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The relationship of the Yucca Mountain repository block to the regional groundwater system: A geochemical model

Nancy Ann Matsuka
University of Nevada, Las Vegas

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Matsuka, Nancy Ann, M.S.

University of Nevada, Las Vegas, 1989

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THE RELATIONSHIP OF THE YUCCA MOUNTAIN
REPOSITORY BLOCK TO THE REGIONAL
GROUND-WATER SYSTEM:
A GEOCHEMICAL MODEL

by

Nancy Ann Matuska

A thesis submitted in partial fulfillment of the
requirements for the degree of

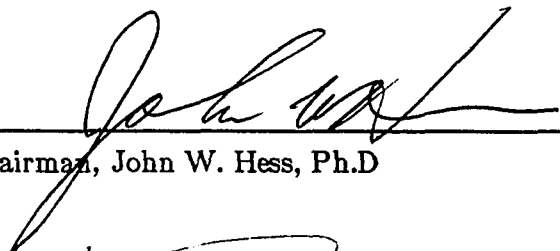
Master of Science

in


Geoscience

Department of Geoscience
University of Nevada, Las Vegas
May, 1989


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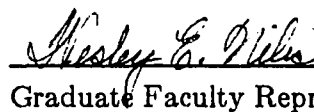
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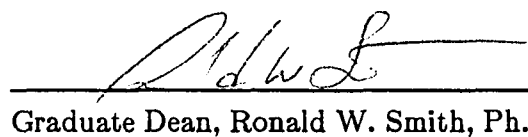
Examining Committee Member, Martin D. Mifflin, Ph.D



Examining Committee Member, David L. Weide, Ph.D



Graduate Faculty Representative, Wesley E. Niles, Ph.D



Graduate Dean, Ronald W. Smith, Ph.D

University of Nevada, Las Vegas
May, 1989

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 thesis 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, with the proposed repository site situated 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 U.S. Air Force and the Bureau of Land Management (Figure 1).

The Department of Energy'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, 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.

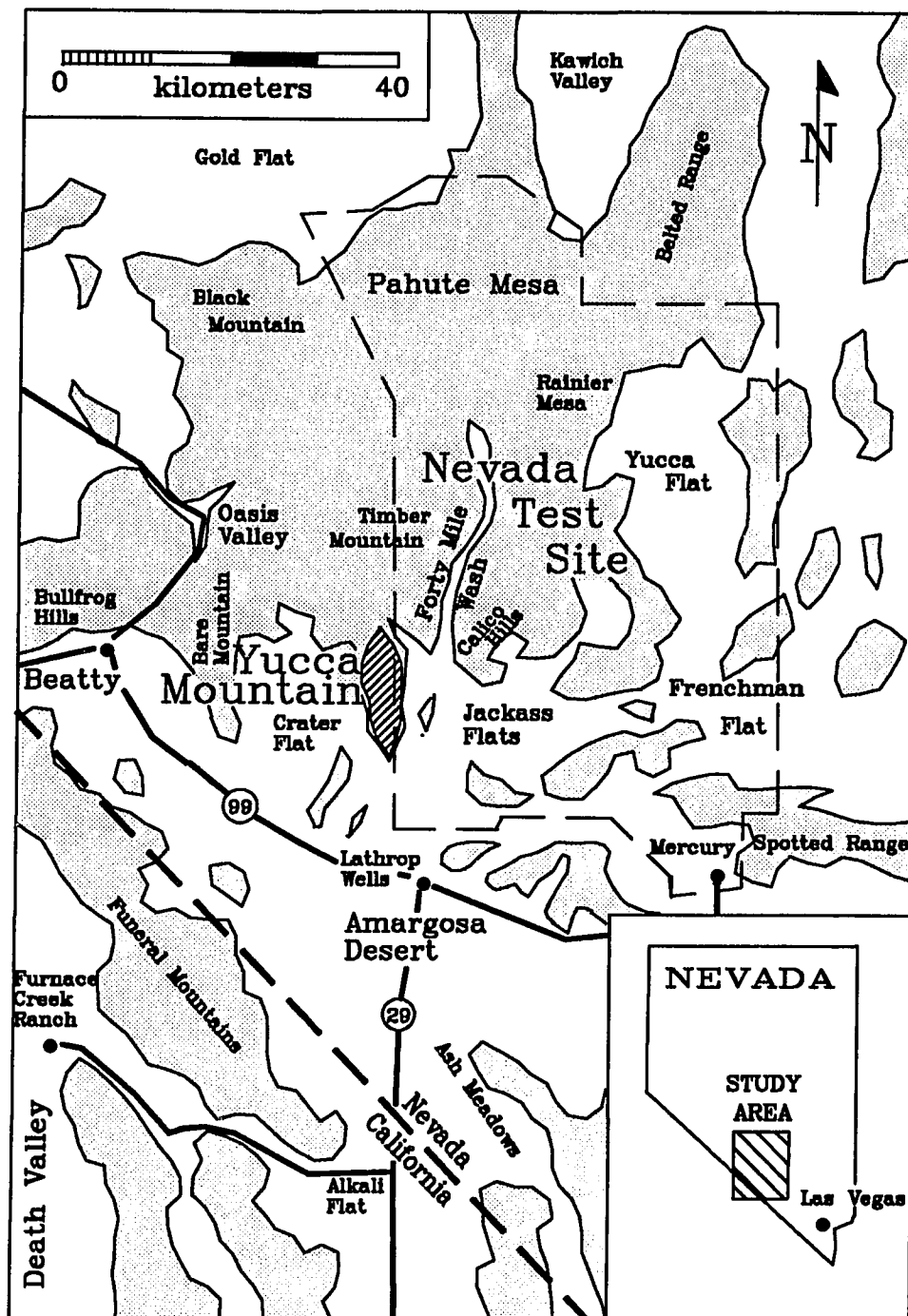


Figure 1: Location of Yucca Mountain and vicinity in southern Nevada.

Purpose

The purpose of this study is to further define the possibility of upward flow from the regional carbonate ground-water 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 wells and springs on Yucca Mountain and 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, using the computer models BALANCE, WATEQDR and PHREEQE, as it moves through a volcanic terrane into a carbonate terrane, and vice versa, and analysis of the resultant water chemistries;
5. comparison of these hypothetical waters to the data base water chemistries;
6. using graphical and analytical methods to differentiate water groups based upon isotopic analysis, and comparing these to the results found in 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 indicate 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, which may exchange cations and therefore may act as retardants to 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. Downward saturated flow through the tuffs is believed to be of low quantity, less than ten 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 others 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 groundwater 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. 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 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} , in the system. 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:

- 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 Department of Energy'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 is useful to understand how the modeling problem is set up, and how the results compare with previous investigations.

Climate

Yucca Mountain and vicinity have been classified as low latitude desert due to geographical influences on the climate. 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 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). Evapotranspiration is 5 to 25 times greater than precipitation (Winograd and Thordarson, 1975). The cause of the arid climate is the rainshadow of the Sierra Nevada Mountains to the west which impede the movement of moisture bearing Pacific air masses.

The primary sources of precipitation to 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 Nevada Test Site 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, brought about receiving both summer and winter precipitation. The Nevada Test Site lies within the transition zone between the two. Parts of NTS, particularly in 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 drill hole 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. ago (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. ago), 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. ago (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. ago, 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-

flows sheets which 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 1-20 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. ago, 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. Locally around Yucca Mountain the geomorphology is controlled by two sets of faults. The first set are 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 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.

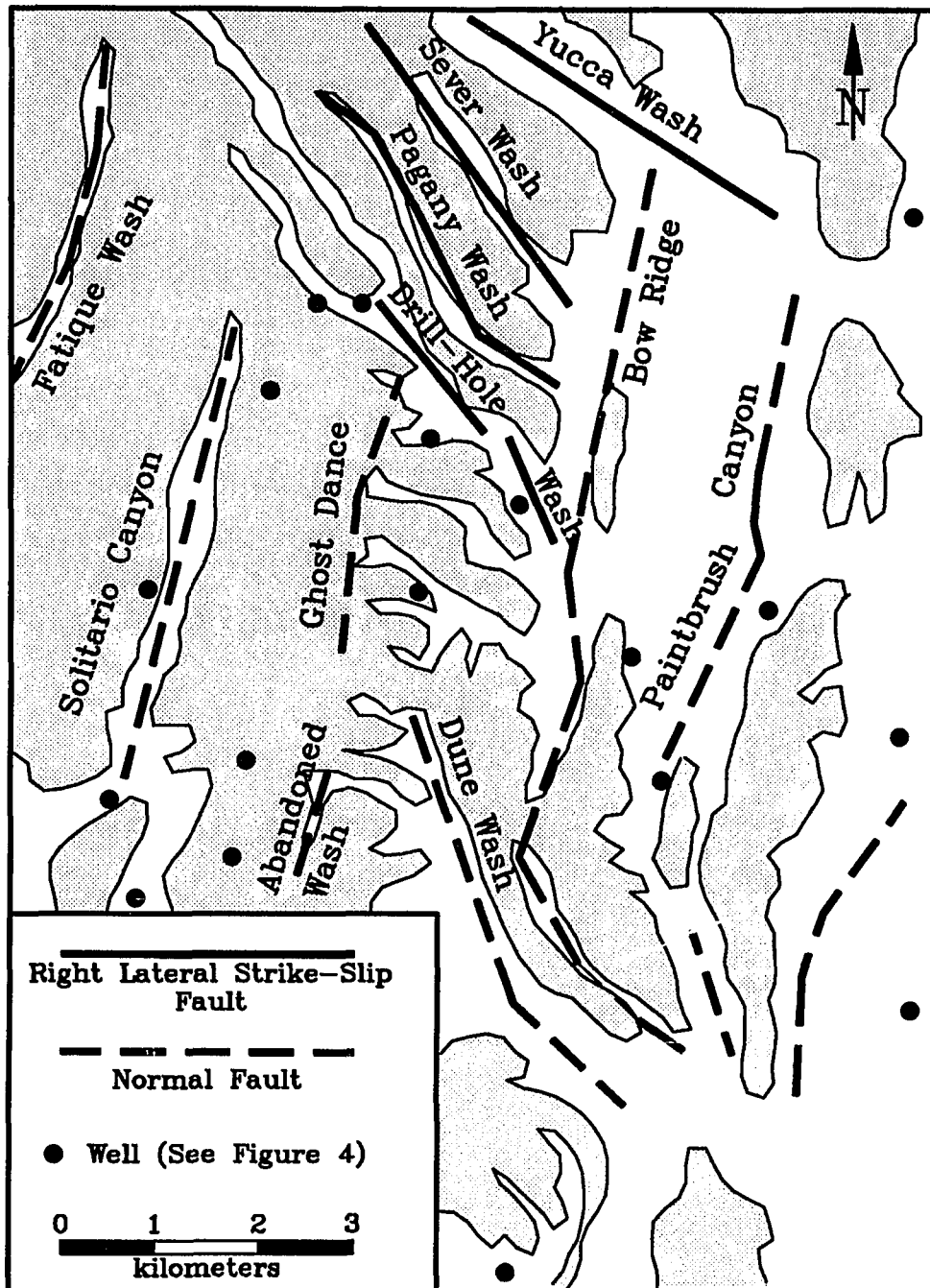


Figure 2: Location of strike-slip and normal faults around Yucca Mountain, Nevada (USGS, 1984).

Hydrologic Studies

Yucca Mountain is located in the Great Basin subprovince of the Basin and Range physiographic province. 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 a local flow system consisting of precipitation recharge on the mountain flanks which moves downward through bedrock into valley fill in the basin, where it is discharged through evapotranspiration (Schoff and Moore, 1964). The local ground-water flow 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, may be used as general aquifer classifications. These three general divisions have been further divided into twelve 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 of importance in this study because they 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 contributes to the majority of interbasin flow. This aquifer is alternately confined and unconfined (Winograd and Pearson, 1976). Saturated thickness is a few hundred to a thousand meters thick and is a function of geology, structure, erosion and depth to the water.

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 Formatio 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; water movement is through secondary permeability developed along fractures with fine-grained rocks having the greatest fracture density. 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 define 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). 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 NTS (Winograd and Thordarson, 1975). In the eastern part of NTS, volcanic rocks frequently transmit water downward to the underlying carbonates; in the western part of 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 Nevada Test Site 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 100's 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

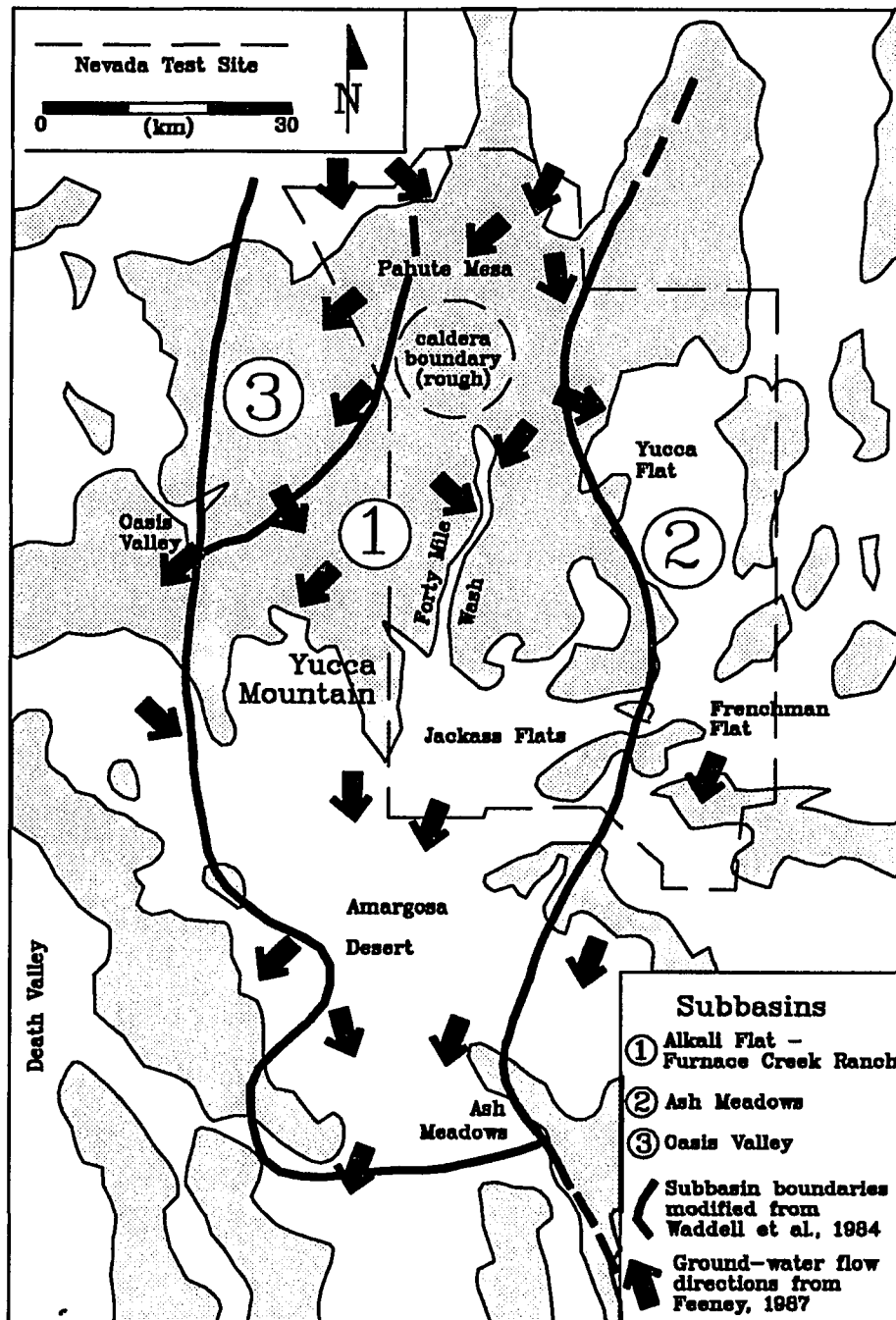


Figure 3: Ground-water flow directions within subbasins of the Death Valley Ground Water Basin in southern Nevada.

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 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 in 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 time, indicating a steady-state hydraulic conditions 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 Nevada Test Site (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 Component (DSC) model using deuterium as a tracer. These flow directions suggest interflow locally across boundaries; possibly indicating connection between the volcanic flow system and the underlying carbonate flow system. Feeney's (1987) flow model suggests that the caldera structure in Pahute Mesa may be locally influencing the flow directions.

About one-half 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 time to the accessible environment of released radionuclides.

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

Mountain. One occurs when 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 move water very quickly below the depth of evaporation, 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, a high degree of hydraulic conductivity anisotropy could be present. Highly fractured welded tuff units might allow for either isotropic or anisotropic flow conditions; in the bedded, nonwelded ash-fall tuffs, vertical flow is likely to be anisotropic. Major fault or fracture zones may penetrate both types of lithologies in local zones 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 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 comprised of volcanic and alluvium aquifers and aquitards, and the lower layer is composed of the lower carbonate aquifer. The amount of vertical leakage is controlled by recharge and discharge, and is the difference between the upper and lower layer transmissivities. From this model Sinton (1987) proposed an upward flux of $44 \text{ m}^3/\text{year}$ 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 NTS and came up with three divisions of ground water: a $(\text{Na}+\text{K})\text{HCO}_3$ type found in the volcanic tuffs and tuffaceous valley-fill alluvium; a $(\text{Ca}+\text{Mg})\text{HCO}_3$ 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 $(\text{Ca}+\text{Mg})\text{HCO}_3$ type, is found to be relatively uniform in terms of 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 $\text{Na}^+ + \text{K}^+$ 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 Nevada Test Site 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 noting by 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 calcite.

Southern Amargosa Desert is suggested as a possible discharge area of the ground water from Yucca Mountain. Winograd and Thordarson (1975) described the ground water as a mixed type which graded into a $(Na+K)HCO_3$ /mixed type to the west. Claassen (1985) divided the water chemistry into three groups, volcanic, carbonate and mixed ground waters, similar to Schoff and Moore's 1964 work on the Nevada Test Site, that reflect the alluvium lithology. Claassen (1985) found that the north-central part of Amargosa Desert has the lowest values of Na^+ , Ca^{2+} , HCO_3^- and SO_4^{2-} , 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 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 CO_2 (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.

Forty Mile Wash (Figure 4) is located to the east of Yucca Mountain. Ground water here 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. 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_{CO₂} and increases of $\delta^{13}\text{C}$ downgradient. An increase in CO₃²⁻ could result from increased CaCO₃ saturation from the dissolution of calcite (perhaps caliche?) by ground water.

Yucca Mountain Ground-Water Chemistry

Integrated ground-water samples have been collected from 21 wells on and surrounding Yucca Mountain (Table 3) which were completed in Tertiary volcanics and the Paleozoic carbonates. Well UE-25 p[#]1 is sampled from separate packed intervals in the volcanics and the carbonate aquifer. 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 equilibrium with the rock it is in contact with. Vadose water in the fractures of the crystalline tuff would likely be higher in

TABLE 3
HYDROGEOLOGY OF WELLS SURROUNDING YUCCA MOUNTAIN, NEVADA

Well	Depth (m)	Hydraulic Head (m) ¹	Screened 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 - Robert 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.

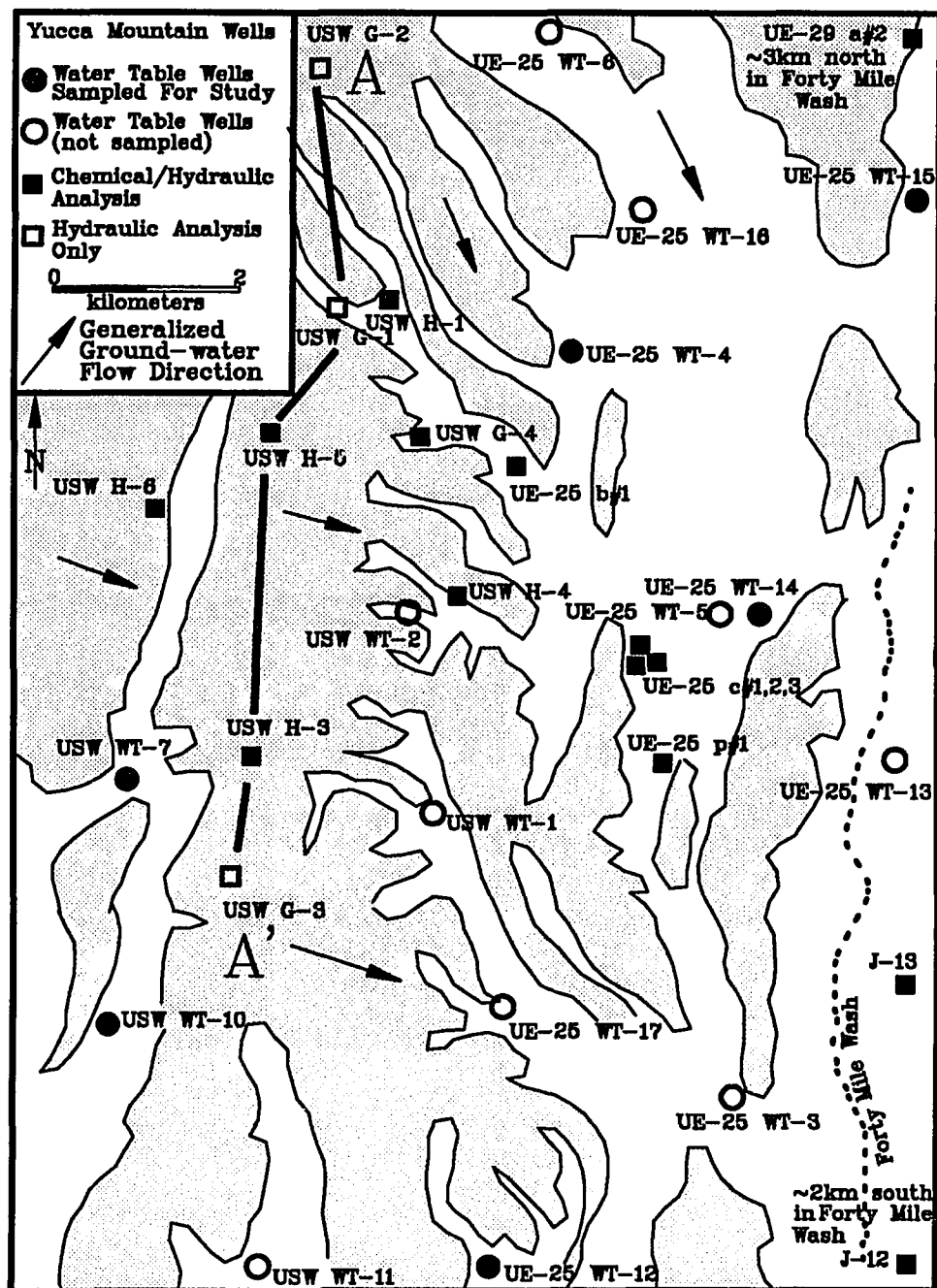


Figure 4: Location of wells with chemical and hydraulic analyses on Yucca Mountain, Nevada. Cross-section A-A' is Figure 7.

Ca^{2+} and lower in Na^+ relative to saturated zone water, while because of glass dissolution, water in the pores of zeolitized tuff should be similar to saturated zone water (Ogard and Kerrisk, 1984). In general, unsaturated zone water should show a higher concentration of ions due to higher evaporation rates than saturated 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, he 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, therefore it was considered to be representative of this aquifer. The amounts of chemical constituents are more concentrated 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 Nevada Test Site, 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 is 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 U.S. Geological Survey, as part of the Nevada Nuclear Waste Storage Investigation (NNWSI) study of the water table in the vicinity of Yucca Mountain, completed sixteen test wells on the Nevada Test Site and Bureau of Land Management lands surrounding Yucca Mountain. These sixteen wells have been

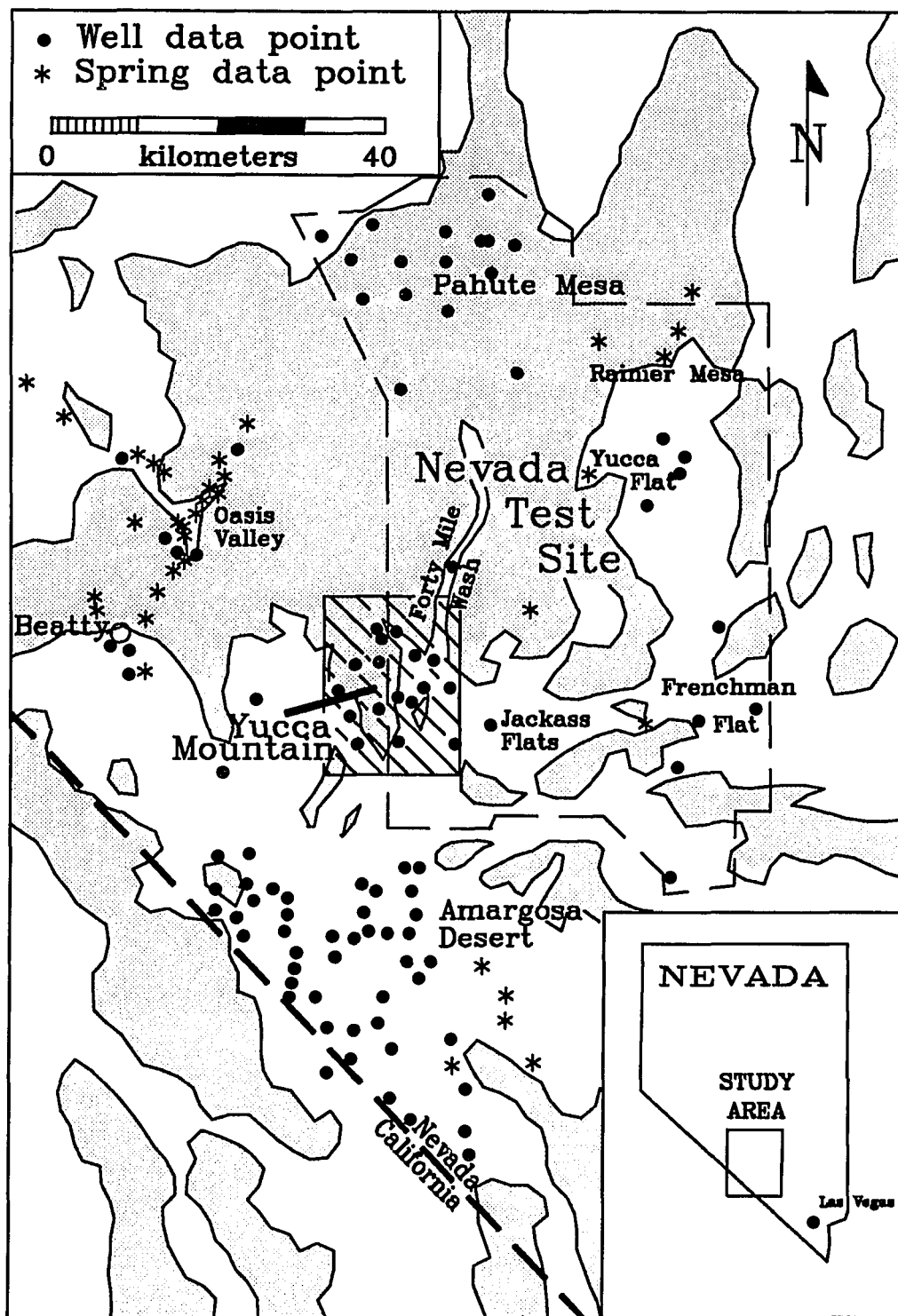


Figure 5: Location of Yucca Mountain and data points in southern Nevada. Hatched box is Figure 2.

monitored by the USGS for water-level data; however, they have 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, 1988 (Appendix B).

