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Geothermal Resource Assessment of the Yucca Mountain Area, Nye County, Nevada

Final Report

December, 1995

Prepared for:

United States Department of Energy
Yucca Mountain Site Characterization Office
Post Office Box 98608
Las Vegas, NV 89193-8608

Prepared by:

University and Community College System of Nevada

University of Nevada, Las Vegas
Harry Reid Center for Environmental Studies
Division of Earth Sciences

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MacKay School of Mines
Nevada Bureau of Mines and Geology

Thomas Flynn, Paul Buchanan, Dennis Trexler

Lisa Shevenell, Larry Garside

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ABSTRACT

An assessment of the geothermal resources within a fifty-mile radius of the Yucca Mountain Project area was conducted to determine the potential for commercial development. The assessment includes collection, evaluation, and quantification of existing geological, geochemical, hydrological, and geophysical data within the Yucca Mountain area as they pertain to geothermal phenomena. Selected geologic, geochemical, and geophysical data were reduced to a set of common-scale digital maps using Geographic Information Systems (GIS) for systematic analysis and evaluation. Available data from the Yucca Mountain area were compared to similar data from developed and undeveloped geothermal areas in other parts of the Great Basin to assess the resource potential for future geothermal development at Yucca Mountain. This information will be used in the Yucca Mountain Site Characterization Project to determine the potential suitability of the site as a permanent underground repository for high-level nuclear waste.

The results of this investigation indicate that thermal fluids ranging in temperature from 40° to 57°C occur throughout the Yucca Mountain area at depths ranging from 400 to 500 m below the surface. Young volcanic extrusive rocks in the Yucca Mountain area are not the heat source for the low level thermal activity and are not the heat source for these fluids. The highest temperature recorded in the area was 121°C, measured in well UE-20f located several miles north of Yucca Mountain, completed to a depth of nearly 4,000 m,. Chemical analyses of fluids throughout the area, and in various lithologic formations, indicate that most waters are non-thermal in origin. Calculated chemical geothermometers were in general disagreement with measured temperatures and are used cautiously in this report. Geophysical data, including gravity, magnetics, seismic, and heat flow data failed to delineate any systematic structural evidence for a thermal anomaly. Hydrological data show that thermal fluids, where they exist, are restricted to faults, fractures, breccia zones, and the deep Paleozoic carbonate aquifers. Compared with the physical attributes of geothermal systems presently developed in other parts of the Great Basin, no economically viable resources were identified within the Yucca Mountain area. Some surface geothermal manifestations were identified within a 50-mile radius of Yucca Mountain, but, based on the present level of development, recreational uses are the only applications considered economic.

INTRODUCTION

Yucca Mountain is being evaluated by the U.S. Department of Energy (DOE) as a potential site for construction of an underground repository for high-level nuclear waste produced in the United States. The purpose of this study is to assess the geothermal energy resource potential of Yucca Mountain and the area surrounding the potential repository site (Figure 1) to a distance of approximately 50 miles (80 km). This assessment was based on a study plan prepared by the U.S. Geological Survey. An assessment of the geothermal energy potential at this site will be used in calculations to determine the possibility of future inadvertent human intrusion.

The study area encompasses approximately 20,000 km² Nevada and portions of California, and includes the Yucca Mountain area, the Nevada Test Site, and parts of Death Valley National Monument and the Nellis Bombing Range. This study required the compilation, analysis, synthesis, and interpretation of geology, geochemistry, geophysics, and drill hole information. Relevant data sets are stored in a digital format for use in a Geographic Information System (GIS). This format was selected for the following reasons.

1. Geothermal resource assessment is based on optimal co-location of a viable resource and a compatible market;
2. geological and engineering studies already in progress at Yucca Mountain have created an extensive base of data already in GIS format; and,
3. allows for easy exchange of these data between this and other studies, present and future.

Geothermal resources are widespread in the Great Basin (Trexler and others, 1983; Reed, 1983), but are restricted to specific geologic environments that include three essential features: a heat source, circulating fluids, and an open and permeable fracture system that allows fluid flow in a reservoir rock. Some geothermal systems also include a cap rock that restricts the fluids from flowing to the surface. The source of geothermal energy in the Great Basin is the high heat flow attributed to Cenozoic extensional tectonics that has produced a relatively thin crust. Recent silicic volcanic activity is restricted to the margins of the province, but small, Quaternary-age basaltic-andesite flows are found in the central portion of the province. Extensional tectonics play a key role in the area's geothermal resources by providing a deeply-penetrating fracture system throughout the province. Hot springs and fumaroles typically occur along well defined fault zones. Logs from deep geothermal production wells indicate that faults, particularly range-bounding faults, are the principal structures controlling fluid movement. The fluid component has been shown, on the basis of stable light-isotopes, to consist of meteoric water with little or no magmatic contribution (Craig, 1963).

The concept of geothermal resource assessment is based on methods established by the U.S. Geological Survey (Godwin and others, 1971), adopted by the geothermal industry, and regulated by the U.S. Bureau of Land Management and various State agencies. In general, the following geologic indicators are considered: late Tertiary or Quaternary volcanism; geysers, fumaroles, mud volcanoes, and thermal springs; and subsurface temperature gradients in deep wells that are two times normal. Additional specific geological indicators include: siliceous sinter; elevated silica content of spring water; the Na/K ratio in spring water; abnormally high heat flow; porosity and permeability of reservoir rocks; electrical, magnetic, gravity, airborne infrared, and other geophysical surveys. Nearby discoveries and commercial developments, as well as competitive interests, are also considered in the evaluation of land deemed valuable for geothermal energy development. This assessment incorporates the concepts described above.

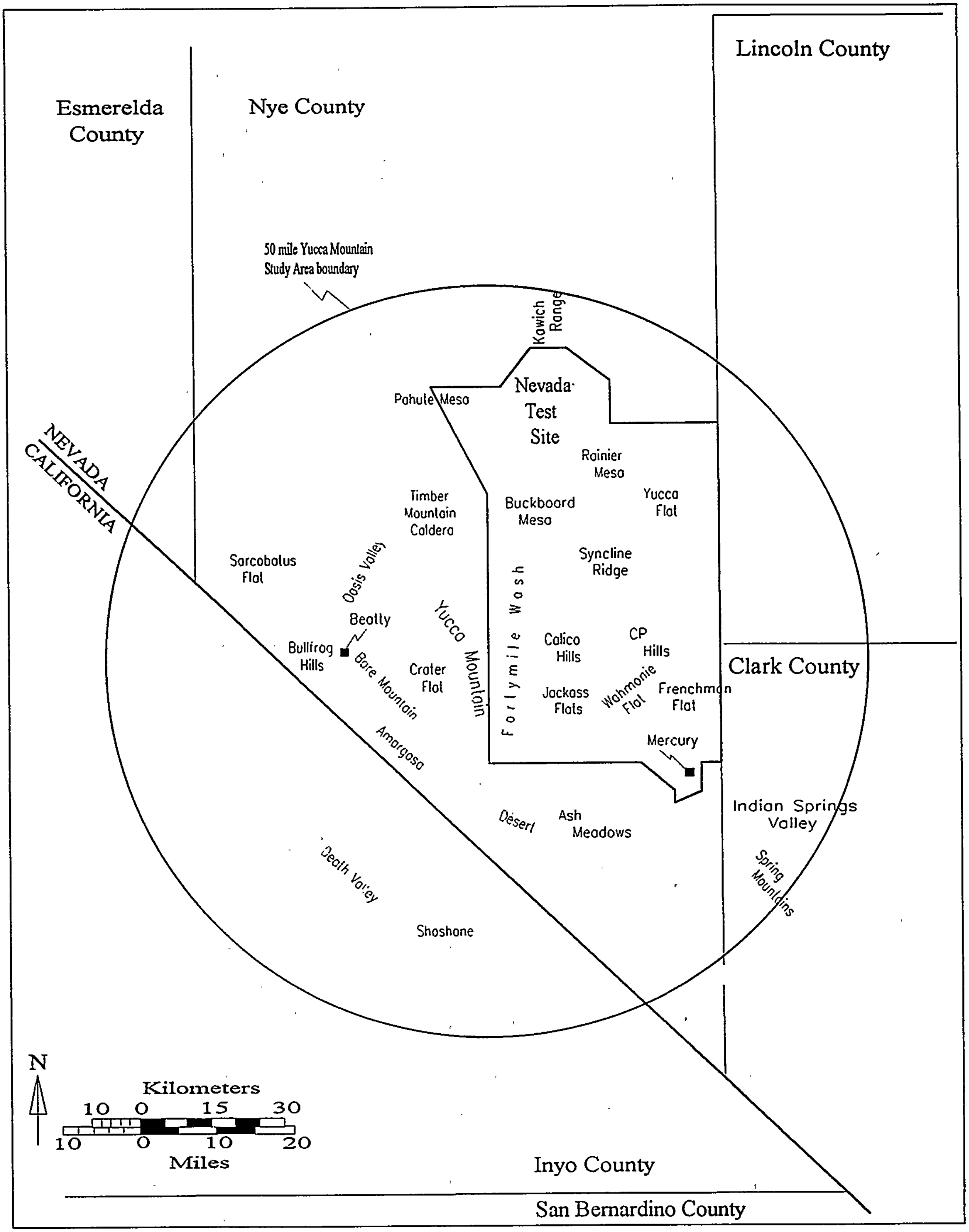


Figure 1. Location map for the Yucca Mountain Project 50 mile study area.

The basic assumption used in this assessment is that geothermal resources throughout the Great Basin, including the Yucca Mountain study area, are defined on the basis of geophysical and geochemical attributes, including temperature, depth, and flow rate, which can be measured and compared. It is also assumed that geothermal resources within the study area occur within the same geologic environments as those in the rest of the Great Basin. The final assumption is that geothermal development is based on established engineering and economic principals and that the present conditions provide a valid projection for the foreseeable future.

Methods

Data compilation was conducted under an established M&O Quality Assurance Program. The activity, including preparation and completion of the geothermal resource assessment report, was evaluated under QAP 2.0 (Quality Administrative Procedures) and determined to be quality affecting because the information in the report will be used for site characterization and license application. The issue of inadvertent human intrusion, because of possible energy or mineral resources, relates to waste isolation if such resources are determined to be present. The purpose, methods, objectives, and rationale for this investigation are based on the study plan developed specifically for study number 8.3.1.9.2.1 - Natural Resource Assessment of Yucca Mountain, Nye County, Nevada, Revision 0 - which was prepared by the U.S. Geological Survey, September 15, 1992. According to section 1.2 of that report, "The presence of natural resources at the site have the potential to encourage activities that could interfere with the isolation of waste (e.g., drilling for resources)." "Information from this study will specifically address the objective of limiting radionuclide releases to the accessible environment as required by 10 CFR Part 60.112 and 40 CFR 191.13." There are no designs, nor design control processes associated with this activity.

This report and the conclusions contained in this report are based on the interpretation of existing data - that is, data developed prior to the implementation of a 10 CFR 60 Subpart G, QA program. These data are largely peer-reviewed (reviewed and revised to conform with established practices, principals, and journal standards) and all may be traced to the primary source. The assessment methods represent a broad cross-section of generally accepted views within the scientific community and established geothermal industry practices regarding geologic, geochemical, geophysical, hydrologic, and drilling surveys.

This project was conducted in three stages. The first stage was a review of previous work on geothermal resources, including a literature search of available data on geology, hydrology, geophysics, and drilling. Digital data sets were also requested from the U.S. DOE contractor, EG&G. Geochemical data on springs and wells, for example, have been routinely collected throughout the study area for more than fifty-years. It was determined that the quantity of existing data, approximately 1,100 chemical analyses, was sufficient for the assessment; therefore, no additional springs or well water samples were collected. The resulting comprehensive bibliography (Flynn and others, 1995) was the first deliverable completed.

The second stage involved the collection of data sets and their conversion for use in a Geographic Information System (GIS). This involved electronically digitizing the locations of point attribute data such as wells and springs, line attribute data such as faults, and polygon attribute data such as geologic formations or administrative boundaries. Nevada state plane coordinates were used as the coordinate system. This resulted in the creation of a series of maps that included geology, geochemistry, volcanic centers, thermal springs, temperature gradient, heat flow, aeromagnetics, and

Bouguer gravity. The second stage of the investigation also produced an extensive geochemical database of the springs and wells in the study area, manipulation of which is described in Appendix 1. By combining these data at a common scale, it was possible to overlay various data sets to identify coincident anomalies. A familiar example is the co-location of many thermal springs in northern Nevada with well-defined fault zones. When completed on the scale of this investigation, information on the spatial distribution of potential heat sources, fluid sources, and fracture systems can be quickly and accurately assembled. Table 1 summarizes the Geographic Information System coverages (files) interpreted and used in this assessment.

Metadata information for the files listed in Table 1, including the location, scale, date, data sources, etc., and documentation related specifically to digital manipulation methods and techniques, are provided in Appendix 2. Also provided in Appendix 2 is a summary of GIS coverages used but not affecting interpretation, such as administrative boundaries. All computer files will be archived in the U.S. Department of Energy Yucca Mountain Project Technical Data Base.

The final stage was a comparison of the attributes of developed geothermal areas with the thermal features identified in the Yucca Mountain area. The principal requirement in geothermal systems is the heat source, and the least equivocal measurement is the temperature gradient log. Temperature gradient logs from Yucca Mountain were compared with representative logs from developed geothermal areas. Finally, the temperature, flow rate, and logistical requirements for successfully developed geothermal areas were numerically ranked and compared to the attributes in the Yucca Mountain area.

Computer software were used for computational support and are all commercially available products. They include: DOS 6.22; WordPerfect 5.1; Microsoft Excel 4.0 and 5.0; Microsoft Word for Windows 6.0; EarthInfo STORET; Macintosh Microsoft Word 5.0; UNIX; Solaris 2.3 operating system; vi text editor; groff, eqn, and tbl text processors; awk; ispell; ArcView 2; PC Arc/Info 3.4.1; ArcInfo 6.0; MapViewer 2.05; and Grapher for Windows 1.25.

Table 1. GIS data coverages used in the preparation of this report.

Coverage Name	Coverage Description	Data Reference	Coverage Name	Coverage Description	Data Reference
GBFLT	Faults, Great Basin	1	YMHFL	Heat Flow, Yucca Mountain	2
GBGWC	Geochemistry, Great Basin	2	YMMAX	Maximum geothermometers	2
GBHFL	Heat Flow, Great Basin	2	YMPOT	Potentiometric surface	3
NTSPR	Geochemistry, Test Site	2	YMSBF	Faults, Yucca Mountain	3
RGGRV	Gravity, regional	2	YMSGE	Geology, lithology and faults	3
RGMAG	Magnetics, regional	2	YMTRV	Travertine Deposits	2
YMALL	Geochemistry, study area	2	YMVOL	Volcanic Centers	3
YMGRV	Gravity, Yucca Mountain	2			

1 U.S. Geological Survey, Reno Field Office 2 University of Nevada Las Vegas, Division of Earth Sciences
3 EG&G Energy Measurements Division

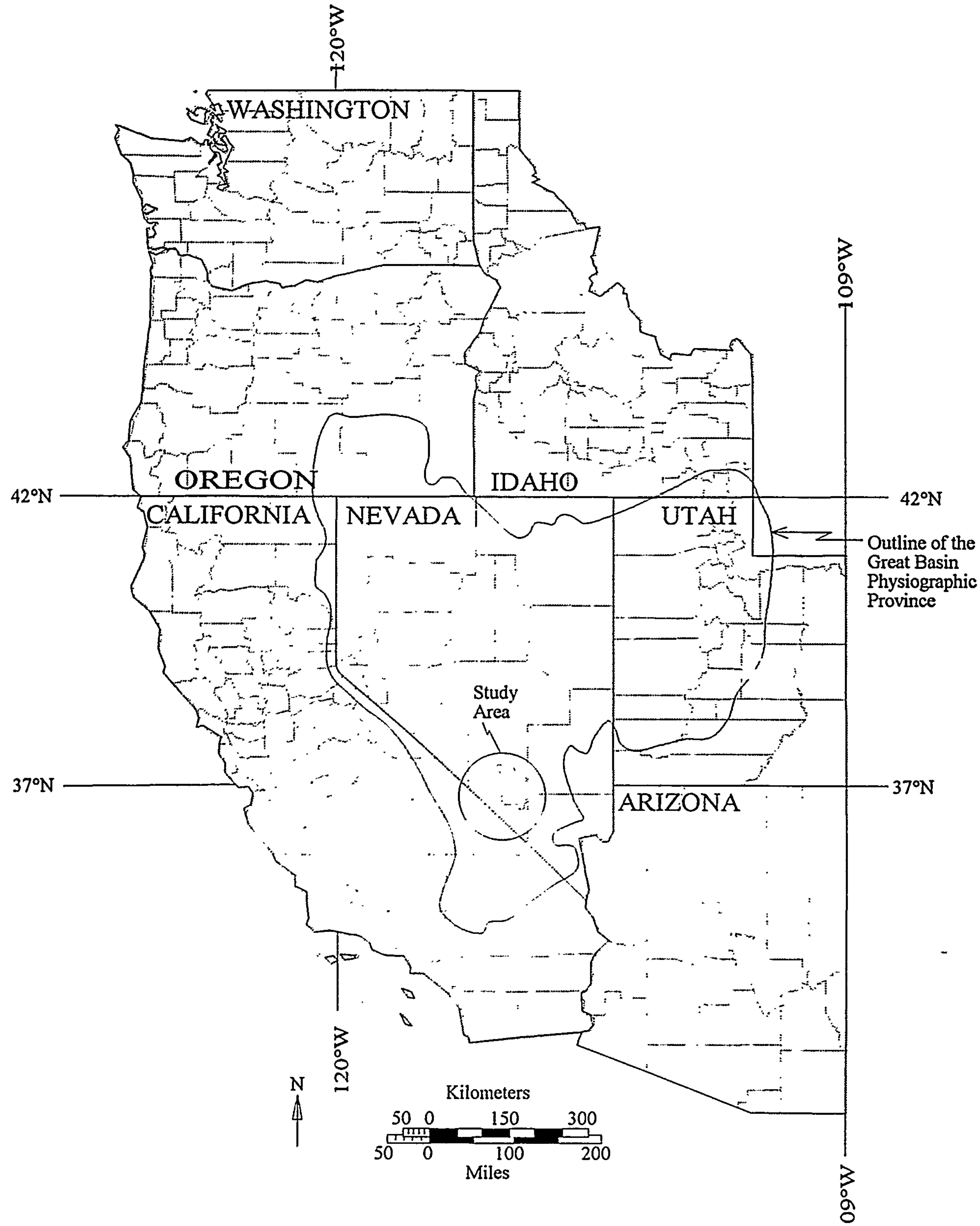


Figure 2. General location map for the Western United States, the Great Basin physiographic province, and the Yucca Mountain Project study area.

Location and Geography

The Great Basin physiographic province of the Western United States (Figure 2) is a topographically elevated and relatively dry region characterized by north- to northeast-trending mountains and valleys, and defined by a regional internal drainage system (Fenneman, 1931). Elevations range from 1,300 to 1,600 meters (m) in the valleys, and from 3,000 to 3,600 m for the highest peaks. The Great Basin is in the northern portion of the Basin and Range geologic province, and corresponds to a vast region of Cenozoic extensional tectonics. The Basin and Range includes most of Nevada and eastern California, and portions of Oregon, Idaho, Arizona and New Mexico.

Rainfall varies greatly throughout the region, controlled by latitude, longitude, and elevation. The higher ranges receive from 20 to more than 40 centimeters (cm) of precipitation per year, usually between November and March. Precipitation at lower elevations ranges from 0 to 10 cm per year. Playas remain dry most of the year, but support ephemeral lakes during periods of high runoff or prolonged precipitation. Most of the basins supported lakes during the Pleistocene. Drainage is internal in the Great Basin, but the Colorado River drains much of the southern portion of the Basin and Range province.

REGIONAL ASSESSMENT

Geology

The Great Basin is geologically complex, and a comprehensive description is beyond the scope of this report. However, a general description of the geological history and principal features will serve as a framework for the ensuing discussions.

Rock units in the Great Basin range in age from Precambrian to Recent. The oldest range in age from Precambrian through middle Paleozoic and occur in the southern and eastern portion of the province. They are the product of extensive clastic and carbonate deposition in shallow seas. The estimated thickness of the sedimentary assemblages in eastern Nevada and western Utah exceeds 6,000 m. Paleozoic and Mesozoic rocks in western Nevada are predominantly deep-sea shales and siliceous siltstones that were thrust over the eastern assemblage of carbonates in a series of orogenies that began in the Devonian Period, 370 million years ago (Ma), and continued through the middle of the Mesozoic Era, 170 Ma. Much of the extreme western Great Basin is underlain by granitic plutons of Mesozoic age, which are best exposed in the Sierra Nevada Mountains of western Nevada and eastern California.

Throughout the Great Basin, valleys contain sediments derived from the adjacent highlands. Sediment size varies from very coarse fanglomerates to extremely fine silts, clays, and evaporites in the central valley playas. Valley sediment accumulations may be as thick as three kilometers (km).

Widespread volcanism began approximately 43 Ma and resulted in the formation of siliceous caldera complexes. Volcanic activity initiated in western Utah and eastern Nevada, spreading west and south across the region. Approximately 6 Ma, the volcanism changed from bimodal (siliceous and basaltic) to principally basaltic. The most recent episode of volcanism was basalt to basaltic-andesite lava flows and cinder cones in west central Nevada, less than 100 thousand years ago (ka).

Faulting throughout the region was also initiated approximately 43 Ma, and is thought to be associated with the volcanic activity. Basin and Range faulting, which produced the present-day topography of elongated mountains and valleys, is the result of regional extensional tectonics that began approximately 13 Ma. This block faulting style produces sub-parallel mountain ranges that are, on average, 10 to 20 km wide and measure 25 to 35 km from crest to crest. Range-bounding faults are responsible for the widespread earthquake activity in the Great Basin and are also believed to be the principal conduits for convecting geothermal fluids.

Geochemistry

Surface thermal fluids vary from dilute, near-neutral pH, potable warm water to moderately saline brines associated with recent volcanic activity. In most of the Great Basin, fluids with a minimum temperature of 20°C are defined as "thermal" by the U.S. Geological Survey. Maximum surface temperatures approach 98°C, which represents the boiling point at these elevations. Temperatures approaching 270°C have been reported in wells in Dixie Valley, Churchill County, Nevada, at depths ranging from 2 to 3 km.

Dissolved Constituents

Thermal fluids are typically classified on the basis of the major dissolved chemical constituents. On this basis, three fluid types occur in the Great Basin. Sodium-chloride rich geothermal fluids occur predominantly in the Carson Sink (western Nevada), site of Pleistocene Lake Lahontan, and in western Utah, site of Pleistocene Lake Bonneville. Sodium-chloride rich geothermal fluids are among the most common throughout the world, and represent the highest temperature geothermal fluids found in the Great Basin.

Sodium-sulfate rich fluids occur in a narrow band parallel to the Walker Lane, a zone of discontinuous strike-slip faults and diverse topography in the western Great Basin (Stewart, 1992). Sodium/calcium-bicarbonate type fluids are widely scattered throughout the eastern portion of the region, which is underlain by Paleozoic carbonates rocks. Low-temperature fluids (< 25°C), for example, exceed 1,000 ppm bicarbonate and are coincident with the location of Pleistocene Lake Lahontan in northern Nevada. These high concentrations are the result of a combination of dissolution of carbonates along the flow path and evaporative concentration in the surface playas. The highest concentrations for geothermal fluids occur in east-central Nevada in the Railroad Valley oil-field brines. Oil wells in this area range from 1.0 to 2.5 km in depth and penetrate a thick wedge of Paleozoic limestones and dolomites, which account for the high carbonate-bicarbonate concentrations.

Silica is an important constituent in geothermal fluids because it can be used to estimate the temperatures of deep geothermal reservoirs (Fournier, 1981). Silica concentrations vary on the basis of temperature, pH, and availability of amorphous silica (Fournier and Rowe, 1966). Elevated concentrations of boron, fluoride, and arsenic are typically associated with geothermal fluids.

Stable Isotopes

Naturally occurring stable isotopes of hydrogen and oxygen have been shown to be effective natural indicators (tracers) of environmental conditions. Hydrogen, deuterium, ^{16}O, and ^{18}O fractionate readily on the basis of temperature and the large percent difference between the atomic masses allows the relative abundance of each isotope to be quantified using mass spectrometry. On the basis of stable light-isotopes, Craig (1963) determined that most geothermal fluids throughout the world were largely of meteoric origin. He also demonstrated that many geothermal fluids were "lighter" or isotopically depleted, compared to non-thermal fluids discharging at the same elevation. Isotopic analyses of thermal fluids from the Great Basin are in agreement with this finding. Isotopic differences in meteoric waters result from variations in temperature, which can be related to sample elevation and latitude. This property of stable light-isotopes has allowed their use as naturally occurring tracers in hydrologic flow models.

Isotopes of hydrogen are particularly effective in tracing geothermal systems because they retain their original meteoric water ratio and are relatively unaffected by rock-water interaction during deep circulation. Oxygen is also a useful tracer at low-temperatures (< 200°C). At elevated temperatures, however, it readily participates in chemical reactions with rocks and yields dubious tracer results. This characteristic "oxygen shift" has been noted at Steamboat Springs, Nevada, Salton Sea, California, Yellowstone National Park, Wyoming, and Larderello, Italy, for example.

Fluid Recharge Models

The origin of geothermal fluids has been debated for more than a century. Dana (1883) identified the components of a hydrothermal circulation system twenty years before the world's first geothermal power plant produced electricity in Larderello, Italy. Observing the action of geysers in Yellowstone Park, Wyoming, he suggested that the process was "owing to the access of subterranean waters to hot rocks, producing steam, which seeks exit by conduits upward." Conceptual models describing fluid recharge to Great Basin geothermal systems include the same components: deep fault zones, penetrating regions with elevated thermal gradients (40 to 60°C/km), providing permeable zones for the downward percolation of meteoric water and the upward migration of thermal fluids (Hose and Taylor, 1974; Muffler, 1979). Later refinements to these general concepts suggested that fluid recharge was associated with alluvial fans that are saturated with meteoric water and overlie range-bounding faults (Wollenberg and others, 1975).

Because geothermal fluids consist principally of meteoric waters, recharge models have inherently relied on stable isotopes as natural tracers. As a result, two classes of geothermal fluid recharge models have been proposed for the Great Basin: high elevation recharge and paleo-recharge. Many geothermal springs in the Great Basin are not located sufficiently close to elevated recharge areas to depend solely on this mechanism, prompting some to propose that geothermal fluids entered the system during a cooler and wetter climate such as the Pleistocene (Welch and others, 1981; Mariner and others, 1983; Flynn and Buchanan, 1990).

Geophysics

The Great Basin has been the focus of regional geophysical investigation for academic and commercial interests for decades (Smith and Eaton, 1978). The principal geophysical surveys include gravity surveys, seismic surveys, magnetic surveys, and heat flow studies designed to obtain information on the geological evolution of the continental lithosphere. In the context of geothermal studies, the important geophysical surveys include gravity, magnetic, and heat flow studies. Although the Great Basin is seismically active, there is little data available that indicates either a positive or negative correlation between seismicity and geothermal activity. Therefore, this correlation is not a typical component of a geothermal exploration package.

Gravity Studies

Gravitational force is a function of both mass and distance. A complete gravity survey includes compilation of the gravity field data, an analysis of the topography, and a determination of the rock density throughout the study area. Gravity survey data are useful for estimating vertical offsets, and possibly horizontal offsets, of suspected faults if sufficient density contrast exists in the rocks under investigation. Simpson and Jachens (1989) provide a thorough discussion of instruments, data collection, reduction, and interpretation used in gravity surveys. The standard for data presentation is given in milligals (mGal). Gravity anomalies are differences between the measured gravity values and theoretical values based on an elliptical Earth. The most common reductions include the free-air reduction, which accounts for the elevation of the station above sea-level, and the Bouguer reduction, which account for the attraction of nearby topographic relief. The result is a map that bears some similarity to topographic maps. The contours, however, are a measure of gravitational attraction (mGal), not of the elevation in feet or meters. Low gravity usually indicates low-density rocks, high gravity usually indicate higher density rocks.

Eaton and others (1978) characterized the Basin and Range, west of longitude 109°W, as a large area (1,000 by 1,300 km) "dominated by an extensive gravity low, having well-defined boundaries, and a near closure of the 90 mGal contour coinciding with a region of pronounced and broadly distributed crustal extension, high heat flow, repeated Cenozoic igneous activity, abundant hot springs, peripheral seismicity and Quaternary volcanism, and outward tilting margins. The gravity and topographic field of the southern half of the province display a well-developed bilateral symmetry, which has been described as somewhat resembling the shape of a butterfly. The line of symmetry constitutes a broad elongate north-trending upwarp, which can be traced from southern California to Idaho."

Gravity survey data are frequently used in geothermal exploration programs. Zoback (1979) modeled available data and confirmed the existence of an asymmetric, tilted, block structure in the Beowawe area, northern Nevada. The gravity gradient contours were consistent with both the location and trend of the Malpais fault zone, which defined the surface location of numerous hot springs and fumaroles at Beowawe. The vertical offset along the fault was estimated to be 520 to 650 m, assuming a density contrast of 0.4 gm/cm^3.

Benoit and others (1982) showed that data from a complete Bouguer gravity survey in the Desert Peak geothermal area in Churchill County indicated a complex pattern of anomalies and gradient trends, many of which did not directly correspond to mapped faults. They concluded that the gravity data neither outlined the geothermal reservoir nor defined any of its boundaries.

Trexler and others (1980), on the other, hand showed that steep gradients in gravity data for Walley's Hot Springs in Douglas County were coincident with the location of mapped faults and flowing hot springs. The gradient trends were shown to be parallel to the trend of the fault. Similar findings were recorded for Darrough's Hot Springs in Nye County (Trexler and others, 1980b). Gravity survey data for the thermal springs in the Pumpernickel Valley and Carlin, Nevada, areas (Trexler and others, 1982) were less diagnostic. In summary, gravity survey data are useful for defining large scale structures and fault offsets if there is sufficient density contrast between the geologic units.

Magnetics

Magnetic surveys are used to identify the location of susceptible iron-bearing minerals, buried plutonic rocks, calderas, and faults. Blakely and Connard (1989) provide a thorough review of the history of magnetic surveys, magnetic rock properties, and data acquisition and reduction techniques presently utilized. They point out that the two principal uncertainties in magnetic data are the non-unique aspects of the data and the navigational errors associated with the survey. However, regional data obtained is often helpful when combined with additional regional data, such as a geologic map.

