.0	0.0	0.0	1.0
15.085		-0.230			12.636	-3.530			
4 1.0		1 1.0	19 1.0		6 1.0	1 1.0	19 1.0		
81					H10				
CAH2PO4+		300 1.0	0.0	0.0	KSO4-	200 -1.0	6.0	0.0	0.0
20.961		-1.120			0.85	2.25			

	16 1.0	100 -1.0	5.0	3.0	0.0	16 1.0	1 8.0	2 8.0	3 4.0	
17	42				0.0	42				
NO3-		100 -1.0	5.0	3.0	0.0	HS-	400 -1.0	-2.0	3.5	
0.0		0.0				33.652	-40.14			1.0
17 1.0						15 1.0	1 1.0			
18						35				
H3AsO3		100 0.0	0.0	0.0	0.0	H2CO3	310 0.0	4.0	0.0	
0.0		0.0				16.681	-5.847	-21.3415	0.056576	6.007.1
18 1.0						15 1.0	1 2.0	3 -1.0		0.0
19						36				
HCO3		100 -3.0	0.0	4.0	2.0	CH4 AQ	400 0.0	-4.0	0.0	0.0
0.0		0.0				41 071	-61.039			
19 1.0						15 1.0	1 10.0	2 8.0	3 -3.0	
20						40				
F-		100 -1.0	0.0	3.5	0.0	H2SO4-	210 -1.0	6.0	0.0	0.0
0.0		0.0				1.987	4.91	-5.3505	0.0183412	557.2461
20 1.0						16 1.0	1 1.0			
21						41				
Li+		100 1.0	0.0	6.0	0.0	S-2	400 -2.0	-2.0	5.0	2.0
0.0		0.0				20.735	-28.04			
21 1.0						16 1.0	1 8.0	2 8.0	3 -4.0	
22						42				
Br-		100 -1.0	0.0	3.0	0.0	HS-	400 -1.0	-2.0	3.5	1.0
0.0		0.0				33.652	-40.14			
22 1.0						16 1.0	1 9.0	2 8.0	3 -4.0	
31						43				
OH-		200 -1.0	0.0	3.5	1.0	H2S	400 0.0	-2.0	0.0	0.0
13.998		13.345				40.344	-65.44			
3 1.0		1 -1.0				16 1.0	1 10.0	2 8.0	3 -4.0	
32						48				
O2 AQ		300 0.0	4.0	0.0	0.0	NO2-	400 -1.0	3.0	3.5	0.0
-86 08		134.79				28.57	-43.76			
3 2.0		1 -4.0	2 -4.0			17 1.0	1 2.0	2 2.0	3 -1.0	
33						49				
H2 AQ		200 0.0	-2.0	0.0	0.0	N2 AQ	400 0.0	0.0	0.0	0.0
-3.15		-1.759				207.08	-312.13			
1 2.0		2 2.0				17 2.0	1 12.0	2 10.0	3 -6.0	
34						50				
HCO3-		211 -1.0	4.0	4.5	1.0	NH3 AQ	400 0.0	-3.0	0.0	1.0
10.33		-3.604	-6.498	0.02379		109.83	-174.58			
15 1.0		1 1.0				17 1.0	1 9.0	2 8.0	3 -3.0	
35						51				
H2CO3		310 0.0	4.0	0.0	0.0	NH4+	400 1.0	-3.0	2.5	0.0
16.681		-5.847	-21.3415	0.056576		119.077	-187.055			
15 1.0		1 2.0	3 -1.0			17 1.0	1 10.0	2 8.0	3 -3.0	
36						52				
CH4 AQ		400 0.0	-4.0	0.0	0.0	NH4SO4-	500 -1.0	3.0	0.0	0.0
41 071		-61.039				120.19	-187.055			
15 1.0		1 10.0	2 8.0	3 -3.0		17 1.0	1 10.0	2 8.0	16 1.0	3 -3.0
40						57				
H2SO4-		210 -1.0	6.0	0.0	0.0	H2BO3-	200 -1.0	0.0	0.0	1.0