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 are cased with steel tubing that is screened over the last four meters.

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 (Appendix C) 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 is 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 time field parameters such as pH, temperature, E.C, alkalinity and flow rate were measured every four to six hours.

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 on site. Quality assurance requirements were met during the sampling procedure by the collection of blanks, duplicates, standards and the required chain-of-custody.

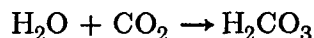
The WT well data from this sampling program were added to the data base (Appendix A) compiled from the literature review. This data base contains information about the location, static water level, lithology, well depths and producing intervals of the wells, in addition to chemical and isotopic analyses.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

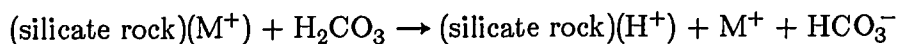
Extensive flow path geochemical modeling has been conducted on Rainier Mesa, 50 km northeast of Yucca Mountain by Claassen and White, 1979, White *et al.*, 1980, and Kerrisk, 1983. Rainier Mesa is geologically similar to Yucca Mountain. Claassen and White, 1979, and White *et al.*, 1980, studied the 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	$(\text{Na}_2, \text{K}_2, \text{Ca}, \text{Mg}) \text{Al}_{14} \text{Si}_{22} \text{O}_{60} (\text{OH})_{12}$
	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	$(\text{Mg}, \text{Fe})_3 (\text{Si}, \text{Al})_4 \text{O}_{10} (\text{OH})_2, \text{Fe}_3 (\text{OH})_6$

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 greater 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 filling 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 (Or₉₉₋₁₀₀) 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 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).

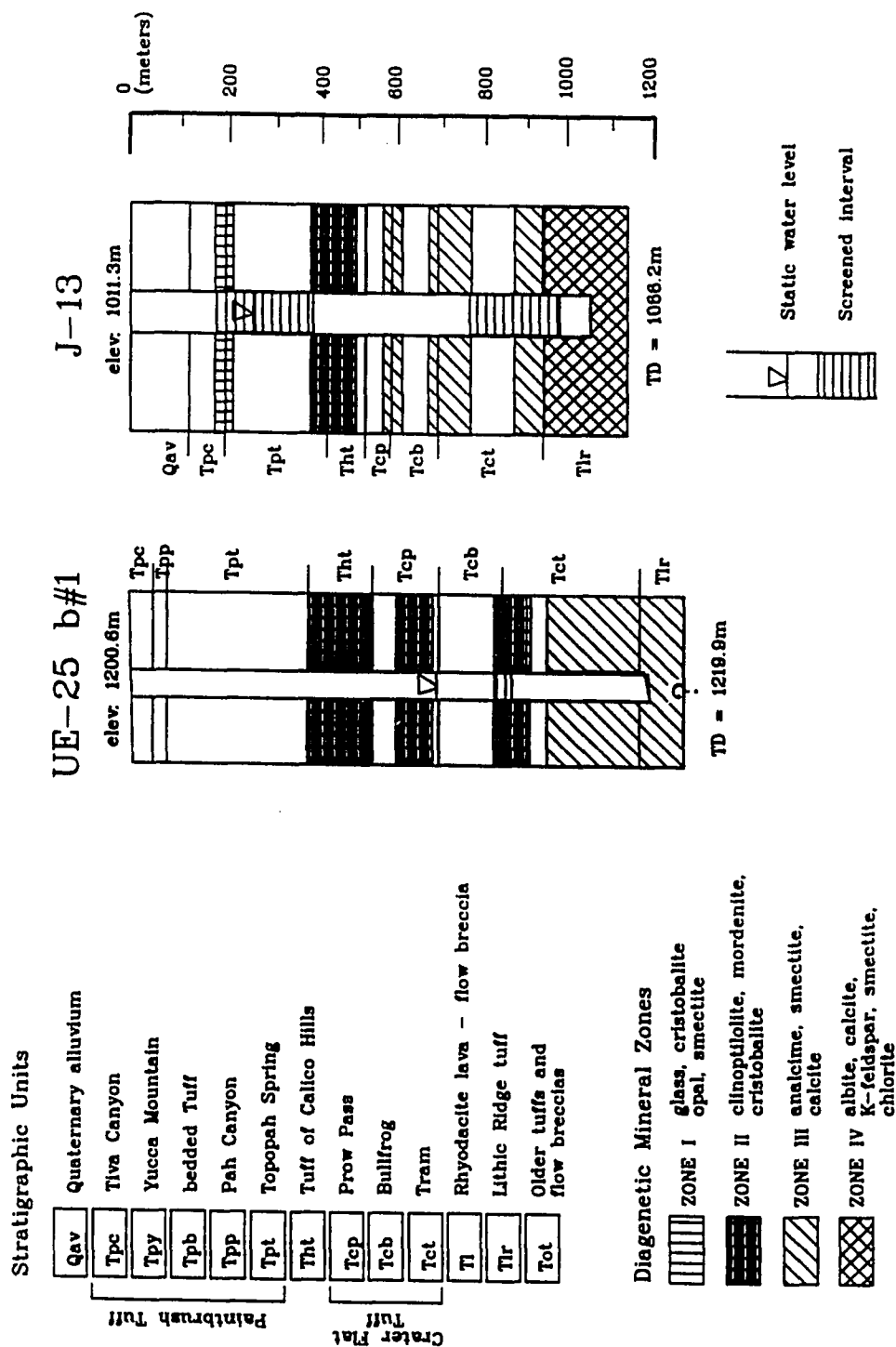


Figure 6: Diagenetic mineral zones of Yucca Mountain wells UE-25 b#1 and J-13. Modified from Bish et al., 1982.

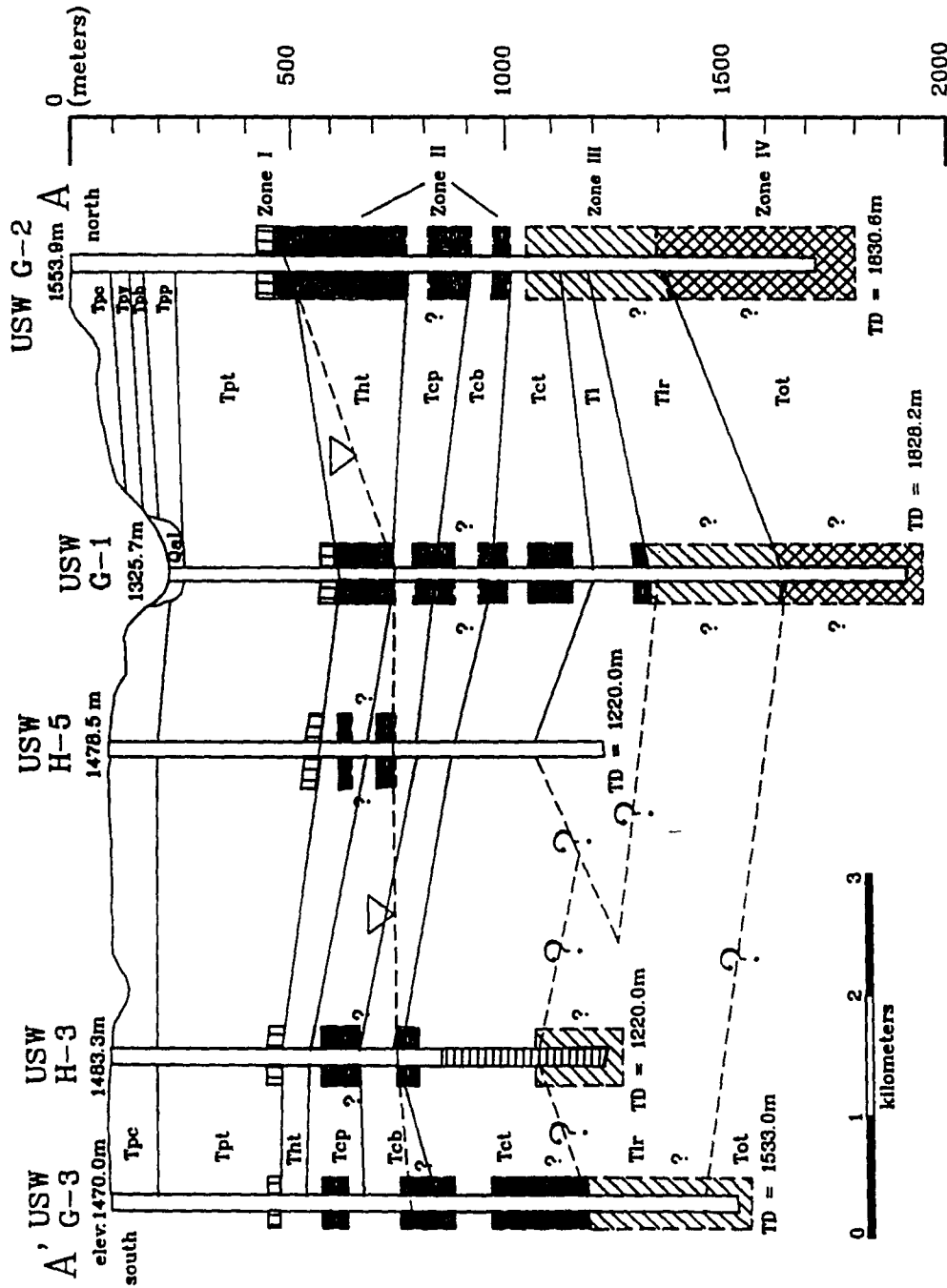


Figure 7: Diagenetic mineral zones of Yucca Mountain, Nevada. Cross section is from Scott and Bonk (1984), along Yucca Mountain crest. See Figure 6 for explanation of zones and lithology. Well data modified from Bish et al., 1982, and Vaniman et al., 1984.

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 Desert Research Institute uses WATEQDR (Bohm and Jacobson, 1981), which is an updated version of WATEQF (Plummer *et al*, 1976). WATEQDR, which is short for WATER EQUilibrium (Desert Research 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 D.

WATEQDR ANALYSIS

An initial analysis of the Yucca Mountain well-water analyses is completed using WATEQDR to solve for equilibrium distribution of the species and mineral phases present. The ground water is 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	-882.69	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
$K_{0.6}Mg_{0.26}Al_{2.3}Si_{3.6}O_{10}(OH)_2 \cdot 4(H_2O)$	illite	-1391.46	-1300.98	66.44	4
$(Mg,Fe)_3(Si,Al)_4O_{10} \cdot 2(Mg,Fe)_3(OH)_6$	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.

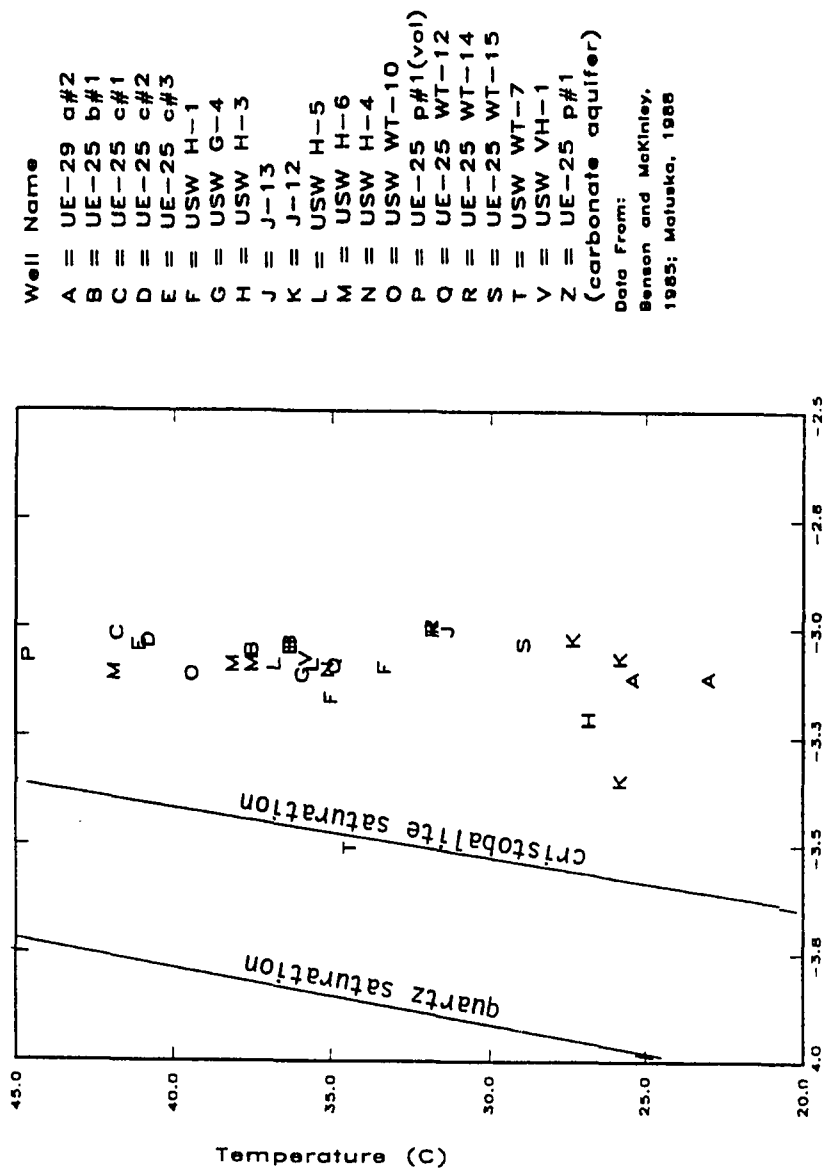


Figure 8: Log activity of H_4SiO_4 and temperature of Yucca Mountain, Nevada, wells. Log activity H_4SiO_4 computed by WATEQDR.

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.

Minerals 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

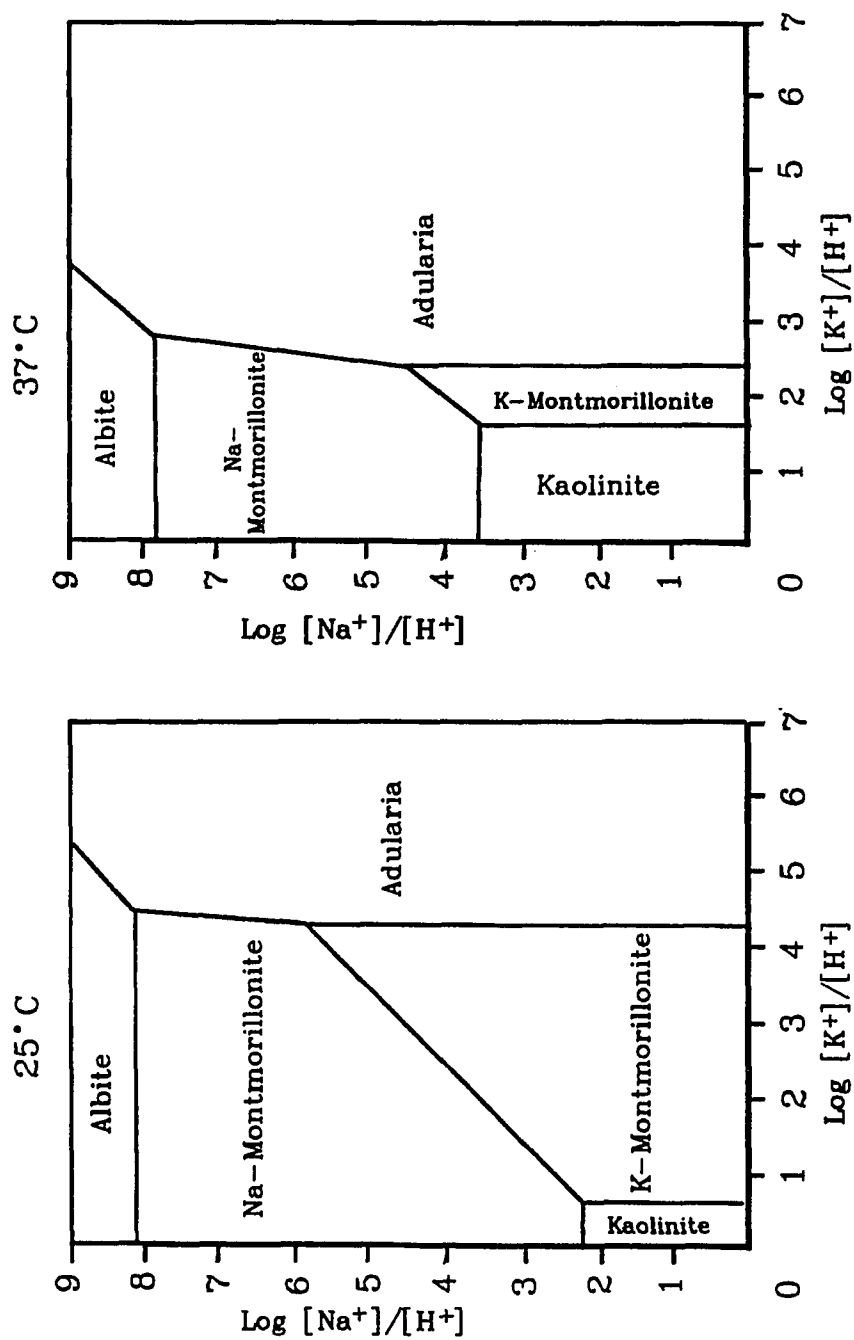


Figure 9: Mineral stability relationships of $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$ system at 1 bar pressure and 25 °C and 37 °C. Thermodynamic data used to plot phase boundaries are from Robie and Waldbaum, 1968; Helgeson, 1969; and Naumov *et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

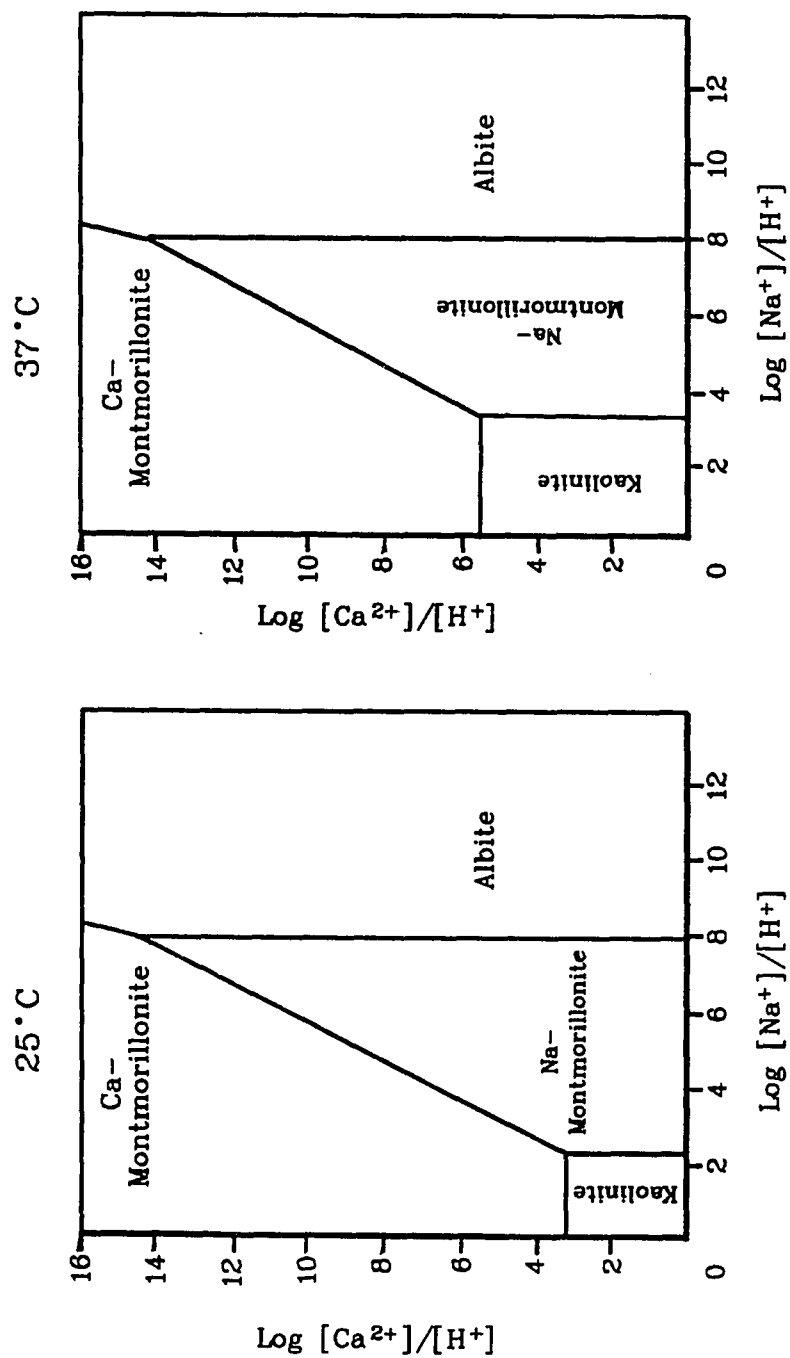


Figure 10: Mineral stability relationships of $\text{CaO-Na}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ system at 1 bar pressure and 25 °C and 37 °C. Thermodynamic data used to plot phase boundaries are from Robie and Waldbaum, 1968; Helgeson, 1969; and Naumov *et al.*, 1974. $\text{Log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

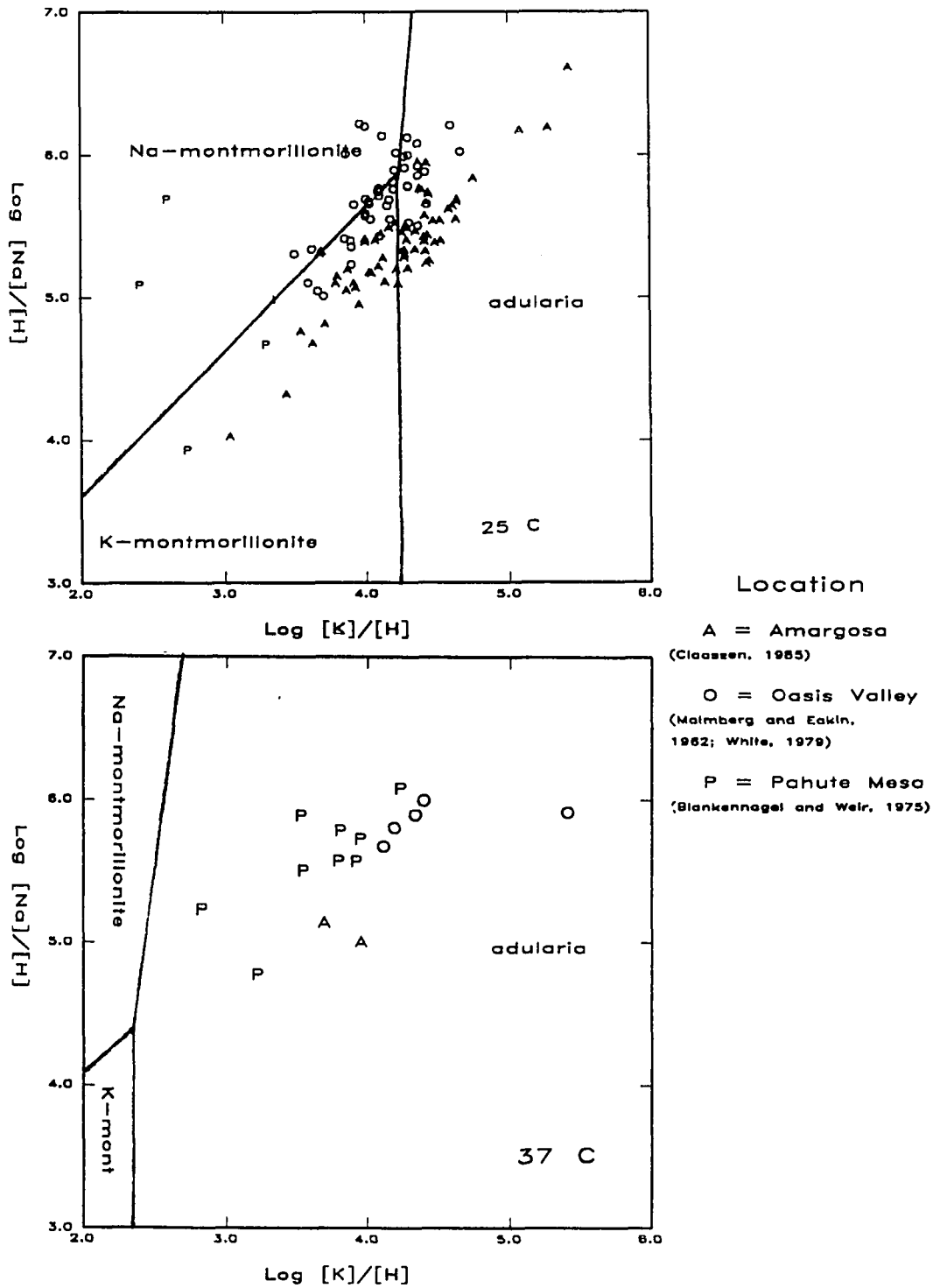


Figure 11: Sodium-potassium mineral stability relationships of wells and springs at 1 bar pressure and 25 °C and 37 °C, of study area in southern Nevada.