In northern Nevada, Mabey and others (1978) identified a prominent, narrow, northwest-trending magnetic high known as the Cortez rift that extends from Eureka, northward into southern Oregon. It is believed that the Cortez rift reflects the first major tectonic extension in the Basin and Range province. The significance of the magnetic anomaly in this area is the proximity of the Beowawe geothermal system, which supports a 16 MWe dual flash geothermal power plant. Beowawe is located about 10 km east of the Cortez rift, on the northeast-trending Malpais fault. Aeromagnetic data from Beowawe are influenced by the north-northwest trend of the Cortez rift, which is believed to be the result of a zone of diabase dike intrusions, 5 km wide, that penetrate the entire thickness of the crust. If this is the case, the proximity of this deeply penetrating structure to the Beowawe geothermal system suggests a degree of connectivity worthy of investigation.

Heat Flow

The Basin and Range province is characterized by numerous hot springs and fumaroles, the result of high heat flow throughout the region. Heat flow is defined as the product of the temperature gradient and thermal conductivity and is reported in units of milliWatts per square meter (mWm^{-2}):

$$q_s = K\delta T/\delta z$$

where q_s is surface heat flow, K is the thermal conductivity of the rock unit in which the gradient is measured, and $\delta T/\delta z$ is the vertical temperature gradient, positive in the downward direction. Sass and others (1971) conducted a systematic analysis of temperature gradients and heat flow in northern Nevada and divided the region into three heat flow provinces: a region of "average" heat flow (approximately 85 mWm^{-2}), a region of elevated heat flow, which they named the Battle Mountain Heat Flow High, and a region of below average heat flow, designated the Eureka Heat Flow Low. All three are shown in Figure 3. The boundaries of the high and low heat flow areas were defined on the basis of available drill hole data and represent a regional, not detailed, interpretation.

Heat flow in the Basin and Range is extremely complex, resulting from the superposition of more than 600 Ma of recurring tectonic and volcanic activity (Blackwell, 1983). Any disturbances in observed heat flow at the surface are related to deep circulation of groundwater. Quaternary silicic volcanic activity perturbs the regional heat flow locally at Coso Hot Springs, Long Valley Caldera and Mono Lake, California, Steamboat Hot Springs, Nevada, and Roosevelt and Cove Fort, Utah.

Blackwell (1983) synthesized existing data from throughout the Basin and Range, factoring in irregular spacing and complicated fluid flow patterns, and concluded that most of the heat flow in the Basin and Range can be accounted for with a simple conceptual model that assumes the presence of a thermal source at a temperature of 1,350°C at a depth between 10 and 20 km. Heat flow was shown to vary with time after emplacement of the heat source (112 mWm^{-2} after 5 Ma and 90 mWm^{-2} after 10 Ma), but very little with position, except in the vicinity of range-bounding faults where heat flow variations were extreme.

Lachenbruch and others (1994) compared the published results of the average regional heat flow of the southern Basin and Range with the northern Basin and Range. The comparison was based on existing data, plus an additional 150 new heat flow values from the crystalline terrain of southern California, the Basin and Range province of Arizona, and Paleozoic sedimentary rocks of the southwestern Colorado Plateau. They found that the average heat flow from the two provinces was only marginally different, 82 ± 3 mWm^{-2} vs. 92 ± 9 mWm^{-2}, and pointed out that the southern Basin and Range has been relatively inactive for the last 10 to 15 Ma. They attribute this phenomena to the relatively slow rate of conductive decay of heat flow in the initial period of quiescence. Heat flow varies widely, but systematically, throughout the Great Basin from < 30 mWm^{-2} to > 120 mWm^{-2}.

Geothermal Resources of the Great Basin

Geothermal resources are widespread in the Basin and Range (Figure 4). Geothermal fluid surface temperatures in northern Nevada range from 20 to 98°C, but subsurface temperatures approach 270°C in some locations. Thermal energy is derived from a region of high heat flow associated with an expanding and tectonically thinned crust. Only on the extreme western and eastern edges of the Basin and Range is there evidence of a volcanic component to the source of heat. The fluids are of meteoric origin (rain and snow), but were probably recharged during the Pleistocene age, 12 to 30 ka. Faults, associated with Basin and Range extensional tectonics that

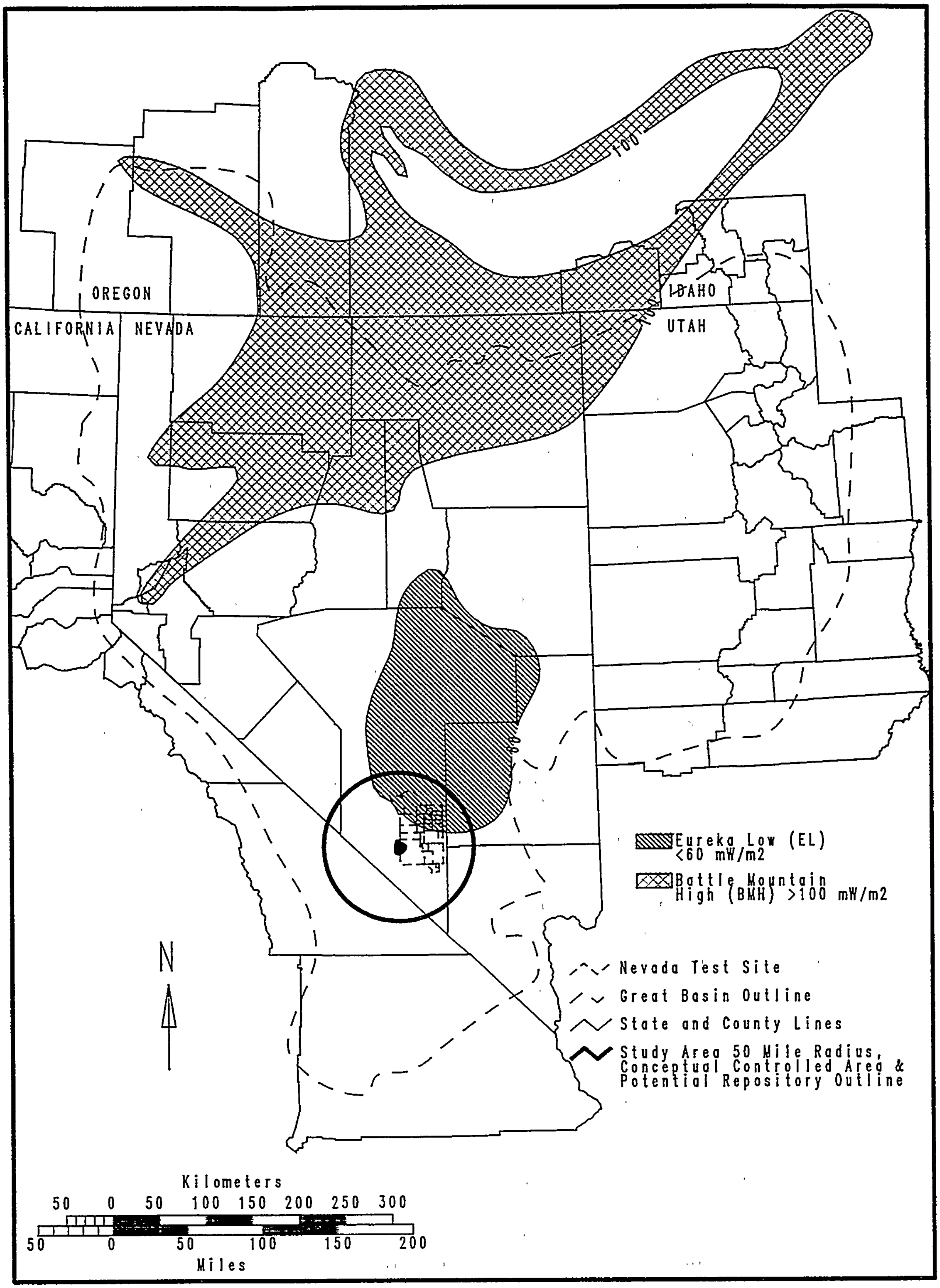


Figure 3. Heat flow map of the Great Basin showing the Battle Mountain Heat Flow High (BMH) and the Eureka Heat Flow Low (EL), after Sass and others (1971).

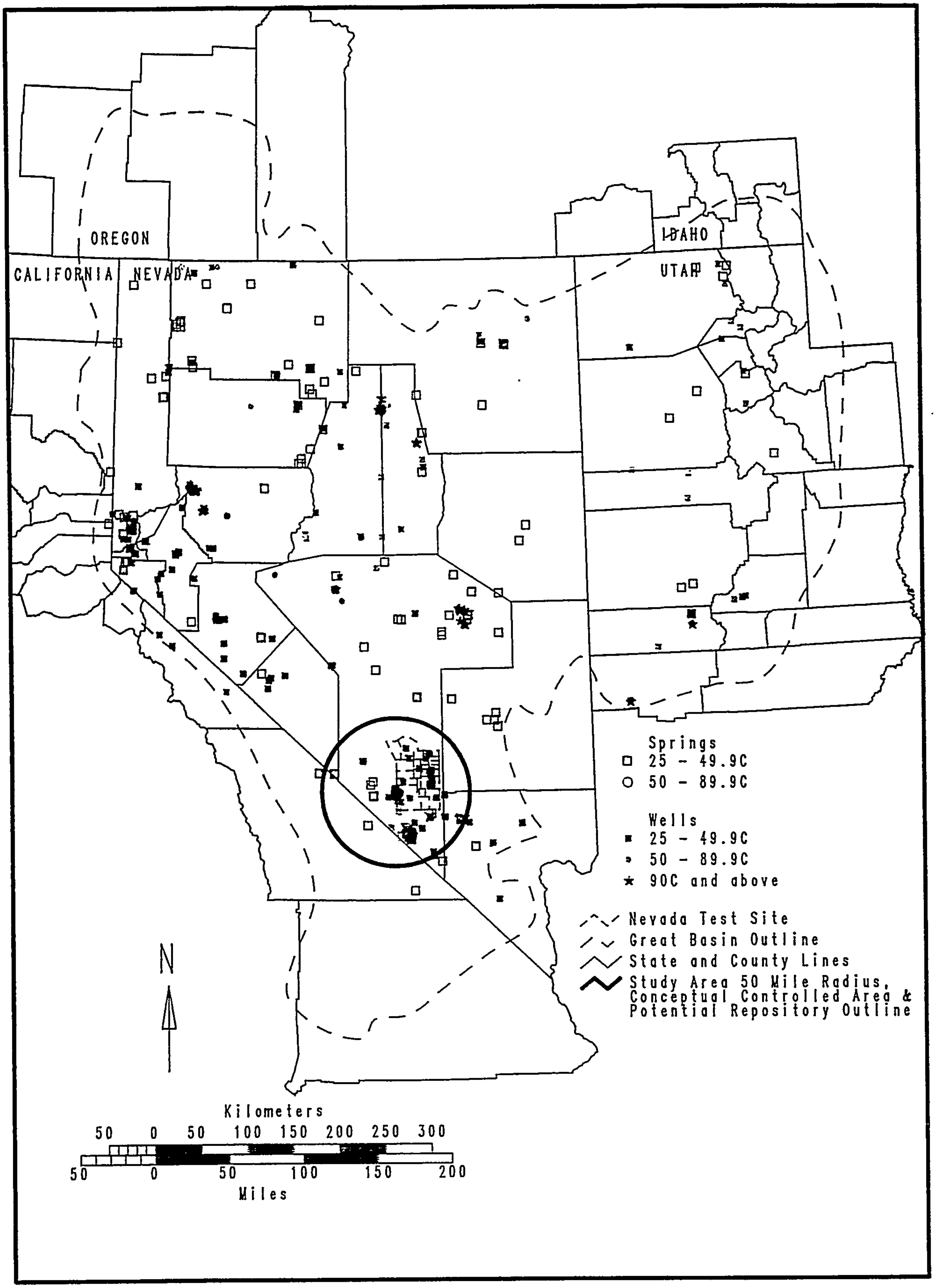


Figure 4. Distribution of geothermal springs and wells in the Great Basin (>25°C). The density of points in some areas was reduced for clarity; the temperature distribution remains the same.

began about 13 Ma, are the principal conduits for circulating fluids. The flow path begins at the surface, continues to depths of 6 to 10 km, and ends at or near the surface.

Edmiston (1982) showed that the high-temperature, commercially viable geothermal resources were located on the eastern and western margins of the Basin and Range province, as well as in the Battle Mountain Heat Flow High (Sass and others, 1971). The interior portions of the province contain widespread low- to intermediate-temperature geothermal resources (Ward, 1983).

Vapor dominated resources are those reservoirs that are saturated with steam. The Geysers geothermal field in California and Cove Fort in Utah are the only known vapor dominated geothermal areas in the United States. Liquid dominated geothermal resources are those in which the reservoir rock is saturated with liquid water instead of steam. Nevada's geothermal resources are liquid dominated, and the fluids are dilute to slightly saline, near-neutral pH waters. The origin of these waters is still the subject of some debate.

Geothermal power plants within the Great Basin (Figure 5) presently produce about 600 MWe at 15 locations. In addition to electric power production, geothermal energy is currently used for space heating and industrial processes throughout the region (Figure 6).

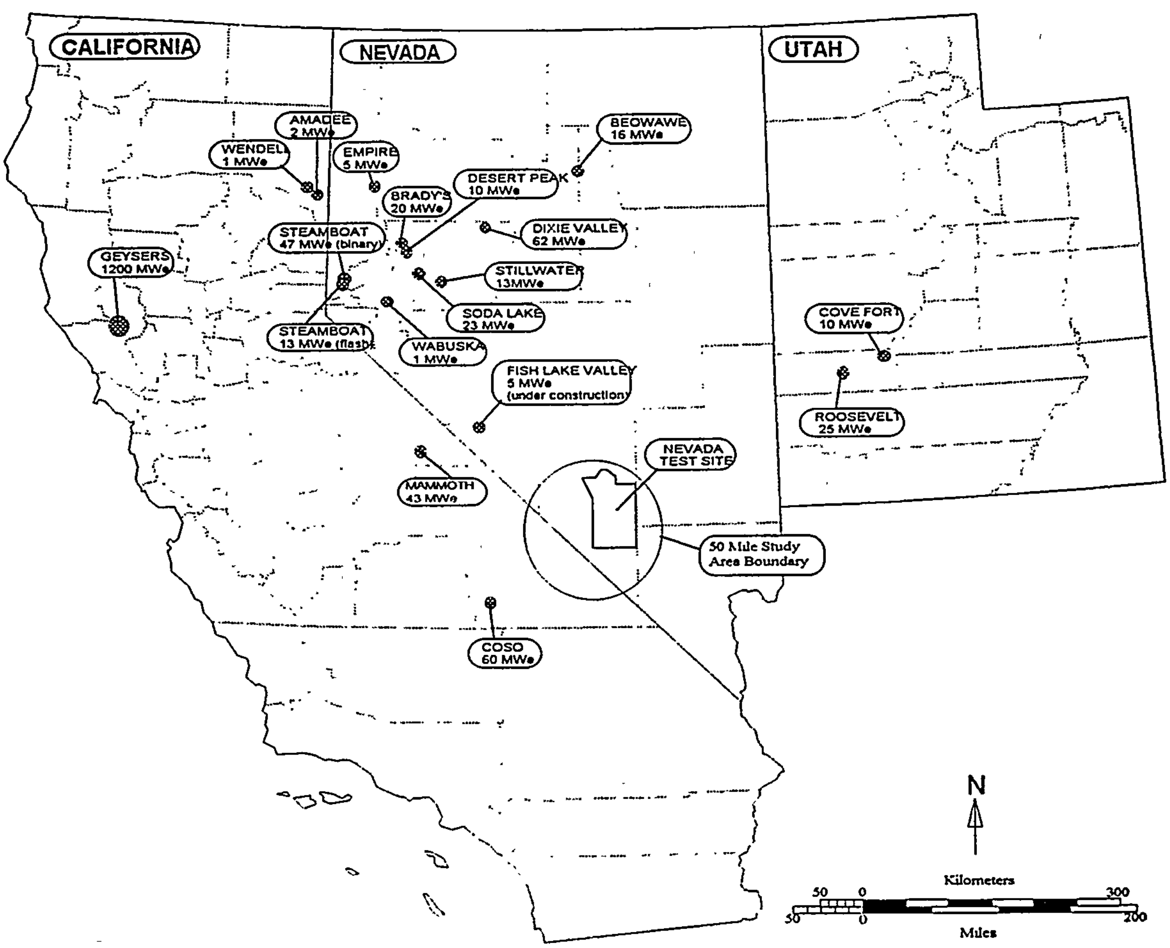


Figure 5. Location and output in MWe of geothermal power plants discussed in this report.

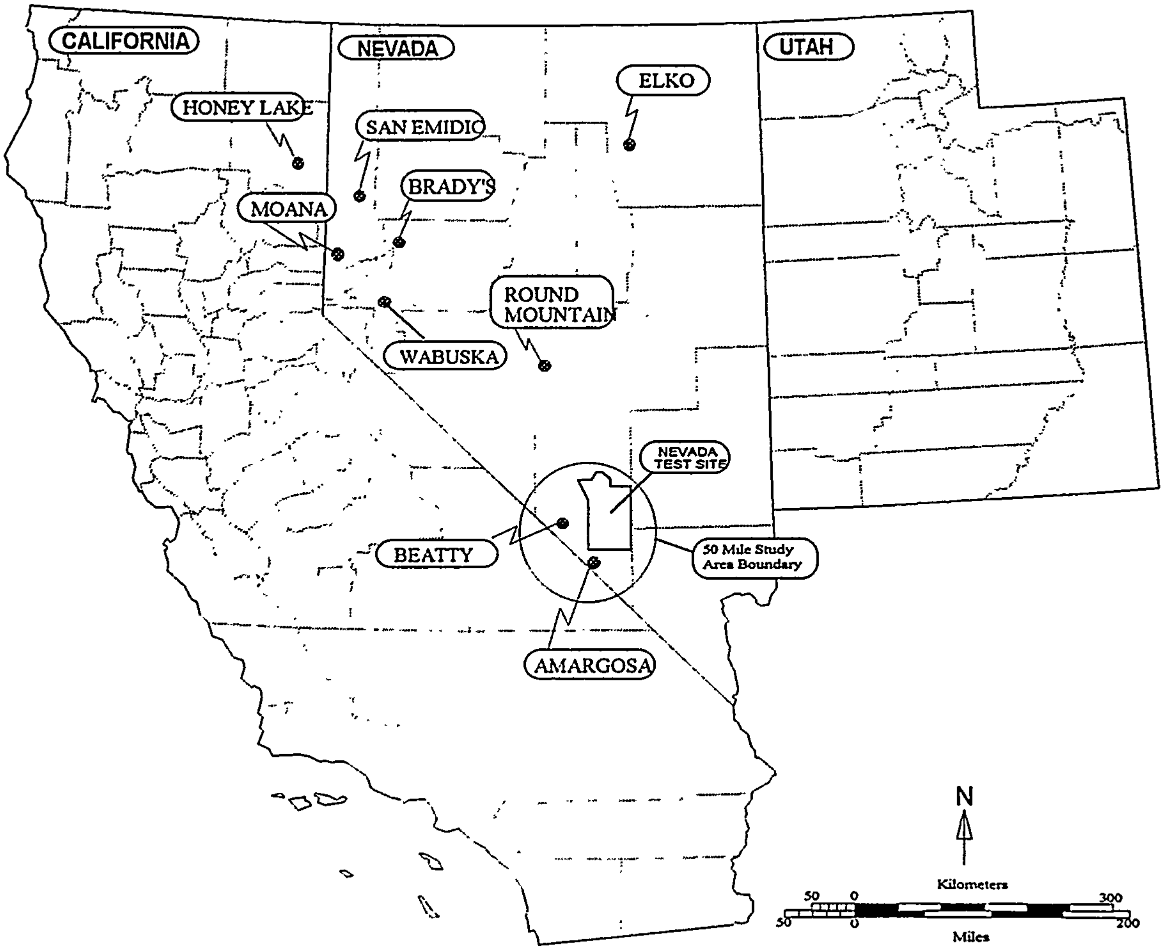


Figure 6. Location of geothermal direct-use projects discussed in this report.

Geothermal fluid recharge has been attributed to high elevation precipitation in mountainous areas near geothermal fields. The Sierra Nevada Mountains west of the Coso area (Fournier and Thompson, 1980); the Carson Range, west of the Steamboat area (Nehring, 1980); the Stillwater Range, west of the Dixie Valley area (Bell and Larson, 1980; Jacobson and others, 1983); the Independence Mountains near the Tuscarora thermal area (Bowman and Cole, 1982); the Mineral Mountains near the Roosevelt Hot Springs hydrothermal system, Utah (Rohrs and Bowman, 1980); and the Wasatch Front in Utah (Cole, 1983) have all been identified as likely recharge sources.

At Leach Hot Springs in Pershing County, Nevada, Welch and others (1981) found no nearby "suitably elevated" recharge area for the local isotopically depleted geothermal fluids. They suggested that either the lateral flow path was at least 160 km (distance to the nearest isotopically depleted source), or the waters were "paleowaters" that had precipitated during a colder, wetter climatic period. At Brady's Hot Springs in Churchill County, Nevada, Welch and Preissler (1986) concluded that local meteoric water, concentrated by evaporation, was the most likely source of the high TDS geothermal fluids. Mariner and others (1983) reviewed data from approximately 150 geothermal springs in the northern Basin and Range province and concluded that the chemistry of the thermal fluids was "almost certainly an indication that the thermal waters probably recharged during times of colder climate, probably the Pleistocene."

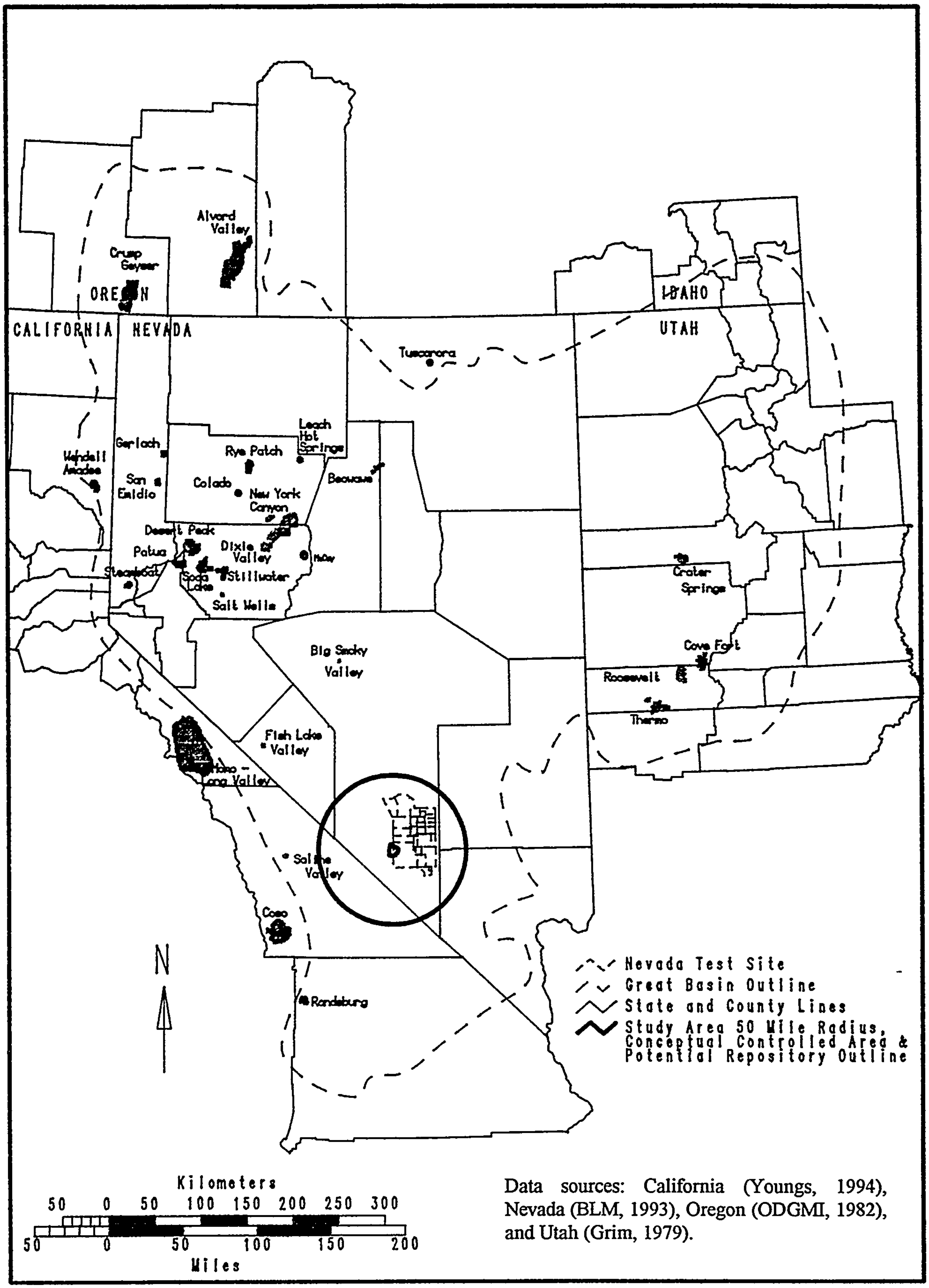
At Beowawe, Day (1987) showed that isotopic concentration in water from geothermal systems in northern Nevada are systematically distributed in a pattern similar to the isotopic concentrations of modern precipitation in the Great Basin. Flynn and Buchanan (1990) identified a similar pattern attributed to paleo precipitation, and determined, on the basis of isotopic data from several different but related sources, that geothermal fluids discharging at the surface throughout the Great Basin were recharged during the Pleistocene period, 20 to 30 ka, by a combination of surface flow and leakage from pluvial lakes.

Many geothermal springs in the Great Basin are associated with, and developed within, fault zones. These faults systems result from extensional tectonics that is literally pulling the Basin and Range province apart. As this occurs, the crust is cracked and thinned, providing avenues for the passage of deeply circulating groundwater. Faults are easily recognized at the surface where the basin meets the range. Several classic examples of fault-controlled geothermal springs in Nevada are Bog and Baltazor Hot Springs in Humboldt County, the Needles Rocks located at the north end of Pyramid Lake and Steamboat Hot Springs in Washoe County, Beowawe in Eureka County, and Sulfur Springs in Elko County (Garside and Schilling, 1979).

Research, exploration, and development programs conducted throughout the Great Basin have culminated in an extensive data base that consists of geology, geophysics, geochemistry, and drill hole data sets. Analysis of these data sets has provided several conceptual flow models of geothermal systems that assist in understanding and eventual development of the resource (Reed, 1983). Various conceptual models that have been developed specifically for Basin and Range geothermal systems require that thermal energy is transferred both vertically and horizontally by deeply circulating meteoric waters. The depth of circulation varies from place to place depending on local heat flow.

Historical Development

Geothermal resources have been commercially developed in the United States since the early 1960's at the Geysers geothermal field in northern California. In the early 1970's, the "oil embargo" contributed to increasing imported petroleum costs from \$5 to nearly \$40 dollars per barrel. This action alone is largely credited with the rise of the present alternative/renewable energy industry, including geothermal. A series of nationwide assessments of geothermal resources followed (Mariner and others, 1974, 1975, 1976; White and Williams, 1975; Muffler, 1979). In 1971, the United States Congress passed the Geothermal Steam Act, which established the framework for exploration and development of steam and hot water found on public lands by designating known geothermal resource areas (KGRA's). According to the Geothermal Steam Act of 1970, a KGRA means "*an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources from an area are good enough to warrant expenditures of money for that purpose*" (Godwin, 1971). The KGRA's, located largely on public land, were classified by the U.S. Department of the Interior on the basis of high-temperature-gradients, hot springs, fumaroles, and other geothermal surface indicators (Figure 7). No sites were identified in the vicinity of Yucca Mountain. Several sites were subsequently offered for lease according to the provisions of the Geothermal Steam Act, and many of these areas today support operating geothermal power plants and other applications.



Data sources: California (Youngs, 1994), Nevada (BLM, 1993), Oregon (ODGMI, 1982), and Utah (Grim, 1979).

Figure 7. Current Known Geothermal Resource Areas, shaded red, in and near the Great Basin. Green symbols are no longer designated KGRAs.

In Nevada, initial exploration efforts were documented by Garside (1974), who mapped the locations of approximately 300 thermal springs and wells and thirteen KGRA's. Subsequent evaluations were carried out throughout the State (Garside and Schilling, 1979; Trexler and others, 1979; Trexler and others, 1983) as well as individual sites at Caliente, (Trexler and others, 1980a), Carson-Eagle Valley and Big Smoky Valley, (Trexler and others, 1980b), Hawthorne, Paradise Valley, and the Carson Sink, (Trexler and others, 1981), Pumpernickel Valley, Carlin, and Moana (Trexler and others, 1982), and Desert Peak (Benoit and others, 1982).

The occurrence and distribution of geothermal fluids is well documented in Utah (Goode, 1978; Mabey and Budding, 1987; Vuataz and Goff, 1987). In California, resources assessment efforts have been completed at regional (Leivas and others, 1981; Leivas and Bacon, 1982) and at site specific scales (Bailey, 1974, 1982; Diment and others, 1980; Lachenbruch and Sass, 1977; Higgins and others, 1983, 1985).

In the late 1970's to early 1980's, a significant effort was focused on the development of high-temperature geothermal resources in Utah and Nevada. This project was known as the Industry Coupled Drilling Program and was jointly administered by the U.S. Department of Energy and the geothermal industry. In Nevada, large scale drilling programs were completed at ten sites: Beowawe, Dixie Valley, Stillwater, Rye Patch, Desert Peak, Soda Lake, Colado, Leach Hot Springs, McCoy, and Tuscarora. In Utah, the drilling program included Cove Fort and Roosevelt Hot Springs. Both of the Utah sites and five of the ten Nevada Sites presently support geothermal power plants. Again, none of the sites selected were near Yucca Mountain.

In summary, geothermal systems in the Great Basin have an extensive history of exploration and subsequent development that is based on an integrated package of geological, geophysical, and geochemical surveys, supplemented by subsurface temperature and lithologic logs. Most of the geothermal power plant production wells produce a combination of water and steam, and are developed in the vicinity of known high-temperature geothermal springs. The location of other geothermal developments are intimately associated with Quaternary age silicic volcanism.