	7 1.0	16 1.0				8 1.0	3 4.0	1 -4.0	2 -1.0	
101						120				
NIPO4-		300 -1.0	0.0			FE2OH2+4	400 4.0	6.0	0.0	0.0
12.636		-3.530				-29.01	33.5			
7 1.0		1 1.0	19 1.0			8 2.0	3 2.0	1 -2.0	2 -2.0	
105						121				
FEOH+		300 1.0	2.0	0.0		FE3OH4+5	400 5.0	9.0	0.0	0.0
-9.500		13.2				-45.4	44.3			
8 1.0		3 1.0	1 -1.0			8 3.0	3 4.0	1 -4.0	2 -3.0	
106						122				
FEOM2		300 0.0	2.0	0.0		FECH+2	300 2.0	3.0	0.0	0.0
-20.570		28.565				-11.55	15.6			
8 1.0		3 2.0	1 -2.0			8 1.0	14 1.0	2 -1.0		
107						123				
FEOM3-		300 -1.0	2.0	0.0		FECL2+	300 1.0	3.0	0.0	0.0
-31.000		30.300				-10.90	10.0			
8 1.0		3 3.0	1 -3.0			8 1.0	14 2.0	2 -1.0		
108						124				
FEOM4		200 0.0	8.0	0.0		FECL3	300 0.0	3.0	0.0	0.0
2.25		3.23				-11.90	10.0			
8 1.0		16 1.0				8 1.0	14 3.0	2 -1.0		
109						125				
FE(HS)2		500 0.0	-2.0	0.0		FE3O4+	300 1.0	9.0	0.0	0.0
76.250		-120.280				-9.11	13.91			
8 1.0		16 2.0	1 18.0	2 16.0	3 -8.0	8 1.0	16 1.0	2 -1.0		
110						126				
FE(HS)3-		500 -1.0	-4.0	0.0		FE3O42-	300 -1.0	15.0	0.0	0.0
111.937		-180.420				-7.61	14.60			
8 1.0		16 3.0	1 27.0	2 24.0	3 -12.0	8 1.0	16 2.0	2 -1.0		
111						127				
FEHPO4		300 0.0	2.0	0.0		FEHPO4+	400 1.0	3.0	0.0	1.0
15.946		-3.530				4.74	12.23			
8 1.0		1 1.0	19 1.0			8 1.0	1 1.0	19 1.0	2 -1.0	
112						128				
FEH2PO4+		300 1.0	2.0	0.0		FEH2P+2	400 2.0	3.0	0.0	0.0
22.253		-4.520				11.95	5.48			
8 1.0		1 2.0	19 1.0			8 1.0	1 2.0	19 1.0	2 -1.0	
115						129				
FE+3		200 3.0	3.0	9.0		FEF+2	300 2.0	3.0	0.0	0.0
-13.032		10.0				-6.8	12.7			
8 1.0		2 -1.0				8 1.0	20 1.0	2 -1.0		
116						130				
FEOM2		400 2.0	3.0	0.0		FEF2+	300 1.0	3.0	0.0	0.0
-15.22		20.4				-2.2	14.7			
8 1.0		3 1.0	2 -1.0	1 -1.0		8 1.0	20 2.0	2 -1.0		
117						131				
FEOM2+		400 1.0	3.0	0.0		FEF3	300 0.0	3.0	0.0	0.0
-18.70		10.0				0.97	15.4			
8 1.0		3 2.0	1 -2.0	2 -1.0		6 1.0	20 3.0	2 -1.0		
118						135				
FEOM3		400 0.0	3.0	0.0		MNOH+	300 1.0	2.0	0.0	1.0
-26.63		10.0				-10.59	14.40			
8 1.0		3 3.0	1 -3.0	2 -1.0		9 1.0	3 1.0	1 -1.0		
119						136				
FEOM4-		400 -1.0	3.0	0.0		MNOH3-	300 -1.0	2.0	0.0	3.0
-34.63		10.0				-34.80	0.0			