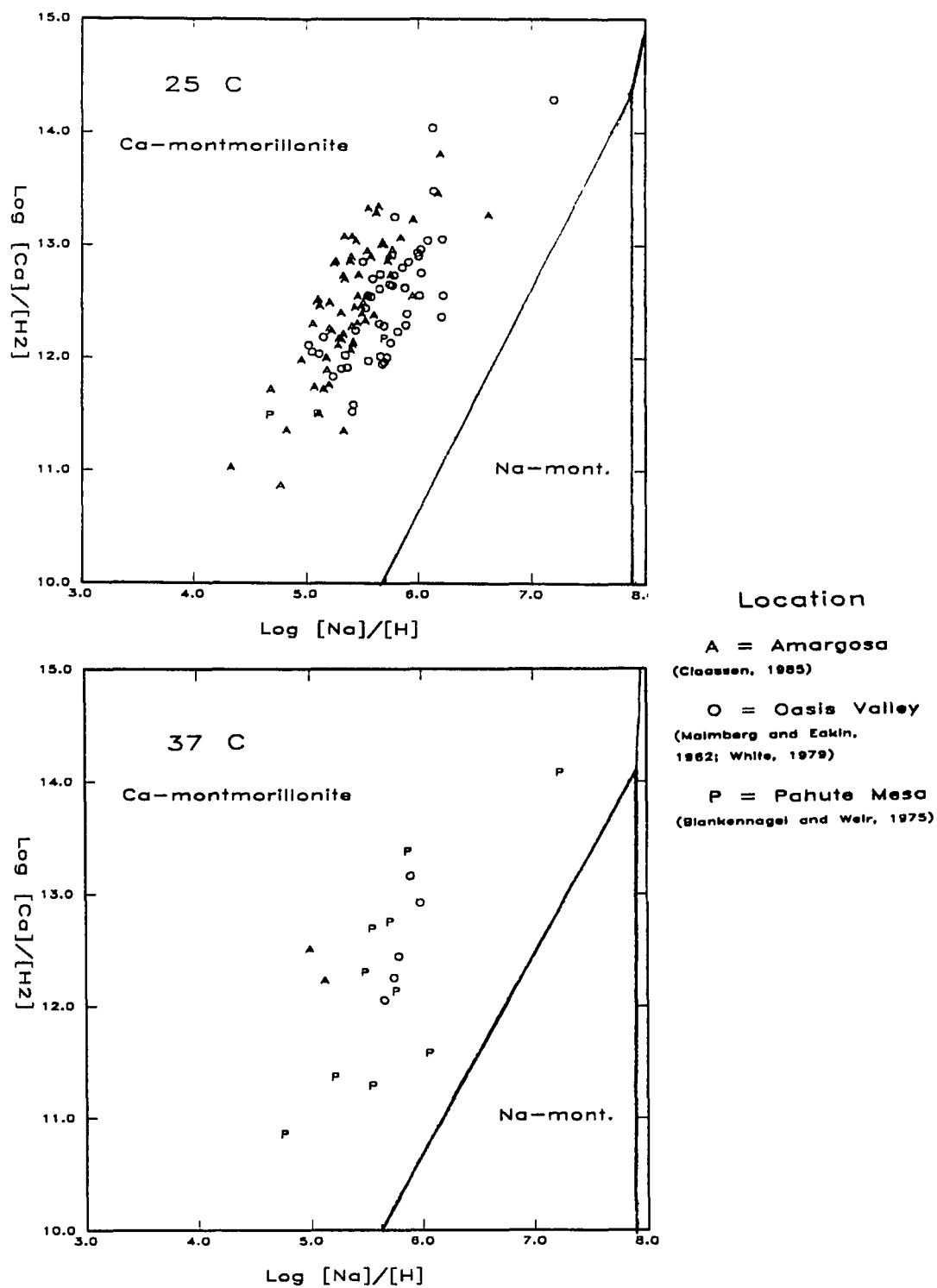


Figure 12: Calcium-sodium mineral stability relationships of wells and springs at 1 bar pressure and 25 °C and 37 °C, of study area in southern Nevada.

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. Another lower temperature well, USW H-3, is 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 and 37°C are located within the Ca-montmorillonite stability field. Again, this may be caused by the either selective removal of Ca^{2+} by ion exchange in montmorillonite, or an increase in the Ca^{2+} content from input of carbonate aquifer ground

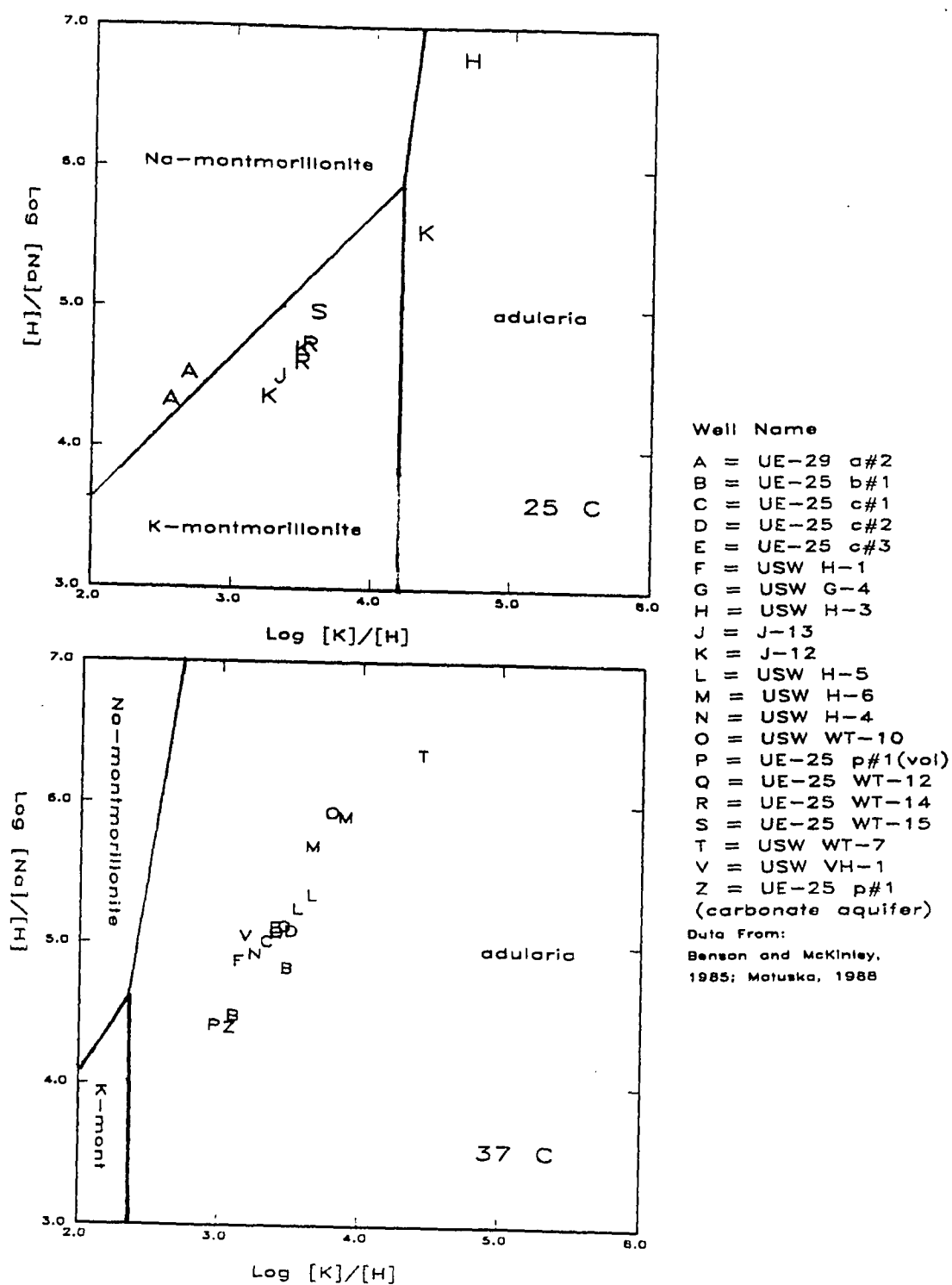
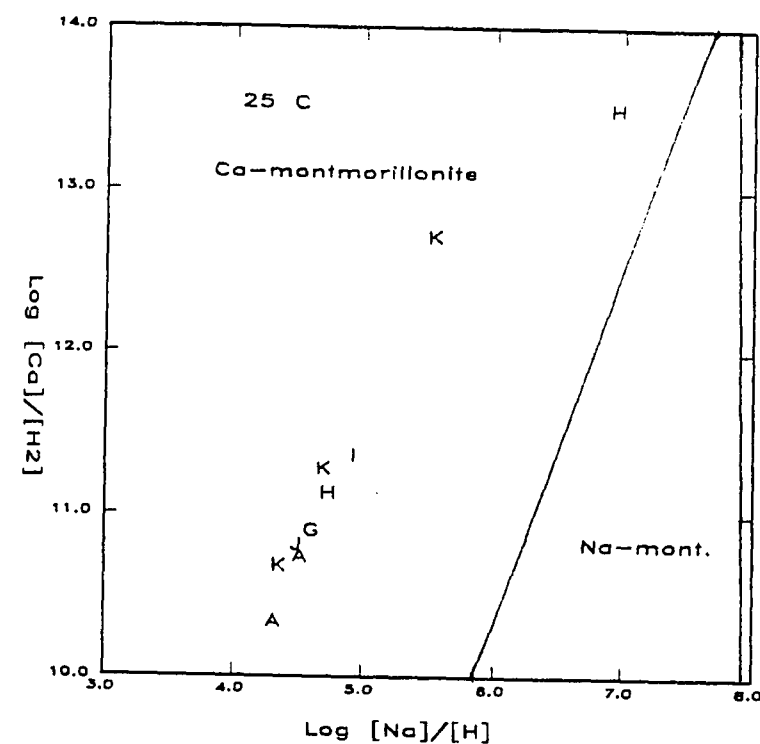


Figure 13: Sodium-potassium mineral stability relationships of wells at 1 bar pressure and 25 °C and 37 °C. Yucca Mountain, Nevada.



Well Name

- A = UE-29 a#2
- B = UE-25 b#1
- C = UE-25 c#1
- D = UE-25 c#2
- E = UE-25 c#3
- F = USW H-1
- G = USW G-4
- H = USW H-3
- J = J-13
- K = J-12
- L = USW H-5
- M = USW H-6
- N = USW H-4
- O = USW WT-10
- P = UE-25 p#1(vol)
- Q = UE-25 WT-12
- R = UE-25 WT-14
- S = UE-25 WT-15
- T = USW WT-7
- V = USW VH-1
- Z = UE-25 p#1 (carbonate aquifer)

Data From:
Benson and McKinley,
1985; Matuska, 1988

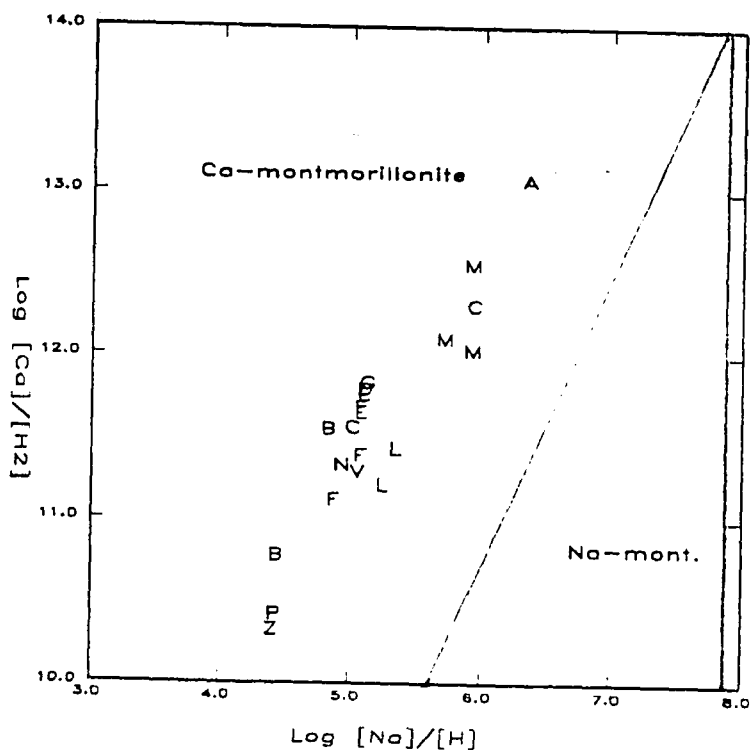


Figure 14: Calcium-sodium mineral stability relationships of wells at 1 bar pressure and 25 °C and 37 °C, Yucca Mountain, Nevada.

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 northeast-southwest 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 points may be made:

- Yucca Mountain ground water is supersaturated with respect to montmorillonites, illites, feldspars and quartz polymorphs.
- The ground water is undersaturated with respect to analcime and calcite.
- 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.
- 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.

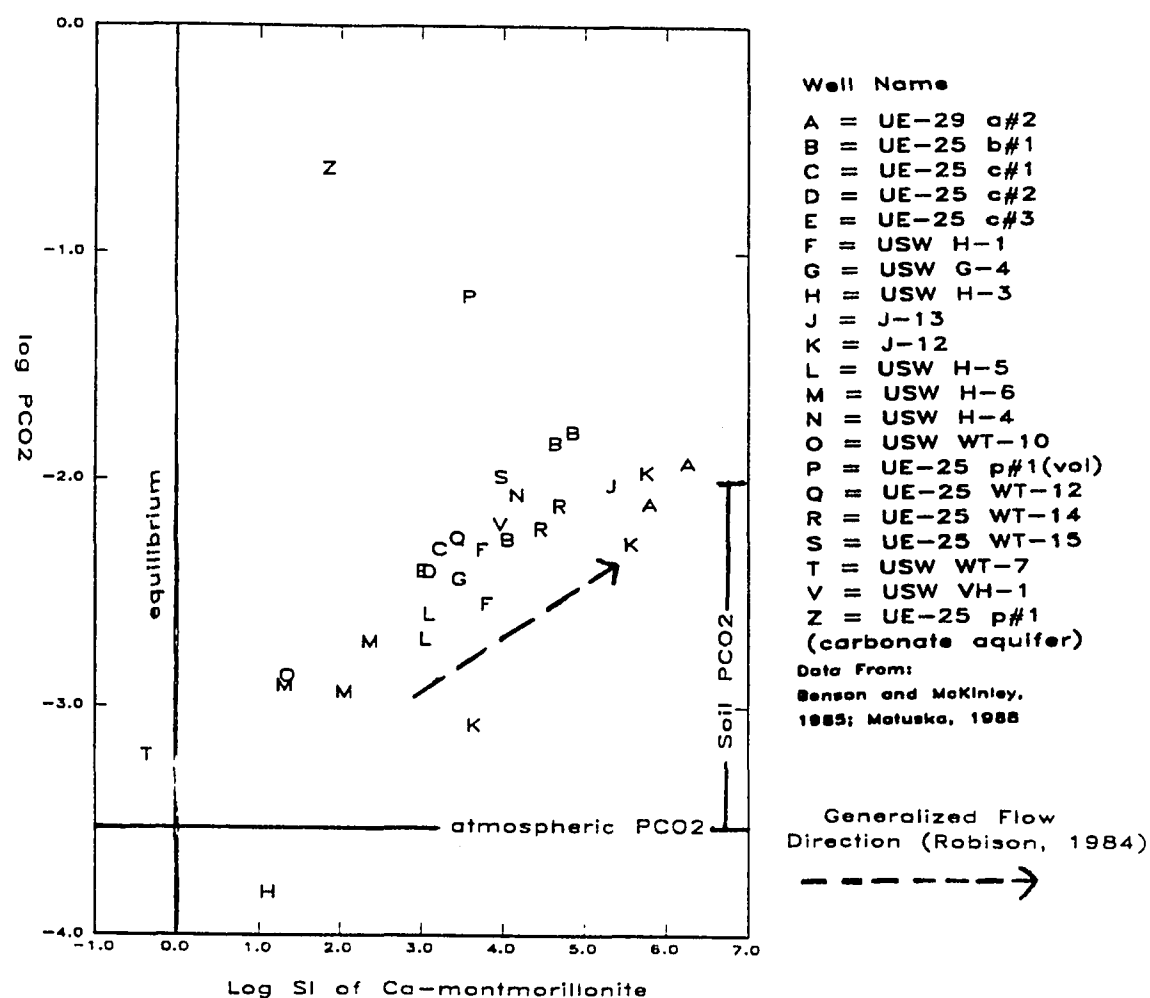


Figure 15: Saturation index of Ca-montmorillonite compared to the partial pressure of CO_2 along a flow path at Yucca Mountain, Nevada.

PHREEQE GEOCHEMICAL MODEL

Geochemical Model Input

The hypothetical ground-water flow path developed in PHREEQE consisted of a solution traveling through a system comprised of zones of mineral assemblages which were defined by the volcanic lithologies discussed previously. In each zone an initial solution interacts with a reaction step that releases ions to form a new solution. This new solution then interacts with a given list of 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 which 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 which 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, p_e 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 runs calculations until the first mineral in the given list has reached 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_{CO_2} ; T
Initial Solution	Soil	Soil	$Ca = 1.84 \times 10^{-4}$ $Mg = 8.88 \times 10^{-5}$ $Na = 1.37 \times 10^{-3}$ $K = 8.03 \times 10^{-5}$ $C = 1.72 \times 10^{-3}$ $Si = 3.99 \times 10^{-4}$	pH: 7.2 log P_{CO_2} : -2.17 T: 25 ° C
I	Dissolution of Volcanic Glass	cristobalite Na-montmorillonite heulandite log P_{CO_2}	$Ca = 2.17 \times 10^{-5}$ $Mg = 8.88 \times 10^{-5}$ $Na = 1.47 \times 10^{-3}$ $K = 8.03 \times 10^{-5}$ $C = 3.57 \times 10^{-2}$ $Si = 2.05 \times 10^{-4}$	pH: 5.0 log P_{CO_2} : 0.00 T: 25 ° C
II	Clinoptilolite Ion Exchange 2Na:2K:1Ca (moles)	cristobalite Na-montmorillonite adularia	$Ca = 5.29 \times 10^{-3}$ $Mg = 8.88 \times 10^{-5}$ $Na = 1.20 \times 10^{-2}$ $K = 1.06 \times 10^{-2}$ $C = 3.57 \times 10^{-2}$ $Si = 2.38 \times 10^{-4}$	pH: 7.3 log P_{CO_2} : -1.04 T: 30 ° C
III	Mordenite Ion Exchange 2Na:2K (moles)	cristobalite Na-montmorillonite K-montmorillonite adularia	$Ca = 5.28 \times 10^{-3}$ $Mg = 8.88 \times 10^{-5}$ $Na = 2.97 \times 10^{-2}$ $K = 5.43 \times 10^{-4}$ $C = 3.57 \times 10^{-2}$ $Si = 2.90 \times 10^{-4}$	pH: 8.9 log P_{CO_2} : -2.16 T: 32 ° C
IV	Analcime Ion Exchange 6Na:2K (moles)	quartz Na-montmorillonite K-montmorillonite Ca-montmorillonite	$Ca = 3.35 \times 10^{-2}$ $Mg = 8.88 \times 10^{-5}$ $Na = 1.51 \times 10^{-5}$ $K = 2.86 \times 10^{-7}$ $C = 3.57 \times 10^{-2}$ $Si = 5.62 \times 10^{-4}$	pH: 10.1 log P_{CO_2} : -4.56 T: 35 ° C
V	No Reaction Step	chalcedony illite chlorite adularia albite calcite	$Ca = 1.57 \times 10^{-5}$ $Mg = 8.53 \times 10^{-8}$ $Na = 3.46 \times 10^{-3}$ $K = 1.37 \times 10^{-5}$ $C = 2.23 \times 10^{-3}$ $Si = 8.28 \times 10^{-4}$	pH: 9.5 log P_{CO_2} : -4.39 T: 40 ° C
UE-25 p#1	Lower Carbonate Aquifer	dolomite calcite chalcedony iron oxides	$Ca = 2.48 \times 10^{-3}$ $Mg = 1.61 \times 10^{-3}$ $Na = 6.32 \times 10^{-3}$ $K = 3.07 \times 10^{-4}$ $C = 9.36 \times 10^{-3}$ $Si = 6.84 \times 10^{-4}$	pH: 6.6 log P_{CO_2} : -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 as 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 was 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: The fourth modeled zone is Part IV, which 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 °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 was to construct a theoretical flow path that would 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 a 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 smectite, zeolites and feldspars, and the solution becomes alternately either Na^+ or Ca^{2+} rich, dependant 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.

Part V, of the five modeled zones, appears to be most analogous to an actual volcanic water in terms of pH, molalities, ionic log activity and saturation indices of minerals (Table 7). When the results of the modeled Part II - Part V are plotted on mineral stability diagrams (points 1-4, Figures 16 and 17), it may be seen that Part V has higher activity ratios than either the other zones or the analyses from the Yucca Mountain wells. Overall, the solution modeled in Part V is most similar to well USW H-3 (point H, Figures 16 and 17). Part V is also similar to another high pH well, USW WT-10, with respect to pH and saturation indices of minerals (Table 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

TABLE 7
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^{-6}	1.9×10^{-6}	7.9×10^{-4}	1.1×10^{-4}	4.2×10^{-4}	4.5×10^{-4}
Mg	8.0×10^{-8}	-	5.1×10^{-4}	4.1×10^{-6}	1.2×10^{-6}	2.9×10^{-6}
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^{-6}	2.8×10^{-6}	1.1×10^{-4}	1.7×10^{-6}	6.6×10^{-6}	7.2×10^{-6}
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.

TABLE 8
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^{-6}	6.8×10^{-6}	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

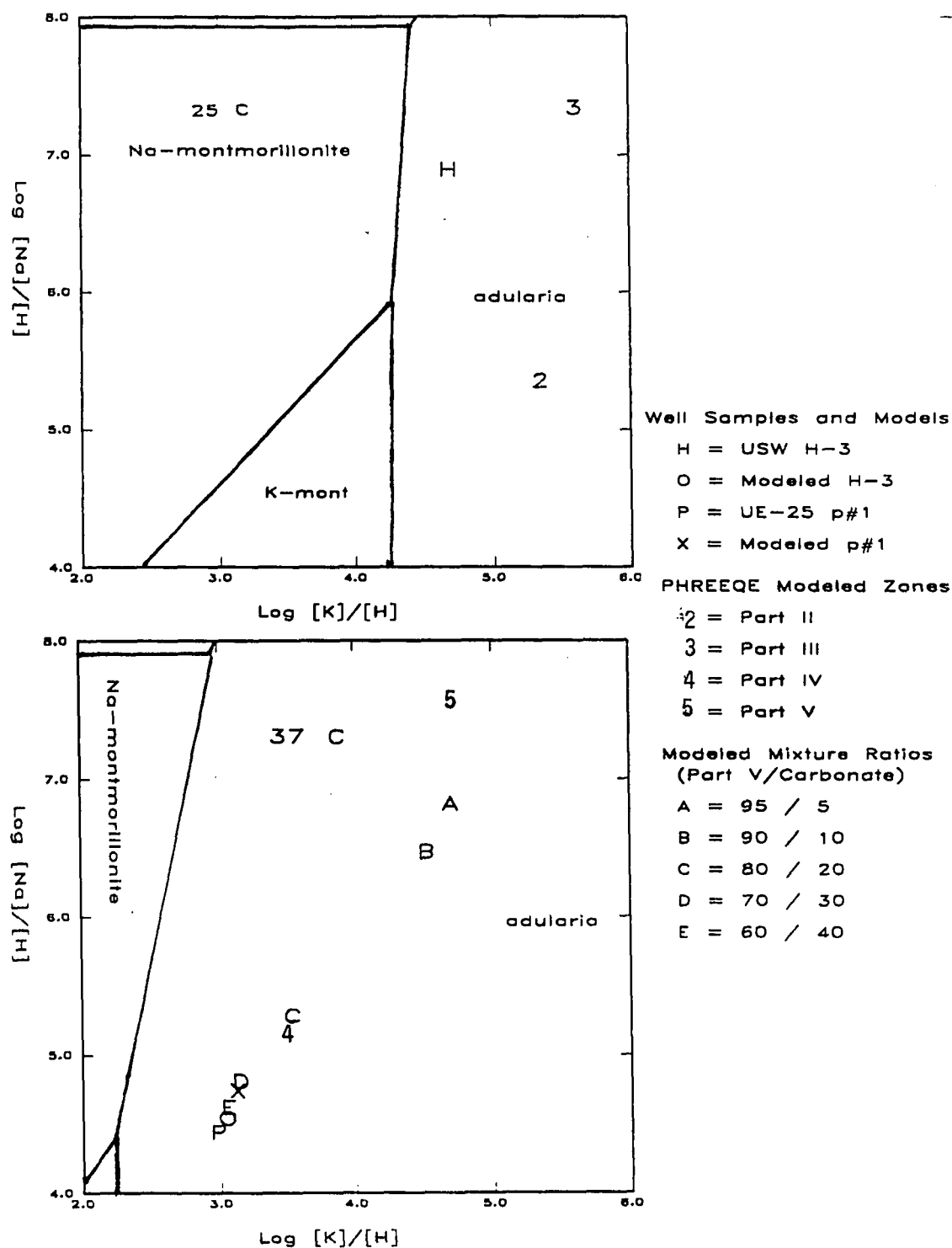


Figure 16: Sodium-potassium mineral stability relationships of flow path model compared to Yucca Mountain, Nevada, wells at 1 bar pressure and 25 °C and 37 °C.