YUCCA MOUNTAIN SITE ASSESSMENT

Geology

The geology of the region, including the southern Great Basin, the Nevada Test Site (NTS), and more recently Yucca Mountain, has been under investigation since the beginning of the 20th century. Investigations have included commercial efforts to determine mineral potential, hydrologic investigations, geologic and geophysical studies associated with nuclear weapons testing, and more recently, similar studies directed at Yucca Mountain as a potential site for nuclear waste storage.

Rocks in this area range in age from Precambrian to Quaternary, but the surface rocks are dominated by late Cenozoic volcanic ash-flow tuffs and lavas associated with a series of calderas that are collectively known as the Southwestern Nevada Volcanic Field (Christiansen and others, 1977). Figure 8 is a 1:1,000,000-scale geology map of the Yucca Mountain area distinguishing the rock units grouped by pertinent time periods and showing the major faults. The map shows the dominant consolidated rocks are Tertiary-age volcanics. Basement rocks throughout the area consist of thick sequences of carbonate and clastic rocks that are deposited unconformably on older crystalline rocks. The geology of the area is represented by a series of maps (Figures 9 through 11 that show the spatial distribution on the basis of age: late Precambrian (Proterozoic) and Paleozoic, Mesozoic, and Cenozoic (Tertiary and Quaternary). The following narrative and accompanying figures provide a brief review of the published literature describing the lithology and stratigraphy of the area.

Figure 9 shows the location of Proterozoic and Paleozoic rocks within the study area. The oldest rocks consist of Proterozoic sedimentary and metamorphic rocks exposed in three areas: to the northeast of the NTS, on the eastern border of the NTS, and south and southwest of the NTS. Overlying the Paleozoic rocks are the Stirling Quartzite and Johnnie Formation, a micaceous siltstone; each is approximately 900 m thick.

Late Proterozoic and early Paleozoic quartzites and carbonates resulted from miogeosynclinal deposition along the margin of the craton (Stewart, 1980). The thick sequences of clastic and carbonate rocks were deposited unconformably on the Proterozoic basement, apparently associated with late Proterozoic rifting along the western margin of the continent. Carr (1984) notes that these older sedimentary rocks include the Pahrump Group and Noonday Dolomite of Jennings (1977) that crop out south of the Yucca Mountain study area. More than 7 km of sedimentary rock accumulated in the vicinity of the Yucca Mountain area by the late Devonian (Stewart and Poole, 1974).

In the late Devonian, the well-documented Antler Orogeny had formed along the western edge of the continent, shedding clastic detritus into a basin that formed over the former site of the carbonate bank (Poole, 1974). During this time, the Upper Devonian and Mississippian Eleana Formation, which consists of a combination of argillite, siliceous siltstone, and very fine-grained quartzite (quartzite-pebble conglomerate, and sparse limestone of Frizzell and Shulters, 1990), was deposited in the Antler foreland flysch basin. The flysch deposits are fine-grained, regionally extensive, and relatively impermeable, resulting in the formation of an aquitard that separates a lower carbonate aquifer from an upper carbonate aquifer. Following deposition of the flysch, carbonate rocks, such as the Tippipah Limestone, were deposited during the Pennsylvanian and early Permian.

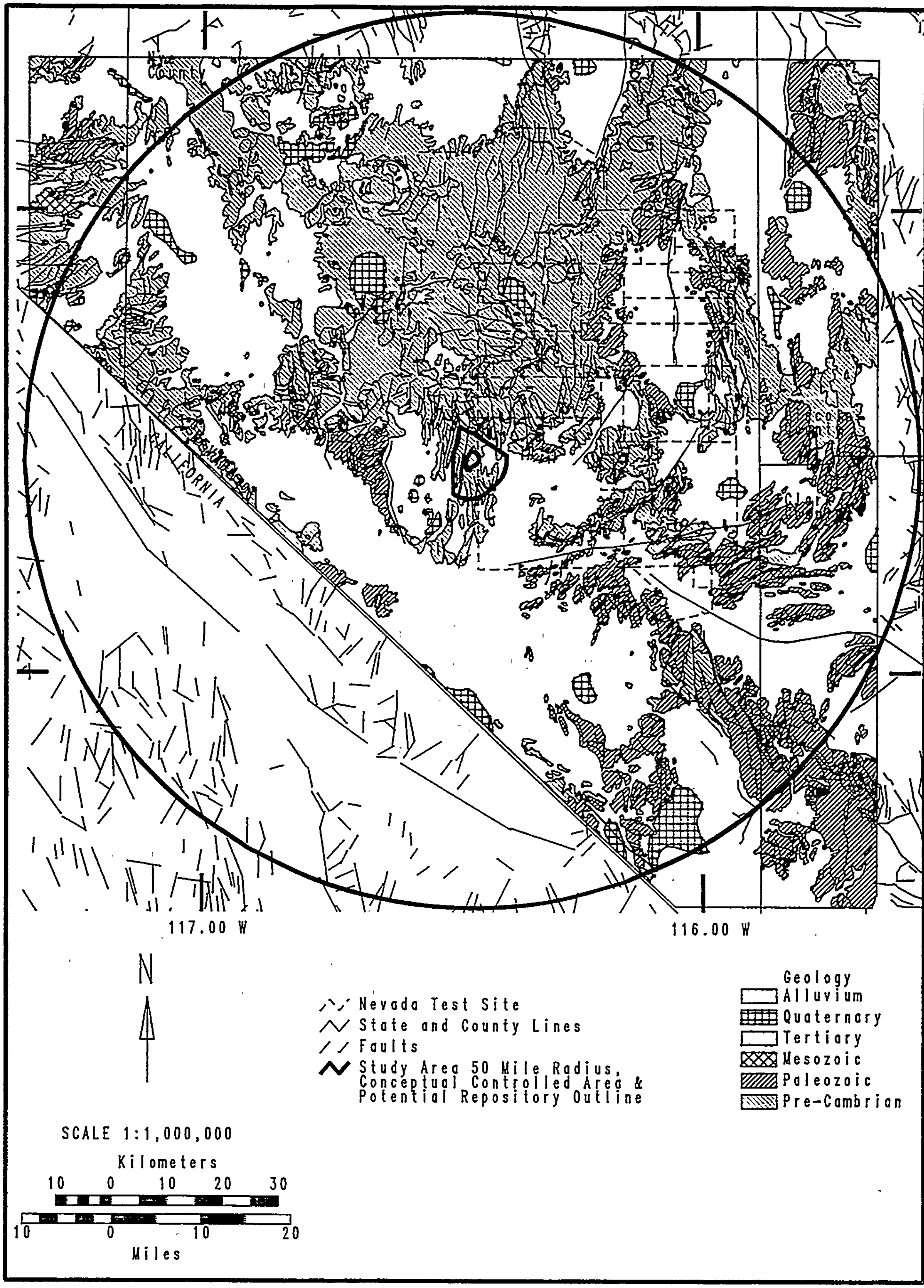


Figure 8. Geology map of the Yucca Mountain area showing rock assemblages divided into five time units and mapped geologic faults.

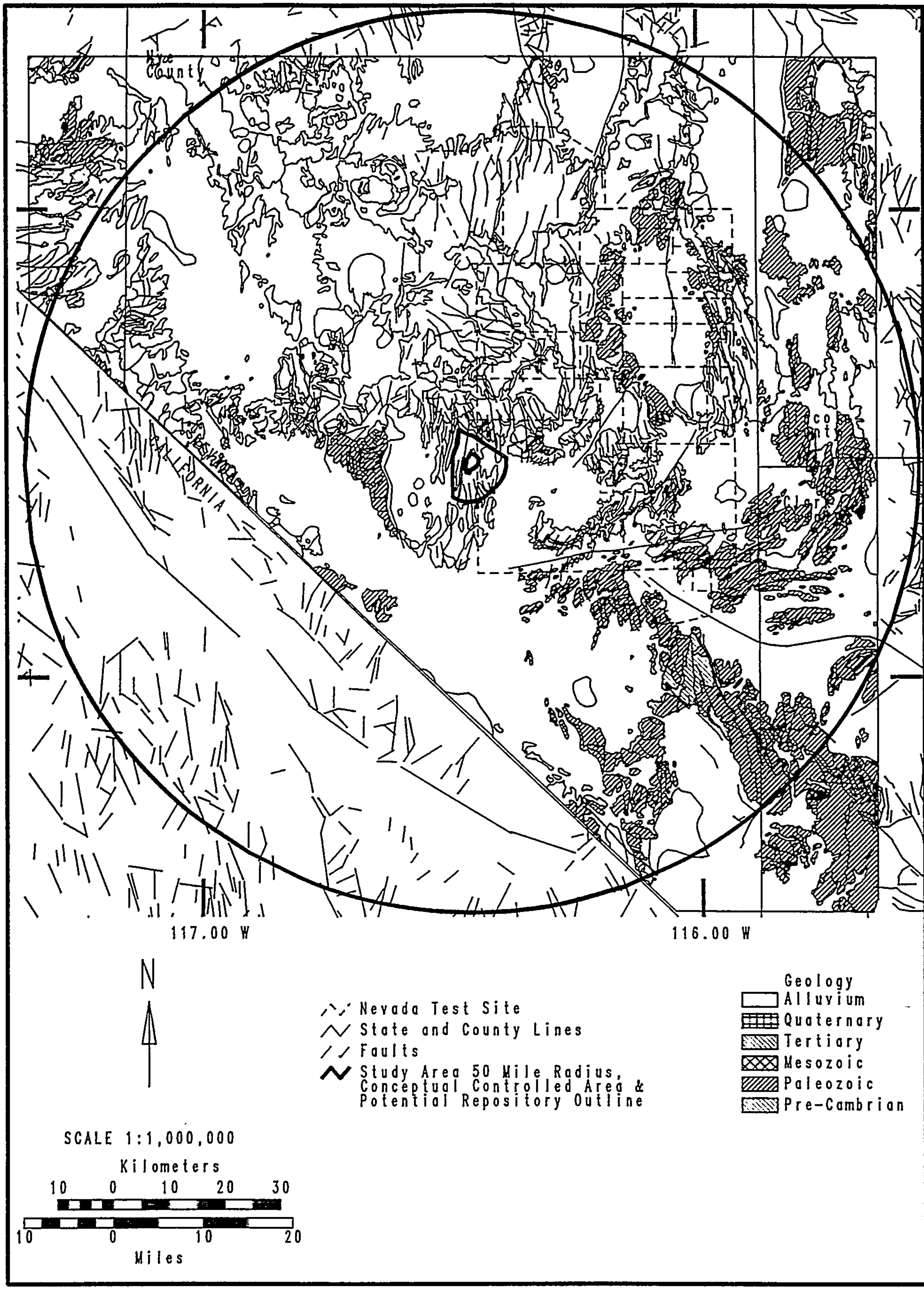


Figure 9. Geology map with only the pre-Mesozoic rock assemblages shaded.

Mesozoic rocks in the study area are restricted to two small outcrops (Gold Meadow and Climax stocks) of medium-grained, porphyritic intrusive rocks composed mostly of granodiorite (Figure 10). These rocks are exposed in the very northern part of the NTS and have been fission-track dated at 90 to 100 Ma. A larger outcrop of Mesozoic intrusive rock occurs west of the NTS on the California-Nevada border.

Cenozoic rocks occur throughout the study area and constitute the vast majority of outcrops. Surface exposures (Figure 11) consist of thick, moderately- to gently-dipping, Miocene ash-flow tuffs, lavas, and volcanic breccias. Most are associated with voluminous ashflow eruptions from the Southwestern Nevada Volcanic Field. These rocks range in composition from rhyolite to dacite. Surface mapping (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Frizzell and Shulters, 1990) and subsurface data from core holes, exploration shafts, and drill holes (Caporuscio and others, 1982; Carroll and others, 1981; Geslin and Moyer, 1995; Geslin and others, 1995; Moyer and Geslin, 1995) provide sufficient data to present a geologic model of the Yucca Mountain area. Stratigraphic nomenclature in published reports has remained generally consistent with Christiansen and Lipman (1965), Lipman and McKay (1965), Orkild (1965), Byers and others (1976), and Frizzell and Shulters (1990). Quaternary-age rocks, shown in Figure 11, consist of alluvium, basaltic volcanic cones and flows, spring deposits, and playas.

Structure

The southwestern Great Basin is a complex geologic province that contains many overlapping structural trends. At least two models of the development of the structures in the study area have been proposed. Carr (1984) described the region as one that resulted largely from a volcano-tectonic depression. Hamilton (1988) suggested that the principal structural fabric is due to detachment faulting and neo-extensional tectonics. For the purposes of this assessment, the origin of the structure, in particular faults, is less important than the location of the faults and their relationship with other geological, geophysical, geochemical, and hydrologic features.

Carr (1984) identified three major structural elements in the Yucca Mountain area: strike-slip faults associated with the Walker Lane; normal faults associated with Basin and Range faulting; and volcano-tectonic features associated with the extensive Cenozoic volcanism. The Walker Lane in the area of Yucca Mountain is about 100 km wide and is characterized by low relief hills in a largely northwest-trending right-lateral shear zone. Large, tectonic, vertical displacements are not characteristic of the Walker Lane, except at intersections with Basin and Range faults.

Basin and Range elements consist of a series of north-trending, block-faulted graben systems, characterized at the surface by prominent ranges and relatively deep and narrow alluvium-filled valleys. Basin and Range structures are the result of Miocene-Quaternary vertical displacements on north-trending faults.

The principal structural volcanic features in this area are associated with the Southwestern Nevada Volcanic Field. These features include the boundaries of the Timber Mountain, Oasis Valley, Silent Canyon, Black Mountain, and proposed Crater Flat calderas (Christiansen and others, 1977). These features are all located within the Walker Lane Belt.

The distribution of faults in the Yucca Mountain area are also shown on Figure 8 and include the prominent Walker Lane-related faults illustrated in the Death Valley area southwest of Yucca Mountain, the Basin and Range style faults exposed in the Tertiary volcanics, and the Las Vegas

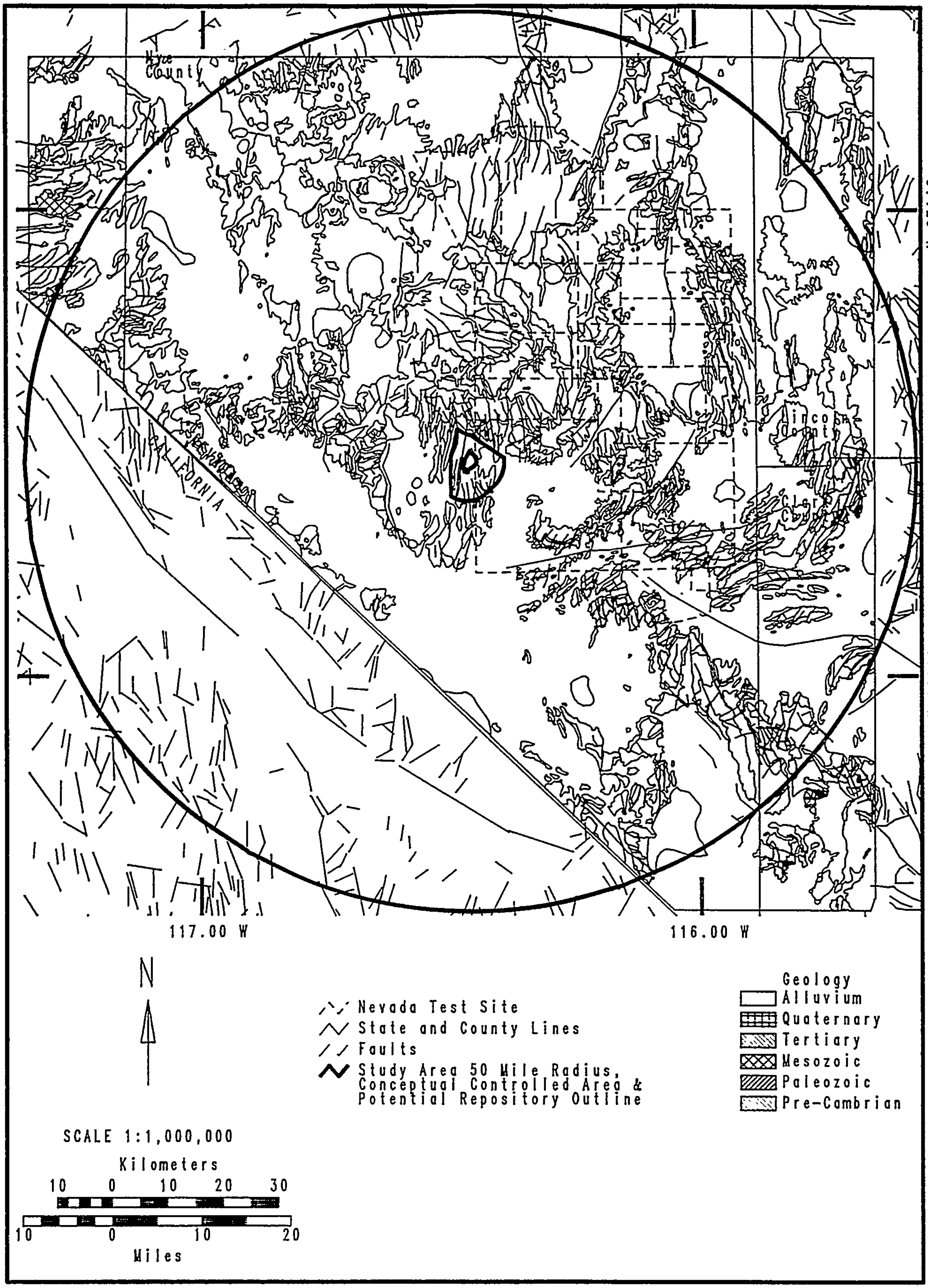


Figure 10. Geology map with only the Mesozoic rock assemblages shaded.

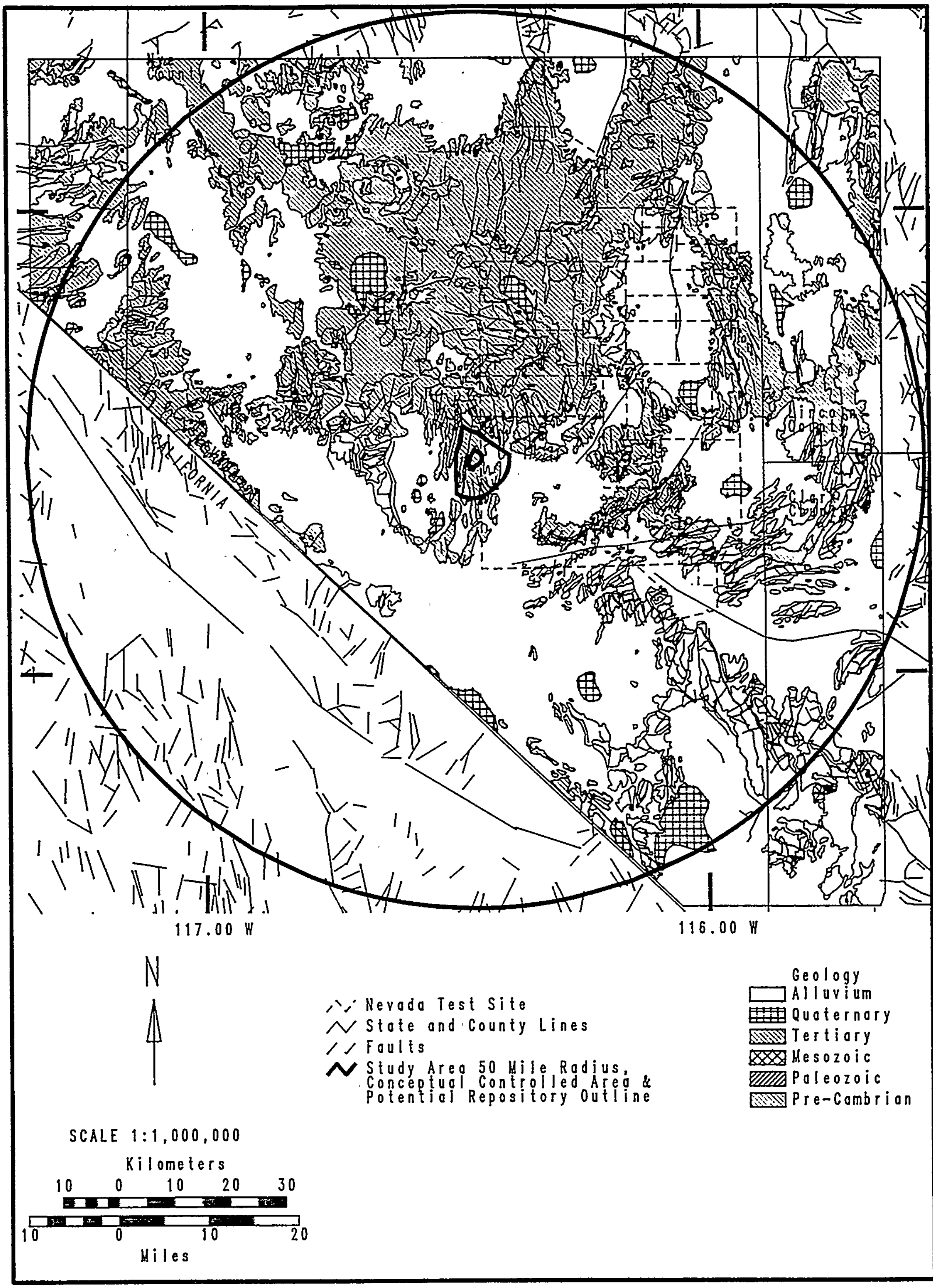


Figure 11. Geology map with only the Cenozoic (Tertiary and Quaternary) rock assemblages shaded.

Shear Zone southeast of the Yucca Mountain area. Extensional tectonism has occurred in the Basin and Range since late Eocene or early Oligocene time, but a distinction between extensional tectonics and Basin and Range faulting has been emphasized by Zoback and others (1981). Two important extensional phases that overlap in time have been identified in the history of the Basin and Range.

1. Older extensional faulting associated with voluminous silicic volcanism from latest Eocene to middle Miocene time (Crowe, 1978; Dickinson and Snyder, 1979). Such faults are characterized by right-lateral, strike-slip movement; and,

2. Basin and Range style faulting, middle Miocene and younger, which controls the present day topography (Stewart, 1978). These are largely north- and northeast-trending faults. Most of the major thermal springs in the northern Basin and Range are associated with such faults.

Low Sun-Angle Photography and Remote Sensing Analysis

Approximately 1,600 frames of low sun-angle aerial photographs (LSAP) were obtained by the Nevada Bureau of Mines and Geology during the late summer and fall of 1987. The set includes both morning and afternoon sun-angle aspects at scales of 1:12,000 and 1:6,000. Frames 6-5-14 through 6-5-28 were examined in May, 1995, to determine the accuracy of several surficial geology maps prepared for the study area.

Many structural features apparent on alluvial surfaces were not noted on the surficial geology maps prepared before 1987 (Swadley, 1983; Swadley and Carr, 1987; Swadley and Parrish, 1988). More detailed studies by Faulds and others (1994) and by Donovan (1991) indicate that many more subtle structural features are present on the alluvial surfaces in the area of Yucca Mountain. Subtle surficial structures on alluvial surfaces can be used to ascertain the location of buried faults that control the location of hot springs (Trexler and others, 1980b; Trexler and others, 1981; and Trexler and others, 1982). LSAP is only one method used in a comprehensive geothermal assessment study.

A regional study of lineaments in the southern Walker Lane by Walker (1986) identified many features which extend more than 1.5 km in length in the vicinity of the potential repository. Faults with both north- and northwest-trends were identified in the vicinity of Yucca Mountain. The data indicate that movement along northwest-trending structures in the southern Walker Lane may have ended 6 Ma. Walker (1986) suggests that focal plane solutions indicate that normal and left-lateral strike-slip motion should occur along sparse northeast-trending faults. She suggests that future detailed studies of recent fault activity in the southern Walker Lane vicinity concentrate on north- and northeast-trending structures rather than those trending northwest. Although the north- and northeast-trending structures are apparently younger, there does not appear to be any correlation between the presence of hot springs and these structures (Figure 12). These features are not considered to be indicative of near surface (<1 km deep) or deeper geothermal resources.

A composite color, unfiltered, Landsat Image (Frame 043-034) obtained on October 8, 1976, was examined with Ronchi ruling plates (line spacing of 200 and 300 lines/inch) to delineate parallel and conjugate lineament features. Based on other geophysical and geological data reviewed in this investigation, the lineament analysis of Landsat imagery defined areas of older tectonic displacement, in agreement with the findings of Walker (1986) and consistent with previous work by Trexler and others (1978).

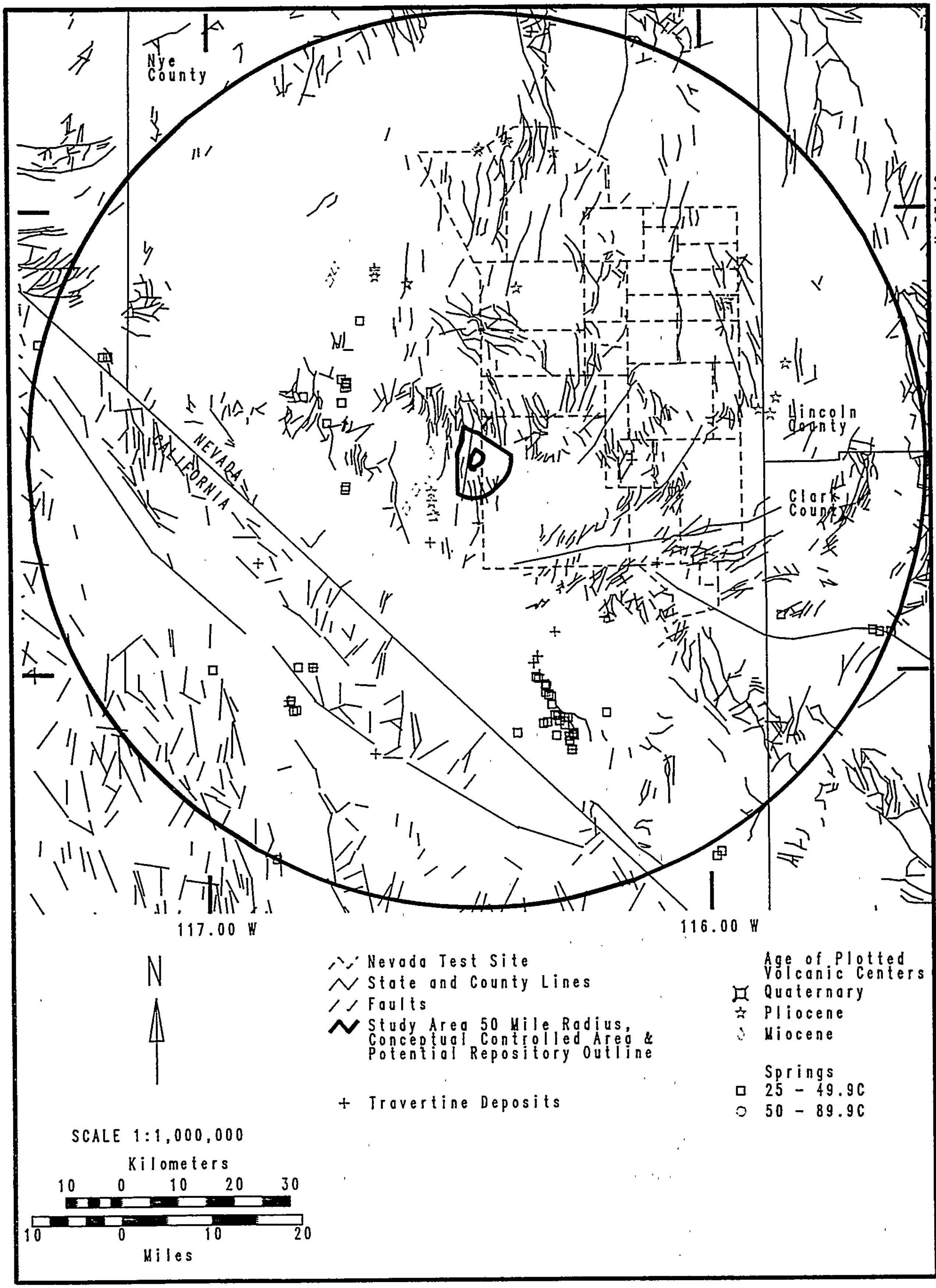


Figure 12. Geologic faults and surface thermal manifestations, including warm springs, volcanic centers and vents, and deposits of siliceous sinter.

Surface Thermal Manifestations

Neogene volcanism associated with the silicic multicaldera volcanic field in the vicinity of Yucca Mountain (the Southwestern Nevada Volcanic Field) began about 15.2 Ma. This period of igneous activity ended in the central cluster of calderas (25 km or less to the north of Yucca Mountain) at about 11.5 Ma. A later period of volcanism, from about 7 to 9 Ma, is recorded in the Black Mountain and Stonewall Mountain volcanic centers, located approximately 50 and 100 km, respectively, to the northeast of Yucca Mountain (Sawyer and others, 1994).

Basaltic volcanism in the Yucca Mountain area is part of a post-6 Ma volcanic episode that produced a number of basaltic volcanic centers in a zone from southern Death Valley to the Pancake Range in south-central Nevada (Smith and others, 1990; Vaniman and others, 1982). In the immediate vicinity of Yucca Mountain, in Crater Flat and at the nearby Lathrop Wells Cone, basalts ranging in age from 3.5 Ma to possibly as young as 10 ka are found as small scoria cones, short lava flows, and associated dikes (Smith and others, 1990). These basalts are hawaiites typical of areas of crustal extension in the Basin and Range and elsewhere in the world, and are believed to have been derived from a mantle source without crustal contamination (Vaniman and others, 1982). Figure 12 shows the distribution of the volcanic areas in the vicinity of Yucca Mountain.

Potential Heat Sources

Silicic volcanism located close enough to Yucca Mountain to have provided heat to the local hydrologic regime ended more than 11 Ma. Magma bodies below larger calderas (>10 km diameter) cool slowly and may be heat sources for up to 2 Ma (Wohletz and Heiken, 1992). Calculations based on theoretical cooling models (Smith and Shaw, 1978) indicate that magma chambers associated with calderas of the central zone of the Southwestern Nevada Volcanic field would have completely crystallized and cooled to ambient temperature several million years ago. Additionally, Sass and others (1988) report that the heat flux at Yucca Mountain is controlled by fluid flow in the Paleozoic carbonate aquifer at depth; thus, heat flow data do not indicate any perturbations in the vicinity of the Southwestern Nevada Volcanic field that could be correlated with residual heat from these old magmatic systems.