	9 1.0	3 3.0	1 -3.0		10 1.0	3 4.0	1 -4.0		
137				0.0	154				
MNCL+	200 1.0	2.0	0.0		ALSO4+	200 1.0	6.0	0.0	0.0
0.607	0.0				3.02	2.15			
9 1.0	14 1.0				10 1.0	16 1.0			
138				0.0	155				
MNCL2	200 0.0	2.0	0.0		ALSO42-	200 -1.0	12.0	0.0	0.0
0.041	0.0				4.92	2.84			
9 1.0	14 2.0				10 1.0	16 2.0			
139				0.0	156				
MNCL3-	200 -1.0	2.0	0.0		ALF+2	200 2.0	0.0	0.0	0.0
-0.305	0.0				7.01	0.0			
9 1.0	14 3.0				10 1.0	20 1.0			
140				1.0	157				
MNFCO3+	300 1.0	2.0	0.0		ALF2+	200 1.0	0.0	0.0	0.0
11.60	-3.604				12.75	20.0			
9 1.0	15 1.0	1 1.0			10 1.0	20 2.0			
141				0.0	158				
MNSO4	200 0.0	8.0	0.0		ALF3	200 0.0	0.0	0.0	0.0
2.26	2.17				17.02	2.50			
9 1.0	16 1.0				10 1.0	20 3.0			
142				0.0	159				
MN(M3)2	200 0.0	12.0	0.0		ALF4-	200 -1.0	0.0	0.0	0.0
0.6	-0.396				19.72	0.0			
9 1.0	17 2.0				10 1.0	20 4.0			
143				0.0	163				
MNF+	200 1.0	2.0	0.0		BAOH+	300 1.0	0.0	0.0	1.0
0.05	0.0				-13.358	15.095			
9 1.0	20 1.0				11 1.0	3 1.0	1 -1.0		
144				0.0	165				
MNIJ	200 3.0	3.0	0.0		SRNH+	300 1.0	0.0	0.0	1.0
25.507	25.76				-13.178	14.495			
9 1.0	2 -1.0				12 1.0	3 1.0	1 -1.0		
145				0.0	170				
MNO4-2	400 -2.0	6.0	0.0		H3SiO4-	210 -1.0	0.0	0.0	1.0
-118.440	150.02				-9.929	8.936	6.368	-0.016346	-3405.9
9 1.0	3 4.0	1 -8.0	2 -4.0		13 1.0	1 -1.0			
146				0.0	171				
MNO4-	400 -1.0	7.0	3.5		H2SiO4-2	210 -2.0	0.0	0.0	2.0
-127.824	176.62				-21.617	29.717	39.478	-0.065927	-12355.1
9 1.0	3 4.0	1 -8.0	2 -5.0		13 1.0	1 -2.0			
150				0.0	172				
ALOH+2	300 2.0	0.0	0.0		SiF6-2	400 -2.0	0.0	0.0	0.0
-4.99	11.9				30.18	-16.26			
10 1.0	3 1.0	1 1.0			13 1.0	1 4.0	20 6.0	3 -4.0	
151				0.0	181				
ALOH2+	300 1.0	0.0	0.0		LiSO4-	200 -1.0	6.0	0.0	0.0
-10.1	0.0				0.640	0.0			
10 1.0	3 2.0	1 -2.0			21 1.0	16 1.0			
152				1.0	LOOK MIN				
ALOH3	300 0.0	0.0	0.0		CALCITE	2 4.0	-8.47	-2.58	1
-16.0	0.0				15 1.0	4 1.0			
10 1.0	3 3.0	1 -3.0			13.543	-0.0401	-3000.0		
153				2.0	DOLomite	3 8.0	-17.001	-8.29	0
ALOH4-	300 -1.0	0.0	0.0		4 1.0	5 1.0	15 2.0		
-23.000	44.06								

SILPHEITE	2	6.0	-10.55	-5.328	0	
8 1.0	15	1.0			0	
RIKAXHR	2	6.0	-10.41	-2.079	0	
9 1.0	15	1.0			0	
STROMIT	2	1.0	4.0	-9.25	-0.69	0
12	1.0	15	1.0			0
GYPSUM	3	6.0	-4.603	0.261	0	
4 1.0	16	1.0	3.2.0		0	
CELESTIT	2	6.0	-6.465	-0.47	0	
12 1.0	16	1.0			0	
BARITE	2	6.0	-9.976	6.28	0	
11 1.0	16	1.0			0	
HYDROMAP	4	0.0	-3.421	-36.155	0	
3 1.0	65	3.0	4.5.0		1 -4.0	
F APATIT	4	4 0.0	-17.6	-20.07	20 1.0	0.0
1 -3.0	4	5.0	65 3.0		0	
FLUORITE	2	0.0	-10.96	4.71	0	
4 1.0	20	2.0			0	
CHALCEDY	2	0.0	-3.523	4.615	0	
13 1.0	3	-2.0			0	
SIO2(M)	2	0.0	-2.72	3.660	0	
13 1.0	3	-2.0			0	
QUARTZ	2	0.0	-4.006	6.22	0	
11 1.0	3	-2.0			0	
GIBBSITE	3	0.0	8.77	-22.8	0	
10	1.0	3	3.0	1	-3.0	
KAOLINIT	4	0.0	-36.921	49.150	0	
3	-7.0	1	2.0	13	2.0 153	2.0
ILLITE	6	0.0	-40.267	54.684	0	0.0
3 -11.2	7	0.6	5 0.25	153 2.3		13 3.5
1 1.2						
CHLORITE	5	0.0	-89.563	54.760	0	0.0
3 -10.0	5	5.0	153 2.0		13 3.0	31 8.0
BYNNSIT*	4	2 4.0	18.091	0.0	0	0.0
1 -4.0	2	-1.0	144 1.0		3 2.0	
SEPIOLIT	4	0.0	-40.079	26.532	0	
5 2.0	13	3.0	31 4.0		3 -4.5	
HEMATITE	2	3.0	-4.008	-30.845	0	
115 2.0	3	3.0	1	-6.0		
GOETHITE	3	3.0	0.5	-14.48	0	
115 1.0	3	3.0	4.891	1 -3.0		
FEONJA	3	3.0	1	0.0		
115 1.0	3	3.0	1	0.0		
PYRITE	4	0.0	-18.48	11.3	0	
1 -2.0	2	-2.0	8 1.0		42 2.0	
FES PPT	3	0.0	-3.915	0.0	0	
8 1.0	42	1.0	1 -1.0		0	
VIVIANIT	3	6.0	-36.000	0.0	0	
8 3.0	19	2.0	3 8.0		0	
PCO2	2	4.0	-1.466	-4.708	0	
15 1.0	3	-1.0			0	
O2 GAS	1	4.0	-2.96	-1.844	0	
32 1.0	1	-2.0	-3.15	-1.759	0	
H2 GAS	33	1.0				