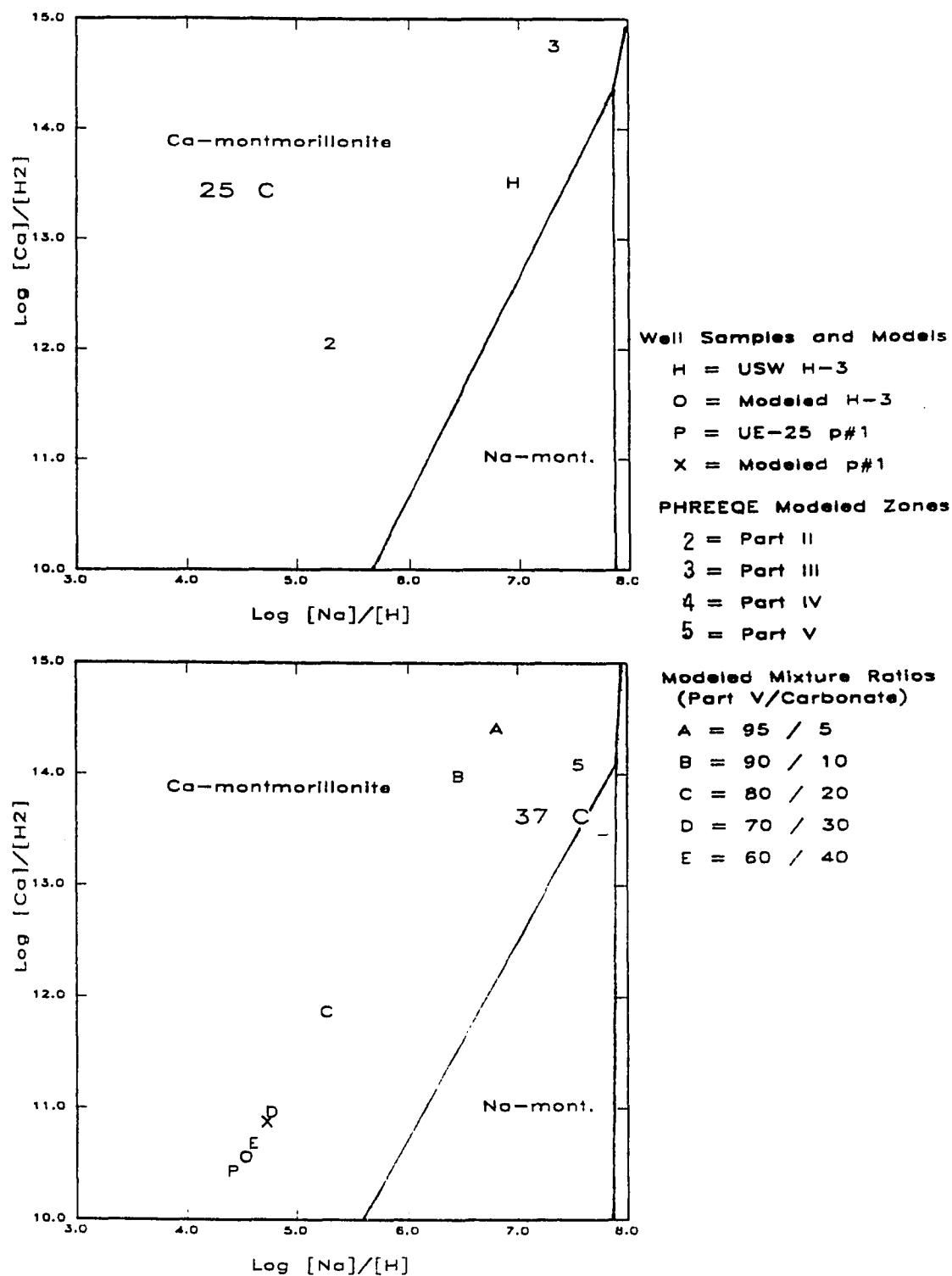


Figure 17: Calcium-sodium mineral stability relationships of flow path model compared to Yucca Mountain, Nevada, wells at 1 bar pressure and 25 °C and 37 °C.

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

MIXING MODELED VOLCANIC AND CARBONATE WATERS

After the geochemical evolution of the water along the hypothetical flow through the tuffaceous aquifer had been established, the resultant solution was computationally mixed with of water from the 1297-1805 meter interval of well UE-25 p#1, which was 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 was 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 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 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 to correctly identify the minerals likely to be present.

Because BALANCE is simply 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 was 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 are 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 is 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 is to mix the hypothetical tuffaceous water and the carbonate aquifer water to determine if the ratio suggested in BALANCE is thermodynamically correct with respect to the actual volcanic water sample from UE-25 p#1. The two water types are titrated together using PHREEQE, and the resulting solution, 68% Part V and 32% carbonate aquifer water, is solved for mineral equilibria. This modeled mixed solution is 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 are similar in pH, P_{CO_2} , molalities of their elements and saturation indices. The waters are 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	UE-25 p#1 (sampled) ²	Element	UE-25 p#1 (modeled) ¹	UE-25 p#1 (sampled) ²
	Log Saturation Index			Molality	
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	7.99×10^{-4}	9.23×10^{-4}
cristobalite	0.325	0.353	Mg	5.11×10^{-4}	4.12×10^{-4}
quartz	0.611	0.640	Na	4.37×10^{-3}	4.00×10^{-3}
chlorite	0.322	-5.114	K	1.07×10^{-4}	1.43×10^{-4}
illite	4.293	1.563	Fe	5.66×10^{-6}	1.74×10^{-6}
Na-mont.	6.322	3.703	Al	2.24×10^{-6}	-
K-mont.	6.307	3.745	Si	7.83×10^{-4}	8.16×10^{-4}
Ca-mont.	5.300	2.707	Cl	3.47×10^{-4}	3.67×10^{-4}
analcime	-1.458	-2.846	C	5.11×10^{-3}	4.62×10^{-3}
heulandite	11.906	9.379	S	5.42×10^{-4}	3.96×10^{-4}
adularia	1.108	-0.072	F	7.87×10^{-6}	1.79×10^{-6}
albite	0.379	-0.976	Li	2.71×10^{-6}	3.31×10^{-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 is a difference between the two analyses in the saturation indices of chlorite and the feldspars, which is 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 16 and 17), the modeled volcanic UE-25 p#1 (X) plots 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 are 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 indicates 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 is 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 is 51 % to 49 %, respectively. However, when this ratio is mixed using PHREEQE, the resulting solution is very dissimilar to the USW H-3 sample (Table 7). In Figures 16 and 17 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 is 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 suggests that this is within the range of standard deviation error of the BALANCE computations, and not actually due to carbonate water.

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 are compared to the Yucca Mountain wells through comparison of molarities 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 16 and 17.

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 are compared to the theoretical flow path and mixing model are generally near-neutral pH wells. In this respect they do 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 is a similarity (A-E, Figures 16 and 17), 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.

Based upon previous literature, the WATEQDR analyses discussed previously, and isotope analyses in the next section, I believe 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 mixture models are analyzed for molality and saturation index of calcite, it may be seen that they are higher in calcium and magnesium than the actual well samples, and supersaturated with calcite (Table 10), which is 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. 88 and Figure 20) which indicate no marine carbonate influence, it appears unlikely that large volumes of carbonate-type ground water are entering the tuffaceous zones. A reason that the mixed zones may resemble the Yucca Mountain wells, especially those with nearly neutral pH, is likely 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 hydrogeologic cycle. Some of their uses include determining the origin (location, period, recharging 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" (‰) 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 ¹⁸Oxygen

The three stable isotopes of oxygen (¹⁶O, ¹⁷O, ¹⁸O) were discovered in 1929 by Giauque and Johnson (Gat, 1980); ¹⁸O 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 ‰. 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 will be 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) determined 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 Nevada Test Site 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 18, 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 (1988) found that Yucca Mountain well waters (except for USW H-3) were slightly δD depleted from the 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 within or very near to the local meteoric water line (Ingraham *et al.*, 1989), which

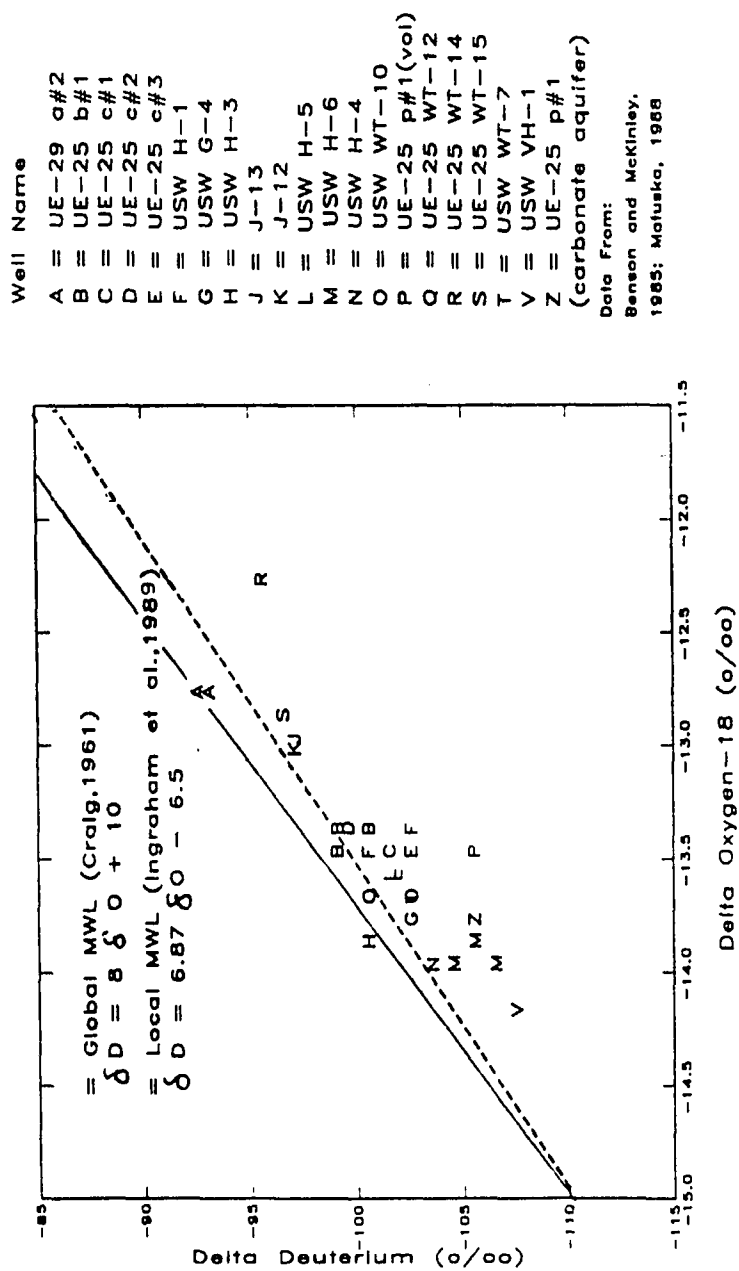


Figure 18: Delta deuterium and delta ¹⁸Oxygen values of Yucca Mountain, Nevada, wells.

might suggest relatively recent recharge which has undergone evaporation, similar to the scenerio 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. However, if 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, this may be a possibility.

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 5730 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 19 and 20 show the relationship of PMC to $\delta^{13}\text{C}$ values for the study area and Yucca Mountain, respectively. In Figure 19, 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 between older ground water with more recent recharge, or simply be a ground water that has been removed from the atmosphere 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

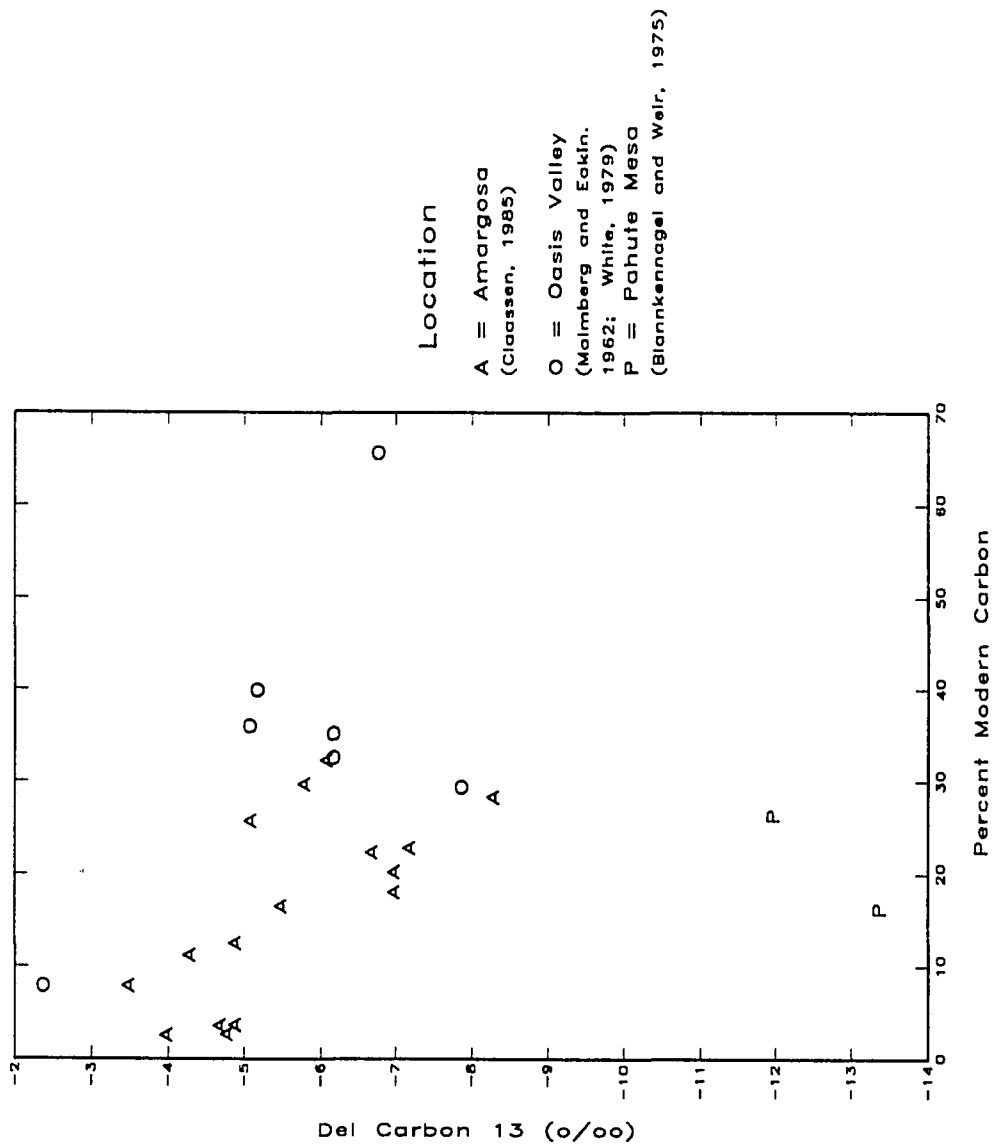


Figure 19: Delta ^{13}C Carbon as a function of percent modern carbon of study area wells and springs in southern Nevada.

the regional carbonate aquifer.

In Figure 20 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 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 trend for increasing $\delta^{13}\text{C}$ with decreasing PMC. This could be due to mixing of older waters with more recent recharge. 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, 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 seems to imply 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‰). An upward gradient 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

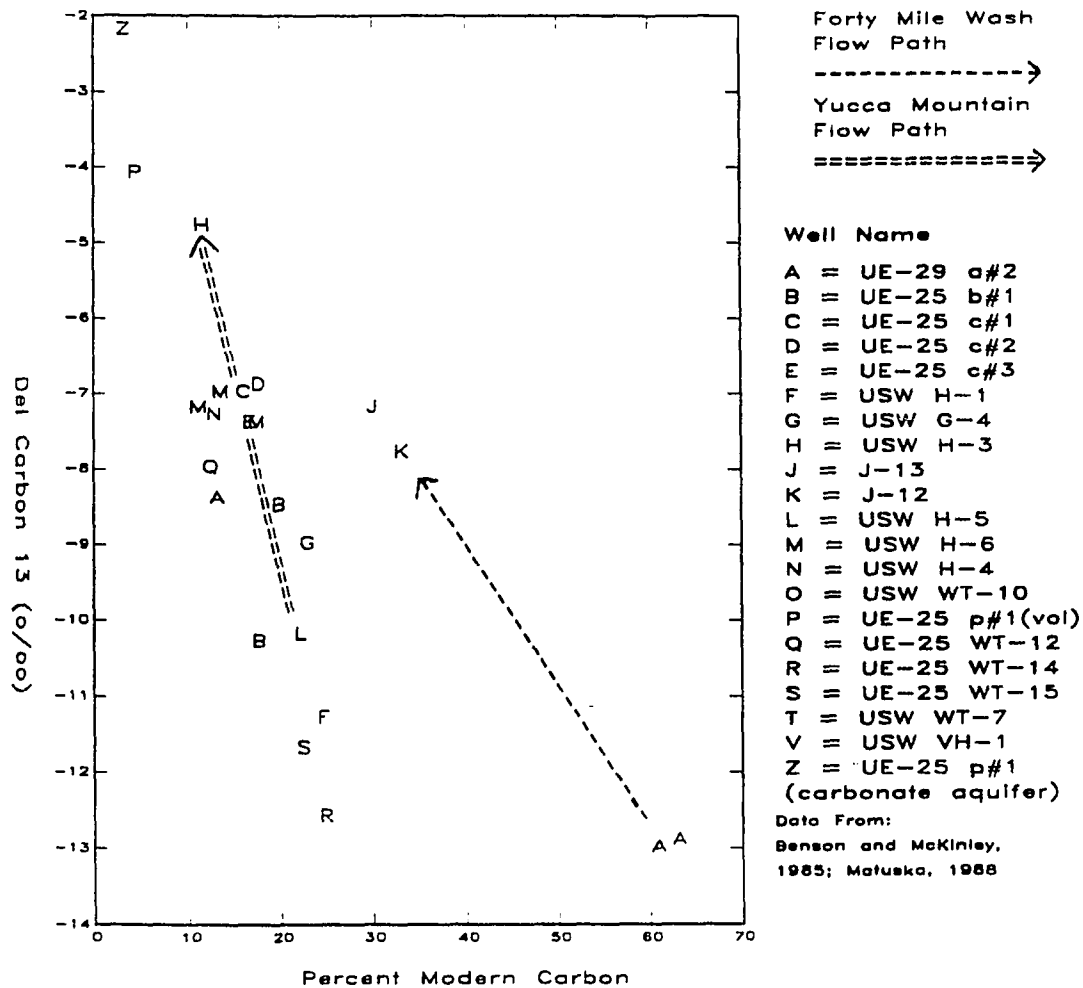


Figure 20: Delta ^{13}C Carbon as a function of percent modern carbon of Yucca Mountain, Nevada, wells. Flow paths from potentiometric data of Robison, 1985.

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 fracture flow, which have passed through a enriched $\delta^{13}\text{C}$ caliche zone. In studies of caliche zones in soil on 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 18), 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.

Comparing Yucca Mountain wells on the mineral stability diagrams, it appears that the ground waters are supersaturated with respect to montmorillonites, illites, feldspars and quartz polymorphs, and undersaturated

with respect to analcime. 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 at Rainier Mesa.

Conclusions From PHREEQE Model

Summary of Results

A hypothetical flow path through a tuffaceous aquifer is modeled using PHREEQE, based upon formation lithologies presented in previous literature. The geochemical model is 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, is 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. The partial pressure of CO_2 generally decreases from Part I to Part V, indicating that the system is closed, rather than an open system as Kerrisk (1987) suggests.

When these modeled zones are compared to Yucca Mountain well samples, the solution of Part V is most similar to tuffaceous waters with high pH, such as USW H-3, or USW WT-10. Wells displaying water with lower pH do 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 most of these wells are 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 seems to 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

The problems with geochemical modeling arise when the extremely complicated system present at Yucca Mountain is made into a simple geochemical model.

The greatest error of the PHREEQE flow path model was to ignore 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 quite 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 with matrix flow. Because of this, 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 dependant 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 be influencing 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 present. This may influence ion-exchange and mineral equilibria. A good topic for further research would be to determine the thermodynamic properties of these minerals, which would allow this model to become more site specific.

In mixing the modeled tuffaceous zone water with the carbonate water, the only analysis of carbonate water in the vicinity of Yucca Mountain was 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 might be a cause of the misleading results of the mixed model attempts.

Other problems with the model may be 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 present day. 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 suggests that Forty Mile Wash may be acting as a local recharge zone.

Carbon isotope data show a 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 with low percent modern carbon in Yucca Mountain well flow paths. The $\delta^{13}\text{C}$ data from Forty Mile Wash wells correlates 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 may 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, as 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 factor 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 studies of this thesis, 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, which could also suggest more recent recharge. Forty Mile Wash appears to be a region of local recharge, extending to as far as UE-25 WT-15.

Further refinement of the geochemical flow path model is desirable to increase confidence in the model of ground-water flow through all the wells of Yucca Mountain. 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 suggest the model is partially successful in terms of modeling high pH wells and the mixed well of UE-25 p#1, and is not as successful in modeling wells with near-neutral pH. However, the results of the model may prove to be a useful start for future studies.

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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 **
AMARGOSA DESERT									
AM 101 Amargosa	1162445	363715	786.3		Q alluvium: mixed	composite		03/30/73	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-9dcc	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-25aa	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-15bbd	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		Q 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
18S/49E-1aba	1162330	362520	664.0		Q alluvium: mixed	composite	664.0	04/06/71	1
18S/49E-2cdc	1162341	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	692.0	06/23/79	1
16S/48E-8ba	1163530	363450	727.0	80	Q alluvium: mixed	composite		06/24/71	1
16S/48E-7bba	1163640	363455	725.0		Q alluvium: mixed	composite		03/30/71	1
16S/48E-7ebc	1163650	363425	722.0		QT alluvium: carbonate	composite		03/31/71	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	90	Q alluvium: mixed	composite	691.0	08/18/62	1
16S/48E-23da	1163135	363244	715.0	140	Q alluvium: volcanic	composite	691.0	02/17/66	1
27N/4E-27bbb	1163215	362700	686.0	90	Q alluvium: mixed	composite	672.0	08/18/62	1
17S/50E-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	1161727	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	03/09/61	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	992.4	372		-	695.2	10/15/51	3
Indian Spg	1160610	372640	2036.0			-	2036.0	05/01/58	3
Marble 3	1160405	371348	1630.0	298	Pogonip-Ordovician	composite	1474.9	07/11/59	3

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 **
Oak Spg	1161421	371441	1768.0		Tunnel beds	-	1768.0	04/28/58	3
Rainier Spg	1161142	371120	1902.0		tunnel beds	-	1902.0	09/18/57	3
TW-8	1161721	370956	1736.0	1673	rhy/tuff of Pahute Mesa	324-567	1410.5	10/15/64	9
Test Hole 4	1160120	365048	1037.8	52	QT alluvium: mixed	284-448	806.2		3
Test Hole 7	1160205	370353	693.0	693	Indian Trail	521-693	729.0	02/04/58	3
Test Well C	1160034	365508	1176.3	518	Carrara Fm	47-486	724.5	09/01/61	10
Test Well F	1160659	364534	1263.0	1036	undiff. Silurian	composite	734.1	03/12/80	4
Tippipah Spg	1161155	370240	1597.0		Tunnel beds	-	1597.0	03/24/58	3
Topopah Spg	1161610	365610	1768.0		Rhy of Calico Hills	-	1768.0	03/25/58	3
U2E-M1	1161230	371105	1877.8	457	Devils Gate/Nv Fm-Cenoz.	composite		11/04/59	3
US-16F	1160925	370209	1957.0	394	QT alluvium: mixed			09/25/77	4
USGS A	1160211	370213	1231.0	570	QT alluvium: mixed	491-570	731.2	09/02/60	3
USGS D	1160430	370428	1265.0	594	Eleana Fm	540-574	737.0	01/13/60	3
USGS E	1160105	370322	1271.6	740		548-585	741.3	02/28/61	3
Well 1	1155445	364950	955.0	265	Q alluvium: mixed	composite	730.9	12/17/50	3
Well 3	1160329	365943	1209.8	548	Piapi Canyon	468-538	730.4	12/02/58	3
Well 5A	1155729	364635	943.0	277	Pavits Springs	167-271	731.7	04/24/58	3
Well 5A	1155729	364635	943.0	277	Pavits Springs	167-271	729.9	02/04/59	3
Well 5B	1155808	364804	942.5	274	Q alluvium: mixed	213-271	734.3	04/04/57	3
Well 5C	1155744	364708	939.0	362	Q alluvium: mixed	270-362	726.5	12/09/58	3
Whiterock Spg	1130752	371209	1540.0		Tunnel beds	-	1540.0	05/19/59	3
OASIS VALLEY									
Ute Spg	1164304	365656	1061.0		Q alluvium: mixed	-	1061.0	07/03/67	7
7S/44E-28bcl	1170350	371800	1221.0	30	Q alluvium: mixed	composite		07/03/67	7
8S/44E-28cbl	1170500	371745	1219.0	62	QT alluvium: mixed	composite		03/13/62	6
8S/43E-23a1	1170705	371340	1192.5		Q alluvium: mixed	composite		03/13/62	6
8S/44E-12b1	1170005	371522	1191.0		Q alluvium: mixed	composite		03/07/62	6
9S/46E-20a1	1165030	370840	1221.0		Q alluvium: mixed	composite		03/13/62	6
9S/46E-35a1	1164725	370647	1230.0		Q alluvium: mixed	composite		03/21/62	6
10S/47E-14b1 (spg)	1164127	370417	1205.0		Q alluvium: mixed	-	1205.0	03/14/62	6
10S/47E-27a1	1164207	370231	1189.0	1	Q alluvium: mixed	composite		03/14/62	6
10S/47E-30c1	1164550	370150	1182.0	7	Q alluvium: mixed	composite		03/14/62	6
10S/47E-30d1 (spg)	1164510	370205	1204.0		Q alluvium: mixed	-	1204.0	03/14/62	6
10S/47E-33a1 (spg)	1164225	365942	1158.0		Q alluvium: mixed	-	1158.0	07/03/67	7
11S/45E-22b1 (spg)	1165530	365010	1365.0		Q alluvium: mixed	-	1365.0	03/15/62	6
11S/46E-26ca1 (spg)	1165503	365640	1219.0		Q alluvium: mixed	-	1219.0	07/03/67	7
11S/46E-26cbl (spg)	1164819	365705	1280.0		Tv	-	1280.0	07/03/67	7
11S/46E-26dcl (spg)	1164742	365640	1219.0		Q alluvium: mixed	-	1219.0	03/15/62	6
11S/47E-4bbl (spg)	1164345	370052	1140.0		Q alluvium: mixed	-	1140.0	03/14/62	6
11S/47E-7dcl	1164526	365925	1206.0		Q alluvium: mixed	composite		02/22/56	6