The individual basaltic eruptions in the Yucca Mountain area are of small volume, and are apparently the products of mantle-derived magma that rose quickly through the crust with little or no contamination. The absence of associated derivative rocks of more silicic affinity suggests that long-lived magma chambers were not established in the crust; instead, the mafic melts seemingly rose directly from the mantle to the sites of eruption. The conduits for these high-temperature (≈1,200°C), low-viscosity magmas are believed to be narrow pipes and fissures (Smith and Shaw, 1975). The eruptive volumes of the Crater Flat basalts are small (0.3 to 1.5 km^3 for each center), as is the cone density (spacing) (Wohletz and Heiken, 1992). Such isolated basaltic vents in a continental setting do not have high-level magma chambers and represent short-term events with little value as a heat source (Edwards and others, 1982). Therefore, they are not believed to contribute significant amounts of heat to the upper crust. The dikes and pipes that feed such isolated, small volume centers do not provide sufficient long-term crustal heat to drive a geothermal system (Delaney, 1987; Wohletz and Heiken, 1992). Therefore, the basalts of the Crater Flat area southwest of Yucca Mountain are not likely sources of heat for geothermal fluids.

Thermal Springs

The closest warm springs to Yucca Mountain are those at Beatty, 20 km to the west. Warm springs in the Amargosa Desert to the south are nearly 50 km away, although warm-water wells are known to be only 20 km to the south. No warm springs have been reported in the immediate vicinity of Yucca Mountain. The Beatty area springs are separated from Yucca Mountain by Bare Mountain and are on a carbonate-aquifer flow path that is not believed to be closely connected to the one under Yucca Mountain (Mifflin, 1968). The Amargosa Desert springs likely represent discharge from the carbonate aquifer present several thousand meters below Yucca Mountain.

Spring Deposits

A search of geologic maps and hydrogeologic literature related to an area within 50 miles of Yucca Mountain was made to find any mention of siliceous or calcareous spring deposits (sinter, travertine, or spring tufa). The presence of sinter is evidence for a hot-water system with present or past subsurface temperatures of more than 180°C (White and others, 1971). There is no mention in the literature of spring sinter of Quaternary age in this area, suggesting that no thermal fluids have discharged to the surface in this area in the last 1.6 Ma from high-temperature reservoirs.

In southern Nevada and adjacent California, many flowing springs associated with extensive areas of travertine are interpreted as discharging from a regional carbonate aquifer as the apparent result of interbasin flow. These springs have several characteristics that suggest their connection to the carbonate aquifer: steady discharge, a temperature of 6 to 15°C above the mean annual air temperature, little change in chemistry with time, larger discharge than would be expected from surface drainage from the surrounding area, the presence of fractured carbonate rocks in the area, and higher pCO_2 and calcite saturation indices than other springs in the area (Mifflin, 1968; Miller, 1977; Quade and others, 1995). Travertine deposition at the ground surface results from the liberation of CO_2 and subsequent supersaturation of the water with $CaCO_3$. Travertine deposits are commonly indicators of low-temperature geothermal reservoirs whose temperature is too low for siliceous sinter to be deposited. In general, springs associated with travertine throughout the world range in temperature from approximately 30 to 100°C (Wohletz and Heiken, 1992).

Calcareous spring deposits (spring tufa and travertine) are known from a number of areas south of Yucca Mountain, especially in Ash Meadows and northern Death Valley. No sites are reported from the region north of Yucca Mountain; this is an area of recharge and relatively deep groundwater. The sites of extensive travertine in the Lathrop Wells - Ash Meadows area are believed to be deposits from presently active and extinct springs that discharge, or previously discharged, waters derived from the regional carbonate aquifer (Winograd and Thordarson, 1975; Winograd and Doty, 1980). A few of the smaller areas of calcareous spring deposits near the south end of Yucca Mountain (Southern Crater Flat and Southern Yucca Mountain localities) may have been deposited from small-volume springs or seeps that derive their waters from the upper volcanic aquifer or the valley fill. The springs that deposited the large areas of travertine likely resembled the large-flow springs in Ash Meadows and Death Valley today, and were probably moderately warm (≈30 to 40°C). However, smaller flow springs that deposited some small areas of calcareous deposits were not necessarily anomalously warm (> 10°C above ambient temperature). The spring deposits described further below likely range in age from less than 10 ka to several hundred thousand years, and some sites have travertine of more than one age.

In summary, available information on spring deposits in the vicinity of Yucca Mountain indicates that presently flowing or pre-existing springs at these sites were or are only moderately warm (probably 30 to 40°C). Sites of calcareous spring deposits closest to the Conceptual Controlled Area (CCA) may represent extinct springs that were not anomalously warm. There is no indication from the spring deposit data that the Yucca Mountain CCA has potential for anything but low-temperature geothermal resources (and those only at depth).

The majority of sites of calcareous spring deposits and calcitic veins within 50 miles of the Yucca Mountain CCA are described briefly below. It is likely that at least some small areas of spring deposits are present (but not reported in the scientific literature) at other sites in the Ash Meadows - Death Valley area.

Keane Wonder Spring - Miller (1977, p. 32) reports that this spring site is located near the south end of a large mound-like mass of gray to tan travertine that marks old discharge sites. The location of the spring is near the north end of Death Valley, at 36.6817°N, 116.8989°W; the temperature is 20°C (data source, D. Perfect database).

Nevares Springs - These springs, located a few miles north of Furnace Creek in Death Valley (36.5120°N, 116.7910°W) emerge from a large travertine mound (Winograd and Thordarson, 1975; Pistrang and Kunkel, 1964). The mound of tan colored travertine is reported to be about 300 m in diameter (Leivas and others, 1981, p. 144). The reported temperature was 39°C in 1968 (data source, T. Flynn database).

Texas Spring - This spring area is located about 1.5 km east of Furnace Creek in Death Valley; it has a reported temperature of 33°C in 1970 (data source, T. Flynn database). Several areas of spring travertine are described from this area (Pistrang and Kunkel, 1964), specifically to the northwest and southwest of Texas Spring (respectively, 36.4584°N, 116.8393°W and 36.4503°N, 116.8393°W).

Devils Hole - A travertine mound is reported from Devils Hole (Szabo and others, 1981) in the Ash Meadows area (36.4270°N, 116.2880°W). Calcitic veins related to the travertine are reported nearby, and fossilized vegetative mats are reported from about 800 m west-southwest of Devils Hole (Winograd and Doty, 1980). The spring had a temperature of 34°C in 1990 (data source, T. Flynn database).

Big Spring - Quade and others (1995) report that the waters of the active spring at Big Spring (36.3750°N, 116.2736°W) produce travertine. The temperature was approximately 29°C in 1990 (data source, T. Flynn database).

Point-of-Rocks (King) Spring - The waters of this spring (31.7°C in 1995; data source, D. Perfect database) are reported to produce travertine (Quade and others, 1995) and tufa spring mounds (Winograd and Doty, 1980). The location is 36.4017°N, 116.2717°W.

East of Lathrop Wells - Kral (1951, p. 207) describes two areas of travertine veins in limestone from an area about 20 km east of Lathrop Wells (now the community of Amargosa Valley). The veins are described as 4 to 5 feet wide; they may represent the roots of travertine spring deposits. Approximate locations for the two localities are: 0.75 km north of the highway (36.5901°N, 116.2063°W) and 1.5 km south of the highway (35.5587°N, 116.2144°W). Winograd and Doty (1980, Table 1) report two calcitic vein sites from the area south of the highway.

Wahmonie travertine/gypsite mound - This mound of spring deposits is located in SW/4 Sec. 35, T12S, R52E, in the Wahmonie mining district. Gypsite and travertine are reported from the spring mound (Hill and Schluter, 1993). A longitude-latitude location is reported in the Yucca Mountain Site Characterization Project Site Atlas (EG&G Measurements, 1993) as 36.8447°N, 116.1469°W.

Travertine Point Area - Travertine deposits are reported from an area about 26 km west of Death Valley Junction. The deposits are associated with a swarm of nearly vertical, dense and finely laminated calcite veins. One reported location is NE/4 Sec. 18, T26N, R3E. A general location near Travertine Point is 36.3715°N, 116.6656°W.

North of Fairbanks Spring - According to Winograd and Doty (1980), dense travertine is reported from float about 800 m northeast of Fairbanks Spring (116.3368°W; 36.4963°N) and three areas of calcitic veins are found in an area approximately 3 to 9 km north and northeast of the spring (116.3368°W, 36.4963°N; 116.3478°W, 36.5162°N; 116.3399°W, 36.5270°N; 116.3049°W, 36.5664°N). Several kilometers further north, tufa or calcrete is reported from a site near the northeast end of the Skeleton Hills (Szabo and others, 1981, locality 154 and 155). A sample from locality 155 gave an age of 70 to 110 ka for the carbonate material.

Mercury Valley - Several calcite (travertine) veins cut bedrock in the northwest part of Mercury Valley (Winograd and Doty, 1980; Szabo and others, 1981). These veins are likely the roots of pre-existing calcareous spring deposits. They are found at several sites in an area of 5 to 10 km². The area is centered on the approximate location 36.6777°N, 116.0990°W. The carbonate material from this area ranges in age from 70 to >700 ka (Szabo and others, 1981).

Southern Crater Flat - Nodular, spring-deposit tufa is reported from near the southern end of Crater Flat (Szabo and others, 1981, sample 199). An approximate location is 36.7137°N, 116.5521°W. A sample from this site yields an age of about 30 ka; this suggests spring activity was at an altitude of 838 m as late as 30 ka (Szabo and others, 1981), yet the present water table is about 120 m lower (Winograd and Thordarson, 1975). The discharge from this spring likely had a source in the upper volcanic or valley fill aquifers. There is no indication that it was anomalously warm.

Southern Yucca Mountain - Seep-deposited tufa or calcrete is reported from a location near the southern end of Yucca Mountain (Szabo and others, 1981, locality 106; Hill and Schluter, 1993, locality 17). An approximate location is 36.7448°N, 116.4556°W. Szabo and others (1981) report an age of 5 to 78 ka) for this material. When this seep was active, it probably had a source in the upper volcanic or valley-fill aquifers, and probably was not anomalously warm.

Fault-controlled thermal springs are mapped in the vicinity of Beatty, Oasis Valley, and in various parts of the Amargosa Desert (Figure 12). In addition, recent volcanic centers, such as Crater Flat, show a preferred north-south alignment along mapped faults. However, the correlation of faults to springs in the study area is spotty, occurring in isolated pockets, without the regional and systematic trend that is found in the northern Great Basin.

Geochemistry

Major and Trace Elements

Groundwaters in the Yucca Mountain vicinity occur in volcanic tuffs, in alluvial and other near-surface unconsolidated deposits, and in the regional carbonate aquifer at depth. However, at Yucca Mountain itself, near surface waters are absent, and the groundwaters occur at depths greater than 300 m within tuffs and the carbonate aquifer below.

A detailed description of the compilation and manipulation of chemical data from five databases appears in Appendix 1. Where sufficient data are available, Piper diagrams (Piper, 1944) were constructed to show the major chemical trends of waters in different lithologies. These plots were constructed to present background information on water quality of different waters in the study area, and they allow for comparisons to be made with water chemistry at the Yucca Mountain site. The plots illustrate the gross similarities and differences in water chemistry throughout the study area, The RockWare Utilities software (RockWare Earth Science Software, 1994) was used to construct the plots. Diagrams were constructed for the entire study area with different symbols representing waters from different lithologies. In addition, one plot of waters solely from the Yucca Mountain CCA was constructed to show the chemical features present specifically at the site. From the data compiled in the combined database created in the current work, a total of 17 wells occur on Yucca Mountain. Five of the sites had insufficient data from which to construct the diagrams. No lithologies were noted for several of the other wells. Hence, U.S. Geological Survey reports were consulted to obtain this information; the references for the individual wells are:

UE-25 b#1	Lahoud, 1984	USW H-4	Erickson and Waddel, 1985
USW G-4	Lobmeyer, 1986	USW H-5	Robison and Craig, 1991
USW H-1	Rush and others, 1983	USW VH-1	Rosenbaum and Snyder, 1984.

Figures 13 through 22 are Piper diagrams with the chemical composition of waters plotted on separate graphs by lithology. Lithologic groupings are based on available data within the compiled geochemical database. Circles show the total dissolved solids (TDS) of the individual sample, where the diameter of the circles shows the TDS in mg/l as indicated on the scale located on each plot. These plots show samples from the Yucca Mountain CCA and from the region within 50 miles.

The data used in these plots was retrieved from the combined database prepared for this work. Most of the wells did not have a notation to indicate which type of lithology was encountered in the completion interval of the well. The waters plotted on these figures are those which contained a notation for lithology, and these data were presumably entered into their respective databases based on notations in the original driller's log. As is typically the case, there can be significant variation in the manner in which different driller's report lithologies that were encountered. For instance, many of the entries for carbonate rocks simply listed a general classification of "carbonate aquifer" whereas other entries were more specific, indicating the well was completed in "dolomites", which are included in the general classification of carbonate aquifer. Similarly, tuffs and rhyolites were specified in some cases, whereas the less specific designation of "Tertiary volcanics" was noted in other entries. Distinction between the alluvial aquifers was also made such that different entries indicated either "valley fill," "alluvial aquifer," or "gravel aquifer." Although it cannot be verified what classification scheme individual loggers may have used, it is assumed that the valley fill and alluvial aquifer are essentially the same (unconsolidated deposits with no distinction in grain size), whereas the gravel aquifer was presumably designated based on the larger size of the material (gravel, cobbles, etc.). In addition, presumably all of the "clastic rocks" are Paleozoic in age. No attempt was made in this work to verify or qualify that data in the databases because this activity was beyond the scope of the project.

Figures 13 through 16 show data for the shallower, unconsolidated aquifers, and considerable variability in the waters is evident. Two general types of waters occur in valley fill aquifers, all with relatively low TDS. One type of water represented is a Na-HCO_3-SO_4 water, which tends to have higher TDS than the Ca-Mg-HCO_3 water. The chemical composition of the gravel aquifer waters also varies somewhat, but they are generally Na-HCO_3 waters with variable SO_4 and Ca. The alluvial aquifer waters and waters associated with lake beds show much greater variability in both water type and TDS (Figures 15 and 16). These waters are varied and represent relatively shallow, non-thermal waters which include both very good quality water and very saline water reflecting extensive evaporation.

The next series of plots show chemical data for sedimentary rocks (Figures 17 through 19). As expected, the waters associated with dolomites (Figure 17) are Ca-Mg-HCO_3 waters. These waters show a distinct linear trend toward increasing Na and SO_4 suggesting that some of the dolomitic waters may be mixing with a water with higher Na and SO_4 concentrations than are typical in dolomites. The waters associated with clastic rocks have higher TDS than those in dolomites in both the shallower ($\approx$20 m) and deeper ($\approx$300 m) intervals. The general character of these waters is Na-HCO_3, although the sandstones and conglomerates typically have higher SO_4 and Cl than the Paleozoic clastics and have greater amounts of Ca. The chemical composition of the carbonate aquifer waters is quite variable, as are their TDS values. Only one sample in the database indicated a differentiation between the upper and lower carbonate aquifer, and this is noted on Figure 19. The carbonate waters show variability in water chemistry, and the one sample representative of the lower carbonate aquifer is within the grouping of the other samples. As expected, the majority of the waters in the carbonate aquifer are Ca-Mg-HCO_3 waters, yet considerable SO_4 and Na are in some of the waters which suggests that mixing has occurred.

Figures 20 through 22 illustrate chemical data for waters from volcanic deposits. Generally low TDS is found in all of the formations (rhyolites, Tertiary volcanics and tuffs). The rhyolites contain Na$\pm$Ca-$HCO_3$$\pm$Cl waters whereas those in the tuffs and Tertiary volcanics are predominantly Na-HCO_3 waters $\pm$Ca and SO_4.

All the previously described plots represent data from within a 50-mile radius of Yucca Mountain. Hence, a wide variety of water types is encountered over this relatively large area. When only samples collected from Yucca Mountain are considered, there is less scatter in the water types, and most samples originate from tuffs (Figure 23). The source rocks for sites which are labeled with a "?" could not be ascertained, although the waters likely originated from tuffs. Only one carbonate aquifer sample was available at Yucca Mountain, and this was collected from UE-25 p#1 which has a total depth of 1,805 m. This sample is not typical of other carbonate samples near Yucca Mountain (Figure 19) in that it is a Na-HCO_3 water with low ($\approx$25%) Ca. This water appears to be influenced in large part by the overlying tuffs which are also Na-HCO_3 waters $\pm$ SO_4.

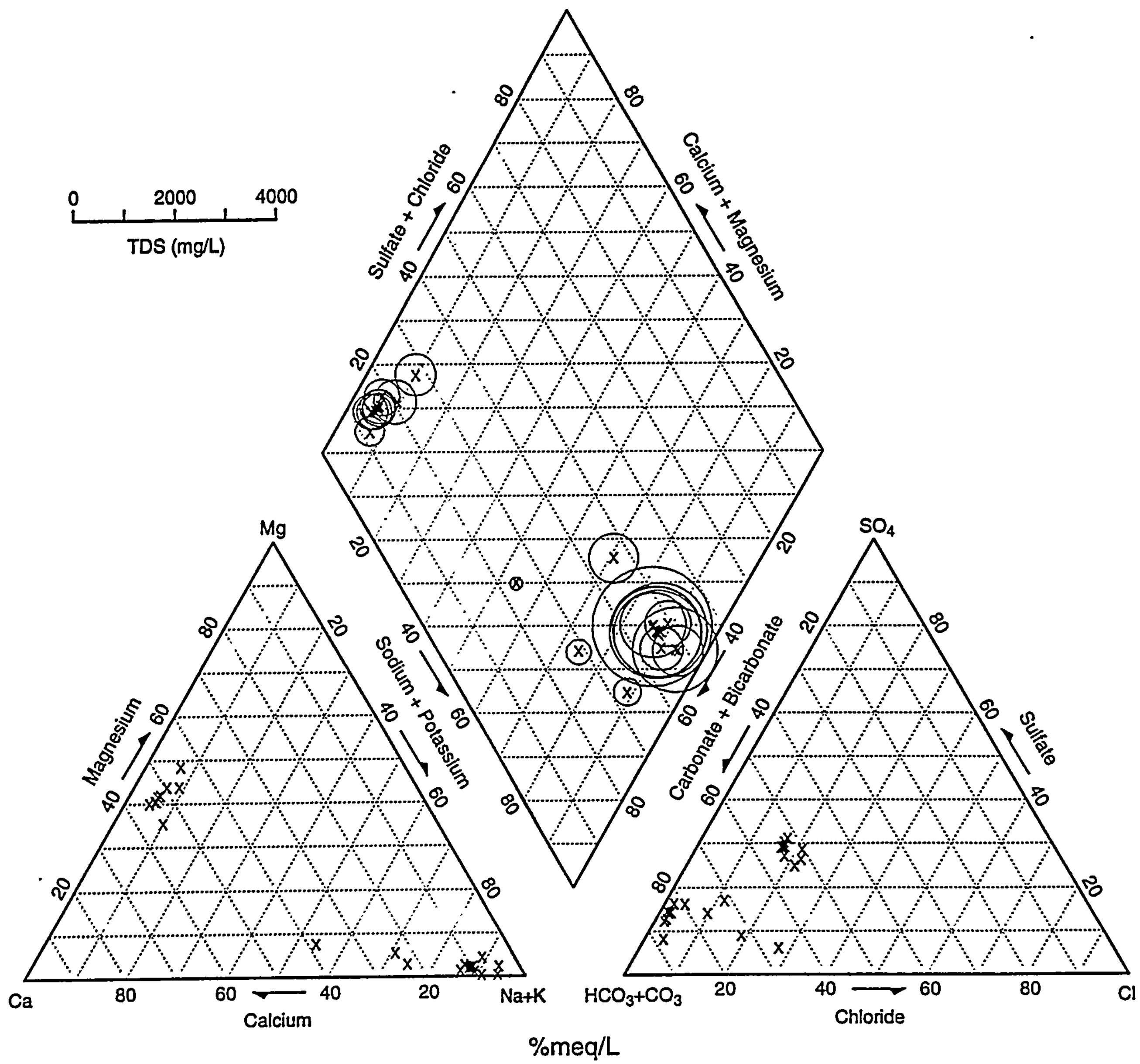


Figure 13. Piper diagram illustrating the chemical composition of waters associated with valley fill in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

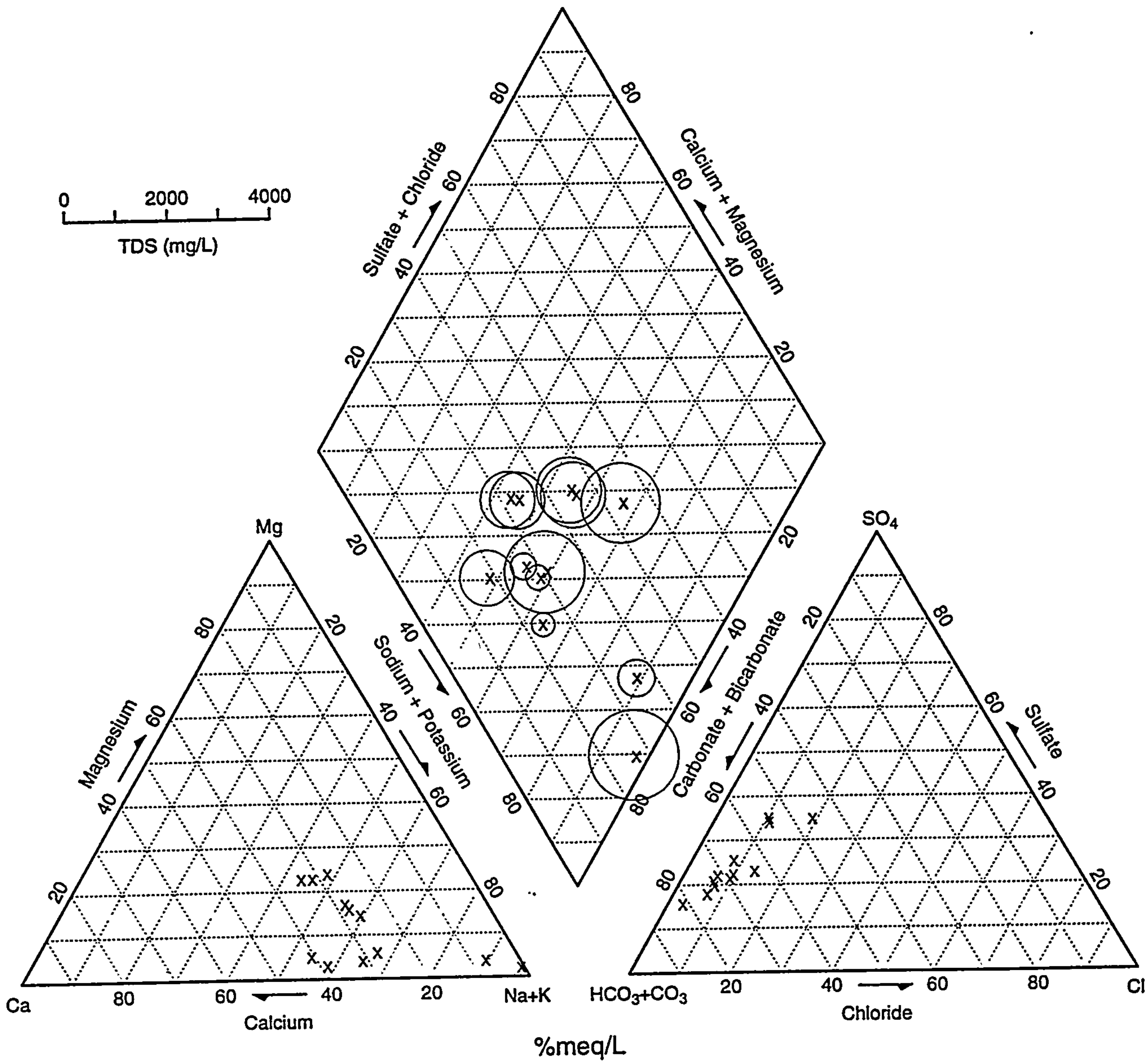


Figure 14. Piper diagram illustrating the chemical composition of waters in gravel aquifers in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

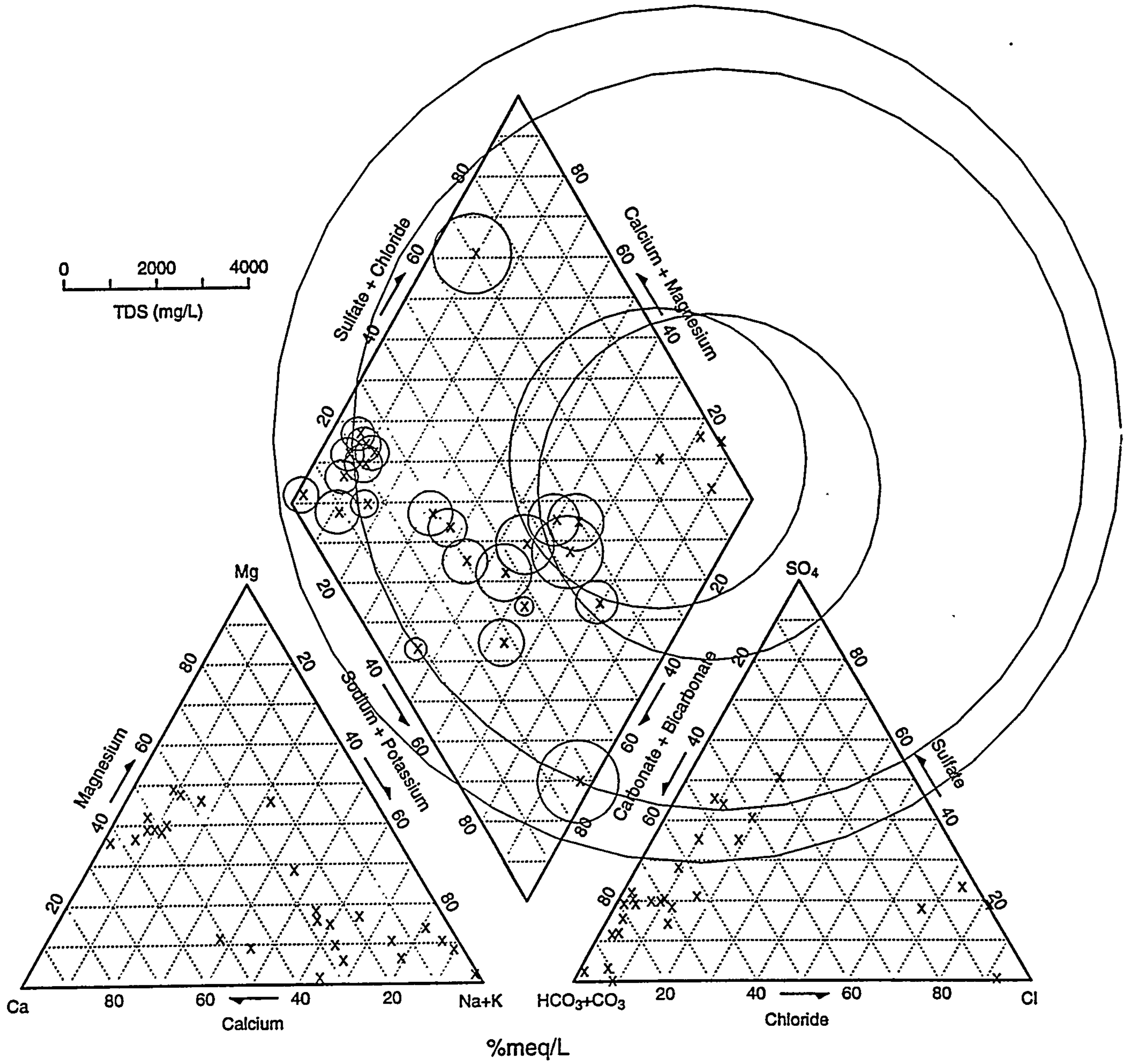


Figure 15. Piper diagram illustrating the chemical composition of waters in alluvial aquifers in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

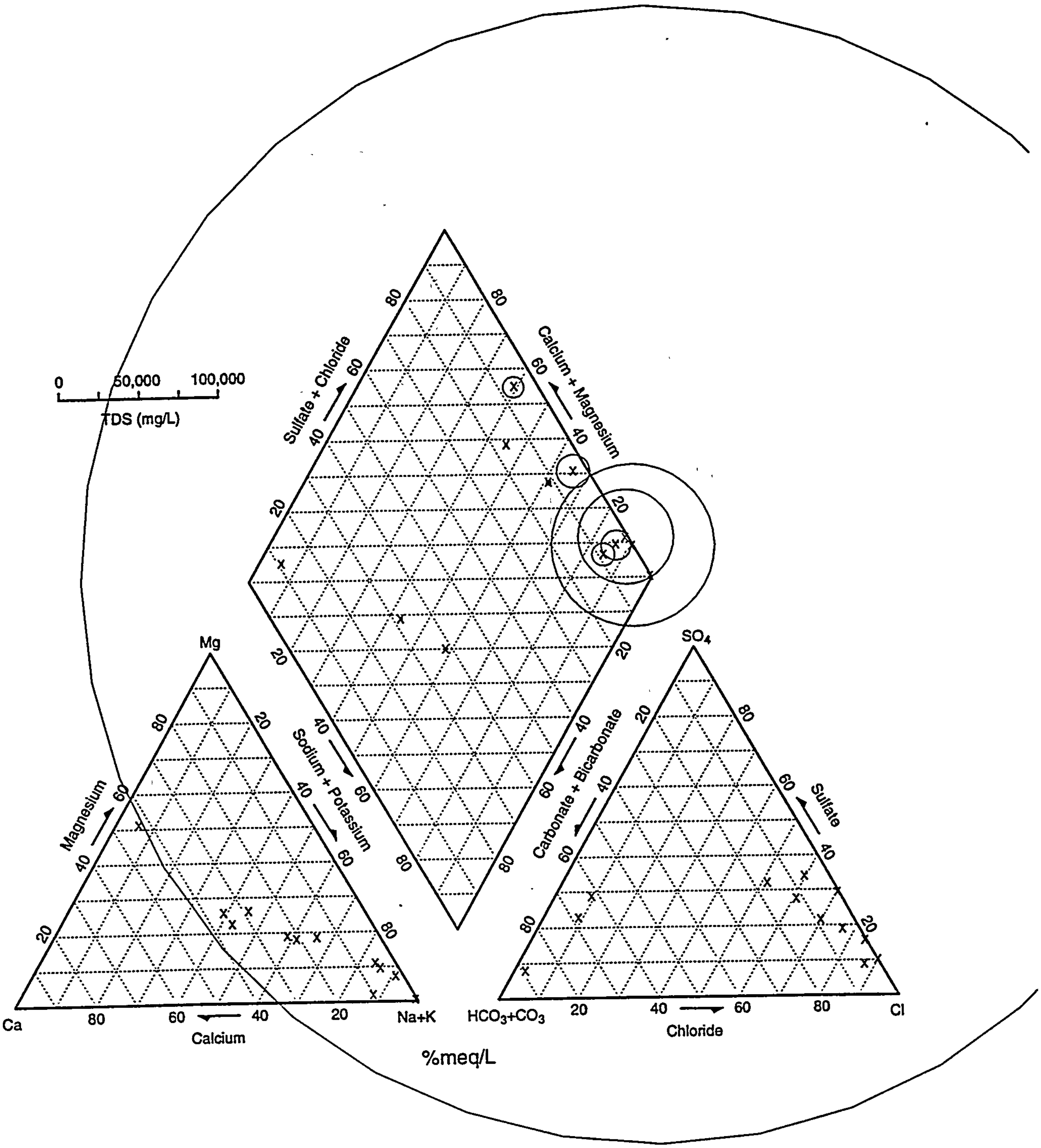


Figure 16. Piper diagram illustrating the chemical composition of waters associated with lake beds in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