SAMPLE PHREEQE OUTPUT
DISSOLVING VOLCANIC GLASS INTO SOIL WATER

INITIAL SOLUTION FROM SOIL WATER (HENNE, 1982)										
10:0001000 0 6 0.00000										
ELEMENTS										
C	15	61								
	0	0.								
SOLUTION 1										
Water from lysimeter 7, Rainier Mesa (Henne, 1982)										
8	15	2	7.20	4.50	25.0	1.00				
13	2	4.00d+01	6	3.150d+01	7	1.200d+00	4	7.400d+00	5	2.160d+00
15	1.050d+02	14	5.000d+00	16	1.600d+00					
LOOK MIN										
CRISTOA	2		-3.69	5.50	0					
13	1.00	3	-2.00	-1.47	-4.71	0				
PCO2	2	3	-1.00							
35	1.00									
NAMONT	5		-46.2	57.1	0					
3	12.0	153	2.33	13	3.67	6	0.330	1	2.00	
K HENT	5		-46.8	58.9	0					
3	-12.0	153	2.33	13	3.67	7	0.330	1	2.00	
CAMONT	5		-45.0	58.4	0					
3	-12.0	153	2.33	13	3.67	4	0.165	1	2.00	
HEULANDI	4		-49.3	62.6	0					
3	-12.0	4	1.00	153	2.00	13	7.00			
ANULARIA	4		-20.6	30.8	0					
3	-8.00	7	1.00	153	1.00	13	3.00			
ALBITE	4		-18.0	25.9	0					
3	-8.00	6	1.00	153	1.00	13	3.00			
ILLITE	6		-40.3	54.7	0					
3	-11.2	7	0.600	5	0.250	153	2.30	13	3.50	
1	1.20									
ANALTIME	4		-12.7	18.2	0					
3	-5.00	6	1.00	153	1.00	13	2.00			
			0.	0.						
Water from lysimeter 7, Rainier Mesa (Henne, 1982)										
SOLUTION NUMBER 1										
153	2.33	13	3.67	4	0.165	1	2.00			
3	-12.0	4	-49.3	62.6	0					
4	1.00	153	2.00	13	7.00					
4			-20.6	30.8	0					
7	1.00	153	1.00	13	3.00					
3	-8.00	4	-18.0	25.9	0					
6	1.00	153	1.00	13	3.00					
6			-40.3	54.7	0					
7	0.600	5	0.250	153	2.30	13	3.50			
3	-11.2									
1	1.20									
3	-5.00	6	1.00	153	1.00	13	2.00			
0			0.	0.						
Water from lysimeter 7, Rainier Mesa (Henne, 1982)										
SOLUTION NUMBER 1										
153	2.33	13	3.67	4	0.165	1	2.00			
3	-12.0	4	-49.3	62.6	0					
4	1.00	153	2.00	13	7.00					
4			-20.6	30.8	0					
7	1.00	153	1.00	13	3.00					
3	-8.00	4	-18.0	25.9	0					
6	1.00	153	1.00	13	3.00					
6			-40.3	54.7	0					
7	0.600	5	0.250	153	2.30	13	3.50			
3	-11.2									
1	1.20									
3	-5.00	6	1.00	153	1.00	13	2.00			
0			0.	0.						