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-9a1 (spg)	1164322	365945	1106.0		Q alluvium: mixed	-	1106.0	03/14/62	6
11S/47E-10a1 (spg)	1164222	365941	1164.0		undiff. tuffs	-	1164.0	03/14/62	6
11S/47E-16d1 (spg)	1164317	365921	1097.0		undiff. tuff	-	1097.0	07/03/67	7
11S/47E-18a1 (spg)	1164530	365910	1208.0		Q alluvium: mixed	-	1208.0	07/03/67	7
11S/47E-21a1 (spg)	1164301	365803	1085.0		Q alluvium: mixed	-	1085.0	07/03/67	7
11S/47E-28a1 (spg)	1164315	365727	1073.0		Q alluvium: mixed	-	1073.0	03/14/62	6
11S/47E-33a1 (spg)	1164343	365631	1061.0		undiff. welded tuff	-	1061.0	07/03/67	7
12S/47E-5a1 (spg)	1164437	365507	1027.0		Q alluvium: mixed	-	1027.0	07/03/67	7
12S/47E-20b1 (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-27c1a	1164819	365705	1164.0	2	Q alluvium: mixed	composite		07/03/67	7
10S/47E-31a1b (spg)	1164517	370151	1268.0		Q alluvium: mixed	-		07/03/67	7
10S/47E-32d1a (spg)	1164400	370110	1134.0		Q alluvium: mixed	-	1134.0	07/03/67	7
10S/47E-33a1b (spg)	1164307	370149	1182.0		Q alluvium: mixed	-	1182.0	07/03/67	7
10S/47E-30d1c	1164530	370200	1183.0	37	Q alluvium: mixed	composite		07/03/67	7
11S/47E-3c1b (spg)	1164230	370020	1170.0		Q alluvium: mixed	-	1170.0	07/03/67	7
11S/47E-4c1d (spg)	1164330	370030	1134.0		undiff. tuff	-	1134.0	07/03/67	7
11S/47E-10b1c (spg)	1164251	365945	1122.0		Q alluvium: mixed	composite	1122.0	07/03/67	7
11S/47E-21d1b	1164320	365756	1079.0		Q alluvium: mixed	-		07/03/67	7
11S/47E-21a1a (spg)	1164315	365825	1094.0		undiff. tuff	-	1094.0	07/03/67	7
11S/47E-21a1b (spg)	1164310	365821	1097.0		undiff. tuff	-	1097.0	07/03/67	7
11S/47E-27c1a	1164246	365658	1061.0	17	Q alluvium: mixed	composite		07/03/67	7
11S/47E-28a1c	1164310	365718	1073.0	8	undiff. tuff	-		07/03/67	7
11S/47E-10c1b (spg)	1164253	365924	1113.0		Q alluvium: mixed	composite	1113.0	07/03/67	7
12S/47E-6c1d	1164540	365455	1030.0	55	Q alluvium: mixed	composite		07/03/67	7
12S/47E-7d1d	1164530	365420	1000.0	91	Q alluvium: mixed	composite		07/03/67	7
12S/47E-19a1c	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
PAHUTE MESA									
Uel8r	1162640	370806	1662.0	1525	undiff tuff, rhyolite	496-1525	1107.0	01/29/68	9
U19as	1162208	371636	2028.0		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-Bltd Rg	702-1282	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	05/27/66	9
UE20h	1162602	371618	1999.0	2197	Belted Range tuff	764-2196	1410.9	08/26/65	9
UE20j	1163201	371801	1798.0	1734	Belted Range tuff	530-1734		10/21/64	9
----- YUCCA MOUNTAIN -----									
J-11	1161706	364706	1050.0	405	Topopah Spg-PtY/Bslt Kiwi	328-396	732.6	12/16/58	3
J-12	1162324	364555	953.5	347	Topopah Spg-PtY	214-264	953.5	03/26/71	2
J-12	1162324	364555	953.5	270	Topopah Spg-PtY	214-264	727.3	02/19/59	3
J-13	1162340	364828	1011.3	1063	Topopah S-PtY/Tram-CFT	207-450	728.1	03/26/71	2
UE-25b#1	1162623	365108	1200.6	1220	Tram/Bullfrog/Promp-CFT	composite	730.3	09/01/81	2
UE-25b#1	1162623	365108	1200.6	1220	Bullfrog-CFT	863-875	730.3	07/20/82	2
UE-25c#1	1162542	364947	1130.4	914	Bullfrog/Tram-CFT		728.4	09/30/83	2
UE-25c#2	1162540	364944	1133.0	913	Bullfrog-CFT			03/13/84	2
UE-25c#3	1162545	364945	1133.0	913	Bullfrog/Tram-CFT			05/09/84	2
UE-25p#1 (v)	1162521	364938	1114.0	1805	Rhy-Calico H-CFT-LRT	381-1197	729.9	02/09/83	2
UE-25p#1 (c)	1162521	364938	1114.0	1805	Silurian-Lone Mtn-Rbt Mtn	1297-1805	751.0	05/12/83	2
UE-25 WTH4	1162608	365150	1167.1	482	Tuff of Calico Hills	474-477	728.2	11/01/83	16
UE-25 WTH12	1162626	364700	1074.6	399	Tuff of Calico Hills	382-388	729.2	10/31/83	16
UE-25 WTH14	1162443	365029	1076.1	399	Tuff of Calico Hills	393-397	729.9	11/07/83	16
UE-25 WTH15	1162343	365120	1082.8	415	Topopah Spg-PBT	403-407	728.6	12/01/83	16
UE-25 WTH17	1162635	364820	1124.5	443		composite	729.9	11/07/83	16
UE-29a#2	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	822-1220	732.4	03/14/84	2
USW H-4	1162654	365032	1248.6	1230	Bullfrog/Tram-CFT	569-1219	730.7	05/17/82	2
USW H-5	1162755	365122	1478.5	1220	Bullfrog/Tram-CFT		774.7	07/26/82	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 WH-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-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-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-23bdb	24.0	7.30	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	Date (m/d/y)	EC (field) (umhos/cm)	EC (lab) (umhos/cm)	F	NO3	PO4	Fe (mg / l)	Li	Sr	Source **
AMARGOSA DESERT										
RM 101 Amargosa	03/30/73	339		.80	.11		.050			4
Ash Tree Spg	03/06/74			2.30	1.50			.060	.210	1
15S/49E-22dc	11/20/72			.90	1.40	.03		.040	.080	1
16S/49E-5acc	03/03/74			1.00	1.70	.18		.040	.040	1
16S/49E-8abb	11/17/72			.70	1.50			.040	.080	1
16S/49E-8acc	04/01/71			.80	6.60			.040	.080	1
16S/49E-9cda	11/18/72			.90	1.70	.03		.040	.200	1
16S/49E-9dcc	03/01/74				1.70	.21		.040	.110	1
16S/49E-18dc	03/01/74			1.20	1.50	.15		.040	.070	1
16S/49E-16ccc	06/26/79									1
16S/49E-19daa	03/05/74			1.00	1.60	.21		.040	.060	1
16S/48E-24aaa	11/15/72			1.50	1.60	.06		.080	.080	1
16S/48E-25aa	03/05/74			1.30	1.70	.21		.050	.080	1
16S/48E-36aaa	03/04/74			1.60	1.60	.25		.040	.060	1
17S/48E-lab	03/05/74			1.70	1.50	.25		.050	.080	1
17S/49E-7bb	03/01/74			1.70	1.50	.25		.060	.100	1
17S/49E-9aa	03/01/74			1.20	1.60	.21		.050	.130	1
17S/49E-8ddb	03/06/74			1.40	1.50	.25		.050	.090	1
17S/49E-15bbd	03/06/74			1.40	1.60	.21		.040	.100	1
16S/49E-23add	06/25/79									1
16S/48E-15dda	06/26/79									1
16S/48E-15aaa	03/31/71			2.00	6.00			.060	.060	1
16S/48E-23bdb	08/19/62			2.00	3.10			.060	1.800	1
16S/48E-10cba	03/31/71			1.90	4.50			.060	.080	1
16S/48E-36dcc	04/05/76			2.80	9.10			.140	.460	1
16S/50E-7bcd	04/01/74			4.50				.200	.890	1
16S/49E-12ddd	06/26/79									1
16S/49E-15aaa	03/31/71			.80	.50			.060	.350	1
16S/49E-36aaa	06/24/79									1
16S/49E-36aba	06/24/79									1
16S/49E-35aaa	06/24/79									1
16S/49E-35baa	06/24/79									1
15S/50E-18cdc	12/15/68			2.10	.86	.03		.090	.080	1
15S/50E-18ccc	04/17/72			2.90	.10	.12		.140	.760	1
17S/49E-11ba	03/07/74									1
16S/48E-15ba	06/24/71									1
17S/49E-15bc	02/17/66									1
17S/49E-28bcd	06/23/79									1
18S/49E-1aba	04/06/71									1
18S/49E-2cbc	11/18/72			3.70	.35	.03		.130	.590	1

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
185/49E-11bbb	25.0	7.56		78.0	34.1	8.5	99.1	11.7		224.0	30.0	90.2
185/50E-6dac		8.22		80.4	23.6	11.9	102.5	13.7		169.0	20.0	106.5
175/49E-29acc	21.0	7.60		72.0	54.1	15.1	160.1	19.9		276.0	68.0	186.2
165/48E-8ba	25.0	7.90		37.8	58.5	6.3	180.5	12.9		296.0	77.6	202.6
165/48E-7bba	24.7	7.40	7.90	69.0	53.0	9.5	140.1	10.1		251.0	61.4	179.5
165/48E-7cbc	24.2	7.70	7.80	64.2	47.0	16.0	130.2	9.4		239.0	60.4	179.5
165/48E-18bcc		7.98		64.2	55.0	10.9	150.7	11.7		239.0	59.3	190.1
165/48E-17ccc		7.69	7.70	77.4	66.2	10.9	170.0	12.1		239.0	80.7	235.0
165/48E-18dad		7.69		16.8	53.0	8.5	150.0	10.6		236.0	61.4	187.2
165/48E-8cda	23.3	7.60	7.90	67.8	48.1	6.8	154.0	10.1		264.0	65.2	179.0
165/48E-17abb	24.0		7.40	75.0	60.1	7.8	157.0	12.1		302.0	67.3	178.0
165/48E-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
175/50E-19aab	16.0	8.60		42.4	7.6	8.5	252.0	27.4		415.0	67.9	79.7
185/50E-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	33.0
King Spg	25.5	7.70	7.90	21.0	47.0	20.0	65.0	7.4		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		486.0	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) (μ mhos/cm)	EC (lab)	F	NO ₃	PO ₄ (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-7ba	03/30/71									1
16S/48E-7cbc	03/31/71			2.00	2.50			.160	.460	1
16S/48E-18bcc	06/24/79									1
16S/48E-17ccc	06/24/79									1
16S/48E-18dad	06/25/79			1.80	2.90					1
16S/48E-8cda	03/31/71									1
16S/48E-17abb	08/18/62			1.20	1.20			.200	.600	1
16S/18S/50E-7aa	02/17/66									1
27N/4E-27bbb	08/18/62			3.60	.20			.140	.600	1
17S/50E-19aab	12/27/71			1.30	.10			.710	.070	1
18S/50E-7aa	12/28/71									1
N.E.C. Well 1	12/16/68									1
Copeland	03/01/74	422		1.20	1.60		.080	.050		4
Devils Hole	10/21/64	686		1.40	.30		.042	.090	.890	13
Fairbanks Spg	10/27/64	686		2.20	9.99			.100	.760	13
Grapevine Spg	06/28/85	674		.20						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										
Amy-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		.20	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.MI		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	22.8	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	22.8	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	23.0	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	23.0
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
75/44E-28bcl		7.60			51.0	3.0	82.0	66.6		229.0	53.0	48.0
105/47E-30dl	14.4	8.10			27.0	4.9	105.0	66.6		278.0	48.0	14.0
105/47E-33al.a (spg)	23.8	8.00			24.0	0.1	127.0	66.6		275.0	65.0	14.0
105/47E-33al.b (spg)	24.0	8.10		38.0	14.0	0.7	196.0	2.3		330.0	52.3	108.5
115/45E-22bl (spg)		7.60			42.0	9.8	60.0	66.6		155.0	68.0	38.0
115/46E-26cal.a (spg)	15.5	7.90		52.0	8.0	1.0	62.0	2.0		131.0	16.0	22.0
115/46E-26cal.b (spg)	21.0	7.90		48.0	6.0	1.0	57.0	1.5		126.0	14.5	17.3
115/46E-26cbl.a (spg)	18.3	8.50			4.8	2.9	76.0	66.6		117.0	17.0	62.0
115/46E-26cbl.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) (umhos/cm)	EC (lab)	F	NO3	PO4 (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	03/23/71	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/4E-28bcl	03/07/62			2.70	6.00		.470	.240	.090	6
10S/47E-30dl	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-26chl. a (spg)	03/15/62	280		.20	8.50		.080			6
11S/46E-26chl. 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	SO ₄
11S/46E-26dcl (spg)	18.3	8.20			8.0	3.9	64.0	66.6		139.0	18.0	24.0
11S/47E-4bb1 (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	24.0	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		287.0	45.8	126.7
11S/47E-18aal.a (spg)	20.5	8.10			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	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-5cal.a (spg)	24.4	8.20		68.0	14.0	1.9	106.0	5.8		194.0	27.0	69.0
12S/47E-5cal.b (spg)	24.0	7.90		54.0	32.1	4.4	106.0	7.4		196.0	36.8	93.1
12S/47E-20bb1.a (spg)	17.8	8.10			32.0	4.9	184.0	66.6		400.0	86.0	48.0
12S/47E-20bb1.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	89.0	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)	18.5	7.60		51.0	14.0	0.5	156.0	7.0		292.0	40.6	91.2
11S/47E-21dbb	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		233.0	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 (mg / l)	Li	Sr	Source **
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-10bec (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	.260	.260	7
11S/47E-21aba (spg)	07/03/67			6.10	.10		.010	.250	.120	7
10S/47E-27cba	07/03/67			18.80	.10		.010	.190	.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
----- PAUTE MESA -----												
10S/47E-31aab (spg)	19.5	7.60		71.0	23.2	4.4	100.0	7.8		228.0	40.6	52.8
10S/47E-32ada (spg)	22.0	7.60		62.0	30.1	5.3	137.0			310.0	35.8	96.0
10S/47E-33aab (spg)	22.0	7.80		54.0	30.1	4.6	169.0	9.0		296.0	66.1	102.7
10S/47E-30dec	22.5	7.80		72.0	24.0	4.6	100.0	7.8		231.0	38.9	58.6
----- YUCCA MOUNTAIN -----												
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	63.0
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	43.0
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	24.0
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	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	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 (mg / l)	Fe	Li	Sr	Source **
PAHUTE MESA										
105/47E-31aab (spg)	07/03/67			2.40	1.20		.011	.080	.179	7
105/47E-32dda (spg)	07/03/67			2.30			.010	.110	.380	7
105/47E-33aab (spg)	07/03/67			4.30	.20		.018	.110	.190	7
105/47E-30dcc	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	.090	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		.130	9
Ue20e-1.a	06/05/64	515		4.60	1.00		.130			9
Ue20e-1.b	03/08/66	352		4.50	.50		.020	.070	.030	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				.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-25b#1.a	08/07/81	318	319	1.50	.91			.950	.044	2
UE-25b#1.b	09/01/81	281	281	1.60				.220	.038	2
UE-25b#1.c	07/20/82	291	297	1.60				.120	.047	2
UE-25c#1	09/30/83	290	310	2.10	1.10			.120	.030	2
UE-25c#2	03/13/84	295	303	2.10	2.10			.094	.045	2
UE-25c#3	05/09/84	298	309	2.00	1.30			.110	.044	2
UE-25p#1 (vol)	02/09/83	628	639	3.40				.230	.180	2
UE-25p#1 (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	183.0	7.8	33.6

TABLE II
CHEMISTRY OF WELLS AND SPRINGS SURROUNDING YUCCA MOUNTAIN

Site Name	Date (m/d/y)	EC (field) (umhos/cm)	EC (lab)	F	NO3	PO4 (mg / l)	Fe	Li	Sr	Source **
UE-25 WT#4	04/13/88	346	0					.080		18
UE-25 WT#12	04/28/88	365	347		4.56			.080		18
UE-25 WT#14	03/26/88	256	251		1.86			.050		18
UE-25 WT#15	04/23/88	347	344		.03			.550		18
UE-29a#2.a	01/08/82	240	255	1.00				.100	.450	2
UE-29a#2.b	01/15/82	258	317	.90	9.70			.110	.033	2
USW G-4	12/09/82	312	307	2.50				.067	.017	2
USW H-1.a	10/20/80	255	258	1.20	.10			.040	.005	2
USW H-1.b	12/08/80	247	266	1.00				.040	.020	2
USW H-3	03/14/84	523	535	5.50				.220	.001	2
USW H-4	05/17/82	340	381	4.60				.130	.027	2
USW H-5.a	07/03/82	275	273	1.40				.082	.009	2
USW H-5.b	07/26/82	278	276	1.40				.071	.004	2
USW H-6.a	10/16/82	372	392	4.70		.06		.082	.008	2
USW H-6.b	06/20/84	360		3.90				.071	.003	2
USW H-6.c	07/06/84	402	408	4.70		.18		.062	.008	2
USW VH-1.a	02/06/81	370	410	2.70				.090	.070	2
USW VH-1.b	02/08/81	395	397	2.70				.090	.070	2
USW VH-1.c	02/11/81	388	402	2.70				.090	.060	2
USW WT-7	06/04/88	422	413		0.04			.080		18
USW 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 **
AMARGOSA DESERT								
AM 101 Amargosa	03/30/73			200.0				4
Ash Tree Spg	03/06/74	-12.4	-102.0			15,900	13.8	1
16S/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/48E-25aa	03/05/74	-13.0	-102.0			13,200	19.3	1
16S/48E-36aaa	03/04/74	-12.6	- 98.5					1
17S/48E-1ab	03/05/74	-13.0	-104.0			13,600	18.4	1
17S/49E-7bb	03/01/74	-12.7	-104.0			18,500	10.0	1
17S/49E-9aa	03/01/74	-12.8	-105.0			13,400	18.9	1
17S/49E-8ddb	03/06/74	-13.0	-102.0			10,300	27.8	1
17S/49E-15bbd	03/06/74				- 8.4	7,300	40.3	1
16S/49E-23add	06/25/79	-13.2	- 99.0			10,400	27.4	1
16S/48E-15dda	06/26/79	-13.4	-103.0					1
16S/48E-15aaa	03/31/71	-13.4	-103.0		- 7.1	14,200	17.1	1
16S/48E-10cba	03/31/71	-13.4	-102.0		- 5.6	14,900	15.6	1
16S/50E-7bcd	08/18/62	-13.8	-105.0		- 3.6	21,400	7.0	1
16S/49E-15aaa	03/31/71	-13.8	-105.0		- 3.4			1
16S/49E-36aaa	06/24/79	-13.7	-104.0		- 4.4	18,300	10.3	1
16S/48E-7cbc	03/31/71	-13.1	-102.0		- 6.2	9,300	31.4	1
16S/48E-18dad	06/25/79	-13.6	-104.0		- 5.7			1
N.E.C. Well 1	12/16/68		-112.0		- 5.9	10,000	28.8	1
Copeland	03/01/74			23.1				4
Crystal Pool	05/24/73	-13.7	-102.0	.6	- 5.0	17,300	11.6	14
Devils Hole	12/14/74	-13.6		.3	- 5.0	28,700	2.8	14
Fairbanks Spg	05/23/73	-13.6	-103.0	.4	- 4.9	31,800	1.8	14
Jacobs East	03/01/74			15.9				4
King Spg	08/20/82	-13.6	-102.0	6.3	- 4.1	24,500	1.7	4
Longstreet Spg	06/02/75		-103.0	.2	- 4.8	29,000	2.7	14
Supply	03/04/74			16.9				4
NEVADA TEST SITE								
Army-1	06/21/82	-13.1	- 99.0			28,700		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			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 Modern Carbon	Source
UE-16F	09/25/77	-14.9	-105.0	43.0	- 8.9	23,823		12
USGS A	06/22/82	-13.0	-107.0	<2.0		14,800		12
Well 5B.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-16dcl (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-6cdd		-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-3laab (spg)		-13.4	-102.0		- 5.3		97.8	5
10S/47E-32dda (spg)		-13.4	-102.0		- 6.0			5
10S/47E-33aab (spg)		-14.0	-108.0		- 4.9		100.0	5
10S/47E-30dcc (spg)		-13.4	-102.0		- 5.2	3,900	35.0	5
PAHUTE MESA								
U20a-2		-14.7	-114.0		-13.5	15,100	15.3	5
UE19c	06/23/82	-14.1	-109.0	< 2.0	-11.6	21,757		12
UE19e	06/??/85	-14.0	-110.0					11
UE19gs		-14.5	-113.0					5
UE19i		-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-25b#1.a	08/07/81	-13.4	- 99.5		-10.7			2
UE-25b#1.b	09/01/81	-13.4	-101.0	< 62.5	-10.4	14,100	16.7	2
UE-25b#1.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-25c#1	09/30/83	-13.5	-102.0	.3	-7.1		15.0	2
UE-25c#2	03/13/84	-13.4	-100.0	.6	-7.0		16.6	2
UE-25c#3	05/09/84	-13.5	-103.0	.6	-7.5		15.7	2
UE-25p#1 (vol)	02/09/83	-13.5	-106.0	< 3.1	-4.2		3.5	2
UE-25p#1 (carb)	05/12/83	-13.8	-106.0	3.1	-2.3		2.3	2
UE-25 WTH#12	04/28/88	-13.7	-101.0		-7.7		11.4	18
UE-25 WTH#14	03/26/88	-12.3	-96.0		-12.7		24.1	18
UE-25 WTH#15	04/23/88	-12.9	-97.0		-11.8		21.6	18
UE-29a#2.a	01/08/82	-12.8	-93.5	11.6	-13.0	2,000	62.3	2
UE-29a#2.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	-103.0	< 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 VH-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

GROUND-WATER SAMPLING OF THE
NNWSI WATER TABLE TEST WELLS
SURROUNDING YUCCA MOUNTAIN,
NEVADA

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

NWPO-TR-

GROUND-WATER SAMPLING OF THE
NNWSI WATER TABLE TEST WELLS
SURROUNDING YUCCA MOUNTAIN,
NEVADA

by:

Nancy A. Matuska
Water Resources Center
Desert Research Institute
University of Nevada System

December, 1988

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.

This study was funded by DOE grant number DE-FG08-85-NV-10461.

INTRODUCTION

The U.S. Geological Survey (USGS), as part of the Nevada Nuclear Waste Storage Investigation (NNWSI) study of the water table in the vicinity of Yucca Mountain, completed sixteen test holes on the Nevada Test Site and Bureau of Land Management lands surrounding Yucca Mountain. These sixteen wells are monitored by the USGS for water-level data; however, they had not been sampled for ground-water chemistry or isotopic composition. As part of the review of the proposed Yucca Mountain high-level nuclear waste repository, the Desert Research Institute (DRI) sampled six of these wells. The goal of this sampling program was to measure field-dependant parameters of the water such as pH, temperature and dissolved oxygen, and to collect samples for major and minor element chemistry and isotopic analysis. This information will be used as part of a program to geochemically model the flow direction between the volcanic tuff aquifers and the underlying regional carbonate aquifer.

WELL DESCRIPTIONS

The NNWSI water-table test wells are located to the east and south in the basins surrounding the Yucca Mountain block. Figure 1 shows the locations of the wells.

The wells are completed in Tertiary ash-flow and bedded tuffs which erupted eight to sixteen million years ago from the Timber Mountain and other older calderas to the north and west. The predominant sequence for the members of the volcanic formations present at Yucca Mountain are multiple ash-flow sheets which 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

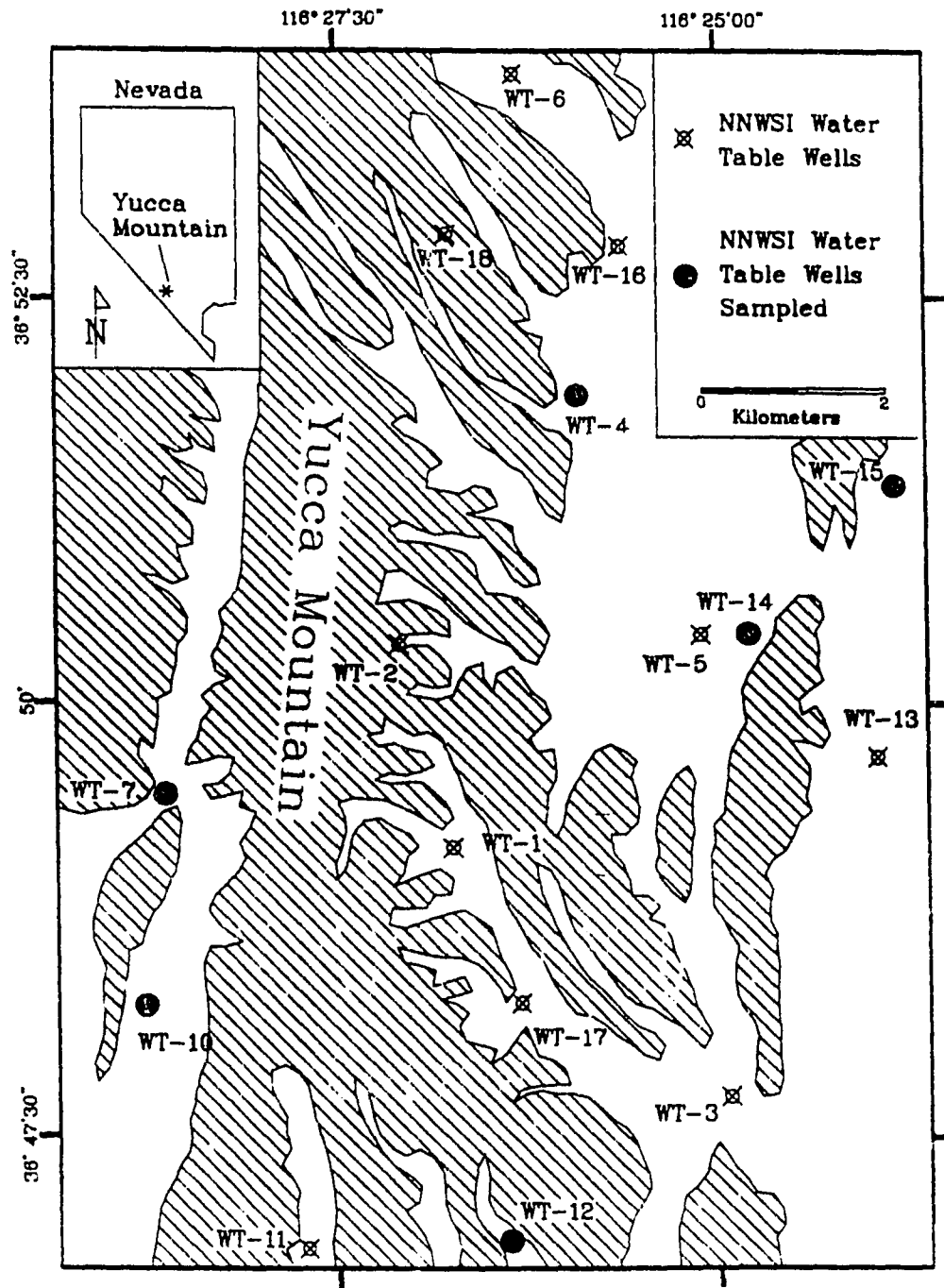


Figure 1: Location of NNWSI Water Table test wells on Yucca Mountain, southern Nevada

TABLE 1
NNWSI WATER TABLE TEST WELLS

Well Name	Longitude	Latitude	Elevation* (m)	Total Depth (m)
UE-25 WT-4	116° 26'08"	36/51/50	1167.1	482
USW WT-7	116° 29'05"	36/49/47	1197.0	491
USW WT-10	116° 29'09"	36/48/21	1123.2	430
UE-25 WT-12	116° 23'26"	36/47/00	1074.6	399
UE-25 WT-14	116° 24'43"	36/50/29	1076.1	399
UE-25 WT-15	116° 23'43"	36/51/20	1082.8	415

* meters above mean sea level

TABLE 2
HYDROLOGY OF WATER-TABLE WELLS

Well Name	Producing Unit	Screened Interval (m)	Hydraulic Head* (m)	Date (m/d/y)
UE-25 WT-4	Tuff of Calico Hills	474-477	728.3	4/11/88
USW WT-7	Topopah Spg/Calico H.	477-481	775.3	6/03/88
USW WT-10	Topopah Spring	399-403	775.9	5/09/88
UE-25 WT-12	Tuff of Calico Hills	382-388	729.2	4/25/88
UE-25 WT-14	Tuff of Calico Hills	393-397	730.0	3/22/88
UE-25 WT-15	Topopah Spring	403-407	728.6	4/18/88

* meters above mean sea level

devitrified, and may have vapor phase crystallization. Diagenetic alteration is best developed in the groundmass and phenocrysts in the nonwelded zones and in fractures of the welded zones, and consists of zeolites, smectites and authigenic feldspars.