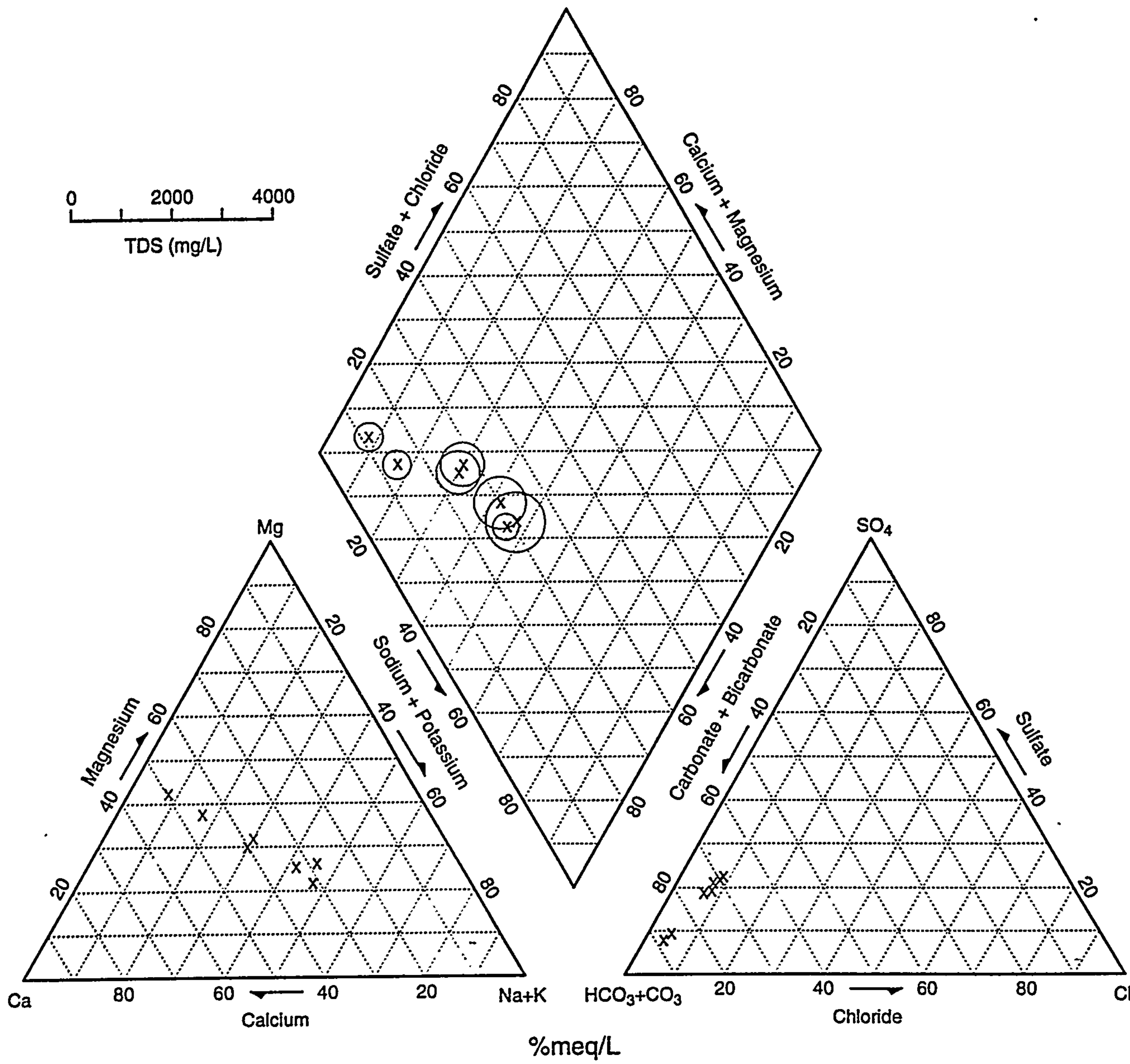


Figure 17. Piper diagram illustrating the chemical composition of waters associated with dolomites in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

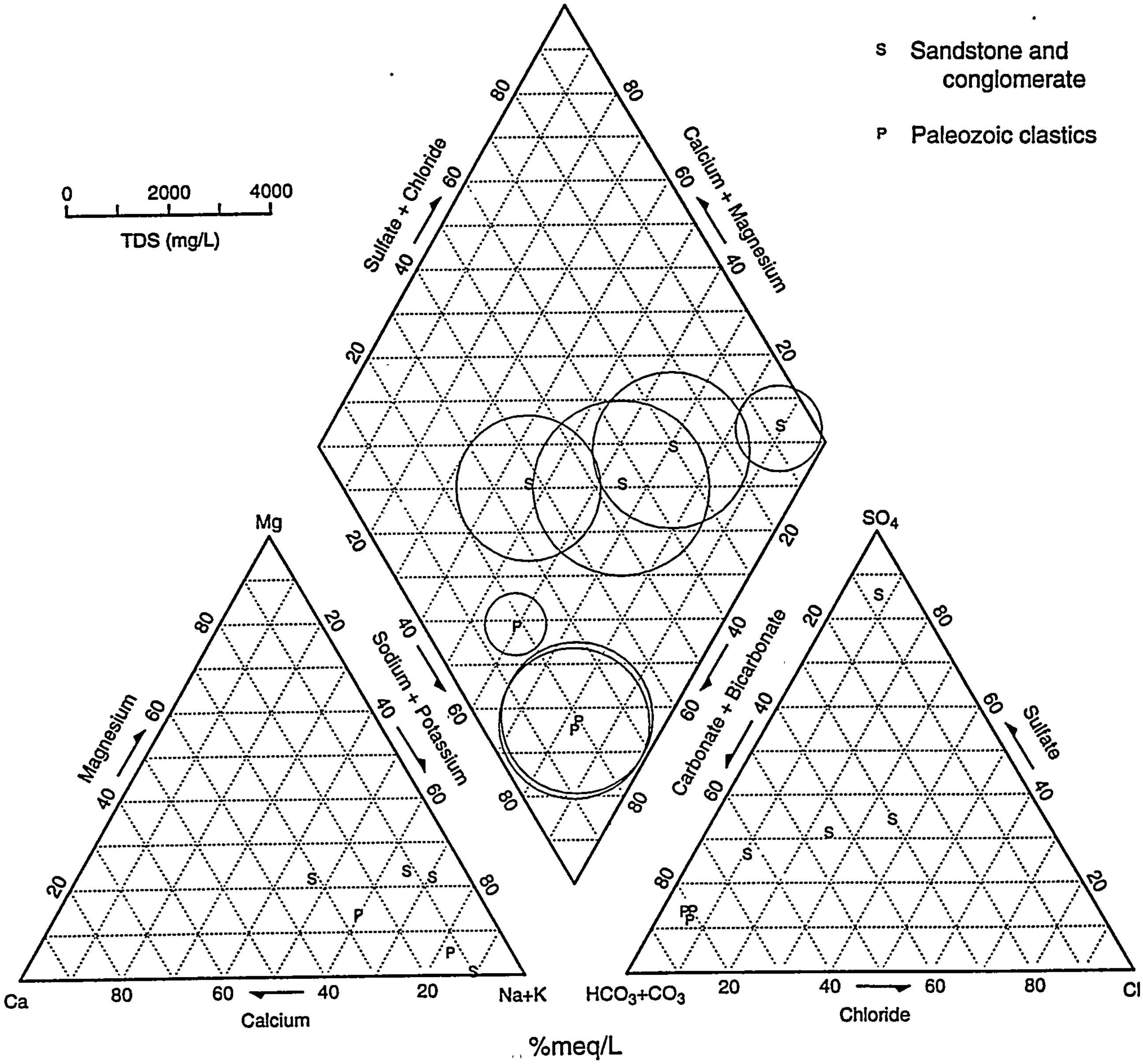


Figure 18. Piper diagram illustrating the chemical composition of waters associated with clastic deposits in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

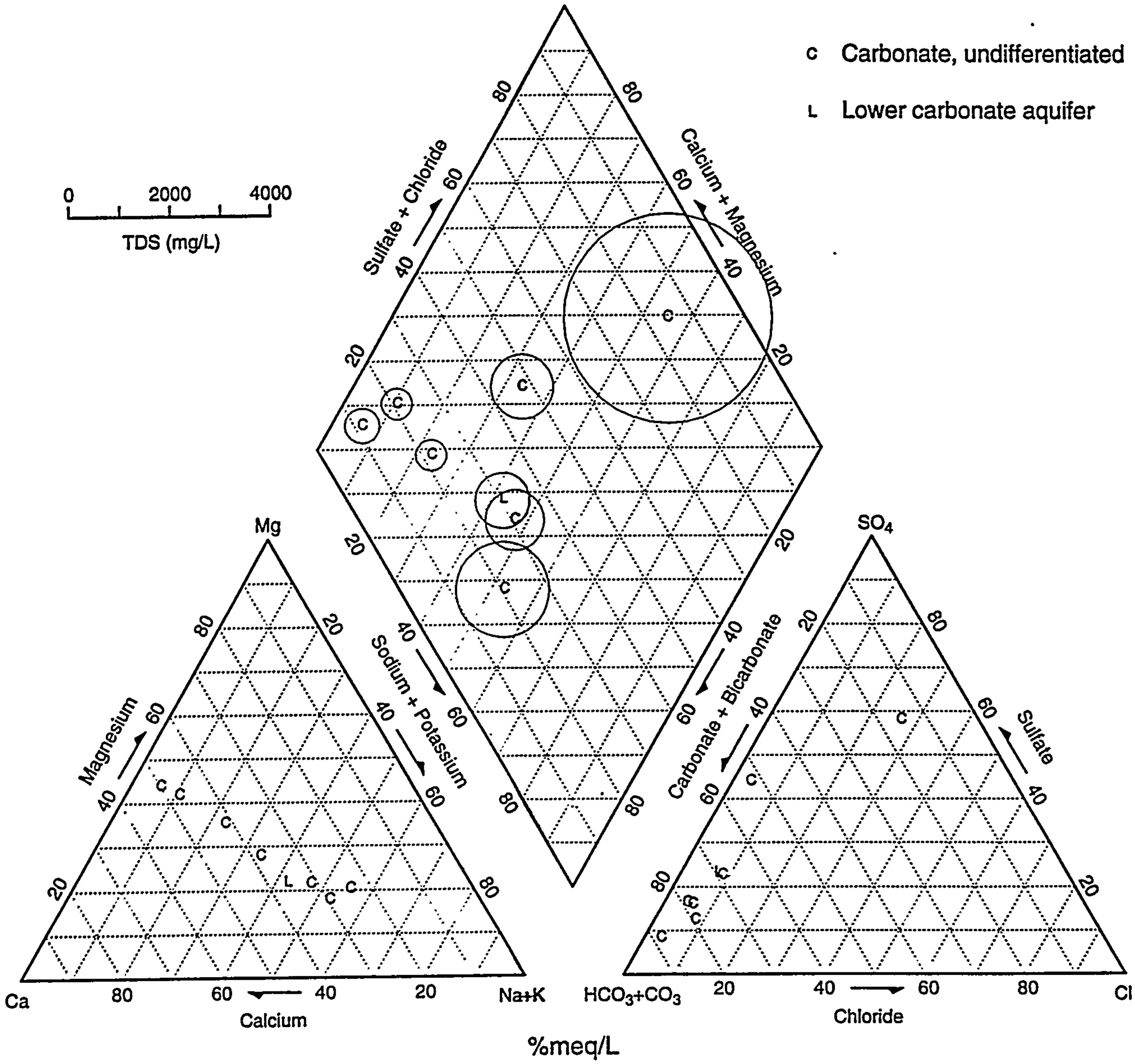


Figure 19. Piper diagram illustrating the chemical composition of waters associated with carbonates in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

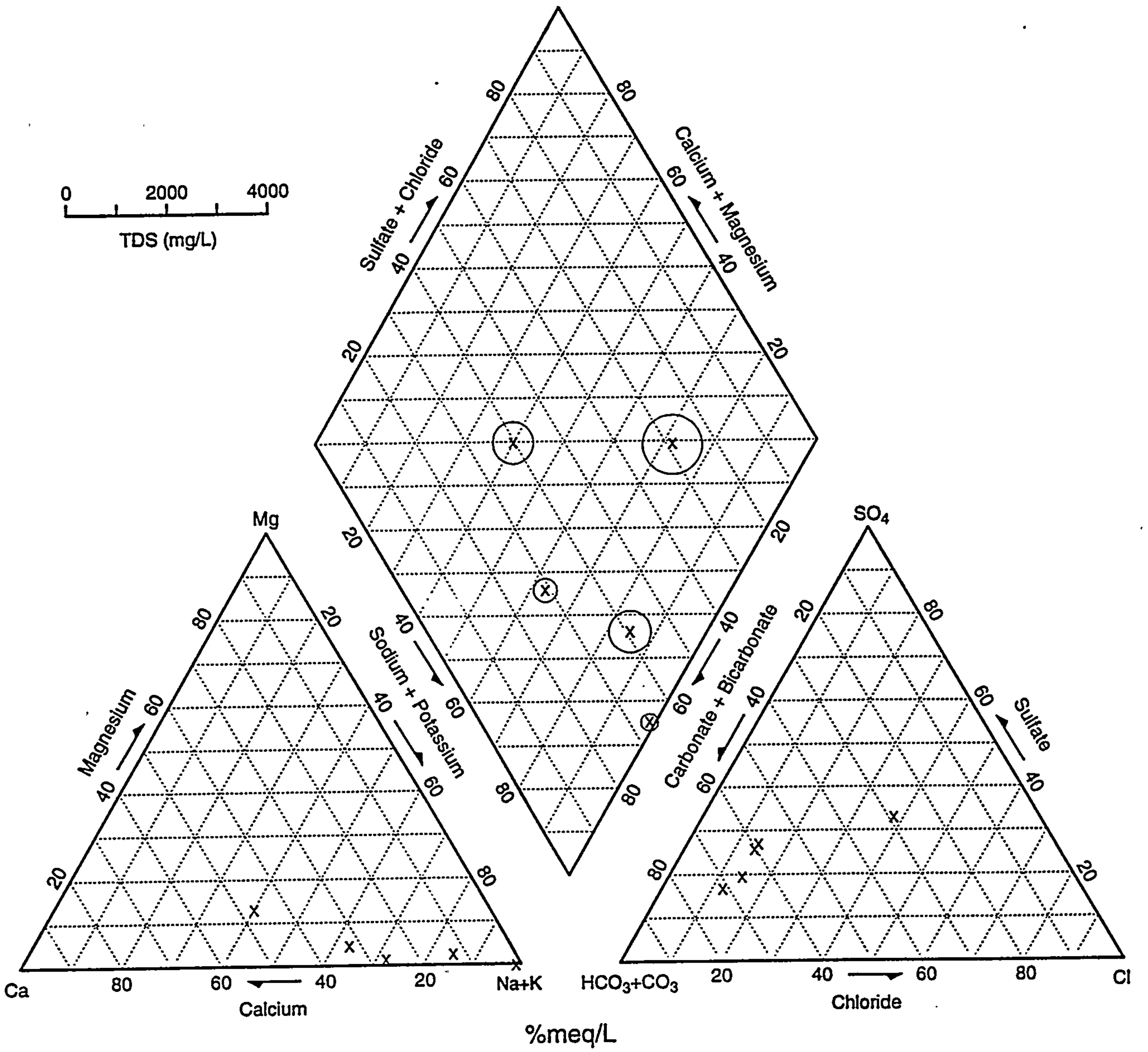


Figure 20. Piper diagram illustrating the chemical composition of waters associated with rhyolites in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

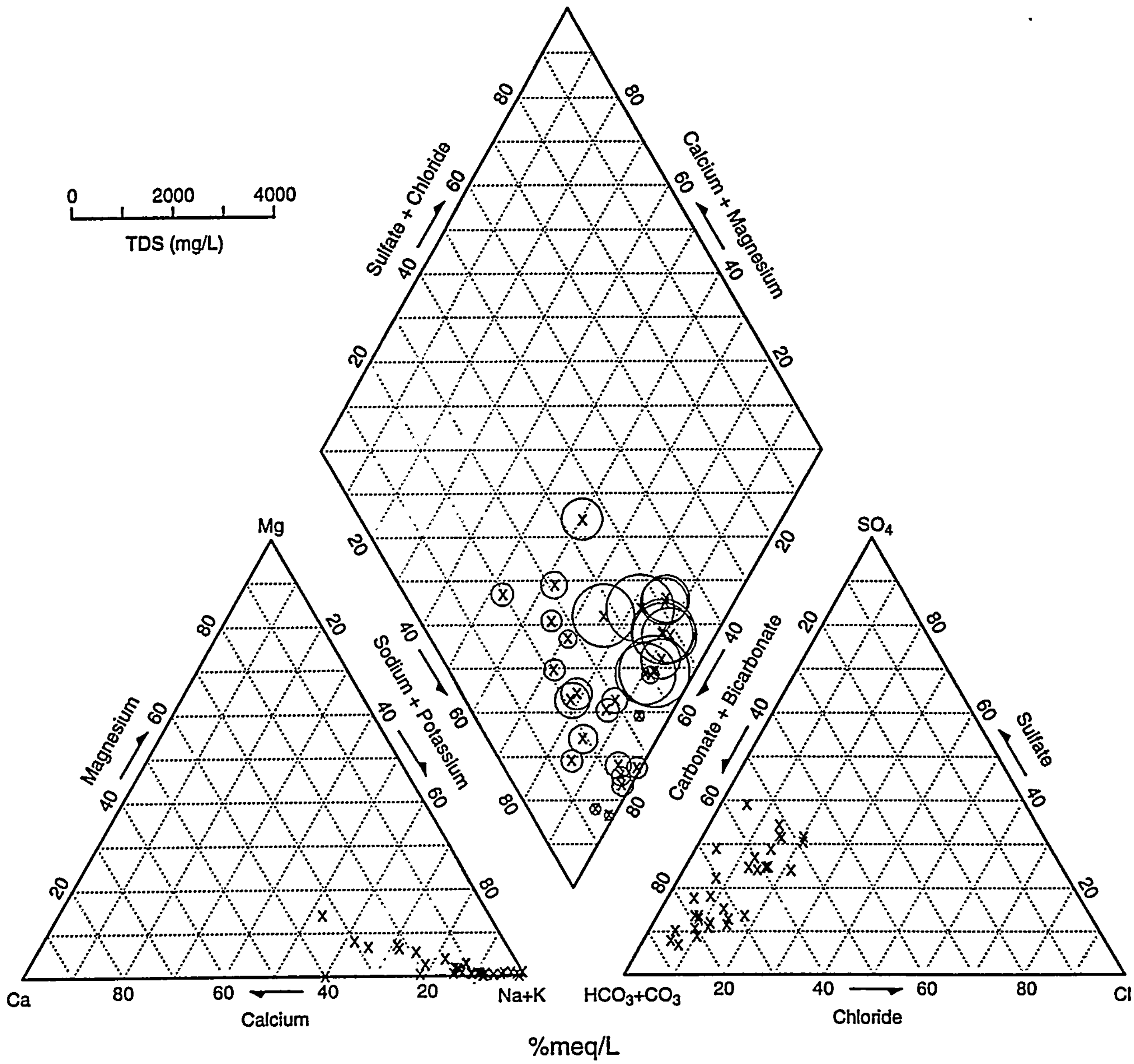


Figure 21. Piper diagram illustrating the chemical composition of waters associated with Tertiary volcanics in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

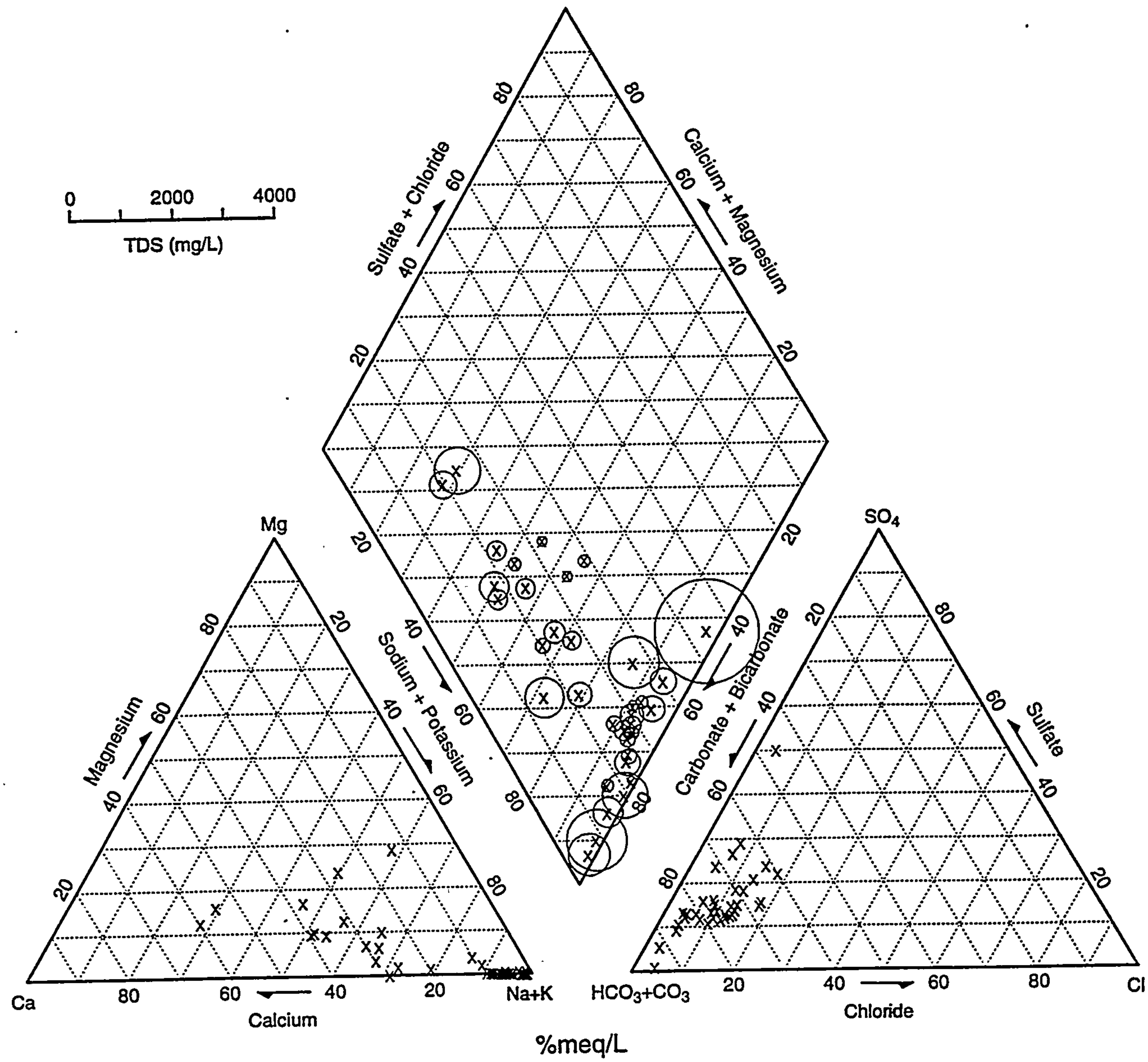


Figure 22. Piper diagram illustrating the chemical composition of waters associated with tuffs in the Yucca Mountain region. Scale bar defines the diameter of the circles representing total dissolved solids.

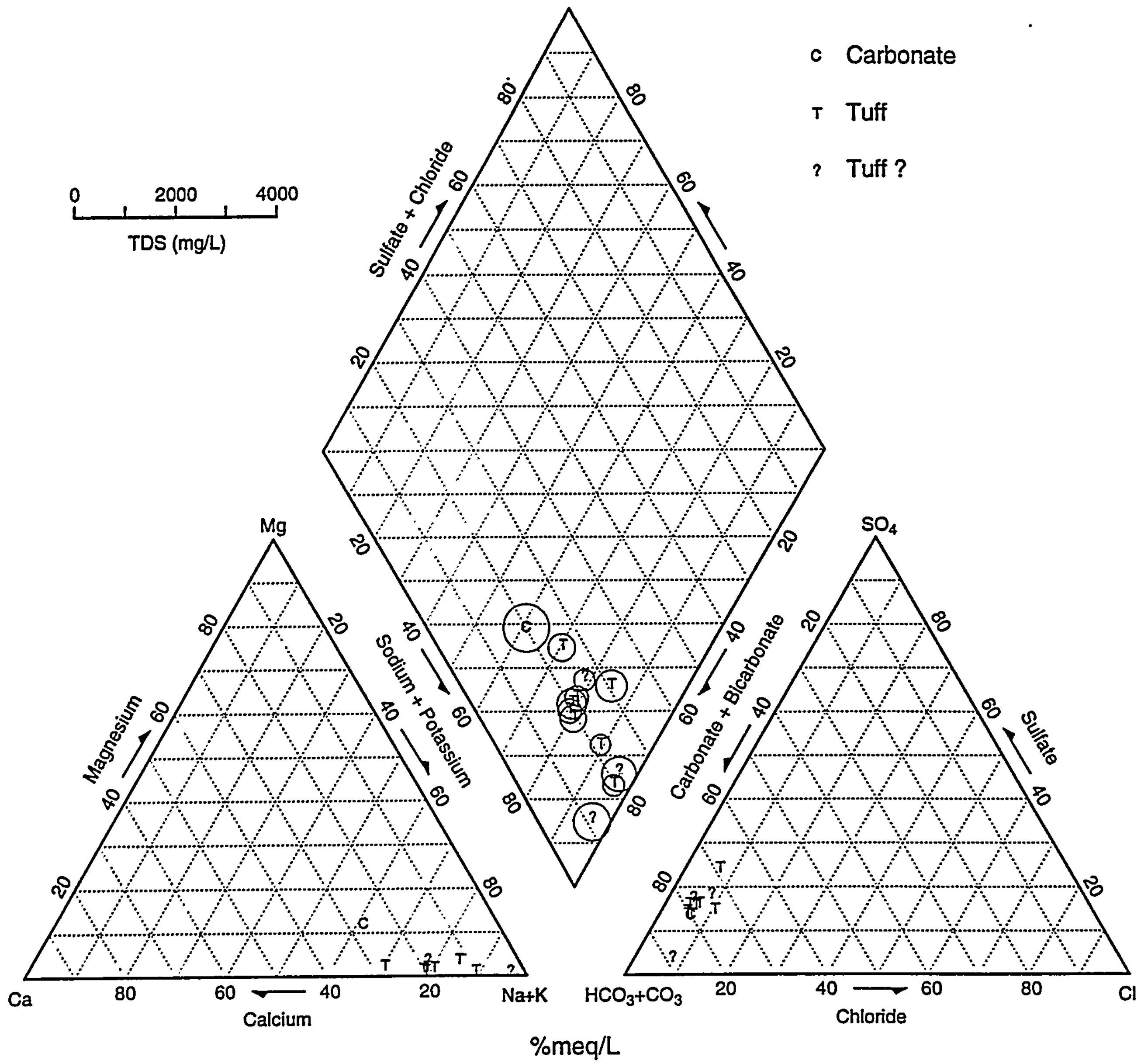


Figure 23. Piper diagram illustrating the chemical composition of waters in tuffs and carbonates penetrated on Yucca Mountain. Scale bar defines the diameter of the circles representing total dissolved solids.

Stable Isotopes

Where data were available, stable isotope analyses were evaluated at the sites to determine if there was any evidence for enrichment of $\delta^{18}O$, and hence, evidence for high-temperature water-rock interactions within the reservoir. Waters are grouped below based on their calculated chalcedony geothermometer temperatures. No high-temperature waters (> 150°C) had associated stable isotope data. Intermediate-temperature waters have chalcedony temperatures between 91 and 150°C, whereas as low-temperature waters have chalcedony temperatures of 25 to 90°C.

An enrichment of $\delta^{18}O$, and not δD, has been observed at high-temperature geothermal systems throughout the world (Truesdell and Hulston, 1979). If there is sufficient permeability and sufficiently long residence time, exchange of $\delta^{18}O$ between water and reservoir rock occurs at temperatures in excess of 100 to 150°C in fine-grained and layered alumino-silicates and calcite (Truesdell and Hulston, 1979). An exchange of ^{18}O in primary quartz, however, is slow even at temperatures over 300°C (Clayton and others, 1968).

All waters near Yucca Mountain and southern Nevada exhibit a deuterium depletion relative to the world meteoric water line (Winograd and others, 1985; Ingraham and others, 1991); hence, the ^{18}O enrichment was estimated based on a local meteoric water line reported by Ingraham and others (1991). The observed deuterium depletion is attributed to "rain-out" of winter storms as they traverse the Sierra Nevada Mountains, producing an isotopic depletion in the air mass. This process is amplified by the high elevations of the Sierra Nevada and low precipitation temperatures. The low δD value is attributed to the loss of most of the initial moisture by precipitation (Ingraham and Taylor, 1991). Deuterium depletion is also attributed to older waters recharged during glacial periods (Harmon and Schwarcz, 1981).