TOTAL MOLALITIES OF ELEMENTS			
ELEMENT	MOLALITY	LOG MOLALITY	
CA	1.84636d-04	-3.7336	
MG	8.88641d-05	-4.0512	
NA	1.370417d-03	-2.8631	
K	3.069733d-05	-4.5129	
SI	3.995099d-04	-3.3985	
CL	1.410569d-04	-3.8506	
TOT ALK	1.721135d-03	-2.7642	
S	1.665922d-05	-4.7783	

-----DESCRIPTION OF SOLUTION-----

PH - 7.2000
 PE - 4.5000
 ACTIVITY H₂O - 0.9999
 IONIC STRENGTH - 0.0022
 TEMPERATURE - 25.0000
 ELECTRICAL BALANCE - 5.2770d-05
 THERM - 7.8940d-03
 TOTAL ALKALINITY - 1.7211d-03
 ITERATIONS - 10
 TOTAL CARBON - 1.9485d-03

-----DISTRIBUTION OF SPECIES-----

I	SPECIES	Z	MOLALITY	LOG MOLALITY	ACTIVITY	LOG ACTIVITY	GAMMA	LOG GAMMA
1	H+	1.0	6.62285d-08	-7.1790	6.30957d-08	-7.2000	9.52697d-01	-0.0210
2	E-	-1.0	3.16228d-05	-4.5000	3.16228d-05	-4.5000	1.00000d+00	0.0000
3	H2O	0.0	9.99929d-01	0.0000	9.99929d-01	0.0000	1.00000d+00	0.0000
4	CA+2	2.0	1.81391d-04	-3.7414	1.47904d-04	-3.8300	8.15386d-01	-0.0816
5	MG+2	2.0	8.72223d-05	-4.0594	7.12361d-05	-4.1473	8.16719d-01	-0.0873
6	NA+	1.0	1.36911d-03	-2.8636	1.30026d-03	-2.8660	9.49712d-01	-0.0224
7	K+	1.0	3.06945d-05	-4.5129	2.91310d-05	-4.5356	9.49062d-01	-0.0227
13	H4SiO4	0.0	3.98725d-04	-3.3993	3.98927d-04	-3.3991	1.00051d+00	0.0002
14	CL-	-1.0	1.41057d-04	-3.8506	1.31872d-04	-3.8733	9.49062d-01	-0.0227
15	CUL2	-2.0	1.47953d-06	-5.8299	1.20678d-06	-5.9184	8.15655d-01	-0.0865
16	SO4-2	-2.0	1.60090d-05	-4.7956	1.30400d-05	-4.8847	8.14539d-01	-0.0891
31	OH-	-1.0	1.67767d-07	-6.7751	1.59210d-07	-6.7980	9.48990d-01	-0.0227
33	H2NO	0.0	2.81695d-27	-26.5502	2.81838d-27	-26.5500	1.00051d+00	0.0002
34	HCO3-	-1.0	1.71126d-03	-2.7667	1.62627d-03	-2.7888	9.50375d-01	-0.0221
35	H2CO3	0.0	2.30170d-04	-3.6180	2.30287d-04	-3.6377	1.00051d+00	0.0002
40	H2SO4	-1.0	8.41187d-11	-10.0751	7.98617d-11	-10.0977	9.49393d-01	-0.0226
75	CACO3	1.0	6.23021d-10	-9.2055	5.91492d-10	-9.2281	9.49393d-01	-0.0226
76	CACO3	0.0	2.53511d-07	-6.5960	2.53640d-07	-6.5958	1.00051d+00	0.0002
77	CAHCO3+	1.0	2.62575d-06	-5.5807	2.49287d-06	-5.6033	9.49393d-01	-0.0226
78	CA2O4	0.0	3.92677d-07	-6.4060	3.92876d-07	-6.4057	1.00051d+00	0.0002
85	MGMH+	1.0	1.91084d-09	-8.7188	1.81414d-09	-8.7413	9.49393d-01	-0.0226
86	MGCO3	0.0	8.20043d-08	-7.0862	8.20458d-08	-7.0859	1.00051d+00	0.0002
87	MGKCO3+	1.0	1.41512d-06	-5.8492	1.34351d-06	-5.8718	9.49393d-01	-0.0226
88	MCSO4	-1.0	1.65104d-07	-6.7822	1.65187d-07	-6.7820	1.00051d+00	0.0002
95	NAHCO3	0.0	3.06346d-08	-7.5130	2.90843d-08	-7.5363	9.49393d-01	-0.0226
96	NAHCO3	0.0	1.18970d-06	-5.9246	1.19031d-06	-5.9243	1.00051d+00	0.0002
97	NASO4-	-1.0	8.95076d-08	-7.0481	8.49779d-08	-7.0707	9.49393d-01	-0.0226
100	KSO4-	-1.0	2.83261d-09	-8.5478	2.69926d-09	-8.5704	9.49393d-01	-0.0226
170	H3SiO4-	-1.0	7.84626d-07	-6.1053	7.44918d-07	-6.1279	9.49393d-01	-0.0226
171	H2SiO4-2	-2.0	2.98195d-11	-10.5255	2.42261d-11	-10.6157	8.12426d-01	-0.0902