The principal aquifers that the wells penetrate are the unconfined tuffaceous aquifers in the Topopah Spring member of the Miocene Paintbrush Tuff, and underlying Crater Flat Tuff. The Topopah Spring member is generally welded and transmits water along fractures, while the Crater Flat Tuff is nonwelded, zeolitic and transmits water by matrix flow.

The sixteen test holes were drilled in 1983 to depths of between 348 meters and 628 meters using conventional rotary methods. A LiBr tracer was added to the air-foam. The boreholes are 22.2 cm in diameter at depth and are cased with steel casing (O.D. 7.3 cm) that is screened over the last four meters.

USGS water-level monitoring transducers were installed in six of the water-table test wells which prevented sampling, and four others were unsuitable for study because they were dry or too deep for proposed sampling methods. Table 1 lists the locations of the six sampled wells, while Table 2 gives their lithologies and hydrologic units.

EQUIPMENT

The pump used for this sampling program was a submersible double-piston type (model 1800-5) manufactured by the Robert Bennett Co. of Amarillo, Texas. The pump was designed to fit inside a five centimeter well casing and has a lift of 460 meters. At this depth, the pump can maintain a flow rate of 1.4 to 1.9 liters per minute (l/m). The pistons are driven by compressed air supplied by an Ingersoll-Rand air compressor; however, no air contacts the sample in the tubing, thus preserving its integrity. The pump, tubing reel and air compressor

are all mounted on a trailer for mobility.

The down-hole logger and chemical sonde used for chemically logging the well for temperature (T) and electrical conductivity (E.C.) were designed by the Desert Research Institute. The sonde 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.

GENERAL SAMPLING PROCEDURES

Ground-water sampling from the NNWSI water-table wells followed the quality assurance sampling program: "Technical Procedure for Ground-water Sampling and Hydrogeologic Data Acquisition, DTP-3.5", which was prepared by the Desert Research Institute. This document contains instructions on collecting ground-water samples, the preparation of the samples for laboratory analysis, as well as the field measurement of unstable parameters.

Prior to sampling, the USGS measured water levels in the wells using steel tape and NaCl crystals. After the USGS water-level measurements, the well was logged with the DRI chemical sonde. This served several purposes: 1) to insure that the well-bore was open and free of obstructions; 2) to determine water table levels; and, 3) to record temperature and electrical conductivity changes within the well.

The pump was then put into place and purging began. Samples were collected from the initial waters for tritium, LiBr and methylene blue active (MBA). Samples for chemical and isotopic analysis (except carbon-14) were also collected

from the initial waters from wells USW WT-10 and UE-25 WT-12. Purging the wells generally required several days of pumping, during which time field parameters such as pH, temperature, E.C., alkalinity and flow rate were measured every four to six hours.

After three well volumes were purged, and the field parameters had stabilized for three successive readings taken 15 minutes apart, samples for chemical and isotopic analyses were collected. Chemical analysis was performed for major ion chemistry (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , HCO_3^-) plus laboratory analysis for alkalinity, SiO_2 , MBA and the LiBr tracer. Isotopic samples were collected for tritium, $\delta^{18}\text{O}$, δD , $\delta^{13}\text{C}$ and carbon-14 analysis. The chemical and isotopic samples, except those for carbon-14, were randomly split with the USGS supervisor on site. The USGS collected their own carbon-14 samples. Quality assurance requirements were met through collection of blanks, duplicates and standards and maintenance of the prescribed chain-of-custody records.

SPECIFIC WELL SAMPLING PROCEDURES

WELL UE-25 WT-14

Well UE-25 WT-14 is located on the east side of Yucca Mountain and was sampled March 21 - 26, 1988. The lithology of the screened interval, 381-397 m, consists of ash-flow nonwelded, zeolitic tuff (Richard Spengler - USGS, written communication, May, 1988). Depth to water was 346 m and total depth of the well is 400 m. One well volume was calculated to be 2420 liters.

The well was logged for temperature and E.C. with the deep downhole logger on the morning of March 22, 1988. Temperature varied only slightly from 31.5°C at the water table to 30.0°C at the bottom of the well. Electrical

conductivity varied greatly, from 1470 $\mu\text{mhos/cm}$ at the water table to 400 $\mu\text{mhos/cm}$ at the bottom of the well. This great difference was attributed to the USGS practice of using NaCl crystals on their water-level steel measuring tapes.

The pump was lowered to a depth of 393.5 m (0.6 m within screened interval) and purging started. Samples were taken from the initial waters for tritium and LiBr analyses. Purging of the well (three well volumes) took approximately 72 hours, from 3/22 to 3/25. Field parameters- T, E.C., pH and flow rate- were measured every 4-6 hours, and remained fairly stable throughout purging time. Electrical conductivity ranged from 250 to 270 μmhos while pH ranged from 7.05 to 7.20. Temperature values measured at the well head had a diurnal cycle, with peak temperatures of 28 °C during the daytime, lower than the value found in logging the well. This was probably caused by the ambient air temperature as the water traveled through the 460 m of tubing. Flow rate increased from 1.4 l/m at the beginning of the purge, to an average of 1.8 l/m throughout. Water clarity changed from green and foamy initially to slightly cloudy with foam present when shaken.

Sample collection started the evening of March 25. Three carboys (50 liters) were filled for carbon-14 analysis. The USGS then left a 55 gallon drum to fill overnight for their carbon-14 sample. Samples for gross chemistry and isotope analyses were collected the following morning on March 26. Water chemistry at time of sampling was as follows: pH = 7.27, E.C. = 255 $\mu\text{mho/cm}$, D.O. = 2.1 mg/l and $\text{HCO}_3 = 119$ mg/l. Samples were labeled and taken to the appropriate laboratories following the prescribed chain of custody. Total volume of water pumped from the well was 9180 liters. The pump was pulled from well by hand until 230 m, at which point the winch motor was able to lift it the remainder of the way.

Well UE-25 WT-4

This well is located to the northeast of Yucca Mountain and was sampled April 11-15, 1988. The well has a total depth of 482 m, is screened between 475-478 m, and has a well volume of 2170 liters. The lithology around the screened interval consists of lava and rhyolite which is devitrified and slightly zeolitic from 457 to 460 m, and nonwelded, zeolitic tuff from 460 to 482 m (Richard Spengler - USGS, written communication, May 1988).

The water table was located by DRI's chemistry sonde at 438.3 m. Electrical conductivity decreased from 3810 $\mu\text{mho/cm}$ at water table surface to 740 $\mu\text{mho/cm}$ at 470 m. The pump was lowered to a depth of 448.6 m, approximately its maximum depth capability, but still 25 m above the screened interval.

Pumping was started at a flow rate of 1.2 l/m. LiBr, MBA and tritium samples were collected from initial waters. After the well was pumped for only three hours, the water level fell below the pump. The water level recovered to its original level within an hour and pumping resumed. However, again the water level fell below the pump. This cycle of pumping, running dry and recovery continued over the next three days. After 40 liters of well water was poured down the well a maximum pumping interval of ten hours occurred; subsequent pumping intervals decreased rapidly to less than one hour durations before water levels were below the pump. Drawdown and recovery tests were performed to verify water levels.

On Thursday April 14, the intake screen became clogged, after only 3030 liters were pumped. The pump was then removed and no final water samples could be collected. The water was still foamy and very cloudy; the flow buckets were stained with rust and contained black sediment. Final water chemistry taken showed a $\text{pH} = 7.61$, $\text{E.C.} = 345 \mu\text{mho/cm}$ and $\text{HCO}_3 = 140 \text{ mg/l}$. However, these chemistry parameters had still not stabilized during the purging.

Two hypothesis proposed for the quick drawdown and slow recovery of the water in this well are:

- 1) The well screen became clogged, in which case the well should be jetted with air or nitrogen to clean the screen.
- 2) The permeability of the rock may be controlled by fractures which were dewatered during the ten hour pumping interval and did not recover. The rock units affected by the well screen are a nonwelded zeolitized tuff (Tuff of the Calico Hills) and a moderately to fully welded tuff (Topopah Spring) which is fractured.

Well UE-25 WT-15

This well is located just west of Fortymile Wash and to the northeast of Yucca Mountain and was sampled on April 18 - 23, 1988. The well is 414.5 m deep and has a screened interval between 403 and 407 m. The lithology around the screened interval is a densely welded, devitrified (slightly argillic or zeolitic) ash-flow tuff from 396 to 414.5 m (Richard Spengler - USGS, written communication May 1988). One well volume was calculated to be 2990 liters. Temperature and electrical conductivity measurements with the downhole logger showed that values were 27.8 °C and 1150 $\mu\text{mho}/\text{cm}$ at water level and 28.6 °C and 485 $\mu\text{mho}/\text{cm}$ at 405 m. The pump was installed and lowered to 404 m, approximately 0.6 m into the screened interval. LiBr, MBA and tritium samples were collected from the initial water.

Temperature, E.C. and pH were measured every four to six hours; which remained fairly stable throughout the purge time. However, as observed before, the temperature values produced a diurnal cycle. There were no problems with the pump or air compressor, and three well volume were purged by 4/22/1988,

with an average pump rate of 1.66 l/m. The water quality at the end of purging was slightly foamy, especially if shaken, and exhibited a slight cloudiness. The water also had a distinct odor indicating anaerobic conditions. Samples for carbon-14 analysis were collected 4/22/1988, and samples for gross chemistry and isotopic analyses were collected the following morning. The pH at time of sampling was 7.5, while E.C. = 350 $\mu\text{mho}/\text{cm}$, D.O. = 0.15 mg/l and $\text{HCO}_3 = 166$ mg/l. Total water volume pumped from well was 10,800 liters. The pump had black silty material clogging the screen and was coated with a green organic matter when pulled from the well.

Well UE-25 WT-12

This well is located at the southern base of Yucca Mountain and was sampled on April 25 - 29, 1988. The well is 398.7 m deep and is screened between 385 - 389 m. The water table is at 345 m below ground surface. Lithology around the screened interval, consists of partially to nonwelded zeolitic (partially vitric) ash-flow tuff from 361 m to 381 m, ash-fall tuff dominantly composed of zeolitic (some vitric) pumice clasts from 381 m to 387 m and nonwelded, zeolitic ash-flow tuff from 387 m to 396 m (Richard Spengler - USGS, written communication May 1988). One well volume was calculated to be 2270 liters.

The well was logged for E.C. and temperature which ranged from 920 $\mu\text{mhos}/\text{cm}$ and 33.1 °C at the water surface to 310 $\mu\text{mhos}/\text{cm}$ and 35.0 °C at 387 m. The pump was installed at 384 m, which was within the screened interval. A complete suite of samples for chemical and isotope analysis (except carbon-14), was collected from the initial water. The water was fairly clear, with very little foam present. This may be due, in part, to the air-jetting the USGS performed on this well at 358 m during its construction in 1983.

Three well volumes were purged by April 28 with a pumping rate of 1.8 l/m. At the end of purging the water was clear and no foam was present. Chemical parameters changed very little during purging. Samples for gross chemical and isotopic analyses were collected the afternoon of 4/28/1988, and carbon-14 analysis was collected that evening. The pH of the water at time of sampling was 7.58, the E.C. = 365 $\mu\text{mho/cm}$, D.O. = 1.7 mg/l and $\text{HCO}_3 = 167$ mg/l. A total of 9460 liters were pumped from the well.

Well USW WT-10

Well USW WT-10 is located at the southern end of Yucca Mountain, at the mouth of Solitario Canyon, and was sampled on May 9 - 16, 1988. Total depth of the well is 430 m. The water table was located at 347.5 m below land surface, and one well volume was calculated to be 5260 liters. Lithology of the screened interval is densely welded, devitrified ash-flow tuff which lies between 381 to 411 m (Richard Spengler - USGS, written communication, May 1988).

The well was logged with the downhole chemistry sonde for temperature and electrical conductivity, which ranged from 39.1 °C and 1110 $\mu\text{mho/cm}$ at water table to 39.1 °C and 310 $\mu\text{mho/cm}$ at 399 meters. The pump was lowered into place at 400 m and the well was purged. Samples for a complete chemical and isotopic suite (except for carbon-14) was collected from the initial water. The water was dark grey/green with a slight oil slick on top. No foam was present, but the water contained black sediment and had a foul anaerobic odor.

After seven days, three well volumes, approximately 17,200 liters, were purged at an average flow rate of 1.7 to 1.8 l/m. Water samples were collected for gross chemistry and isotope analyses. Water chemistry at time of sampling was pH = 8.28, E.C. = 415 $\mu\text{mho/cm}$, D.O. = 2.7 mg/l and $\text{HCO}_3 = 202$ mg/l. At the end of purging, water clarity had changed to having no foam or

odor, and was fairly clear.

Well USW WT-7

Well USW WT-7, located at the mouth of Solitario Canyon at the southwestern edge of Yucca Mountain, was sampled between June 3-5, 1988. The well is 490.7 m deep, with a water table at 421.5 m from the surface and a screened interval between 477 - 481 m. One well volume was calculated to be 3260 liters. The lithology between 426 - 457 m is nonwelded, vitric (slightly silicified ?) ash-flow tuff from 426 to 433 m; ash-fall tuff composed of argillic and zeolitic pumice clasts from 433 to 438 m; and nonwelded zeolitic ash-flow tuffs from 438 to 466 m (Richard Spengler - USGS, written communication, May 1988).

The well was logged with the DRI downhole chemical sonde. The E.C. at the water table, 421.4 m, was only about 300 $\mu\text{mho/cm}$. This was in sharp contrast to the E.C. values at the water table in previous wells which were usually over 1000 $\mu\text{mho/cm}$ immediately after the USGS had taken a water level measurement using steel tape and NaCl crystals. A complete logging of the well was impossible because an obstruction was reached at approximately 431 m. Since the sonde was unable to pass this obstruction, the logging was ceased. When removed, the chemical sonde had a rusty smudge along the edge of one side, indicating an encounter with a break or shear in the casing. Due to the anomalously low E.C. values, the obstruction and the rust smudge on the sonde, it is believed that the casing has a shear at approximately 431 m.

The pump was lowered down the well to a depth of 428 m, just above the obstruction, and pumping began. The first water was slightly cloudy and produced foam and some rust-brown sedimentation. Samples for LiBr, MBA and tritium analysis were collected from the initial water. After only a few hours of

pumping, the water table fell below the pump. The pump was shut off and the well was allowed to recover for an hour and a half. Pumping was then resumed and the well produced water for approximately another hour before the water table again fell below the pump. The pump was shut off and the well was allowed to recover overnight.

The next day, June 4, the well was pumped again, with the same results. As it appeared fruitless to try to purge three well volumes from this well, samples were taken at this time. Due to extremely high winds and blowing dust, two five-gallon cubitainers were filled at the pump and aliquots were taken for chemical and isotopic analysis, except for carbon-14, inside the trailer from this water. Field measurements at the time of collection was $\text{pH} = 8.70$, $\text{E.C.} = 420 \mu\text{mho/cm}$, and $\text{HCO}_3 = 252 \text{ mg/l}$. Unfortunately, less than one well volume was pumped.

CHEMICAL AND ISOTOPIC RESULTS

Samples for chemical and isotopic analysis were collected from four of the wells after successfully purging three well volumes. Unfortunately, the other two wells could not maintain sufficient discharge to allow three complete well volumes to be purged, and only USW WT-7 was sampled. Samples collected from the five wells were randomly split between DRI and the USGS and analyzed by their respective laboratories. In addition, samples were collected from the initial water produced in wells USW WT-10 and UE-25 WT-12. Table 3 lists all of the chemical analyses from the wells.

Field measurements of pH, E.C., temperature and alkalinity followed general trends. Electrical conductivity was anomalously high at the water table,

TABLE 3
CHEMISTRY OF WATER TABLE WELLS

Well	Date (m/d/y)	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺ (mg / l)	SiO ₂	Cl ⁻	SO ₄ ²⁻	NO ₃ ²⁻
USW WT-4 ¹	4/11/88	-	-	-	-	-	-	-	-
USW WT-7 ¹	6/4/88	96.6	2.07	2.63	0.18	20	12.5	7.2	<0.04
USW WT-10 ¹	5/9/88	94.3	1.18	2.49	0.12	38	17.9	29.6	2.61
USW WT-10 ²	5/16/88	93.8	1.14	2.72	0.07	47	7.8	33.6	4.25
UE-25 WT-12 ¹	4/25/88	67.2	2.15	11.70	0.25	33	14.7	14.1	0.04
UE-25 WT-12 ²	4/28/88	65.7	2.33	14.10	0.04	47	7.3	26.1	4.56
UE-25 WT-12 ³	4/28/88	66.0	2.60	15.00	0.30	47	7.9	28.0	-
UE-25 WT-14 ²	3/26/88	42.4	5.54	9.23	0.79	58	7.5	18.6	1.86
UE-25 WT-14 ³	3/26/88	45.0	5.00	10.00	0.80	57	8.2	22.0	-
UE-25 WT-15 ²	4/23/88	61.8	4.6	11.60	1.71	53	11.5	16.1	<0.04

TABLE 3 continued...
CHEMISTRY OF WATER TABLE WELLS

Well	pH		E.C.		HCO_3^-		Li	Br	MBA
	field	lab	field	lab	field	lab			
			($\mu\text{mho}/\text{cm}$)		(mg / l)				
UE-25 WT-4 ¹	7.6	-	346	-	140	-	0.08	2.99	107.00
USW WT-7 ¹	8.7	8.1	422	413	252	228	0.15	0.35	30.20
USW WT-10 ¹	8.4	7.8	-	416	175	183	0.10	0.66	<0.02
USW WT-10 ²	8.3	8.4	416	407	202	183	0.09	0.41	<0.02
UE-25 WT-12 ¹	-	8.1	361	340	-	168	0.08	0.13	0.60
UE-25 WT-12 ²	7.6	8.0	365	347	167	163	0.07	0.09	<0.02
UE-25 WT-12 ³	7.6	7.8	365	358	167	166	0.07	0.01	<0.02
UE-25 WT-14 ²	7.3	7.3	256	251	119	116	0.05	0.45	-
UE-25 WT-14 ³	7.3	7.4	256	260	119	116	-	-	-
UE-25 WT-15 ²	7.5	7.6	347	344	252	228	0.39	0.05	14.00

¹ DRI analysis of initial water

² DRI split analysis after three well volumes purged.

³ USGS split analysis after three well volumes purged.

due to the use of NaCl crystals on the steel tape for water level measurements. However, at the screened interval E.C. decreased to approximately $300\mu\text{mhos/cm}$. Because of the long distance (460 m) the water traveled in the pump and tubing, water temperature measured at the well head reflected the ambient air temperature, rather than actual formation water temperature. Therefore, the temperature recorded during the downhole logging, about 30°C , is thought to be more representative of the true temperature. Water was slightly alkaline, with pH of 7.3 - 8.7, and alkalinity values of 140 - 250 mg/l.

Comparing the analyses of the first waters with those collected after three well volumes were purged, several trends in water chemistry may be noticed. The initial water samples are higher in Cl^- and Br^- and lower in SO_4^{2-} , NO_3^{2-} and SiO_2 than the later samples. The later samples are considered to be more representative of formation water. Assuming that these trends would be observed in water from well USW WT-7, which could not be successfully purged due to an obstruction in the casing, the final water after purging three well volumes may be inferred. Based on comparisons with USW WT-10 and UE-25 WT-12, the sample from USW WT-7 appears lower in NO_3^{2-} and SiO_2 , and higher in Cl^- than representative formation water. Concentrations of Na^+ , K^+ and Mg^{2+} may be fairly representative. In addition, the low E.C. found when logging the well indicates that this well had input of water into the well casing at the obstruction at 431 m. This water is most likely representative of the formation water. Unfortunately, samples could not be collected from UE-25 WT-4 due to purging problems discussed previously.

Chemically, the water from the WT wells is a NaHCO_3 type. There is a division of eastern (WT-12, WT-14, WT-15) wells and western (WT-7, WT-10) wells with respect to Ca^{2+} . Eastern wells have more Ca^{2+} , with $\text{Na}+\text{K}/\text{Ca}+\text{Mg}$ epm ratios of 3.8-4.0, compared to 28.0 in the western wells. This agrees well

with previous work on Yucca Mountain wells by Kerrisk (1987), who suggested calcite solubility and ion exchange in smectites and zeolites as the cause of this division.

Isotopic analyses are given in Table 4. This table is still incomplete, pending sample analysis, but some general trends are apparent. Most of the water table wells are similar in their hydrogen and oxygen isotope ratios to the isotopic values reported for other Yucca Mountain wells as shown in Figure 2, and plot below the meteoric water line. In contrast, water from wells UE-25 WT-14 and UE-25 WT-15 are more enriched in both δ deuterium and δ ^{18}O than most of the Yucca Mountain wells, and thus are similar to water from wells J-12, J-13 and UE-29a#2 in Forty Mile Wash.

Carbon-13 values range from -6.5 to -12.7, and are more enriched (> -8.1 ‰) in wells USW WT-7, USW WT-10 and UE-25 WT-12, than in the wells to the north (< -11.0).

Because of the similarity in chemical constituents and isotopic ratios between the initial and final water samples, and the generally low values of LiBr and MBA, it appears that most of the wells were fairly clean of drilling fluids prior to the purging. This indicates that there is ground-water flow through the wells. Flow through wells UE-25 Wt-15 and USW WT-10, which had an anaerobic odor and green coating on the pump during sampling, may not be as good as the other wells.

TABLE 4
ISOTOPIC ANALYSIS OF WATER TABLE WELLS

Well	Tritium (T.U.)	$\delta^{18}\text{O}$ ‰	δD ‰	$\delta^{13}\text{C}$ ‰	% Modern Carbon
UE-25 WT-4 ¹	-	-	-	-	-
USW WT-7 ¹	-	-13.7	-104	-	-
USW WT-10 ¹	-	-13.4	-104	-6.5	-
USW WT-10 ²	-	-13.7	-103	-6.6	-
UE-25 WT-12 ¹	-	-13.7	-101	-8.9	-
UE-25 WT-12 ²	-	-13.6	-102	-7.7	-
UE-25 WT-12 ³	0.96	-	-	-8.1	11.4
UE-25 WT-14 ²	-	-12.3	-96	-11.8	-
UE-25 WT-14 ³	0.96	-	-	-12.7	24.1
UE-25 WT-15 ²	-	-12.9	-97	-11.1	-
UE-25 WT-15 ³	1.3	-	-	-11.8	21.5

NOTE: Data with "-" = analysis not received from lab

¹ DRI analysis of initial water.

² DRI split analysis after three well volumes purged

³ USGS split analysis after three well volumes purged.

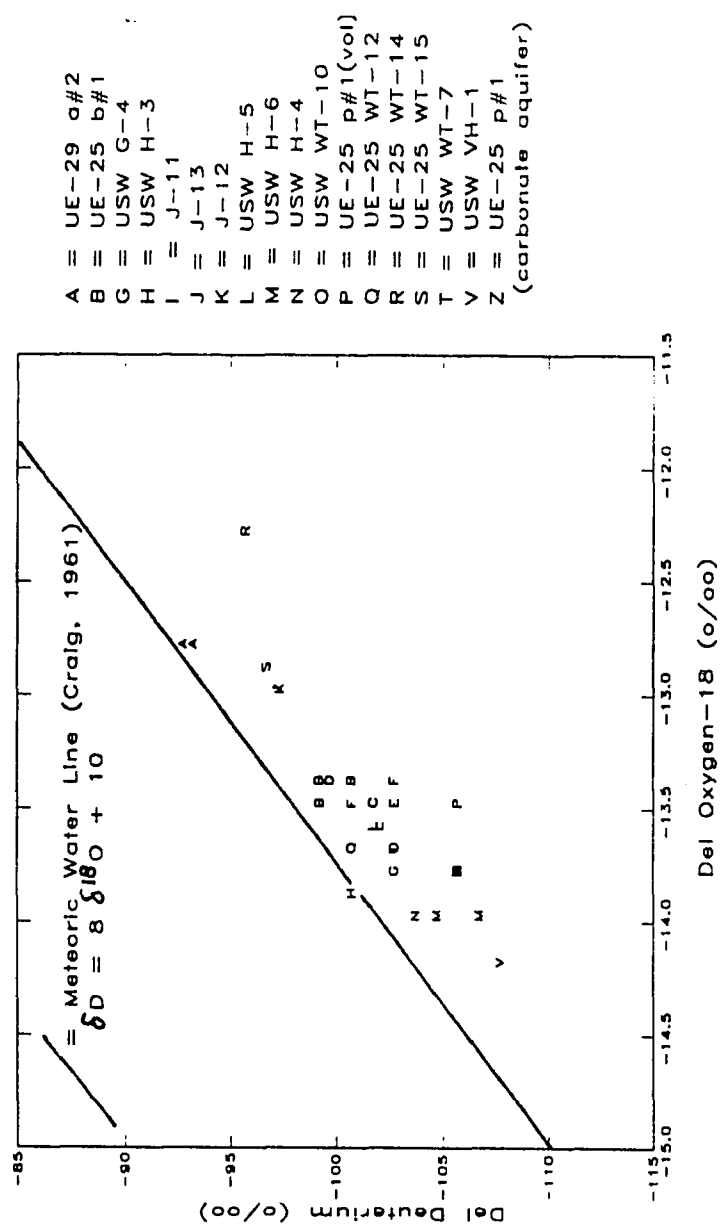


Figure 2: Del Deuterium and Del Oxygen-18
Values Of Yucca Mountain Wells
(Benson and McKinley, 1985)

SUMMARY

The Desert Research Institute successfully purged and sampled four water table wells which surround Yucca Mountain. A fifth well, USW WT-7, was not completely purged due to an obstruction in the casing; however, comparisons of chemical samples between it and the other wells indicate that the sample collected may be considered fairly representative of formation waters. The attempt to sample UE-25 WT-4 was unsuccessful due to excessive drawdown, thus samples were collected. The other wells appeared to be fairly free of drilling fluid prior to sampling, indicating ground-water movement. The data collected from this sampling program will be used in a geochemical model of ground-water flow between the volcanic tuffs and carbonate aquifer at Yucca Mountain.