Over a period of six years, in southern Nevada 275 precipitation samples from 14 locations and 70 spring samples at two springs (Cane and Whiterock Springs) were collected. From these data, Ingraham and others (1991) found that the local meteoric water line is represented by

$$\delta D = 6.87\delta^{18}O - 6.5, R^2 = 0.97.$$

This line is labeled NMWL (Nevada Meteoric Water Line) in the plots that follow. The world meteoric water line (Craig, 1963) is identified with WMWL.

<u>*Potential Intermediate-Temperature Waters*</u>

Ninety sample sites in the study area had chalcedony geothermometer temperatures between 91 and 142°C. All but one of the intermediate-temperature waters (Nellis AFB #13) showed enrichment in $\delta^{18}O$ relative to the southern Nevada meteoric water line (NMWL, Figure 24). The observed enrichments generally ranged from a low of 0.05 per mil, to a high of 1.5 per mil, indicating that some high-temperature water rock interactions could have occurred at some of the sites. Ash Tree Spring shows the largest enrichment and it is believed to be a relatively old water (13.8 percent modern carbon (pmc), 15.9 ka), thus allowing for a significant amount of time during which waters could become enriched in ^{18}O. No data are available to determine the source aquifer for this spring (U.S. DOE, 1988). All intermediate-temperature waters with sufficient data are old waters based on ^{14}C (10 to 40 pmc, 10 to 15.9 ka). Even the non-thermal waters show enrichments in $\delta^{18}O$, with enrichments ranging from 0.2 to 13.3 per mil and with the larger values likely representing the effects of evaporation. Hence, none of the intermediate-geothermometer temperature waters necessarily have indications of high-temperature water-rock interactions within the reservoir.

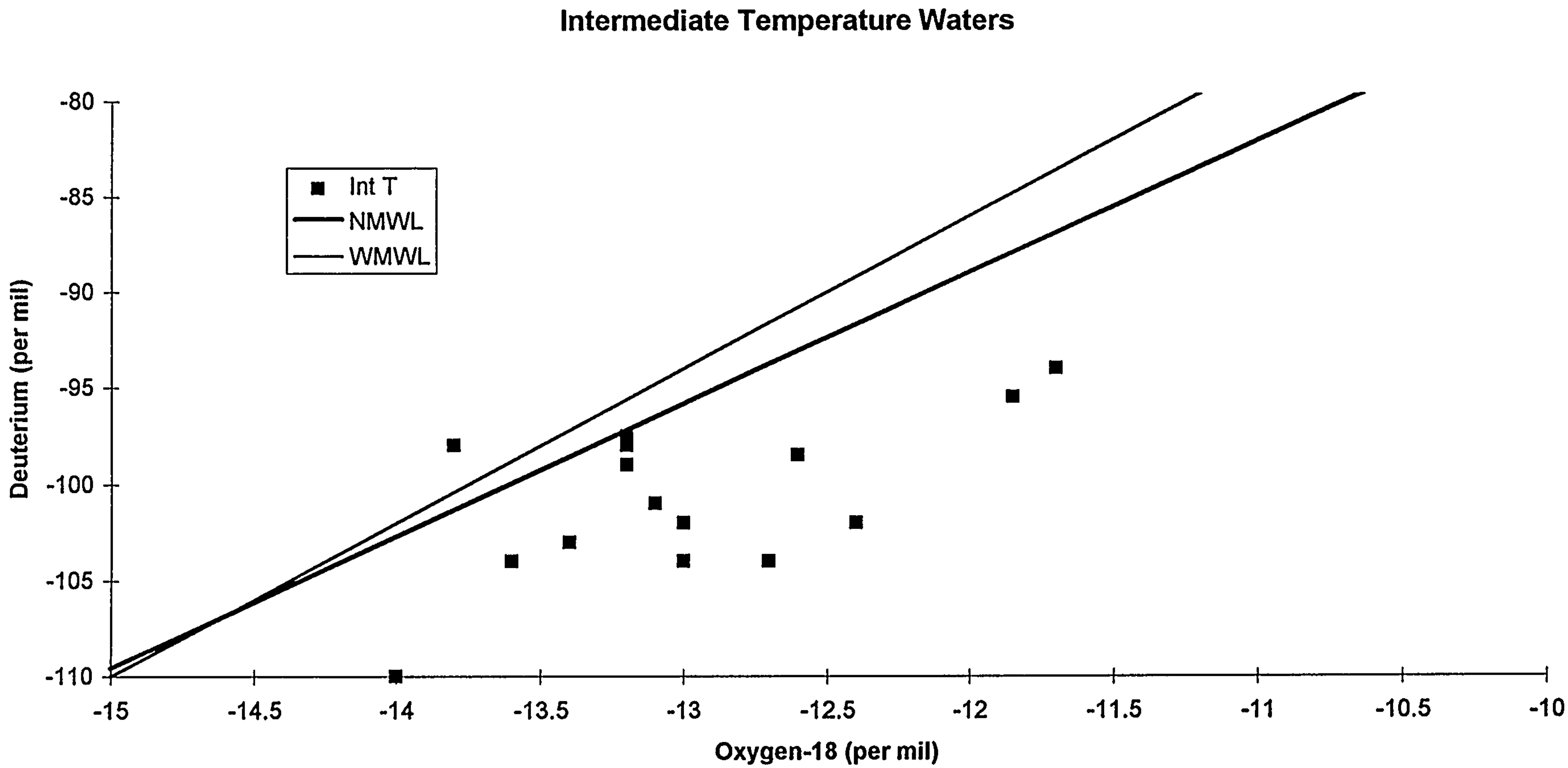


Figure 24. δD vs. $\delta^{18}O$ for intermediate temperature waters.

Potential Low-Temperature Waters

Stable isotope data were considered in the evaluation of waters for which available data show an ^{18}O shift, as this is often indicative of high-temperature isotopic exchange within the reservoir (Figure 25). Enrichments in ^{18}O as high as 7.7 per mil are seen in the data set. This enrichment is in the GS-16 well which has very enriched δD and $\delta^{18}O$ of -59.5 and -0.20 per mil, and is also a relatively concentrated water (57,800 mg/l TDS). Hence, the high isotopic value is likely the result of evaporative enrichment, perhaps from former playa waters. The next highest enrichment also occurs in a relatively high TDS (41,600 mg/l) water, the GS-18 well. Other waters with enrichments of ^{18}O also occur both at and away from the Yucca Mountain area (Cane Spring, Gravel Pit well, well 10, GS-5 well, White Rock Spring, well 5, Bill Copeland Well, Indian Spring, Grapevine Spring, Hick's Hot Spring, well 5C, Amargosa well #9, test well 8, well C, Lone Tree Spring, well 13, Saratoga Spring, and Tule Spring). Figure 26 shows data for the Yucca Mountain CCA for the following wells: UE-25 p#1, UE-25 b#1, UE-25 c#1, UE-25 c#2, UE-25 #3, UE-25 WT#14, UE-25 WT#15, USW H-1, USW H-3, USW H-4, USW H-5, USW H-6, USW WT-10 and USW WT-7. All of these wells have chalcedony temperatures in the low-temperature range, yet ^{18}O enrichments from the NMWL also occur in these waters (Figure 26). Note that similar scatter and enrichment in data points is observed in the non-thermal waters (Figure 27). Hence, there is no evidence from stable isotope data of high-temperature isotopic exchange that is indicative of equilibration temperatures >150°C within the Yucca Mountain CCA.

Chemical Geothermometers

Geothermometer calculations must meet several prerequisites to reliably estimate subsurface temperatures. The most important require that (1) temperature-dependent reactions exist between water and rock in the reservoir, (2) there is a sufficient abundance of reacting constituents (supply is not a limiting factor), (3) chemical equilibration occurs in the reservoir, (4) no change in water composition occurs at lower temperatures as waters flow toward the surface, and (5) no mixing occurs between reservoir waters and other waters at shallower depths (Fournier and others, 1974). In addition, more reliable data are obtained using the chemical composition of the hottest fluid discharging in a spring group because it is less likely to have been affected by dilution than the cooler springs. As existing data were used and most waters are cool, this last condition could not be met. Also, because most waters represented by the Yucca Mountain data are relatively cool, conditions (4) and (5) are not likely to be met in most cases. Thus geothermometers should be interpreted with considerable caution.

Most of these geothermometers are applicable to geothermal waters where equilibrated reservoir temperatures are ≥ 180°C. Above 180°C, the Na/K ratio is a very useful geothermometer which is controlled by mineral equilibria related to feldspar alteration (Henley and Ellis, 1983). Yet, in many areas, the Na-K geothermometers yield unreasonably high-temperatures where deep temperatures are < 200°C (Henley and others, 1984). However, the Na-K-Ca geothermometer is based on equilibria involving plagioclase, epidote, and calcite; this geothermometer results in more acceptable temperatures when reservoir temperatures range from 100 to 300°C. The Na-K-Ca geothermometer is considered to be one of the more reliable subsurface temperature estimators if sufficient time has been available for fluids to equilibrate. The rules for use of this geothermometer are relatively complex. The $\beta = 4/3$ value is used if the temperature is <100°C and if $[\log(\sqrt{Ca}/Na) + 2.06] > 0$. If the temperature using the $\beta = 4/3$ equation is >100°C and the previous function is negative, the

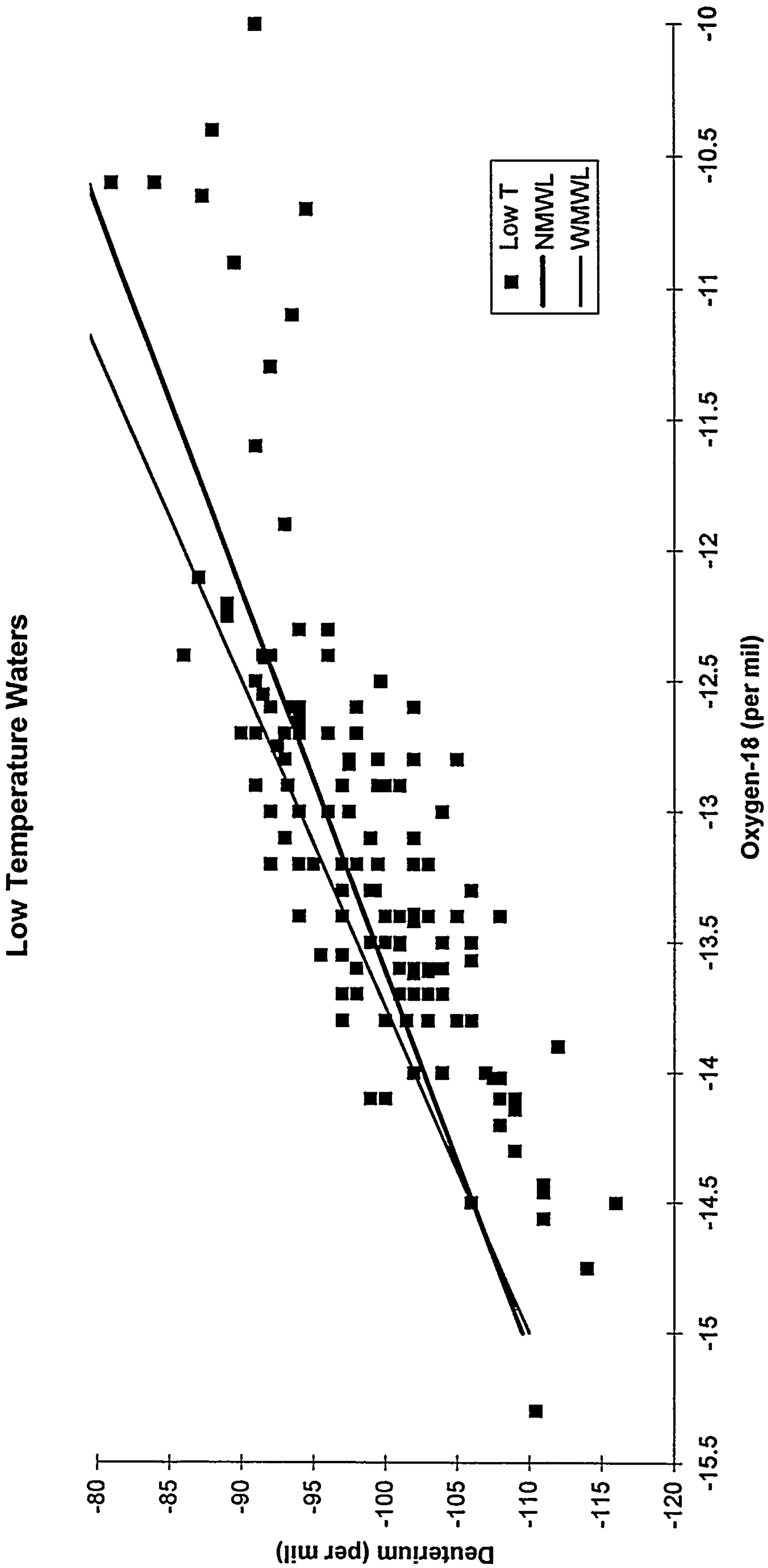


Figure 25. δD vs. $\delta^{18}O$ for low temperature waters.

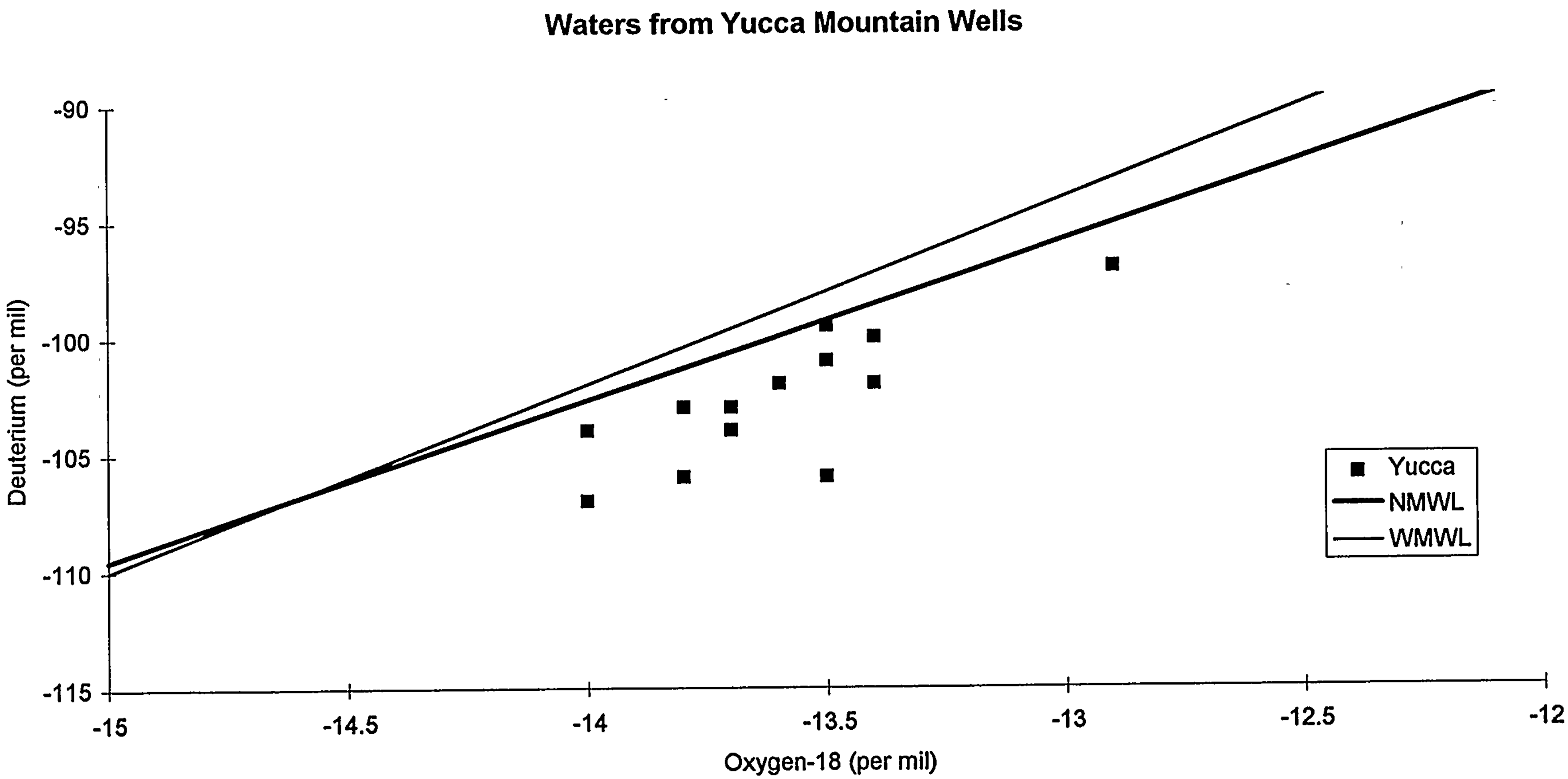


Figure 26. δD vs. $\delta^{18}O$ for well waters near the Yucca Mountain Conceptual Controlled Area.

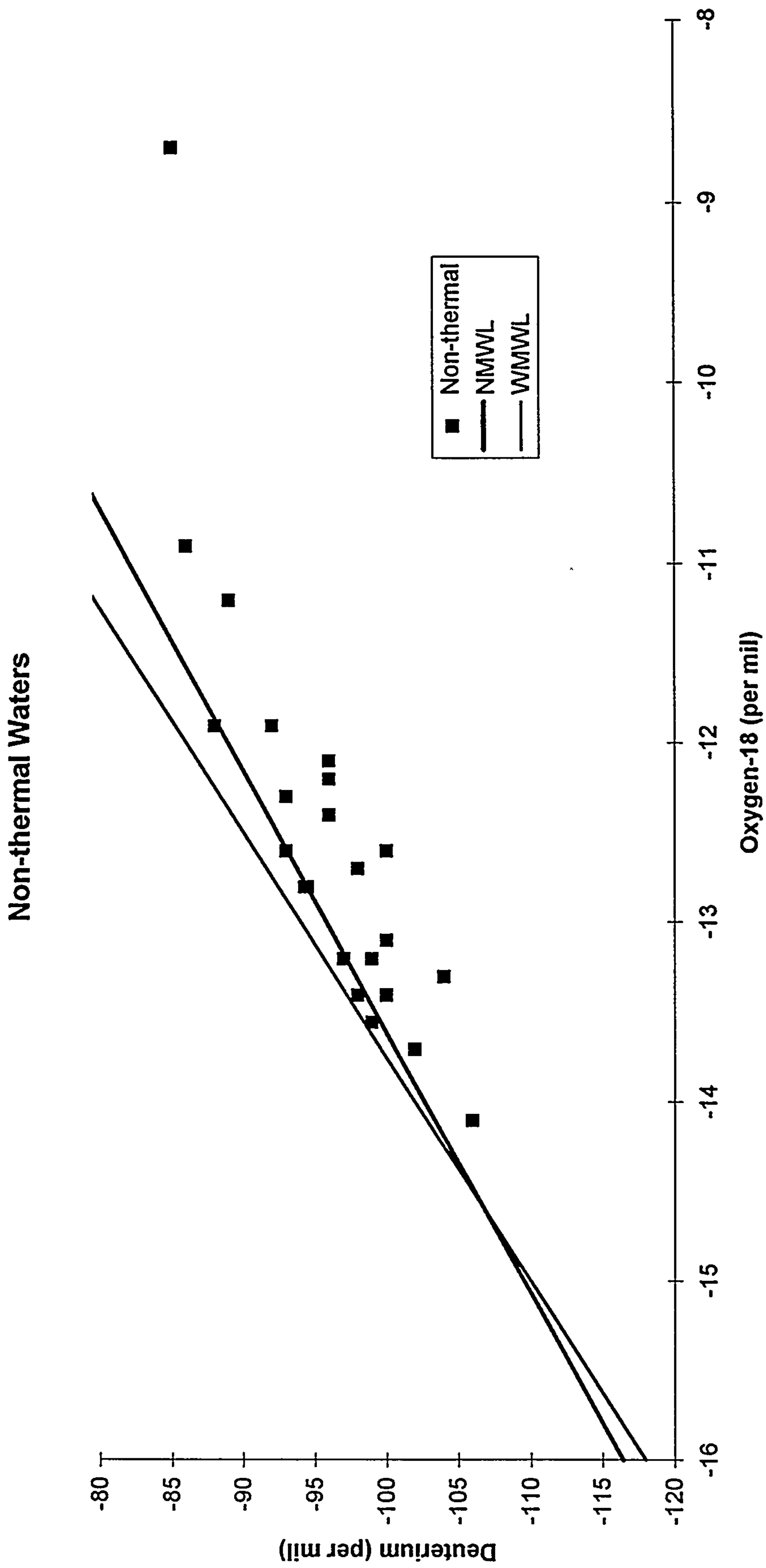


Figure 27. δD vs. $\delta^{18}O$ for non-thermal waters.

$\beta = 1/3$ temperature is selected. In addition, high Mg contents of waters at lower temperatures affect the Na-K-Ca geothermometer, requiring an empirical correction (Fournier and Potter, 1979). It is generally accepted that the Na-K geothermometer should not be applied to high Ca waters because it tends to yield temperatures that are unrealistically high. In high Ca waters, it is more appropriate to use the Na-K-Ca geothermometer. Nearly all estimated equilibration chalcedony temperatures are < 150°C in the Yucca Mountain area and the Na-K (F) geothermometer may be unreliable for this system. Only two sites indicated chalcedony temperatures > 150°C (U20C RING B HOLE N903296 E556214 with an estimated temperature of 208°C and DRI LG105 with an estimated temperature of 220°C).

In the application of the Mg-correction to the Na-K-Ca geothermometer, the correction is generally not made in waters with high Mg concentrations because the high Mg often suggests either near-surface mixing of the thermal waters or cool reservoirs. If much of the Mg and Ca in the fluids results from dissolution of soluble sulfates, then the Mg-corrected values to the Na-K-Ca geothermometer are not realistic.

The quartz geothermometer generally provides excellent results for waters from deep wells. This geothermometer assumes that waters have equilibrated with rocks in the geothermal reservoir, silica precipitation does not occur, mixing with non-thermal waters does not occur, and no additional water-rock reactions occur as the water migrates from the reservoir to the point where water is sampled. In systems in which the actual reservoir temperatures are < 190°C, the chalcedony geothermometer is generally found to be superior to the quartz geothermometer (Henley and others, 1984). When other geothermometers suggest equilibration temperatures of < 190°C for spring waters, the chalcedony geothermometer should be considered more reliable than the quartz geothermometers. It is generally accepted that fluids are in equilibrium with chalcedony when estimated temperatures are < 150°C and that the fluids MAY be in equilibrium with quartz if the calculated temperatures are > 150°C (Fournier, 1981; White, 1970). For a measure of comparison, Table 2 lists the measured surface temperatures, silica content of the water, and estimated reservoir temperatures for 14 geothermal sites in the northern Great Basin. Reservoir depths and subsurface measured temperatures are discussed later in this report.

Table 2. Temperature and geothermometers (°C) for selected sites in the northern Great Basin.

Location	Surface. temp.	Silica (ppm)	Chal. (°C)	Quartz (no steam loss)
Beowawe	98	320	247	214
Steamboat	94	270	228	201
San Emidio	89	205	201	182
Stillwater	96	170	184	170
Bradys	98	164	181	167
Humboldt	77	162	180	166
Mammoth	90	150	173	161
Wendell	96	125	158	150
Dixie Valley	72	115	152	145
Wabuska	94	110	148	143
Moana	85	106	146	141
Amadee	96	98	140	136
Darrough's	95	98	140	136
Hobo	46	47	93	99

Reference: Mariner and others 1983

The Na-Li geothermometer is described as a "slow to equilibrate" (Fouillac and Michard, 1981; McKenzie and Truesdell, 1977) geothermometer, controlled by cation exchange reactions with clays and zeolites, rather than formation of mineral phases. Two separate equations have been developed: one for waters in which Cl < 11,000 mg/kg and one for higher salinity waters. The Na-Li geothermometer may not equilibrate within reservoirs whose temperatures are < 250°C (Fouillac and Michard, 1981). Therefore, the estimated reservoir temperatures calculated in all cases with the Na-Li geothermometer are unrealistic because the reservoir temperatures are likely to be < 250°C.

Other geothermometers calculated include the K-Mg and K-Na geothermometers of Giggenbach (1988). The K-Mg geothermometer is useful in situations in which Na and Ca do not equilibrate sufficiently rapidly, such as in cases where sea water occurs in a low-temperature aquifer. This restriction indicates that the K-Mg geothermometer is probably not appropriate for use at the Yucca Mountain site, except for use in comparison with other geothermometers.

The maximum geothermometer file was predominantly used in evaluating the geothermometers. All entries with maximum collection temperatures of < 25°C and for which the chalcedony geothermometer temperature was less than or equal to the sample collection temperature were deleted from the file and placed in the file geot-del.xls. In addition, if the maximum measured temperature was < 25°C, and the chalcedony geothermometer temperature was within 7°C of the measured temperature, the entry was placed in the geot-del.xls file and deleted from the maximum geothermometer file. It is assumed that the geothermometer temperatures for these sites are either unreliable (if less than the measured values) or the sites represent truly non-thermal waters. If the maximum measured sample temperature was > 25°C and the geothermometer temperature was either < 25°C or within ± 7°C of the measured temperature, then the entries were retained in a separate file (geoth-25.xls). Even with relatively elevated measured temperatures (e.g., 46°C, site 230 S15 E50 25BD 1), nearly equal or lower geothermometer temperatures indicate the fluids probably do not originate from a significantly higher temperature source area, and no geothermal potential can be attributed based on the entries. In many cases, entries in the geot-del.xls file with low chalcedony values also had estimated temperatures based on other geothermometers which were near sample temperatures. For instance, note the following in the geoth-25.xls file:

Site	Temp. (°C)	N-K (Four) (°C)	Na-K-Ca (°C)	K-Mg (°C)
LVVWD #1A	25.1			31
Wilcox Well	25.6			23
NLVWD Robinson Well	25.7			23
212 S21 E60 35ADAB1	26.0			35
LVVWD #11A	26.0			35
NLVWD Desert Aire Well	26.4			20
212 S21 E60 21DD 1	26.5			30
015S045E31M02M	29.7	29		
Well Near Pahrump Spring	25.0			19
Well 8-17S-52E	28.8		27	

Evaluation of the waters in the study area was conducted by consulting the chalcedony geothermometer temperatures which were used to categorize the waters by: (1) non-thermal waters (T < 25°C), (2) low-temperature waters (25 ≤ T < 90°C), (3) intermediate-temperature waters (90 ≤ T < 150°C), and (4) high-temperature waters (T ≥ 150°C). Figure 28 shows a plot of measured versus chalcedony temperature at the data sites. All non-thermal waters (based on geothermometer temperatures) lie at or below a line with a slope = 1, suggesting these are relatively cool waters where the geothermometer temperatures can not be considered reliable. Some of the low-

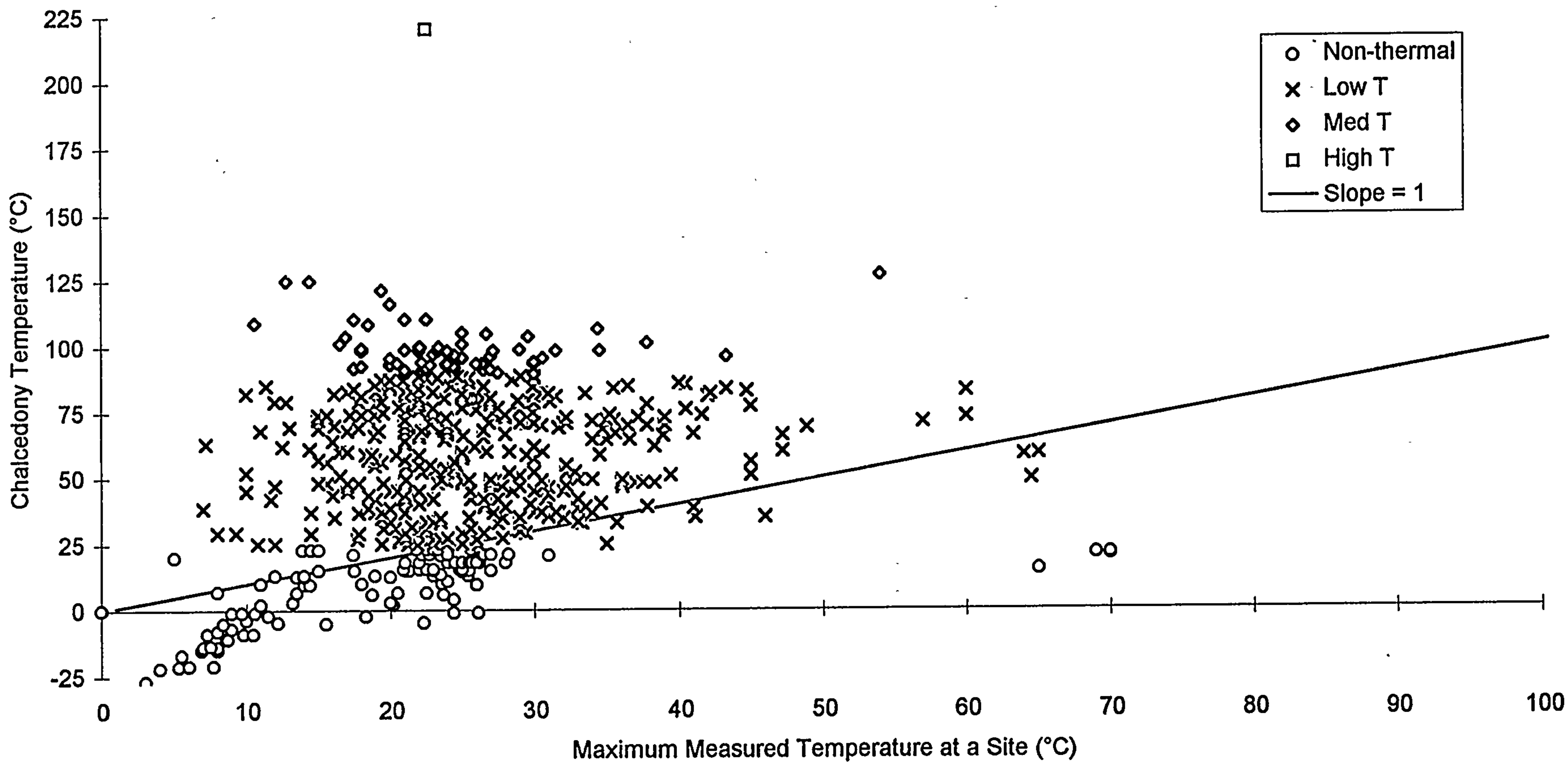


Figure 28. Chalcedony geothermometer temperature vs. the maximum measured temperature at a site.

temperature waters lie along the slope = 1 line indicating that many waters do not originate from a resource at temperatures higher than the discharge temperature. However, the majority of the low (Low T), intermediate (Med T), and high (High T) waters lie above the line indicating a slightly higher temperature resource likely is present at depth below most of those sample locations.