----- LOOK MIN IAP -----

IPART 1: VOLCANIC GLASS DISSOLUTION									
0060101000 0 6 0.00000									
ELEMENTS									
C	15	61.							
	0	0.							
MINERALS									
CRISTOBA	2	0.	-3.69	5.50	0				
13	1.00	3	-2.00		0				
NAMORT	5	0.	-46.2	57.1	0				
3	-12.0	153	2.33	13	3.67	6	0.330	1	2.00
HEULANDI	4	0.	-49.3	62.6	0				
3	-12.0	4	1.00	153	2.00	13	7.00		
PCO2	2	4.00	-1.47	-4.71	0				
35	1.00	3	-1.00		0.				
	0	0.	0.	0.	0				
REACTION									
6	5.600	0.000	7	4.200	0.000	4	0.100	0.000	8
10	9.600	0.000	13	51.900	0.000				
IERR= 0									
1STEP NUMBER 1									

PHASE	LOG IAP	LOG KT	LOG IAP/KT						
CALCITE	-9.7484	-8.4749	-1.2735						
DOLOMITE	-19.8141	-17.0010	-2.8131						
GYP SUM	-8.7148	-4.6030	-4.1118						
CHALCEDY	-3.3990	-3.5230	0.1240						
SiO2(AM)	-3.3990	-2.7200	-0.6790						
QUARTZ	-3.3990	-4.0060	0.6070						
SEPIOLIT	-45.6839	-40.0790	-5.6049						
PCO2	-3.6377	-1.4660	-2.1717						
O2 GAS	-39.2801	-2.9600	-36.3201						
H2 GAS	-26.5500	-3.1500	-23.4000						
CRISTOBA	-3.3990	-3.6870	0.2880						

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
CA	1.846636d-04	-3.7336
MG	8.888641d-05	-4.0512
NA	1.370417d-03	-2.8631
K	3.089733d-05	-4.5129
SI	3.995099d-04	-3.3985
CL	1.410569d-04	-3.8506
TOT ALK	1.948505d-03	-2.7103
S	1.665922d-05	-4.7783

-----PHASE BOUNDARIES-----

PHASE	DELTA PHASE*	LOG IAP	LOG KT	LOG IAP/KT
CRISTOBA	0.000000d100	-3.6870	-3.6870	0.0000
**				
NAMONT	9.304748d-05	-46.2400	-46.2400	0.0000
HEULANDI	-1.644744d-04	-49.2600	-49.2600	0.0000
PCO2	3.347172d-02	-1.4700	-1.4700	0.0000

* NEGATIVE DELTA PHASE INDICATES PRECIPITATION AND POSITIVE DELTA PHASE INDICATES DISSOLUTION.

** 1.186063d-05 MOLES OF REACTION HAVE BEEN ADDED TO THE SOLUTION TO REACH THE CRISTOBA PHASE BOUNDARY.

REACTION IS:

5.60 MOLES OF NA	VALENCE =	0.000
4.20 MOLES OF K	VALENCE =	0.000
0.10 MOLES OF CA	VALENCE =	0.000
0.70 MOLES OF FE	VALENCE =	2.000
9.60 MOLES OF AL	VALENCE =	0.000
51.90 MOLES OF SI	VALENCE =	0.000

----- LOOK MIN IAP -----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
CALCITE	-12.9176	-8.4749	-4.4427
DOLOMITE	-25.2163	-17.0010	-8.2153
SIDERITE	-13.3218	-10.5500	-2.7718
GYPHUM	-9.6316	-4.6030	-5.0286
CHALCEDY	-3.6870	-3.5230	-0.1640
SiO2(AH)	-3.6870	-2.7200	-0.9670
QUARTZ	-3.6870	-4.0060	0.3190
GIBBSITE	8.6583	8.7700	-0.1117
KAOLINIT	-36.0571	-36.9210	0.8639
ILLITE	-43.8980	-40.2670	-3.6310
CHLORITE	-122.4675	-89.5630	-32.9045
SEPIOLIT	-55.3495	-40.0790	-15.2705
HEMATITE	4.0018	-4.0080	8.0098
GOETHITE	2.0008	0.5000	1.5008
FEOMHA	2.0005	4.8910	-2.8905
PYRITE	-100.4485	-18.4800	-81.9685
FES PPT	-58.0135	-3.9150	-54.0985
PCO2	-1.4700	-1.4660	-0.0040
O2 GAS	-45.2648	-2.9600	-42.3048
H2 GAS	-23.5579	-3.1500	-20.4079
CRISTOBA	-3.6870	-3.6870	0.0000
NAMONT	-46.2400	-46.2400	0.0000
K-MONT	-46.6560	-46.8400	0.1840
CAHONT	-46.0833	-45.0300	-1.0533
HEULANDI	-49.2600	-49.2600	0.0000
ANULARIA	-24.5212	-20.5700	-3.9512
ALBITE	-23.2605	-18.0000	-5.2605
ANALCIME	-19.5738	-12.7000	-6.8738