Further work should include sampling of the remaining water table wells, including resampling of the six sampled under this effort. It may be of interest to further study the obstruction in well USW WT-7, as this well is located at the mouth of Solitario Canyon, in close proximity to the Solitario Canyon fault.

TABLE 4
ISOTOPIC ANALYSIS OF WATER TABLE WELLS

Well	Tritium (T.U.)	$\delta^{18}\text{O}$ ‰	δD ‰	$\delta^{13}\text{C}$ ‰	‰ Modern Carbon
UE-25 WT-4 ¹	-	-	-	-	-
USW WT-7 ¹	-	-13.7	-104	-	-
USW WT-10 ¹	-	-13.4	-104	-6.5	-
USW WT-10 ²	-	-13.7	-103	-6.6	-
UE-25 WT-12 ¹	-	-13.7	-101	-8.9	-
UE-25 WT-12 ²	-	-13.6	-102	-7.7	-
UE-25 WT-12 ³	0.96	-	-	-8.1	11.4
UE-25 WT-14 ²	-	-12.3	-96	-11.8	-
UE-25 WT-14 ³	0.96	-	-	-12.7	24.1
UE-25 WT-15 ²	-	-12.9	-97	-11.1	-
UE-25 WT-15 ³	1.3	-	-	-11.8	21.6

NOTE: Data with "-" = analysis not received from lab.

¹ DRI analysis of initial water.

² DRI split analysis after three well volumes purged.

³ USGS split analysis after three well volumes purged.

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APPENDIX C

TECHNICAL PROCEDURE FOR GROUND-WATER
SAMPLING AND HYDROGEOLOGIC DATA
ACQUISITION

DTP-03.5

STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE
TECHNICAL PROCEDURE

DTP-03.5
REVISION 0 (DRAFT 3)
1 JUNE 1988
W.P. LOCATION:RK2177

TITLE: TECHNICAL PROCEDURE FOR GROUND-WATER SAMPLING AND
HYDROGEOLOGIC DATA ACQUISITION

APPROVED:

Project Manager

Quality Assurance Manager

Administrator of Technical Programs

1.0 PURPOSE

- 1.1 This procedure governs the activities of Desert Research Institute (DRI) personnel when operating under the jurisdiction of the Agency for Nuclear Projects/Nuclear Waste Policy Office (NWPO) Quality Assurance (QA) Program for the collection of ground-water samples, the preparation of samples for several different laboratory analyses, and the field measurement of unstable variables. The samples collected under this procedure shall be from DRI and/or DOE-sponsored deep wells and/or wells sponsored by other organizations at the Yucca Mountain site and vicinity.
- 1.2 This Technical Procedure implements requirements of Section 03 of the NWPO QA Program controlling data acquisition and data analysis.

2.0 DEFINITIONS

- 2.1 Refer to the Glossary for the following definitions:
 - 2.1.1 Technical Procedure
- 2.2 The following terms are defined in this section.
 - 2.2.1 Acidified sample
A water sample collected for analysis of major cations to which a reagent grade HNO_3 has been added as a preservative. This minimizes the loss of solutes by oxidation, precipitation, and/or adsorption to the container surface.

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- 2.2.2 Alkalinity
Chemically defined as the equivalent sum of the bases that are titratable with a strong acid. In ground water systems, it is considered to be the concentration of carbonate and bicarbonate.

$$\text{Alkalinity} = M[\text{HCO}_3^-] + 2M[\text{CO}_3^{2-}]$$

- 2.2.3 Bailer
A cylindrical tube that is either open at the top or the bottom, attached to a rope that is used for removal or collection of ground water from a well. To use, the bailer is lowered to the desired depth in the well, allowed to fill with water, then removed.
- 2.2.4 Conductance, specific
The ability of water to transmit an electrical current. Specific conductance is related to the concentration and charge of ions present in the water and is a way to measure the concentration of dissolved solids in the water.
- 2.2.5 Dissolved oxygen
The oxygen that is dissolved in the ground water, derived from contact with the atmosphere. The amount of dissolved oxygen in the aquifer is dependant upon the partial pressure of oxygen, dissolved solids in the water and temperature.
- 2.2.6 Down hole dummy
A piece of pipe that is the same size or slightly larger than the bailer, pump or equipment that is to be used in the well. The down hole dummy is lowered down and raised back up the well hole prior to putting equipment down the hole, to ensure that the equipment will fit in the well hole.
- 2.2.7 Flow-through box
A box, open at the top, constructed so that water from the pump enters one end and exits the other. Clamps across the top are used to hold buffers or solutions in the water, allowing them to equilibrate in temperature with the well water.

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- 2.2.8 Ground water
That part of the subsurface water that is in the zone of saturation. Synonymous with phreatic water.
- 2.2.9 Interferences
Factors that cause erroneous values in a ground water property during collection and analysis. Examples are aeration of a sample collected for dissolved oxygen analysis, and large temperature differences between ground-water temperature and pH calibration buffers, causing erroneous calibration of the pH meter.
- 2.2.10 Major anions
The most common negatively charged ions found in ground water consisting of
 Cl^- , F^- , SO_4^{-2} , HCO_3^- , NO^- , CO_3^{-2} .
- 2.2.11 Major cations
The most common positively charged ions found in ground water consisting of
 Ca^{+2} , Mg^{+2} , Na^+ , K^+ , NH_4^+ , Fe_2^+ , Fe_3^+ .
- 2.2.12 Membrane filter
A thin filter used to remove larger sediments from water prior to collection in sample bottles. Generally made of cellulose-nitrate or cellulose-acetate in a standard 0.45 μm pore size.
- 2.2.13 Methylene Blue Active (MBA)
A laboratory test for any compound which will react with methylene blue dye and which can then be extracted with chloroform. These are mainly chelating agents and common detergents, but this procedure is non-specific. See subsection 7.7 herein.
- 2.2.14 pH
A measure of the effective hydrogen ion concentration in the ground water, formally defined as the negative logarithm of the hydrogen ion.
- 2.2.15 Pump, gas operated squeeze (bladder)
A collapsible membrane inside a long rigid housing, compressed gas supply and appropriate control valves. Water enters through a check valve on the bottom of the pump assembly, compressed gas is used to inflate the

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membrane and force the water to the surface. The compression/release cycle is repeated until an adequate sample is obtained. Also known as a bladder pump.

- 2.2.16 Pump, piston motor
A positive displacement pump with one or more pistons that is lowered down the well. When drawn upward, check valve of the piston closes by gravity and the water pressure above it. This lowers the water pressure below the piston and water flows through the intake valve into the pump cylinder. As the piston moves downward the intake valve closes by pressure. The water in the cylinder is forced upward into the discharge pipe on the next upstroke.
- 2.2.17 Pump, submersible
The motor of the pump is submerged and supported by sample tubing and electrical cable. Water enters through an intake screen between the motor and bowl assembly, passed through one or more pumping stages and is discharged directly through the pump column to the surface. A portable generator is required to supply electricity to both the pump and winch.
- 2.2.18 Purging
The removal of old, stagnant water from a well by either bailing or pumping. This results in a fresh, more representative ground-water sample.
- 2.2.19 Sample collection round
The total of all activities necessary to collect a single set of samples or observations. For deep wells a sampling round may last several days and consist of purging the well, taking measurements in the field such as pH and temperature, and collecting samples for laboratory analysis.
- 2.2.20 Specific conductance
See Conductance, specific
- 2.2.21 Trace concentrations
Elements which occur in the ground water in concentrations of less than 1 mg/l (1 ppm).
- 2.2.22 Turbidity
Cloudiness in the water due to suspended or colloidal organic and inorganic material.

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- 2.2.23 Well volume
The volume of water in a well. determined from measurement of water depth in a well and the diameter of the well specified in the drilling log.

3.0 INTERFACING PROCEDURES

- 3.1 QAP-2.2 Preparation and Control of Technical Procedures
- 3.2 QAP-17.1 Quality Assurance Records
- 3.3 DTP-12.1 Technical Procedure for Calibration and Control of Equipment
- 3.4 DTP-12.2 Technical Procedure for Calibration of Portable Conductance Meters
- 3.5 DTP-12.3 Technical Procedure for Calibration of Portable pH Meters
- 3.6 DTP-12.4 Technical Procedure for Preparation of Standard Water
- 3.7 DTP-12.5 Technical Procedure for Calibration of Portable Dissolved Oxygen Meters
- 3.8 DTP-13.1 Identification and Control of Samples

4.0 ACTIVITIES AND REQUIREMENTS

4.1 General

- 4.1.1 The Project Manager or his/her designee shall assign a qualified individual as Sampler and may assign qualified Technicians to assist the Sampler.
- 4.1.2 The Project Manager shall determine, with consultation from the Department of Energy, the wells to be sampled and the time sampling is to be performed.

4.2 Preparation

- 4.2.1 Prior to the field trip for sample collection and field

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analysis the Sampler shall organize the materials and equipment that will be used. The list of equipment required is given in Appendix B of this procedure. In addition, the activities described in the following 5 subparagraphs shall be performed.

- 4.2.1 The Sampler shall review sites scheduled to be sampled and determine specific equipment requirements, number of sample containers needed, amount of buffer and standard solution that will be used. For sampling from wells, note the characteristics and geometry of each well from the drilling logs to determine the appropriate sampling method.
- 4.2.2 The Sampler shall inspect all equipment, repair and calibrate as necessary using the technical procedure appropriate for the equipment. Check buffer and standard solutions for expiration dates and loss of integrity, replace as necessary.
- 4.2.3 The Sampler shall fill all sample bottles with distilled water and store for at least two days (to leach water soluble materials). Then empty, drain, and close securely before transporting them into the field. The Sampler shall obtain a list of sample numbers to be used from the DRI Controller of Technical Procedures.
- 4.2.4 The Sampler shall clean and package all equipment that will contact the samples. Inspect carrying cases and service as needed.
- 4.2.5 The Sampler shall contact REECo., Laboratory Operations Section, and arrange for an empty water truck to be available for purge water collection at the sampling site.

4.3 Field Activities

Paragraphs 4.4 through 4.20 describe activities performed in the field at each sampling site by the Sampler and her/his technical assistants. They shall also log appropriate identification information, such as time and date of sampling, identification and general condition of well, names of crew members, and general weather conditions. This information may be entered into logbooks or onto prepared sampling forms directly such as the checklist of Appendix A of this

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Technical Procedure. If sampling forms are used they shall have unique type and serial numbers, and these numbers shall be entered into the logbook of the sampling technician. Serial Numbers are assigned as specified in Section 5.3 of this Technical Procedure. If logbooks are used the entries made shall contain the information specified in Appendix A of this Technical Procedure.

- 4.3.1 If the U.S. Geological Service (USGS) request sample splits DRI personnel shall collect 2 of each sample described below with the exception of C-14. Samples shall be randomly divided between DRI and USGS at the end of the collection time. C-14 samples shall be collected for USGS if they provide carboys.
- 4.4 Rinse the depth-to-water probe with distilled water, measure and record the depth to an accuracy of 0.1 foot. Calculate purge volume from this information and the geometry of the well given in the well drilling log.
- 4.5 Rinse the down-hole dummy with distilled water, then check well for size limits by lowering and raising the dummy to within two meters of the bottom of the well screen.
- 4.6 Clean pump as necessary and rinse with distilled water, then lower to screened interval and purge 3 well volumes or more. Purge water should be passed through the flow-through water bath with reagents in place in order to equilibrate reagents and buffers to well water temperature. Discharge purge water into the water truck described in Subsection 4.2.5 herein.
 - 4.6.1 At the beginning of purging
 - 4.6.1.1 Fill a 500 ml polyethylene bottle with filtered purge water. Seal with parafilm and electricians tape. Label as a Lithium Bromide sample.
 - 4.6.1.2 Fill a 500 ml polyethylene bottle with unfiltered purge water. Seal with parafilm and electricians tape. Label as a MBA sample.
 - 4.6.1.3 Fill a 1 L glass bottle with unfiltered purge water. Seal with parafilm and electricians tape. Label as a

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tritium sample for analysis by REECO.

- 4.6.2 If the well pumps dry during purging, stop pumping and allow the standing water level to return to its original level. Then continue with this procedure.
- 4.6.3 If pumps are not available or are not in working order, bailers or a deep-hole grab sampler may be used. Under this condition oxygen sensitive analyses shall not be performed, oxygen sensitive samples shall not be collected, and the well shall not be purged. Samples shall be taken from the screened interval. Clean bailers with distilled water before use.

Water Resources Center-DRI

Sample # _____	Date _____
Location _____	Time _____
Well No. _____	Temp. _____
Preservative _____	Sample Type _____
Collected By _____	Filt/Unfilt _____
Sampling Device _____	
Remarks _____	Depth _____

Figure 4.7-1
 The standard DRI water sample label

- 4.7 Final preparation of sample containers may be done in the field while the well is purging. Each container shall have an attached label indicating: 1) sample identification number including the letters NWPO to identify the sample as belonging to the NWPO QA Program, 2) well identification or location (Station), 3) date, time of collection and temperature, 4) analysis for which sample is intended (Sample Type), 5) sample preparation such as filtering or adding preservative, 6) Depth of sampling, and 7) signature or initials of technician. The Remarks section of the label shall contain a cross reference to the sampling in a logbook or checklist.

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- 4.8 Continue purging through water bath until at least 3 well volumes have been pumped and the temperature of the reagents is within 2 degrees celsius of the well water temperature as measured with a partial immersion mercury thermometer. Then calibrate pH meter using the procedure of DTP-12.3 if it has not yet been calibrated today. Also calibrate the EC meter using the procedure of DTP-12.2. While well is purging, which usually lasts several days, flow rate, temperature, EC and pH shall be measured at least every 8 hours and bicarbonate shall be determined daily.
- 4.9 Using the U.S.G.S. procedures referenced in Section 7.9 of this technical procedure, measure temperature, conductivity, and pH of water in water bath. Repeat and record measurements at 15 minute intervals until readings stabilize to within 5 percent for two successive measurements.
- 4.10 Measure temperature of water in water bath using U.S.G.S. procedure pages 10-12, Section 7.9 of this technical procedure, and record value in notebook or on a sample form.
- 4.11 Measure conductance of a water sample collected from the pump hose into a 250 ml beaker using U.S.G.S. procedure pages 9-10, Section 7.9 of this technical procedure, and record value in notebook or on a sample form.
- 4.12 Measure pH of a water sample collected from the pump hose into a 250 ml beaker using U.S.G.S. procedure pages 12-15, Section 7.9 of this technical procedure, and record value in notebook or on a sample form.
- 4.13 Disconnect water bath from pump hose and connect it to a dissolved oxygen flow-through chamber. Measure dissolved oxygen following the instructions of the manufacturer of the meter and probe and record value in notebook or on a sampling form.
- 4.14 Measure alkalinity using U.S.G.S. procedure pages 15-18 and pages 22-24, Section 7.9 of this technical procedure, and record value in notebook or on a sample form.

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- 4.15 The following subparagraphs describe the collection of samples for laboratory analysis. These samples are collected directly from the pump hose, using containers prepared at paragraph 4.7.
- 4.15.1 Carbon-13: fill a one liter flint glass bottle just to overflowing. If water is muddy, filter in the field. Before capping precipitate carbon by adding one scoop (5 grams) of SrCl. Then add NaOH tablets until pH is increased to 12 (generally takes 8 or more tablets). Stir by capping and shaking bottle. Cap with no air space. Seal with parafilm and electricians' tape. Check the next day to insure that all carbon has precipitated by adding a few more crystals of SrCl to the bottle. If more precipitate forms add another scoop of SrCl.
- 4.15.2 Carbon-14
- 4.15.2.1 Determine volume of water necessary by the following formula (IAEA, 1971) or from the table in Appendix C.
 $\text{Vol of water (liters)} = 15000 / \text{HCO}_3^- \text{ (ppm)}$
- 4.15.2.2 Determine number of carboys needed (one carboy = 50 liters), fill them with nitrogen gas and seal with parafilm.
- 4.15.2.3 Fill the carboys
- 1) Turn off water pump.
 - 2) Remove cap leaving parafilm in place.
 - 3) Put tubing from water pump into carboy by slipping it under the parafilm seal. Run tubing to bottom of carboy.
 - 4) Put tubing from a nitrogen cylinder into carboy in the same way as the pump tubing. Tubing ends at top of carboy. Leave a slight air space around tubing and bleed nitrogen into carboy to keep air flushed out.
 - 5) Place carboy on platform over opening of water tank on the water truck so that overflow drains into the tank. Turn on pump and fill carboy to top. Keep bleeding nitrogen into tank while filling.
 - 6) When carboy is full turn off nitrogrn. Continue overflow filling until approximately one carboy volume has overflowed into the tank.

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- 7) Remove tubing, place a new piece of parafilm over opening, secure cap over parafilm, and seal with electricians tape.
- 4.15.3 Tritium: fill a one liter flint glass bottle and cap with no air space. Seal with parafilm and electricians' tape.
- 4.15.4 Deuterium and oxygen-18: fill a 12 milliliter borosilicate glass vial and cap with no airspace. Seal with parafilm and electricians' tape.
- 4.15.5 MBA (Methylene Blue Active): fill one 500 milliliter polyethylene bottle and store in a cool place and out of direct sunlight.
- 4.16 The following subparagraphs describe samples filtered by connecting a 0.45-micrometer filter to the pump hose. Spare filter holders should be at hand in case a filter clogs. Filters should be handled with clean plastic forceps or plastic gloves to avoid contamination.
 - 4.16.1 Major anion chemistry: fill a 500 milliliter polyethylene bottle. Seal with parafilm and electricians' tape. Label.
 - 4.16.2 Major cation chemistry: prepare a 500 milliliter polyethylene bottle by adding 1.0 milliliter reagent grade nitric acid (Ultrex). Fill and seal with parafilm and electricians' tape. Label.
 - 4.16.3 Lithium Bromide: fill a 500 ml polyethylene bottle. Seal with parafilm and electricians' tape. Label.
- 4.17 Control samples shall be collected as described in the following subparagraphs.
 - 4.17.1 Each tenth sample of each type shall be a duplicate of the ninth sample.
 - 4.17.2 Except for tritium, oxygen-18, carbon-13, and deuterium, for each twenty samples of each type, add a distilled water blank prepared in the field. At least one such sample shall be added for each round of sampling.

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- 4.17.3 For every 20 samples of each type add a sample of the "standard known" water prepared under DTP-12.4. At least one such sample shall be added for each round of sampling. These samples may be added at the time samples are submitted to the laboratory.
- 4.18 All samples shall be kept on ice in an ice chest during transportation.
- 4.19 The chain-of-custody requirements detailed in DTP-13.1 shall be followed. Chemistry samples shall be delivered to the DRI Water Chemistry Laboratory in Reno and isotope samples shall be delivered to the DRI Isotope Laboratory in Las Vegas.
- 4.20 Prior to submission to the laboratory, the order of a batch of samples of each type shall be randomized by the Sampler using a random sequence of integers supplied by the DRI Controller of Technical Procedures. New labels shall be applied to the containers that are noninformative about sampling sequence and location. A copy of the cross reference listing of original to randomized sample labels shall be sent to the NWPO Quality Assurance Archives, and a copy shall be maintained by the DRI Controller of Technical Procedures until sample analysis has been completed. The original labels shall be attached to logbook pages or cross reference forms. A copy of the cross reference shall be a part of the final report of the Sampler.
- 4.21 The information specified in following paragraphs shall be entered in logbooks or on sampling forms or checklist such as Appendix A of this technical procedure. If sampling forms or checklist are used they shall have unique serial numbers which shall be recorded in the samplers logbook at the time of sampling.
- 4.21.1 The Sampler shall prepare and submit to the Project Manager a Sampling Report at the termination of each sampling event. This report may be an abstract of entries made in the Samplers logbook, or a copy of the checklist or other sampling form used during the sampling.

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- 4.21.2 The Project Manager shall review and verify the Sampling Report, satisfy any discrepancies by consulting with the Sampler, and transmit a corrected copy to the NWPO QA Archives.
- 4.21.3 The sampling report shall contain the information specified in paragraph 5.2 of DTP-12.2 if conductance measurements are made in the field.
- 4.21.4 The sampling report shall contain the information specified in paragraph 5.2 of DTP-12.3 if pH measurements are made in the field.
- 4.21.5 The sampling report shall contain the information specified the Checklist of Appendix A of this technical procedure.
- 4.21.6 The sampling report shall contain the names and business locations of any observers who happened to witness the sampling.

5.0 OUTPUT DOCUMENTS

- 5.1 Sampling Reports, Sampling Forms, or Sampling Checklist shall be transmitted to the NWPO QA Archives by the Project Manager as soon as they are reviewed and validated by him/her.
- 5.2 The monthly report of the sampler, submitted to the Project Manager at the end of each month and summarizing activities for the month, shall contain the cross reference listing of original and randomized sample labels, an inventory of samples collected but not yet submitted to the laboratories, and an inventory of samples submitted that were collected in previous months. Copies of chain of custody records and shipping invoices shall be attached to monthly reports for all samples commercially shipped to analytical laboratories.
- 5.3 Sampling checklist, Appendix A of this Technical Procedure shall contain a Serial Number assigned and recorded by the DRI Controller of Technical Procedures.

6.0 REVISIONS

- 6.1 Revisions to documents shall be prepared, reviewed,

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verified, approved, and distributed in the same manner as the original issue and in accordance with Section 6.0 of Procedure QAP-6.1 as applicable, and the requirements stated in this procedure for the original documents.

- 6.2 Revisions may be made to a single page, several pages, or the entire document.
- 6.2.1 If single page revisions are made, only the revised page(s) need be issued as replacement pages.
- 6.2.2 Revised portions of documents shall be identified by a vertical line in the left margin adjacent to the revised area(s), or by use of the "redline/strikeout" feature of word processing programs, except as noted in Subsection 6.2.3 of this Procedure. When later revisions are made, the earlier revision indicators shall be deleted.
- 6.2.3 Technical documents marked "Preliminary" or "DRAFT" may be revised without adherence to Subsections 6.1 and 6.2.2 above. Preliminary documents shall be controlled by the preparer to prevent distribution and use before review and approval or before verification. The "preliminary" or "DRAFT" markings shall be removed before submission for approval or verification.
- 6.3 A revision summary shall be included as a part of all revised technical documents. The dated signatures of the Revision Preparer, Reviewer and Approver or of the Preparer and Verifier shall be included as a part of the revision summary. The revision summary shall indicate the pages revised.
- 6.4 Recipients of technical documents shall destroy superseded pages or mark them "VOID" or "SUPERSEDED."

7.0 REFERENCES

- 7.1 NWPO QA Program Section 03, Data Acquisition and Analysis.
- 7.2 NWPO QA Program Section 07, Control of Purchased Materials, Equipment, and Services.
- 7.3 NWPO QA Program Section 08, Sample Identification and

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Control.

- 7.4 NWPO QA Program Section 12, Control of Measuring and Test Equipment.
- 7.5 NWPO QA Program Section 13, Sample Handling, Storage, and Shipping.
- 7.6 NWPO QA Program Section 17, Quality Assurance Records.
- 7.7 American Public Health Association, 1980. Standard Methods for the Examination of Water and Wastewater, 15th Ed. Section 512A, "Methylene Blue Method for Methylene Blue Active Substances," pp530-532. Washington, D.C. 20036, ISBN: 0-87553-078-8. Co-published by the American Water Works Association and the Water Pollution Control Federation.
- 7.8 Brown, E., Skougstad, M.W., and Fishman, M.J., 1970, "Methods for Collection and Analysis of Samples for Dissolved Minerals and Gasses," Chapter A1 of Techniques of Water-Resources Investigations of the United States Geological Survey, Book 5 Laboratory Analysis.
- 7.9 IAEA, 1971, "Sampling of Water for C-14 Analysis," International Atomic Energy Agency, Vienna.
- 7.10 Wood, W.W., 1976, "Guidelines for Collection and Field Analysis of Ground-Water Samples for Selected Unstable Constituents," Chapter D2 of Techniques of Water-Resources Investigations of the United States Geological Survey, Book 1 Collection of Water Data By Direct Measurement.

8.0 FLOWCHART

None

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DTP-05.1 APPENDIX A

WELL WATER SAMPLING CHECKLIST

SAMPLING IDENTIFICATION

Date_____ Time sampling procedure began_____

Well Identification_____

General description of well location_____

Samplers_____

Weather Conditions at beginning of sampling

☐ Hot (over 100) ☐ Warm (70-100) ☐ Mild (50-70)
If a thermometer is available, record temperature_____

☐ Cold (under 50) ☐ Snow on ground☐ Calm ☐ Light breeze ☐ Windy☐ Clear ☐ Partly cloudy ☐ Overcast ☐ Rain☐ Snowing☐ Dummy successfully lowered and recovered. Date _____

If not, enter comments_____

Depth of well_____ Bore diameter at depth_____

Screened interval_____

Depth to water_____ Depth of water_____

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PURGE HISTORY

Purge volume (water depth*3.14*radius squared) _____
Make sure all measurements are in feet, volume in cubic feet

Purge volume in gallons = cubic feet * 7.5 = _____

Approximate purge time for 3 well volumes = 3 * purge volume in
gallons/pump rate in gallons per minute = _____ minutes.