When no chalcedony geothermometer temperature could be calculated for a site, the Na-K-Ca geothermometer was consulted. If the estimated temperature and the measured temperature were both < 25°C, then the entry was placed in the nontherm.xls file. Note that numerous entries had Na-K-Ca geothermometer temperatures of < 0°C. After these entries were placed in their respective files, it was found that there were 66 entries without reliable geothermometer temperatures. Also, in order to evaluate the lower temperature waters, the entries in the file geoth-25.xls were considered part of the low-temperature waters. The final tally of water types is:

Type	File	Number	Percent of Total
Non-thermal waters	nontherm.xls	165	
Non-thermal waters	geot-del.xls	81	
Total non-thermal		246	24.1%
Low-temperature waters	lowt.xls	680	66.5%
Intermediate-temperature waters	medt.xls	90	8.8%
High-temperature waters	hight.xls	6	0.59%

Hence, 24.1% of the waters are definitely non-thermal in origin, and are not considered further in the evaluation of geothermal potential at Yucca Mountain. The greatest percentage of the samples indicate that the waters may originate from a low-temperature source area.

Potential High-Temperature Waters

Two sites have indications of high-temperature origins based on chalcedony geothermometer temperatures and none of the sites provided isotope data. Two of the sites have chalcedony temperatures > 150°C: (1) U20C RING B HOLE N903296 E556214 (depth 1,463.4 m) with an estimated temperature of 208°C, and (2) DRI LG105 (sample temperature 22.5°C) with an estimated temperature of 220°C. However, the Na-K geothermometer temperature is 338°C for the DRI well, in substantial disagreement with the chalcedony temperatures, and the K-Mg temperature is 83°C. When other geothermometers suggest temperatures >150°C, the quartz geothermometer is preferred over the chalcedony geothermometer. In the case of the DRI LG105 sample, the chalcedony and quartz maximum steam loss temperatures agree fairly well, with the quartz geothermometer indicating a subsurface temperature of 210°C. The K-Mg geothermometer (Giggenbach and others, 1983) appears to be sensitive to rapid re-equilibration of fluids due to cooling or mixing. This suggests that the composition of the water in the DRI well may have been overprinted by a cooler, shallower water and that subsurface temperatures from which this water originates may be on the order of 200°C at depth. The U20C well, on the other hand, had an elevated chalcedony temperature; the quartz no-steam-loss and maximum steam-loss geothermometers indicate temperatures of 222 and 202°C respectively, indicating that this water may also originate from a high-temperature resource. Only silica geothermometers are available at the U20C site and no comparisons can be made with cation geothermometers. Only one analysis was available for each of these wells and no minimum geothermometer values are available.

Four other sites are classified as high-temperature waters (an unnamed well, an unnamed spring, Well NR Badwater, and U.S. Geological Survey well #3) based on cation geothermometers. All of the Na-K-Ca geothermometer temperatures for these sites are unrealistic (640 to 938°C). The Na-K geothermometer indicates subsurface temperatures may be 161, 193, 141, and 256°C, respectively, at these sites. Without confirmation of these values with silica geothermometer values, an estimate of subsurface temperatures should not be attempted. However, one could expect relatively cool reservoir temperatures given the dramatic disagreement between the Na-K and Na-K-Ca geothermometer values. In addition, the TDS of these four sites are very high (23,040 (well), 10,960 (spring), 282,540 (Badwater), and 40,422 (well #3) mg/l). The Badwater well contains 22,600 mg/l SO_4 and 150,000 mg/l Cl. Hence, only two sites (U20C and DRI LG105) have data which may indicate a useful high-temperature resource at depth; neither of these sites is located within the Yucca Mountain CCA. Figure 29 shows locations where chalcedony temperatures are ≥ 90°C, and there are no occurrences on Yucca Mountain. Therefore, the potential for the existence or discovery of a high-temperature geothermal resource at or within 50 miles of the Yucca Mountain site is minimal.

Potential Intermediate-Temperature Waters

Ninety sample sites had chalcedony geothermometer temperatures between 91 and 142°C indicating an intermediate-temperature geothermal resource is possible within 50 miles of Yucca Mountain. Although some of the sites near Yucca Mountain (e.g., well 3 and well A on Yucca Flat) indicate intermediate-temperatures (93 and 99°C) may occur at depth, all chalcedony geothermometer temperatures within the Yucca Mountain CCA are < 90°C (Figures 29 and 30). This indicates that the Yucca Mountain site has considerably less potential for a productive intermediate-temperature resource than many other areas within 50 miles of the site.

Potential Low-Temperature Waters

Six-hundred and eighty sample sites had either measured temperatures or chalcedony temperatures between 25 and 90°C. When geothermometer temperatures are < 125°C, the reliability of the estimates are in question (Renner and others, 1975). In addition, if the Na-K-Ca and SiO_2 temperatures differ by more than approximately 20°C, the estimates should also be viewed with skepticism. Of the 680 sites, only 68 had Na-K-Ca temperatures within 20°C of the chalcedony temperature (Table 3). For the low-temperature waters, measured temperatures ranged from 21.0 to 35.7°C, chalcedony temperatures varied from 25.0 to 44.0°C, and Na-K-Ca geothermometer temperatures ranged from 13.7 to 39.3°C. Hence, estimated subsurface temperatures for the sites listed in Table 3 are expected to be low in all cases and, in many cases, the estimated subsurface temperatures are not appreciably greater than those of collected samples (see Chal. minus Temp. column, Table 3). For instance, 47 entries have an estimated chalcedony temperature which is within 10°C of the measured temperature, and no higher temperature resources are indicated at depth. Only one site within the CCA (USW WT-7) appears in Table 3 and the data indicate that the water originates from a very low-temperature resource (chalcedony = 31°C and Na-K-Ca = 35°C). Because all other sites belonging to the low-temperature category have chalcedony temperatures < 125°C, the temperatures can not be considered reliable.

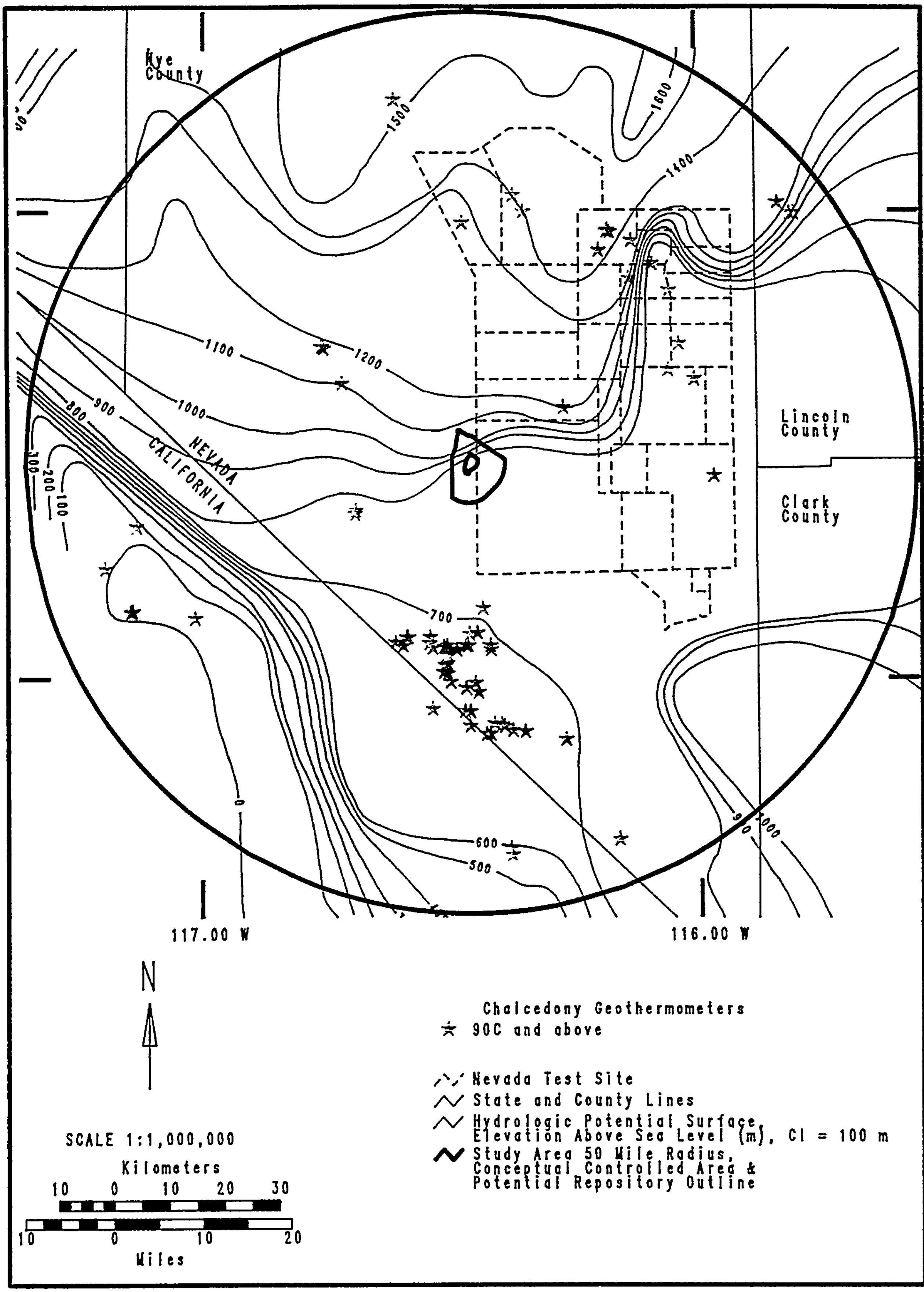


Figure 29. Water level elevations and the distribution of waters with chalcedony geothermometer temperatures ≥90°C.

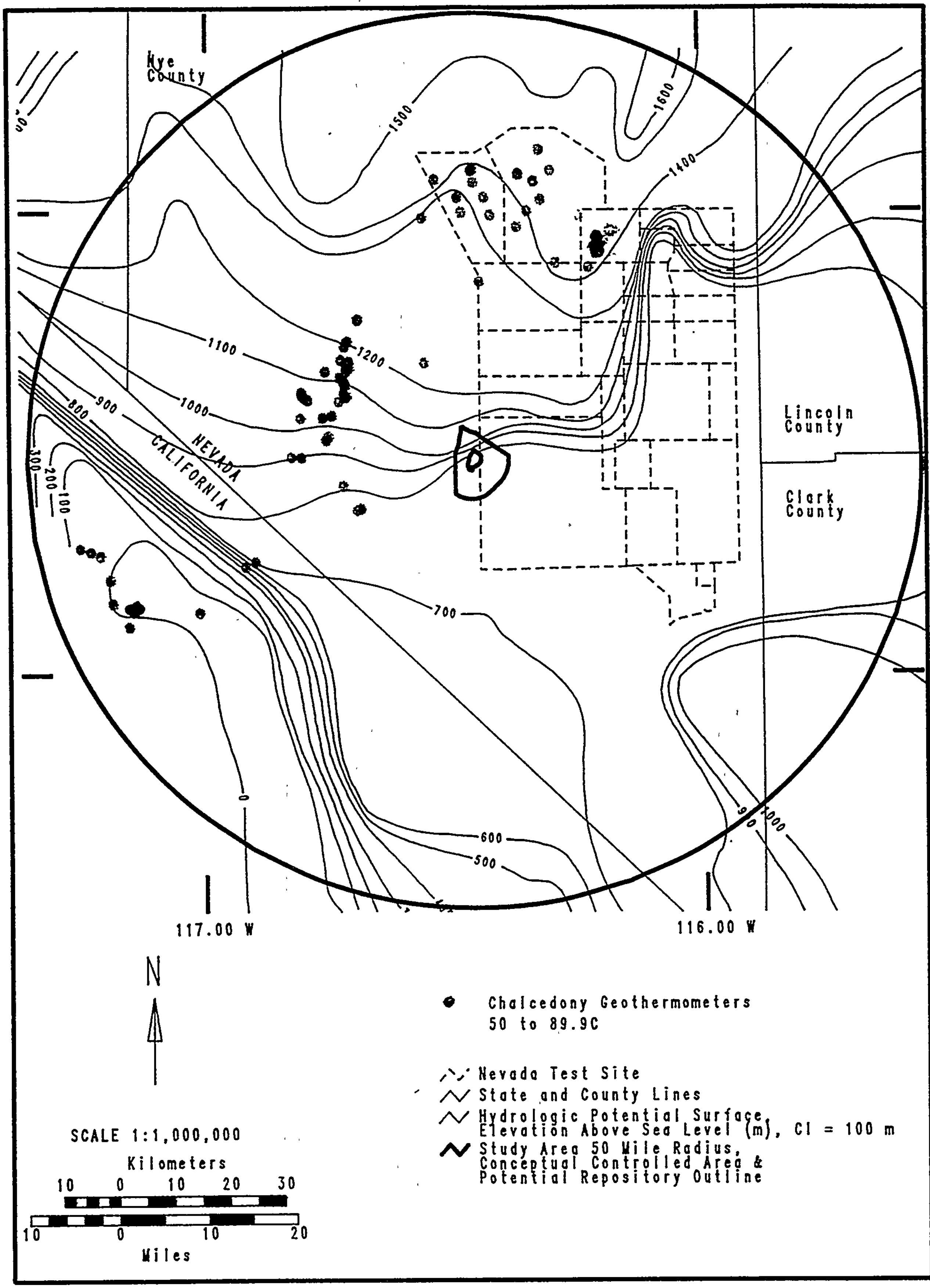


Figure 30. Water level elevations and the distribution of waters with chalcedony geothermometer temperatures ≥50 and <90°C.

Table 3. Na-K-Ca and silica geothermometers of waters for the situation in which the two temperature estimates are wihin 20°C of one another.

Site Name	Temp °C	Max T °C	Latitude	Longitude	Sample Date	Quartz No steam	Quartz Max steam	Chalced	Na-K-Ca	Na-K-Ca - Chal	Chalced-Temp
Low Temperature Waters											
WELL UE15d YUCCA FLAT	35.0	35.0	37.2092	116.0414	4/11/69	57	64	25	33	8.45	-10.0
UE15d	35.0	35.0	37.2092	116.0414	4/11/69	57	64	25	33	8.45	-10.0
WATERTOWN #4 GROOM LAKE	35.7	35.7	37.2881	115.9367	9/4/69	65	71	33	36	3.45	-2.7
INDIAN SPRING	26.1	26.1	36.5617	115.6550	12/15/12	57	64	25	14	-10.88	-1.1
INDIAN SPRINGS	26.1	26.1	36.5617	115.6550	12/15/12	57	64	25	14	-10.88	-1.1
16S 56E 16bb	26.1	26.1	36.5617	115.6550	12/0/12	57	64	25	14	-11.04	-1.0
17S 52E 8c	28.0	28.0	36.4833	116.1433	04/0/58	60	65	27	21	-6.80	-0.7
UNNAMED WELL	28.0	28.0	36.4833	116.1433	4/27/58	60	65	27	21	-6.80	-0.7
AMARGOSA DESERT 17S/52-8c1	27.8	27.8	36.4833	116.1528	4/27/58	60	65	27	21	-6.80	-0.5
"63-64a, 17S/52-8"	27.8	27.8	36.4853	116.1564	4/27/58	60	65	27	21	-6.80	-0.5
WELL 63-64a	27.8	27.8	36.4853	116.1564	4/27/58	60	65	27	21	-6.80	-0.5
16S-52E-15add	29.4	29.4	36.5600	116.1083	5/1/64	62	67	29	39	9.61	0.0
S16 E52 15 ADD	29.4	29.4	36.5600	116.1083	5/1/64	62	67	29	39	9.61	0.0
2 - (Table 3)	29.0	29.0	36.5640	116.1190	05/0/64	62	68	30	39	9.47	0.8
WEST TRENCH 14	23.9	23.9	36.7647	116.6939	3/22/89	57	64	25	18	-6.85	1.3
Main Spring	33.3	33.3	36.4617	116.3133	10/0/70	67	72	35	21	-13.98	1.7
WELL 8-17S-52E	28.8	28.8	36.4833	116.1528	5/23/71	63	69	31	27	-3.86	2.2
KING SPRING	32.8	32.8	36.4014	116.2706	10/26/64	67	72	35	16	-19.25	2.2
230 S17 E50 23BBCA1	34.0	34.0	36.4653	116.3178	8/24/90	69	74	37	20	-16.83	2.9
S17 E50 23 BBCA1	34.0	34.0	36.4653	116.3178	8/24/90	69	74	37	20	-16.83	2.9
MANY SPRINGS 18S/51-07DBA	31.0	31.0	36.4014	116.2714	10/0/70	67	72	35	20	-14.75	4.0
NAVEL SPRING	23.0	23.0	36.3811	116.7147	5/16/74	60	65	27	34	6.80	4.0
WHITE'S WELL	22.8	22.8	36.5086	116.1797	1/10/61	60	65	27	27	-0.03	4.2
"Well 2, USGS Tracer "	30.6	30.6	36.5383	116.2317	02/0/68	67	72	35	18	-16.78	4.4
6 - (Table 3)	31.0	31.0	36.5410	116.2130	09/0/69	67	73	36	20	-15.22	4.5
6 - (Table 3)	31.0	31.0	36.5410	116.2130	09/0/69	67	73	36	20	-15.22	4.5
Indian Seep	32.0	33.5	36.3983	116.2700	10/0/64	69	74	37	17	-20.18	5.0
POINT OF ROCK SPR (SMALL)	31.7	32.0	36.4014	116.2708	10/26/64	69	74	37	17	-20.10	5.2
KING SPRING	31.7	31.7	36.4014	116.2706	2/28/49	69	74	37	17	-19.46	5.2
KING SPRING	31.7	31.7	36.4014	116.2706	2/28/49	69	74	37	17	-19.46	5.2
"WELL, UNNAMED"	33.5	33.5	36.4267	116.2872	3/0/67	70	75	39	21	-18.13	5.5
WELL 5	31.5	31.5	36.4072	116.2831	10/0/70	69	74	37	21	-16.41	5.5
Devil's Hole Well	33.0	33.0	36.4267	116.2817	03/0/67	70	75	39	21	-17.75	5.7
D.H. WELL	33.0	33.0	36.4267	116.2817	3/10/67	70	75	39	21	-17.75	5.7
DEVIL'S HOLE WELL	33.0	33.0	36.4267	116.2817	3/10/67	70	75	39	21	-17.75	5.7

Table 3, continued.

Site Name	Temp °C	Max T °C	Latitude	Longitude	Sample Date	Quartz No steam	Quartz Max steam	Chalced	Na-K-Ca	Na-K-Ca - Chal	Chalced-Temp
18S 51E 7bbb	31.0	31.0	36.4083	116.2767	03/0/71	69	74	37	20	-16.43	5.9
Devil's Hole	27	33	36.4270	116.2880	10/0/64	65	71	33	17	-15.79	6.3
DEVIL'S HOLE	27.0	33	36.4270	116.2880	10/0/64	65	71	33	17	-15.79	6.3
WELL 4 18S/51-07CAA	30.5	30.5	36.4006	116.2753	10/0/70	69	74	37	19	-17.76	6.5
WELL 4	30.5	30.5	36.4006	116.2753	10/0/70	69	74	37	19	-17.76	6.5
WELL SM4	30.0	30.0	36.4000	116.2700	10/20/70	69	74	37	20	-17.27	7.0
WELL SM 4	30.0	30.0	36.4000	116.2700	10/20/70	69	74	37	20	-17.27	7.0
Fairbanks Spring (Table 3)	27.0	28.0	36.4910	116.3390	09/0/69	67	73	35	22	-12.85	8.0
KLARE SPRING	22.5	22.5	36.8428	117.0931	11/17/68	63	69	31	14	-17.26	8.5
CRYSTAL POOL	33.0	33.0	36.4206	116.3225	11/20/66	74	78	42	23	-18.81	9.0
"WELL, UNNAMED"	25.5	25.5	36.4250	116.2683	3/0/71	67	72	35	24	-10.76	9.6
WELL SM 3	29.0		36.4018	116.2667	10/20/70	70	75	39	23	-15.76	10.0
COOK'S WELL	30.6	30.8	36.5736	116.3972	4/1/71	74	78	42	36	-6.03	11.4
CRYSTAL SPRING	30.0	33.0	36.4183	116.3300	12/30/71	74	78	42	22	-20.00	12.0
TULE SPRING TEST WELL	21.0	27.5	36.2444	116.8861	3/22/70	65	71	33	19	-14.00	12.0
DEVIL'S HOLE	27.2	34.6	36.4256	116.2908	12/9/66	72	77	40	20	-20.08	13.1
JACK RABBIT SPRING	25.5	28.0	36.3886	116.2794	10/0/70	70	75	39	37	-2.00	13.5
S17 E52 08 CDB 1	27.5	27.5	36.4914	116.1492	8/24/90	74	78	42	27	-15.14	14.5
S21 E61 09 BBBB1	21.0	21.0	36.1439	115.1717	10/22/81	69	74	37	21	-15.63	15.9
AMARGOSA DESERT	25.6	25.6	36.7675	116.3867	4/25/58	74	78	42	30	-11.49	16.4
5 - (Table 3)	21.0	21.0	36.4660	116.2080	08/0/72	75	79	44	36	-7.78	22.6
WE24-35	20.8		36.4611	116.2028	8/2/72	75	79	44	36	-8.49	23.2
WELL 89-68			37.2033	116.0383		57	64	25	39	13.90	25.0
USW WT-7			36.8300	116.4850	06/0/88	63	69	31	35	4.14	31.0
POINT OF ROCKS HWY WELL			36.5592	116.1117	6/30/64	63	69	31	37	5.87	31.0
JAP RANCH SPR			36.4583	116.3500	11/20/66	67	72	35	18	-17.34	35.0
LONGSTREET SPRING		27.8	36.4678	116.3250	11/18/66	67	72	35	18	-16.94	35.0
FAIRBANKS SPRING		27.2	36.4906	116.3417	9/27/66	69	74	37	19	-17.92	36.9
	Min	21.0						25	13		
	Max	35.7						44	39		
Intermediate Temperature Waters											
U19as PAHUTE MESA		No T	37.2750	116.3700	6/7/65	128	125	100	91.00	-8.99	100.0
212 S21 E62 22DCBA1	18.0	18.0	36.1031	115.0347	1/13/87	121	119	93	100.00	7.29	74.7

SiO_2 versus Enthalpy Diagrams

The SiO_2 geothermometer temperatures can be affected by mixing thermal and non-thermal waters or by boiling. SiO_2 versus enthalpy diagrams can be used to determine the pre-mixing or pre-boiling temperatures of thermal waters affected by these processes. Although it is not possible to determine if there had been boiling of fluids for which data are available in this study, it is likely that mixing occurred in many cases. In order to select springs for which the silica-enthalpy mixing model may be appropriate, the measured water temperatures should be at least 50°C less than the calculated silica and Na-K-Ca geothermometers and the silica (quartz or chalcedony) geothermometer temperature should be significantly less than the Na-K-Ca temperature, and only a small amount of conductive cooling can occur during upflow (Fournier, 1991). It can not be determined if the last criteria is met at any of the sites, but the first two criteria can be readily evaluated. None of the potentially high-temperature waters satisfied the criteria, yet five low-temperature waters and four intermediate-temperature waters satisfied the first two criteria; these sites are listed in Table 4. None of these sites occurs within the Yucca Mountain CCA. The intermediate-temperature waters ranged from 10.6 to 31.5°C and silica content from 82 to 97 mg/l, whereas the low-temperature waters ranged from 19.4 to 31.0°C and 48 to 67 mg/l SiO_2.

Figure 31 shows the silica solubility curve and data points for the sites listed in Table 4 for the scenario of mixing. The open circle is assumed to represent the end-member non-thermal water and is taken to be a 10.5°C water (Willow Spring) with 7 mg/l SiO_2. None of the intermediate-temperature or low-temperature waters lies on reasonable mixing lines (Figure 31). Hence, a second silica-enthalpy plot was constructed assuming adiabatic cooling and single-stage steam separation. As noted earlier, this assumption can not be verified, yet the analysis was conducted to estimate what the maximum reservoir temperature must be if this condition were met. The pre-cooling, pre-steam-loss reservoir temperature can be determined by finding the intersection between the silica solubility curve and a line drawn between the sample and a point which characterized the steam separated from the water at the water's discharge temperature (Fournier, 1991). Figure 32 shows four of these lines for the sites illustrated on the plot. Three of the intermediate-temperature waters (230 N24 E06 18C SP-50, S14 E44 36 K01m, and Stovepipe Wells Hotel, temperatures of 23.4, 31.5, and 29.0°C) indicate the reservoir from which these waters originate is 118°C. The chalcedony geothermometers for these three sites are 100, 99, and 99°C, respectively, which is in reasonably good agreement with the temperature determined with the silica-enthalpy evaluation. Hence, all three of these waters are likely to originate from an intermediate-temperature source reservoir near100 to 120°C.

A reservoir temperature of 131°C is indicated for the other intermediate-temperature site (Mclean Spring) listed in Table 4. This site has a measured temperature of only 10.6°C, yet has a high SiO_2 of 97 mg/l that indicates a subsurface temperature of 109°C.

All of the low-temperature waters plot at lower indicated temperatures than the intermediate-temperature waters, which is reasonable. Three sites may originate from a reservoir of up to 108°C (61-59, Salt Creek near Stovepipe, and well 13). Measured temperatures of these waters are 19.4, 22.0, and 20.9°C respectively, whereas chalcedony temperatures indicate reservoir temperatures may be between 84 and 87°C for these waters. In contrast, the other low-temperature waters have higher measured temperatures, yet indicate they may originate from a slightly lower temperature source reservoir. Sites S15 E44 36 M01M and S15 E44 36 J06M have measured temperatures of 31 and 30°C, and chalcedony temperatures of 82 and 81°C.

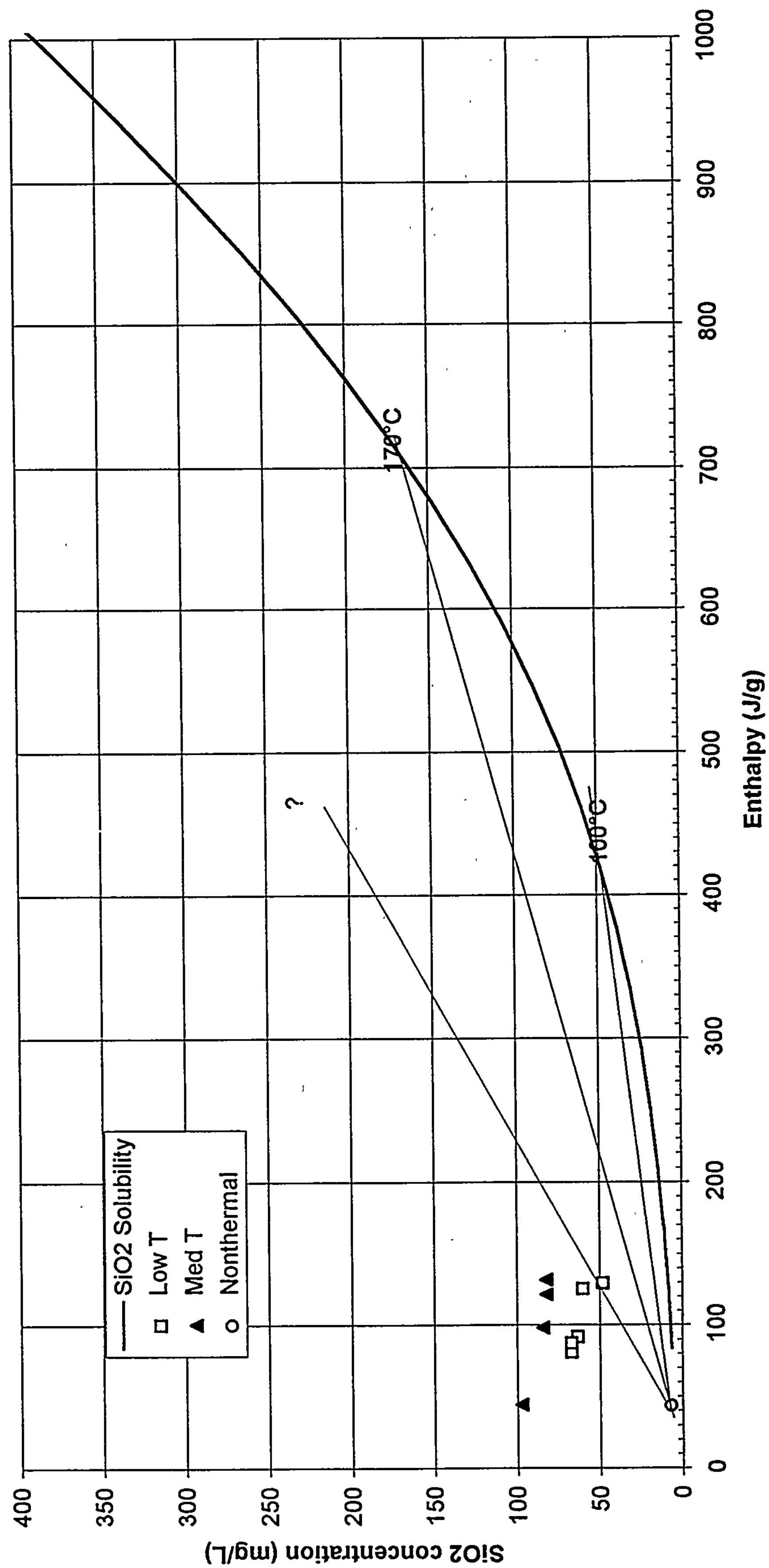


Figure 31. Enthalpy vs. SiO_2 plot showing possible mixing trends.