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
CA	2.137523d-05	-4.6701
HG	8.888641d-05	-4.0512
NA	1.467542d-03	-2.8334
K	8.051196d-05	-4.0941
FE	8.302439d-06	-5.0808
AL	1.713815d-06	-5.7660
SI	2.052397d-04	-3.6877
CL	1.410569d-04	-3.8506
C	3.542023d-02	-1.4507
S	1.665922d-05	-4.7783

----DESCRIPTION OF SOLUTION----

PH = 4.9967
 PE = 5.2073
 ACTIVITY H2O = 0.9994
 IONIC STRENGTH = 0.0019
 TEMPERATURE = 25.0000
 ELECTRICAL BALANCE = 5.2769d-05
 TITOR = 1.4180d-01
 TOTAL ALKALINITY = 1.5723d-03
 ITERATIONS = 20

-----DISTRIBUTION OF SPECIES-----

1	SPECIES	Z	MOLALITY	LOG MOLALITY	ACTIVITY	LOG ACTIVITY	GAMMA	LOG GAMMA
1	H+	1.0	1.05462d-05	-4.9769	1.00773d-05	-4.9967	9.55546d-01	-0.0198
2	E-	-1.0	6.20476d-06	-5.2073	6.20476d-06	-5.2073	1.00000d+00	0.0000
3	H2O	0.0	9.99363d-01	-0.0003	9.99363d-01	-0.0003	1.00000d+00	0.0000
4	CA+2	2.0	2.1044d-05	-4.6769	1.73871d-05	-4.7598	8.26210d-01	-0.0829
5	Mg+2	2.0	8.73958d-05	-4.0585	7.23104d-05	-4.1408	8.27391d-01	-0.0823
6	NA+	1.0	1.46627d-03	-2.8338	1.39723d-03	-2.8547	9.52916d-01	-0.0210
7	K+	1.0	8.05043d-05	-4.0942	7.66682d-05	-4.1154	9.52349d-01	-0.0212
8	FE+2	2.0	8.28346d-06	-5.0818	6.85626d-06	-5.1639	8.27705d-01	-0.0821
10	AL+3	3.0	7.02900d-07	-6.1531	4.6687d-07	-6.3308	6.64145d-01	-0.1777
13	H4SiO4	0.0	2.05237d-04	-3.6877	2.05327d-04	-3.6876	1.00044d+00	0.0002
14	CL-	-1.0	1.41057d-04	-3.8506	1.34335d-04	-3.8718	9.52349d-01	-0.0212
15	CO3-2	-2.0	8.41252d-09	-8.0751	6.95257d-09	-8.1579	8.26455d-01	-0.0828
16	SO4-2	-2.0	1.62950d-05	-4.7879	1.34510d-05	-4.8712	8.25467d-01	-0.0833