Purge time in hours (minutes/60) = _____

|__| Pump lowered and start purging. Depth = _____

Begin purge day/time _____

Water quality: |__| Clear |__| Cloudy |__| Foamy

Other _____

INITIAL SAMPLE COLLECTION

After water flow is established collect the following three samples.

|__| Collect Lithium Bromide sample from initial purge water, filtered through a 0.45µm filter, in a 500 ml polyethylene bottle. Seal with parafilm and electricians' tape and label as LiBr sample.

|__| Collect MBA (soap) sample in a 500 ml polyethylene bottle, do not filter, from the initial purge water. Seal with parafilm and electricians' tape and label as MBA sample.

|__| Collect a tritium sample in a 1 liter glass bottle from the initial purge water. Seal with parafilm and electricians' tape and label as a Tritium sample for analysis by REECO.

End purge day/time _____

Notes for purging:

Purge time will vary due to pump/air compressor variability, notes should be made of flow rate every 4-6 hrs. during purging to keep track of volume pumped.

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METER AND INSTRUMENT STATISTICS AND CALIBRATION

- ☐ Water bath setup, buffers and reagents in place.
- ☐ Connect pump tubing to water bath.
- ☐ Sample containers prepared.
- ☐ Temperature of buffers stabilized to within 2 degrees C of the well water.

Temperature

Calibration correction for thermometer _____

Temperature of water in bath is _____ C

Specific conductance (DTP12.2)

Identification of meter _____

Time and date of measurement of conductance _____

Last cell constant determination

Date _____, time _____, logbook _____

Value of cell constant = _____

Measurement Record

standard	temp(°C)	tmp corr factor	meter read	tmp corr meter	cell constant
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

new cell constant _____

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pH (DTP12.3)

Identification of meter _____

Logbook reference to last servicing of the meter

pH of calibration buffer _____

pH of 2 delta percent buffer _____

pH of check buffer _____

meter reading _____

Dissolved oxygen (DTP12.5)

Identification of meter used _____

|__| Probe prepared for operation

|__| Meter electrical adjustments completed

Probe temperature is _____ C

Temperature calibration factor is _____ PPM

Altitude above sea level is _____ ft.

Altitude calibration factor is _____

Compute calibration value (temperature calibration
value * altitude calibration value)

_____ * _____ = _____ PPM

|__| Switch meter to CALIBRATE and adjust to value
computed in previous step.

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ALKALINITY

Alkalinity determination as carbonate and bicarbonate using the HACH equivalent buret method.

$$\text{ml acid} = \text{HACH \#} * N_e / (N_t * 800)$$

$$\text{HCO}_3 = (\text{ml acid HCO}_3 - \text{ml acid CO}_3) * 1000 / (\text{ml sample})$$

N_e = normality of digital titrator capsule

N_t = normality of buret titrant (0.01639)

800 = HACH multiplier

Date of preparation of acid titrant _____

Is initial pH less than 8.3? ☐ yes ☐ no
 If yes skip carbonate determination

Carbonate in mg/l = $1000 * \text{ml acid} * 0.9835 / \text{ml sample}$

ml acid used to endpoint near pH 8.3 = _____

pH at endpoint = _____

volume of water sample in ml = _____

carbonate content = _____ mg/l

Bicarbonate in mg/l = $1000 * \text{ml acid added} / \text{ml sample}$

ml acid added from endpoint near
 pH 8.3 to endpoint near pH 4.0 = _____

pH at endpoint = _____
 (Point of greatest change is the endpoint)

bicarbonate content = _____ mg/l

☐ Temperature, pH, and conductance of water pumped
 through water bath stabilized. Repeat measurements
 every 15 minutes and record readings on the next page.

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Carbonate/bicarbonate titration record

[illegible]

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STABILIZED MEASUREMENTS OF FIELD CHEMISTRY

Date_____

Repeat the following measurements until two successive measurements are within 5% agreement.

time	Tmp.	pH	E.C.
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

DISSOLVED OXYGEN

Oxygen meter reading

Place probe in flow chamber

Time elapsed for reading to stabilize_____

Dissolved oxygen value to nearest 0.1 is _____mg/l

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Volume of water in liters needed for carbon-14

$\text{Vol} = 15000/\text{HCO}_3^- (\text{ppm}) = \underline{\hspace{2cm}}$

Number of carboys needed
(1 carboy = 50 liters)

TABLE FOR CARBON-14 SAMPLE SIZE DETERMINATION

Number of carboys(50l)	HCO_3^- (ppm)	
	Minimum	Optimum
1	>200	>400
2	100-200	200-400
3	70-100	130-200
4	50-70	100-130
5	40-50	80-130

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LABORATORY SAMPLES

Samples may be collected in any order, generally collect filtered samples together.

Samples for laboratory analysis are collected from pump discharge tube.

Identification of carbon-13 sample bottle _____
One liter flint glass

Field precipitation of carbon-13

add 1 scoop (5 grams) of SrCl and NaOH tablets to raise pH above 12.0. Generally takes over 8 tablets. Check next day to insure that all carbon-13 has precipitated by adding a few more crystals of SrCl; continue adding crystals until no more precipitate forms.

bottles are then capped with no air space,
sealed with parafilm and electricians' tape.

Volume of water needed for carbon-14 (from page A-9) _____

Identification of carbon-14 carboys _____
Purged with nitrogen and filled as prescribed in
paragraphs 4.15.2

Identification of tritium sample bottle _____
One liter flint glass, capped with no air space,
sealed with parafilm and electricians' tape.

Identification of deuterium and oxygen-18 sample bottle

_____ 12 milliliter borosilicate vial, capped with no
airspace, sealed with parafilm and electricians' tape.

Identification of MBA sample bottle _____
500 mp polyethylene bottle, capped and sealed with parafilm
and electricians' tape.

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FILTERED SAMPLES

Identification of major anion sample bottle _____
500 ml polyethylene bottle, capped and sealed with
parafilm and electricians' tape

Identification of major cation sample bottle _____
500 ml polyethylene bottle with 1.0 ml nitric acid,
cap and seal with parafilm and electricians' tape.

Identification of LiBr sample bottle _____
500 ml polyethylene bottle, capped and sealed with parafilm
and electricians' tape.

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Control samples, blanks, or standards added to
sample batches shall be noted in the technicians logbook.

|__| Samples stored in an ice chest with chain-of-custody
maintained.

Note any significant weather changes during sampling, or
enter "none."

Names of observers of sampling, or enter "none."

Cross reference to Samplers logbook entry

End time/date_____

Samplers signature_____

Verifiers signature_____ Date_____

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DTP-05.1 APPENDIX B

EQUIPMENT CHECKLIST FOR GROUNDWATER SAMPLING

A number in parentheses preceding an item indicates the number of items required for each well sampled.

1. submersible (Bennett) pump, power supply, tubing
2. deep hole grab sampler
3. winch (on logging trailer)
4. depth to water measuring device (on logging trailer)
5. dummy for checking size of well bore (on logging trailer)
6. water filters
0.45 micrometer cellulose acetate or cellulose
nitrate filters, 3 filter holders, plastic
forceps or plastic gloves
7. pancake filter
8. flow-through water bath box with reagent holders
9. (2) partial immersion thermometers with calibration
record
10. specific conductance meter with calibration
record or calibration standards
11. portable pH meter with calibration buffers and
denatured alcohol for cleaning connectors
12. distilled water, 12 to 25 gallons
13. (2) plastic squeeze wash bottle labeled for distilled
water
14. (4) 250 ml plastic beakers
15. chemical tissues for cleaning probes
16. KCl solution for pH meter

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AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT OFFICE
TECHNICAL PROCEDURE

DTP-03.5
REVISION 0 (DRAFT 3)
1 JUNE 1988
W.P. LOCATION:RK2177

17. HACH kit
18. digital titrator
19. capsules of acid standards, 1.6N and 0.159N
20. 125 ml erlenmeyer flask
21. (2) 1 liter borosilicate glass bottles with caps
22. (1) 12 ml borosilicate glass vial with cap
23. (6) 500 ml polyethylene bottles
24. parafilm and electricians tape
25. disposable gloves or clean plastic forceps
26. paper towels
27. notebooks, logbooks, sampling forms, procedures,
checklist, chain-of-custody forms
28. sample labels, marking pens
29. first-aid kit
30. tool kit
31. nitric acid (Ultraspec) preservative for cation
samples
32. ice chest or cooler for sample transport and ice
33. quality assurance materials
- bottles of standard water
- bottles for duplicates and blanks
34. Nitrogen tank with regulator and valve
35. (3) 50 liter polyvinyl carboys
36. Dissolved oxygen meter,
batteries,
electrodes,
spare membranes and electrolyte

STATE OF NEVADA
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37. Dissolved oxygen flow-through measurement chamber
end of equipment list

APPENDIX D

COMPUTER LISTING OF PHREEQE FLOW PATH AND MIXING MODELS

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

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.	1.		
1324.		631.5	71.2	47.4		52.16
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.
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.
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.
3-11.2		70.6	50.25		1532.3	133.5
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

3-12. 1532.33 133.67 60.33

HEULANDI 4 0. -49.26 62.60 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

3-12. 1532.33 133.67 60.33

ADULARIA 4 0. -20.57 30.82 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. 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

ADULARIA 4 0. -20.57 30.82 0 0. 12.

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. 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

```

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
ADULARIA      4      0.      -20.57      30.82      0
3-8.      71.      1531.
ALBITE      4      0.      -18.00      25.89      0
3-8.      61.      1531.
ILLITE      6      0.      -40.267      54.68      0
3-11.2      70.6      50.25      1532.3
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

DATA: CARD IMAGES FROM DISK

ELEMENTS SPECIES LOOK MIN											
1											
ELEMENTS											
CA	4	40.08	CA+2								
MG	5	24.305	MG+2								
NA	6	22.9898	NA+								
K	7	39.0983	K+								
FE	8	55.847	FE+2								
MN	9	54.9380	MN+2								
AL	10	26.9815	AL+3								
BA	11	137.33	BA+2								
SR	12	87.62	SR+2								
SI	13	60.0843	SiO2								
CL	14	35.453	CL-								
C	15	61.0171	HCO3-								
S	16	96.06	SO4-2								
N	17	62.0049	NO3-								
B	18	10.81	B								
P	19	94.9714	PO4-3								
F	20	18.9984	F-								
LI	21	6.941	LI+								
BR	22	79.904	BR-								
SPECIES											
H+	1	100 1.0	0.0	9.0							
		0.0			0.0						
	1	1.0									
H+	2	100 -1.0	0.0	0.0							
		0.0			0.0						
	2	1.0									
H2O	3	100 0.0	0.0	0.0							
		0.0									
	3	1.0									
CA+2	4	101 2.0	0.0	6.0	5.0	0.165					
		0.0									
	4	1.0									
MG+2	5	101 2.0	0.0	8.0	5.5	0.20					
		0.0									
	5	1.0									
NA+	6	101 1.0	0.0	4.0	4.0	0.075					
		0.0									
	6	1.0									
K+	7	101 1.0	0.0	3.0	3.5	0.015					
		0.0									

	18 1.0	20 1.0		4 1.0	1 2 0	19 1.0	
59	18 1.0	400 -1.0	0.0	42	200 1.0	0.0	0.0
BF2-412	7.638	1 6 5	0.0	CAF+	3.798	0.0	0.0
18 1.0	20 2.0	1 1.0	3 -1.0	85	20 1.0		
60				MGCH+	300 1.0	0.0	0.0
BF3-41-	400 -1.0	0.0	0.0	-11.794	15.419	1 1.0	
13.666	1.58			86	5 1.0		
18 1.0	1 2.0	20 3.0	3 -2.0	MGCO3	210 0.0	4.0	0.0
61				2.980	2.713	0.9910	0.00667
Hr4-	400 -1.0	0.0	0.0	5 1.0	15 1.0		
20.274	-1.795			87			
18 1.0	1 3.0	20 4.0	3 -3.0	MGHCO3+	310 1.0	4.0	0.0
65				11.396	-2.527	-4.1790	0.01273
HP04 2	200 -2.0	0.0	4.0	5 1.0	1 1.0	15 1.0	
12.346	3.53			88			
19 1.0	1 1.0			MGSO4	200 0.0	6.0	0.0
66				2.250	1.4		
H2P-4	200 -1.0	0.0	4.5	5 1.0	16 1.0		
19.553	4.52			89			
19 1.0	1 2.0			MGPO4-	200 -1.0	0.0	0.0
69				6.589	3.100		
HF 60	200 0.0	0.0	0.0	5 1.0	19 1.0		
3.163	3.46			90			
1 1.0	20 1.0			MGHP04	300 0.0	0.0	0.0
70				15.216	-0.230		
HP2-	200 -1.0	0.0	0.0	5 1.0	19 1.0		
3.749	4.55			91			
1 1.0	20 2.0			MGH2PO4+	300 1.0	0.0	0.0
75				21.066	-1.120	39 1.0	
CAOH+	300 1.0	0.0	0.0	5 1.0	1 2.0		
-12.598	14.535			92			
4 1.0	3 1.0	1 -1.0		MGF+	200 1.0	0.0	0.0
76				1.820	4.674		
CAHO3	210 0.0	4.0	0.0	5 1.0	20 1.0		
3.153	4.023	-27.393	0.05617	95			
4 1.0	15 1.0			NACO3-	200 -1.0	4.0	0.0
77				1.268	8.911		
CAHCO3+	310 1.0	4.0	0.0	6 1.0	15 1.0		
11.345	1.806	4.448	0.03709	96			
4 1.0	15 1.0	1 1.0		NAHCO3	300 0.0	4.0	0.0
78				10.080	-3.604		
CASO4	200 0.0	6.0	0.0	6 1.0	1 1.0	15 1.0	
2.309	1.470			97			
4 1.0	16 1.0			NASO4-	200 -1.0	6.0	0.0
79				0.700	1.120		
CAPO4	200 -1.0	0.0	0.0	6 1.0	16 1.0		
6.459	3.100			98			
4 1.0	19 1.0			NAHPO4-	300 1.0	0.0	0.0
80				12.636	-3.530		
CAHPO4	300 0.0	0.0	0.0	6 1.0	1 1.0	19 1.0	
15.085	-0.270			100			
4 1.0	1 1.0	19 1.0		KSO4-	200 -1.0	6.0	0.0
81				0.85	2.225		
CAH2PO4+	300 1.0	0.0	0.0				
20.961	-1.120						

	7 1.0	16 1.0	7 1.0	0.0	0.0	1.0	8 1.0	3 4.0	1 -4.0	2 -1.0	
101	101	300 -1.0	0.0	0.0	0.0	1.0	120	400 4.0	6.0	0.0	0.0
102	102	-3.530	19 1.0	0.0	0.0	1.0	FE2OH2+4	33.5	0.0	0.0	0.0
103	103	12.636	19 1.0	0.0	0.0	1.0	8 2.0	3 2.0	1 -2.0	2 -2.0	0.0
104	104	7 1.0	19 1.0	0.0	0.0	1.0	121	3 2.0	1 -2.0	2 -2.0	0.0
105	105	300 1.0	2.0	0.0	0.0	1.0	FE3OH4+5	400 5.0	9.0	0.0	0.0
106	106	300 1.0	2.0	0.0	0.0	1.0	FE3OH4+5	44.3	0.0	0.0	0.0
107	107	300 1.0	2.0	0.0	0.0	1.0	8 3.0	3 4.0	1 -4.0	2 -3.0	0.0
108	108	300 1.0	2.0	0.0	0.0	1.0	122	300 2.0	3.0	0.0	0.0
109	109	300 1.0	2.0	0.0	0.0	1.0	FECL2	15.6	0.0	0.0	0.0
110	110	300 1.0	2.0	0.0	0.0	1.0	FECL2	15.6	0.0	0.0	0.0
111	111	300 1.0	2.0	0.0	0.0	1.0	8 1.0	14 1.0	2 -1.0	0.0	0.0
112	112	300 1.0	2.0	0.0	0.0	1.0	123	300 1.0	3.0	0.0	0.0
113	113	300 1.0	2.0	0.0	0.0	1.0	FECL2+	10.0	0.0	0.0	0.0
114	114	300 1.0	2.0	0.0	0.0	1.0	8 1.0	14 2.0	2 -1.0	0.0	0.0
115	115	300 1.0	2.0	0.0	0.0	1.0	124	300 0.0	3.0	0.0	0.0
116	116	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
117	117	300 1.0	2.0	0.0	0.0	1.0	8 1.0	14 3.0	2 -1.0	0.0	0.0
118	118	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
119	119	300 1.0	2.0	0.0	0.0	1.0	8 1.0	14 3.0	2 -1.0	0.0	0.0
120	120	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
121	121	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
122	122	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
123	123	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
124	124	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
125	125	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
126	126	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
127	127	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
128	128	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
129	129	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
130	130	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
131	131	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
132	132	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
133	133	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
134	134	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
135	135	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
136	136	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
137	137	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
138	138	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
139	139	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
140	140	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
141	141	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
142	142	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
143	143	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
144	144	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
145	145	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
146	146	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
147	147	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
148	148	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
149	149	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
150	150	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
151	151	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
152	152	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
153	153	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
154	154	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
155	155	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
156	156	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
157	157	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
158	158	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
159	159	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
160	160	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
161	161	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
162	162	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
163	163	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
164	164	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
165	165	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
166	166	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
167	167	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
168	168	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
169	169	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
170	170	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
171	171	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
172	172	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
173	173	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
174	174	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
175	175	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
176	176	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
177	177	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
178	178	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
179	179	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
180	180	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
181	181	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
182	182	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
183	183	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
184	184	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
185	185	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
186	186	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
187	187	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
188	188	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
189	189	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
190	190	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
191	191	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
192	192	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
193	193	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
194	194	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
195	195	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
196	196	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
197	197	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
198	198	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
199	199	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0
200	200	300 1.0	2.0	0.0	0.0	1.0	FECL3	10.0	0.0	0.0	0.0

SILICITE	2	6.0	-10.55	-5.328	0		
8 1.0	15	1.0			0		
RHODACHUR	2	6.0	-10.41	-2.079	0		
9 1.0	15	1.0			0		
STRONTIT	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		
MARITE	2	6.0	-9.976	6.28	0		
11 1.0	16	1.0			0		
HYDROXAP	4	0.0	-3.421	-36.155	0		
3 1.0	65	3.0	4.5.0	1 -4.0			
F APATIT	4	0.0	-17.6	-20.07	0		
1 -3.0	4	5.0	65 3.0	20 1.0	0		0.0
FLUORITE	2	0.0	-10.96	4.71	0		
4 1.0	20	2.0			0		
CHALCEPY	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		
13 1.0	3	-2.0			0		
GIBBSITE	3	1.0	0.0	8.77	-22.8	0	
10	3	0.0	3.0	1 -3.0	0		
KNOLINIT	4	0.0	-36.921	49.150	0		
3	-7.0	1	0.0	2.0 13	2.0 153	0	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 1.0		31 8.0	0.0
BIRNIT*	4	4.0	18.091	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	0		
HEMATITE	3	3.0	-4.008	-30.845	0		
115 2.0	3	3.0	1 -6.0		0		
GOPHITE	3	3.0	0.5	-14.48	0		
115 1.0	3	3.0	1 -3.0		0		
FECHJA	3	3.0	4.891	0.0	0		
115 1.0	3	3.0	1 -3.0		0		
PYRITE	4	0.0	-18.48	11.3	0		
1 -2.0	2	-2.0	8 1.0	42 2.0	0		
FES PPT	3	0.0	-3.915	0.0	0		
6 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		
35 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	1	-2.0			0		
33 1.0							

INITIAL SOLUTION FROM SOIL WATER (HENNE, 1982)

1000001000 0 6 0.06000

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 2.400d+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

CRISTOBA 2 -3.69 5.50 0

13 1.00

PCO2 2 -1.47 -4.71 0

35 1.00

3 -1.00

NAMONT 5

3 12.0

K-MONT 5

3 -12.0

CAMONT 5

3 -12.0

HEILANDI 4

3 -12.0

AMULARIA 4

3 -8.00

ALBITE 4

3 -8.00

ILLITE 6

3 -11.2

1 1.20

ANALCIME 4

3 -5.00

1ERR- 0

SOLUTION NUMBER 1

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

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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	3.069733d-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
 THOR = 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	-0.0886
5	MG+2	2.0	8.72223d-05	-4.0594	7.12361d-05	-4.1473	8.16719d-01	-0.0879
6	NA+	1.0	1.36911d-03	-2.8636	1.30026d-03	-2.8860	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	1.33872d-04	-3.8733	9.49062d-01	-0.0227
15	CO3-2	-2.0	1.47953d-06	-5.8299	1.20678d-06	-5.9184	8.15655d-01	-0.0885
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	-6.7753	1.59210d-07	-6.7980	9.48990d-01	-0.0227
33	H2 AQ	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	9.50335d-01	-0.0221
35	H2CO3	0.0	2.30170d-04	-3.6380	2.30287d-04	-3.6377	1.00051d+00	0.0002
40	HSO4-	-1.0	6.41187d-11	-10.0751	7.98617d-11	-10.0977	9.49393d-01	-0.0226
75	CNQH+	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	CNHCO3H	1.0	2.62575d-06	-5.5807	2.49287d-06	-5.6033	9.49393d-01	-0.0226
78	CASO4	0.0	3.92877d-07	-6.4060	3.92876d-07	-6.4057	1.00051d+00	0.0002
85	MGOH+	1.0	1.91084d-09	-8.7188	1.81414d-09	-8.7413	9.49393d-01	-0.0226
86	MHCO3	1.0	1.41512d-06	-5.8492	1.34351d-06	-5.8718	1.00051d+00	0.0002
87	MHCO3H	1.0	1.41512d-06	-5.8492	1.34351d-06	-5.8718	9.49393d-01	-0.0226
88	MGSO4	0.0	1.65104d-07	-6.7822	1.65187d-07	-6.7820	1.00051d+00	0.0002
95	NACO3-	-1.0	3.06346d-08	-5.9246	2.90843d-08	-5.9433	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	XS04-	-1.0	2.83261d-09	-8.5478	2.68926d-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 -----

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

PHASE	DELTA PHASE*	LOG IAP	LOG KT	LOG IAP/KT
CRISTOBA	0.000000d+00	-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
4.20 MOLES OF K
0.10 MOLES OF CA
0.70 MOLES OF FE
9.60 MOLES OF AL
51.90 MOLES OF SI

VALENCE = 0.000
VALENCE = 0.000
VALENCE = 0.000
VALENCE = 2.000
VALENCE = 0.000
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
GYPSUM	-9.6316	-4.6030	-5.0286
CHALCEDY	-3.6870	-3.5230	-0.1640
STO2(AM)	-3.6870	-2.7200	-0.9670
QUARTZ	-3.6870	-4.0060	0.3190
GIBBSITE	8.6583	8.7700	-0.1117
NAOLINIT	-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
FECH3A	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
CAMONT	-46.0833	-45.0300	-1.0533
HEULANDI	-49.2600	-49.2600	0.0000
ADULARIA	-24.5212	-20.5700	-3.9512
ALBITE	-23.2605	-18.0000	-5.2605
ANALCITE	-19.5738	-12.7000	-6.8738

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
CA	2.137523d-05	4.6701
MG	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
 THOR = 1.4180d-01
 TOTAL ALKALINITY = 1.5723d-03
 ITERATIONS = 20

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

I	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	2.10444d-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	4.68627d-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	-2.8043	1.49642d-02	-2.8249	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	H5O4-	-1.0	1.38114d-08	-7.8598	1.31572d-08	-7.8808	9.52634d-01	-0.0211
75	CrOH+	1.0	4.56749d-13	-12.3403	4.35115d-13	-12.3614	9.52634d-01	-0.0211
76	CrCO3	0.0	1.71708d-10	-9.7652	1.71783d-10	-9.7650	1.00044d+00	0.0002
77	CAICO3+	1.0	2.83063d-07	-6.5481	2.86568d-07	-6.5692	9.52634d-01	-0.0211
78	CASO4	0.0	4.76202d-08	-7.3222	4.76411d-08	-7.3220	1.00044d+00	0.0002
85	MGOH+	1.0	1.20963d-11	-10.9173	1.15233d-11	-10.9384	9.52634d-01	-0.0211
86	MGOH2	0.0	4.79604d-10	-9.3191	4.79815d-10	-9.3189	1.00044d+00	0.0002
87	MHCO3+	1.0	1.31728d-06	-5.8803	1.25488d-06	-5.9014	9.52634d-01	-0.0211
88	MGSO4	0.0	1.72888d-07	-6.7622	1.72964d-07	-6.7620	1.00044d+00	0.0002
95	NACO3-	-1.0	1.89011d-10	-9.7235	1.80058d-10	-9.7446	9.52634d-01	-0.0211
96	NHCO3	0.0	1.17644d-06	-5.9294	1.17695d-06	-5.9292	1.00044d+00	0.0002
97	NASO4-	-1.0	9.88774d-08	-7.0049	9.41940d-08	-7.0260	9.52634d-01	-0.0211
100	KSO4-	-1.0	7.66381d-09	-8.1156	7.30081d-09	-8.1366	9.52634d-01	-0.0211
105	FeOH+	1.0	2.25703d-10	-9.6465	2.15013d-10	-9.6675	9.52634d-01	-0.0211
106	FeOH2	0.0	1.81406d-16	-15.7413	1.81485d-16	-15.7412	1.00044d+00	0.0002
107	FeOH3-	-1.0	7.01927d-22	-21.1537	6.68680d-22	-21.1748	9.52634d-01	-0.0211
108	FeSO4	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	FeOH+2	2.0	8.01741d-11	-10.0960	6.60297d-11	-10.1803	8.23579d-01	-0.0843
117	FeOH2+	1.0	2.27609d-09	-8.6428	2.16828d-09	-8.6639	9.52634d-01	-0.0211
118	FeOH3	0.0	2.52525d-12	-11.5977	2.52635d-12	-11.5975	1.00044d+00	0.0002
119	FeOH4-	-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	FESO4+	1.0	1.21113d-14	-13.9168	1.15377d-14	-13.9379	9.52634d-01	-0.0211
126	FESO42-	-1.0	5.15166d-18	-17.2881	4.90765d-18	-17.3091	9.52634d-01	-0.0211
150	ALOH+2	2.0	5.75212d-07	-6.2402	4.71733d-07	-6.3245	8.23579d-01	-0.0843
151	ALOH2+	1.0	3.82810d-07	-6.4170	3.64678d-07	-6.4381	9.52634d-01	-0.0211
152	ALOH3	0.0	4.55089d-08	-7.3419	4.55289d-08	-7.3417	1.00044d+00	0.0002
153	ALOH4-	-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	H2SiO4-	-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