31	OH-	-1.0	1.04619d-09	-8.9804	9.96270d-10	-9.0016	9.52287d-01	-0.0212
33	H2 AQ	0.0	2.76664d-24	-23.5580	2.76785d-24	-23.5579	1.00044d+00	0.0002
34	HCO3-	-1.0	1.56946d-03	-2.6043	1.49642d-03	-2.6749	9.53465d-01	-0.0207
35	H2CO3	0.0	3.38480d-02	-1.4705	3.38628d-02	-1.4703	1.00044d+00	0.0002
40	H2SO4	-1.0	1.38114d-08	-7.8598	1.31573d-08	-7.8800	9.52634d-01	-0.0211
75	CAH1+	1.0	4.56749d-13	-12.3403	4.35115d-13	-12.3614	9.52634d-01	-0.0211
76	CAH2+	0.0	1.71708d-10	-9.7652	1.71783d-10	-9.7650	1.00044d+00	0.0002
77	CAHCO3+	1.0	2.83063d-07	-6.5481	2.69566d-07	-6.5692	9.52634d-01	-0.0211
78	CAH2O4	0.0	4.76202d-08	-7.3223	4.76411d-08	-7.3220	1.00044d+00	0.0002
85	H2O	1.0	1.20963d-11	-10.9173	1.15233d-11	-10.9384	9.52634d-01	-0.0211
86	H2CO3	0.0	4.79604d-10	-9.3191	4.79815d-10	-9.3189	1.00044d+00	0.0002
87	H2CO3+	1.0	1.31728d-06	-5.8803	1.25488d-06	-5.9014	9.52634d-01	-0.0211
88	H2SO4	0.0	1.72888d-07	-6.7622	1.72964d-07	-6.7620	1.00044d+00	0.0002
95	NAHCO3	-1.0	1.89011d-10	-9.7235	1.80058d-10	-9.7446	9.52634d-01	-0.0211
96	NAHCO3	0.0	1.17644d-06	-5.9294	1.17695d-06	-5.9292	1.00044d+00	0.0002
97	NAHCO4	-1.0	9.88774d-08	-7.0049	9.41940d-08	-7.0260	9.52634d-01	-0.0211
100	K2O4	-1.0	7.66381d-09	-6.1156	7.30081d-09	-6.1166	9.52634d-01	-0.0211
105	FEH1+	1.0	2.25703d-10	-9.6465	2.15013d-10	-9.6675	9.52634d-01	-0.0211
106	FEH2	0.0	1.81406d-16	-15.7413	1.81485d-16	-15.7412	1.00044d+00	0.0002
107	FEH3-	-1.0	7.01927d-22	-21.1537	6.68680d-22	-21.1748	9.52634d-01	-0.0211
108	FEH4	0.0	1.63928d-08	-7.7853	1.64000d-08	-7.7852	1.00044d+00	0.0002
115	FE+3	3.0	1.54561d-13	-12.8109	1.02651d-13	-12.9886	6.64145d-01	-0.1777
116	FEH1+2	2.0	8.01741d-11	-10.0960	6.60297d-11	-10.1803	9.52634d-01	-0.0843
117	FEH2+	1.0	2.27609d-09	-8.6428	2.16828d-09	-8.6639	9.52634d-01	-0.0211
118	FEH3	0.0	2.52525d-12	-11.5977	2.52635d-12	-11.5975	1.00044d+00	0.0002
119	FEH4-	-1.0	2.62992d-15	-14.5801	2.50536d-15	-14.6011	9.52634d-01	-0.0211
120	FE2OH2+4	4.0	2.55069d-19	-18.5933	1.17349d-19	-18.9305	4.60067d-01	-0.3372
121	FE3OH4+5	5.0	1.74758d-25	-24.7576	5.19510d-26	-25.2844	2.97274d-01	-0.5268
122	FECL+2	2.0	5.07981d-16	-15.2942	4.18363d-16	-15.3784	8.23579d-01	-0.0843
123	FECL2+	1.0	2.63522d-19	-18.5792	2.51041d-19	-18.6003	9.52634d-01	-0.0211
124	FECL3	0.0	3.37089d-24	-23.4723	3.37236d-24	-23.4721	1.00044d+00	0.0002
125	FE3O4+	1.0	1.21113d-14	-13.9168	1.15377d-14	-13.9374	9.52634d-01	-0.0211
126	FE3O42-	-1.0	5.15166d-18	-17.2881	4.90765d-18	-17.3091	9.52634d-01	-0.0211
150	ALH1+2	2.0	5.75212d-07	-6.2402	4.73733d-07	-6.3245	8.23579d-01	-0.0843
151	ALH2+	1.0	3.82810d-07	-6.4170	3.64678d-07	-6.4381	9.52634d-01	-0.0211
152	ALH3	0.0	4.55089d-08	-7.3419	4.55289d-08	-7.3417	1.00044d+00	0.0002
153	ALH4+	-1.0	4.73956d-10	-9.3243	4.51507d-10	-9.3453	9.52634d-01	-0.0211
154	ALSO4+	1.0	6.90217d-09	-8.1610	6.57524d-09	-8.1821	9.52634d-01	-0.0211
155	ALSO42-	-1.0	7.37465d-12	-11.1323	7.02534d-12	-11.1533	9.52634d-01	-0.0211
170	H3SiO4-	-1.0	2.51993d-09	-8.5986	2.40057d-09	-8.6197	9.52634d-01	-0.0211
171	H2SiO4-2	-2.0	5.93525d-16	-15.2266	4.88815d-16	-15.3109	8.23579d-01	-0.0843

**DATE
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9/8/93

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