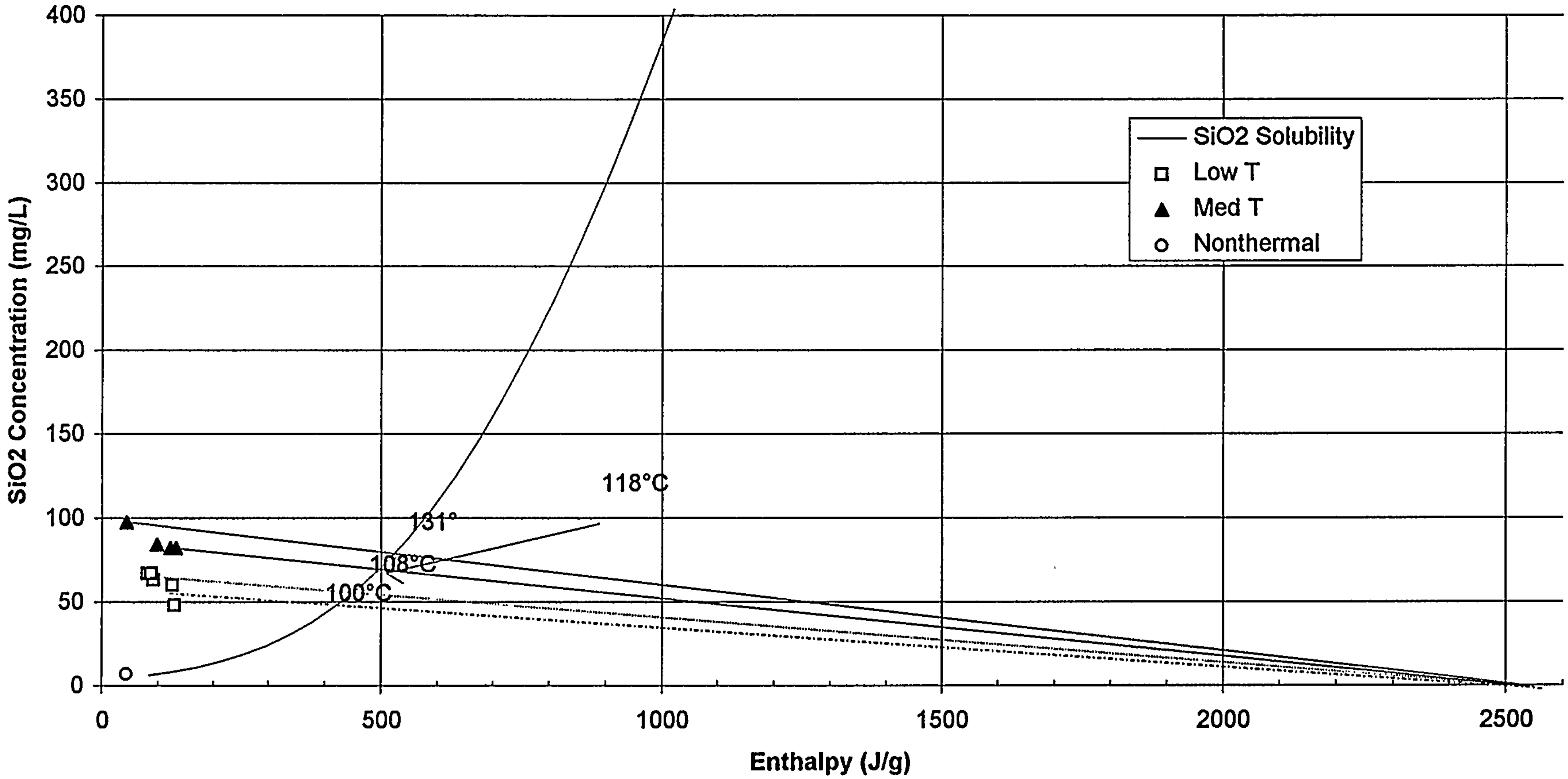


Figure 32. Enthalpy vs. SiO_2 plot assuming adiabatic mixing trends.

Table 4. Sites for which silica versus enthalpy plots are constructed.

Site Name	Max. Temp. °C	Lat.	Long.	Date	Calc. TDS	Well Depth (m)	Chal. minus Temp.	Chal minus Na-K-Ca	Enthalpy	SiO2
LOW TEMPERATURE WATERS										
015S044E36M01M	31.0	36.6058	117.1550	9/25/84	6049		54	-554	130.0	48
"61-59, 17S/50-29daa"	19.4	36.4458	116.3569	8/18/62	974	143.6	68	-460	81.4	67
SALT CREEK NEAR STOVEPIPE	22.0	36.5994	117.0128	9/28/84	11708		62	-576	92.3	63
S15 E44 36 J06M	30	36.6067	117.1419	9/27/84	7790		51	-539	125.8	60
WELL 13	20.9	36.2453	116.3919	11/17/83	2462		66	-367	87.7	67
INTERMEDIATE TEMPERATURE WATERS										
230 N24 E06 18C SP-50	23.4	36.2136	116.3786	4/27/88	3656		77	-406	98.2	84
MCLEAN SPRING N/2 6-16S-46E	10.6	36.5978	117.0150		9357		97	-524	44.5	97
S15 E44 36 K01M	31.5	36.6067	117.1461	3/21/67	9375		67	-477	132.1	82
STOVEPIPE WELLS HOTEL	29	36.6083	117.1417	3/21/67	9347	24	70	-479	121.6	82

Insufficient data on B, Li, and Cl are available from any of the sites listed in Table 4 to construct B vs Cl or Li vs Cl plots to evaluate if the sites are chemically related. The enthalpy-silica relations indicate a thermal source for the waters discussed, but the temperature of the subsurface reservoir at depth is relatively low.

Summary of Chemical Geothermometers

Chemical analyses from over 1,100 distinct sampling locations were compiled and evaluated to determine the geothermal potential of Yucca Mountain and the area within 50 miles of this site. Plate 1 shows the distribution of measured temperatures in springs and wells throughout the study area. It is clear from the diagram that the area is dominated by surface water temperatures < 50°C and, in much of the area, temperatures are < 25°C. Subsurface temperatures measured in wells do not show significant departure from the surface measurements; all of the elevated temperatures were recorded in deep wells and are discussed in the temperature gradient section of this report. Because most waters sampled in the Yucca Mountain CCA are relatively cool, geothermometers require cautious interpretation. Based on chalcedony geothermometer values, all waters within 50 miles of Yucca Mountain were categorized by their potential to originate from a low-temperature (< 90°C), intermediate-temperature (90 ≤ T < 150°C), or high-temperature (> 150°C) resource. Plate 2 shows the distribution of chalcedony geothermometers calculated for springs and wells throughout the study area. Like Plate 1, the data do not reveal any anomalous areas of elevated temperature. Only two sites (U20C and DRI LG105) have data which may indicate a useful high-temperature resource at depth, and neither of these sites is located within the Yucca Mountain CCA. Figure 29 shows locations where chalcedony temperatures are ≥ 90°C; none of these occur on Yucca Mountain. Therefore, the potential for the existence or discovery of a high-temperature geothermal resource at or within 50 miles of the Yucca Mountain site is minimal.

All chalcedony geothermometer temperatures within the Yucca Mountain CCA have temperatures < 90°C (Figures 29 and 30), indicating that the Yucca Mountain site has considerably less potential for a productive intermediate-temperature resource than many other areas within a 50 mile radius of the site.

Only one site within the CCA (USW WT-7) has similar Na-K-Ca and chalcedony geothermometer temperatures suggesting that the geothermometer temperatures are reliable. The data indicate that the water originates from a very low-temperature resource (chalcedony = 31°C and Na-K-Ca = 35°C). Because other sites in the CCA belonging to the low-temperature category have chalcedony temperatures < 125°C, the temperatures can not be considered reliable, but are indicative of a relatively low-temperature resource. Hence, the majority of sample sites indicate a low-temperature or nonthermal resource occurs beneath Yucca Mountain and that the potential for this low-temperature resource at Yucca Mountain is no greater than in other parts of the Great Basin. In fact, the utility of such a resource is less at Yucca Mountain than at many other Great Basin sites because the water table is very deep beneath Yucca Mountain.

Geophysics

Gravity

In the Yucca Mountain area, gravity data have been principally used to model the surface of the basement beneath the thick Cenozoic sedimentary and volcanic sections. Gravity data available for the Yucca Mountain study area includes surveys completed by the U.S. Geological Survey for the U.S. Department of Energy. Tabulations of data, field procedures, evaluation techniques, and data reduction routines (terrain and other corrections) are contained within the original reports, which are listed in the bibliography. No additional gravity measurements were made during this study. Data presented are contoured from published sources and the associated metadata from manipulation of these data are listed in Appendix 2.

Ponce and Oliver (1994) state that gravity investigations were begun at the NTS as early as 1977 to determine the general configuration of the basement, to identify concealed faults and caldera structures, and to determine the tectonic stability of the area. Healy and Miller (1979) investigated the Timber Mountain Caldera and identified the large circular gravity low, which is reflected at the surface by extensive outcrops of low-density Tertiary volcanic rocks.

Snyder and Carr (1982) completed the first large scale gravity survey of the area and provided the foundation for subsequent studies, adding 423 new gravity sites to the existing 934 stations which forms the data base for the study. Density determinations, collected from surface rocks at 1,200 sites, were combined with three borehole gamma-gamma logs and one borehole gravity study to provide rock density control in three dimensions. The borehole gravity study from drill hole USW G-1, for example, shows a linear increase in density of 0.026 $g/cm^3/km$. The authors suggest that, if this increase is due to a combination of alteration, compaction, and lithostatic loading, then the gradient may be applicable to all thick tuffs in the study area.

Figure 33 shows the results of the contoured gravity data for the Yucca Mountain study area (after Saltus, 1988). The most distinctive feature is the Bare Mountain - Funeral Mountain gravity high, which is a reflection of the thick exposures Precambrian-Paleozoic carbonates, argillites and quartzites. Additional gravity highs occur at the Calico Hills, where a northeast-trending remnant of Paleozoic rocks may cause the high, and the Wahmonie area, where other geophysical data suggest the presence of granitic intrusive rocks.

The gravity high in the southeast corner of the study area encompasses both the Little Skull Mountain and Striped Hills and is also related to exposed, high-density Paleozoic rocks. Profiles of this gravity anomaly indicate that the Paleozoic rocks steepen abruptly near Topopah Wash,

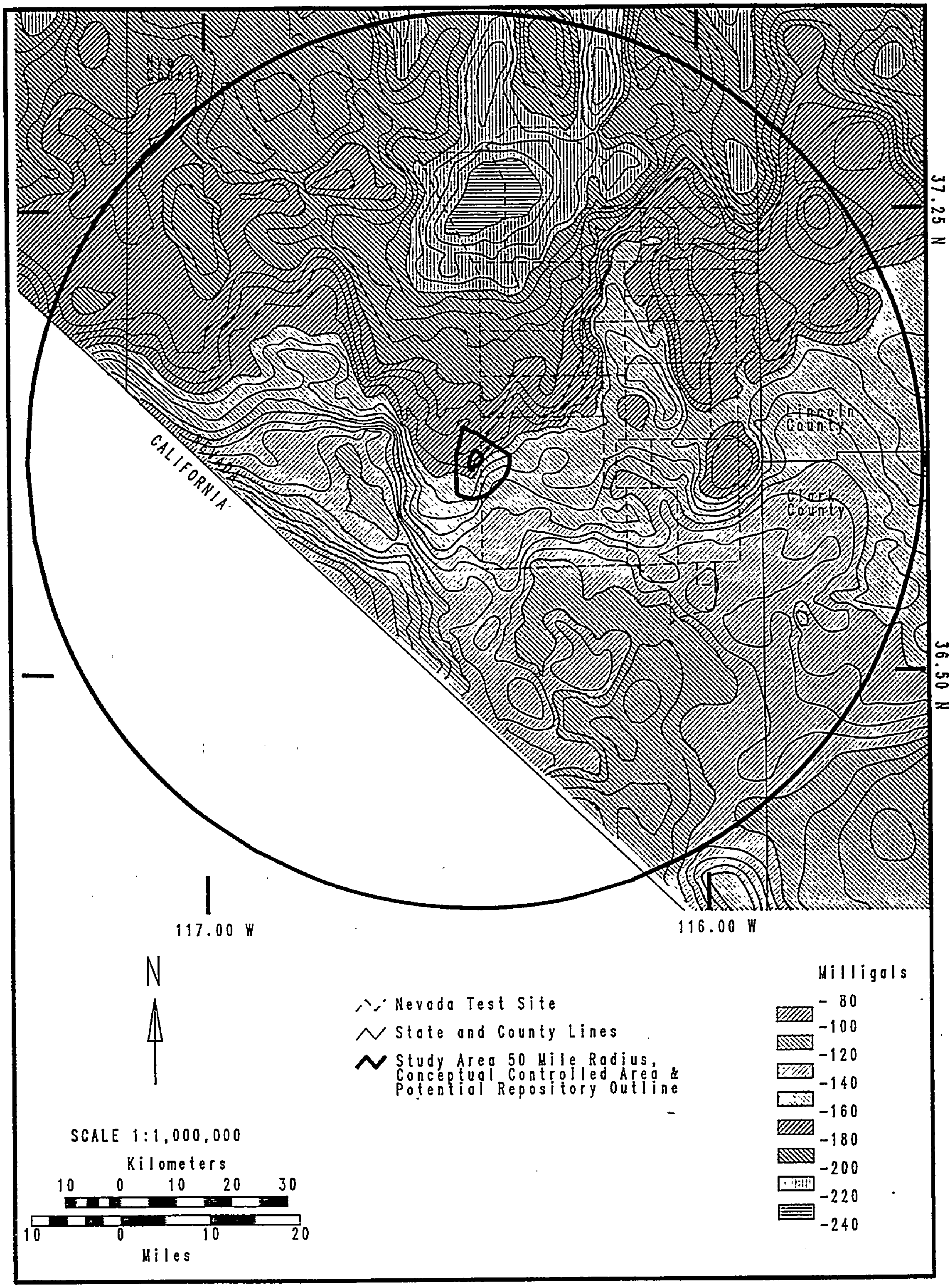


Figure 33. Regional Bouguer gravity within the Yucca Mountain study area (Saltus, 1988).

indicating a north-northwest-trending buried fault with rocks downthrown to the west (Snyder and Carr, 1982).

Model results in the Crater Flat - Yucca Mountain area suggest that the large gravity low indicates that the pre-Cenozoic basement may be as much as 2,500 m below sea level. By using a density of 2.0 g/cm^3 for the Tertiary volcanics (instead of the 2.67 g/m^3 used with the State-wide gravity map) Snyder and Carr (1982) were able to achieve a much greater resolution of small-scale features. The new model allowed the gravity field to be correlated more directly with the pre-Tertiary surface. However, there is some uncertainty in the density contrast estimates for the tuff underlying Crater Flat and Yucca Mountain. As a result, the minimum thickness of tuff supported by drill hole data is 1,830 m. Three-dimensional modeling suggest the thickness could be as much as 3,400 m +/- 400 m.

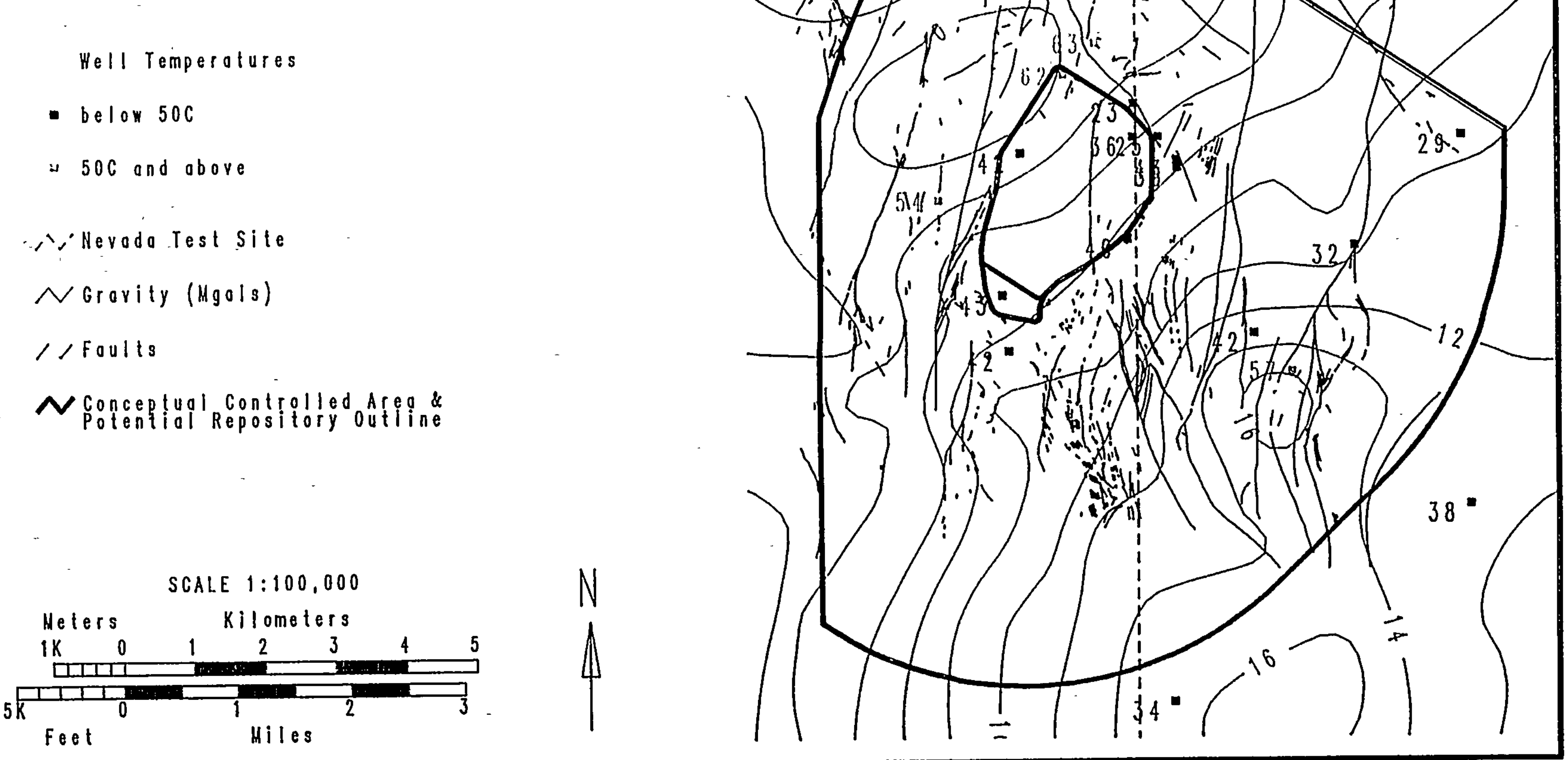
The lack of active surface thermal features, such as hot springs and fumaroles, makes the discussion of a detailed relationship between gravity and geothermal activity speculative at best. In addition, surface fault trends are both parallel and perpendicular to gravity gradient trends. To demonstrate the lack of a cohesive pattern, Figure 34 shows the outline of the CCA, the mapped faults, gravity contours, and wells with measured temperatures >50°C. Wells USW G-1, G-2, H-1, and H-6 are associated with a gravity low (2 mGal or less), while the well UE-25 p#1 occurs on the Calico Hills gravity high.

In summary, the gravity data for this area delineate the known distribution of the high-density Paleozoic rocks which crop out in the Funeral Mountain - Bare Mountain area, and the low-density volcanic rocks in the Timber Mountain area. Gravity highs associated with exposures of Paleozoic rocks trend northwest, parallel to the Walker Lane belt, and surround the Timber Mountain area. The general northward depression of gravity values corresponds with the occurrence of the Timber Mountain caldera and the associated increased thickness of low-density Tertiary volcanic rocks. Gravity gradient trends on the western, southern, and eastern margins of the caldera, along with the concentric gravity low at Timber Mountain, support the concept of a volcano-tectonic depression (Carr, 1982). The total gravity relief in a northward direction is 160 mGal. Geometrically, the pattern resembles a north-dipping "ramp." Geologically, the evidence suggests a large, asymmetrical north-dipping graben, possibly associated with caldera collapse (Carr, 1984).

Magnetics

Oliver and others (1994) reviewed the status of magnetic surveys in the vicinity of Yucca Mountain and reported that 50 aeromagnetic surveys had been conducted in southern Nevada and adjacent areas of California. Figure 35 is the magnetic map for the Yucca Mountain study (Zietz and others, 1979). The most prominent feature is the northwest-trending regional magnetic high that extends from the Wahmonie area, east of the Yucca Mountain area, through the Calico Hills, and through Timber Mountain and Black Mountain calderas to the north. The magnetic high over the Wahmonie area is coincident with Miocene intrusive rocks (Ponce, 1984), while the Calico Hills high is associated with the Mississippian Eleana argillite. Bath and Jahren (1984) note that the magnetic high of the Eleana Formation is the result of high magnetite content, probably introduced by the heating effects of an underlying pluton. Poole and others (1961) report that the argillite member of the Eleana Formation contains cubic iron oxide pseudomorphs after pyrite. The Timber Mountain and Black Mountain anomalies probably reveal the locations of ring dikes and collapse features within the caldera.

Figure 34. Detailed Bouguer gravity, Scott and Bonk (1984) fault mapping, and well temperatures (°C) within the Yucca Mountain CCA.



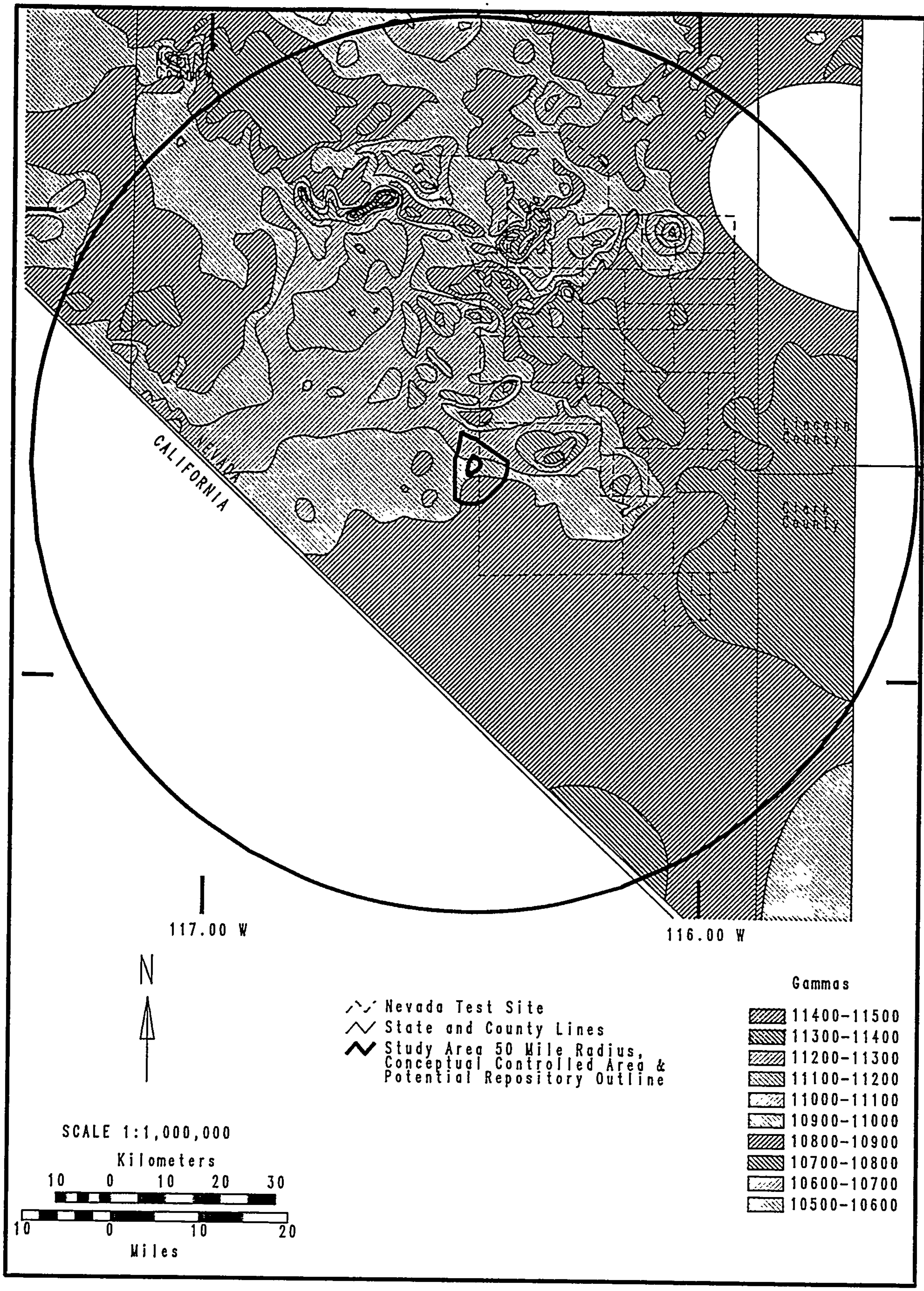


Figure 35. Regional aeromagnetics within the study area (Zietz and others, 1979).

Detailed magnetic and gravity surveys along five profiles across Midway Valley (Ponce and others, 1993) show prominent anomalies associated with known faults and reveal a number of possible concealed faults. The Paintbrush Canyon fault, on the west flank of Fran and Alice Ridges, is characterized by a gravity anomaly with an amplitude of about 2 mGal and a magnetic anomaly with an amplitude of about 320 nT, which is the largest gravity and magnetic anomaly in Midway Valley. They infer a vertical offset of about 100 m for the Bow Ridge Fault and about 200 m for the Paintbrush Canyon Fault. Smaller amplitude anomalies (as little as 0.5 mGal and 80 nT to 210 nT) characterize small-scale faulting and concealed faults in Midway Valley.

Langenheim and others (1993) completed five gravity and magnetic traverses across and along Yucca Wash. These surveys were completed to assist in locating the site of a borehole to be drilled to help characterize the "hydrologic gradient." The results do not indicate a vertical offset greater than about 100 m, but do not preclude the existence of major vertical offsets. Their model uses a density contrast of 0.2 to 0.3 g/cm^3; a broad magnetic anomaly was found to coincide with the location of the hydrologic gradient.

Unlike the gravity data for the area, the magnetic data show little correlation with surface geologic features. The most significant anomalies are associated with magnetization of Paleozoic sedimentary rocks. Other smaller anomalies are associated with east-west-trending Quaternary volcanic rocks. The principal magnetic alignment is northwest, parallel to the Walker Lane.

Seismic

Mooney and Schapper (1994) described five seismic refraction surveys completed to define the velocity structure of the upper crust in the vicinity of Yucca Mountain. These data were combined with lithologic logs from core holes and other geophysical information to provide a three-dimensional view of the subsurface structure in the vicinity of Yucca Mountain. Profiles were conducted in a north-south direction though Crater Flat and Forty Mile Wash and in an east-west direction near Beatty, across Yucca Mountain, and across the Amargosa Valley.

Along the Yucca Mountain survey, which trends east-west across Bare Mountain, Crater Flat and Yucca Mountain, three drill holes that are located within 2 km of the traverse did not prove to be useful in correlating the stratigraphic contacts with the velocity layers identified in the survey. Sonic logs revealed seismic heterogeneities associated with lava flows, fractures, and various degrees of cementation and welding. The drill hole data was used to confirm the pre-Tertiary contact. Seven seismic horizons were identified, including the Paleozoic carbonates section with velocities of 5 km/s or more. The survey identified a zone of faulting and brecciation in the upper 425 m of dolomite in UE-25 p#1. This has been described as a vuggy and brecciated section and is marked by a "noticeable pull-down" in the velocity at the top of layer 6. Data along this profile are equivocal and it is impossible to ascertain with any degree of certainty whether a low velocity reflection is from a tightly welded tuff or a brecciated dolomite. In addition, the averaging effects of seismic inhomogeneities is apparently responsible for the lack of conformity between velocity layers and stratigraphic layers.

Along the Crater Flat section, the pre-Tertiary surface may have been identified within a depth range of 2.0 to 3.2 km based on an increase in velocity from less than 4 to more than 5 km/s. Under Crater Flat itself, the model shows the pre-Tertiary surface has a seismic velocity that ranges from 6.1 to 6.8 km/s. Along the Beatty traverse, the authors believe they identified the northward extension of the Boundary Canyon detachment fault in the velocity section between Death Valley and the Bullfrog Hills. Along the Forty Mile Wash survey, the pre-Tertiary surface is identified as a velocity layer separating a sub 4 km/s layer from a lower layer greater than 5 km/s. Lateral velocity changes are attributed to lithologic changes, not to faults or offset beds. A domal structure was identified that is coincident with the location of a magmatic anomaly (U.S. Geological Survey, 1978). The velocity data suggests the presence of a basalt flow sandwiched between two layers of lower velocity material. The Amargosa profile had velocities that were much lower than those interpreted on other profiles. This is due possibly to extensional faults, such as the nearby left-lateral Rock Valley fault, to less cementation, and to a lower grade of metamorphism.

The authors conclude that there is sufficient velocity contrast between the Tertiary and pre-Tertiary surface, when interpreted with gravity and other data to yield a reliable representation of the pre-Tertiary surface. In addition, the study identified a structural depression beneath Yucca Mountain that dips asymmetrically westward into Crater Flat to a depth of 3.5 km. Under Yucca Mountain itself, the Tertiary section is about 1.25 km thick. In most cases, the seismic refraction horizons do not correlate very well with the known depth and thickness of stratigraphic formational boundaries identified in drill holes.

Seismic reflection data collected across the Beatty scarp (Harding, 1988) are inconclusive and inconsistent; across Windy Wash, the data are described as complex; along the East Slope of Bare Mountain, there is insufficient quality; and across Tarantula Canyon, the data are incoherent. A summary report of data collected from 1980 to 1982 (McGovern, 1983) suggests that useful seismic reflection data cannot be acquired from the Yucca Mountain site. This is based on the argument over the acquisition parameters needed to produce optimal interpretable images. On the other hand, Oliver and others (1994) indicate that the Ghost Dance Fault was adequately imaged and appears to be a part of a several-hundred-meter-wide complex zone of faulting that extends to a depth of at least 1 km. In summary, however, unless a target geothermal reservoir is identified in the subsurface, structural information provided by seismic surveys has limited applications.

Temperature Gradients

Temperature gradient is defined as the change in temperature, positive or negative, divided by the change in depth. Gradients may be averaged from the surface to total depth or may be calculated between any two depths within the well bore. The general formula is:

$$\text{Temperature gradient} = \frac{\text{measured temperature - mean annual surface temperature}}{\text{depth of measured temperature}} .$$

Temperature gradient data in this area have been collected for more than 30 years. Lachenbruch and others (1987) reported that four, shallow-depth holes drilled in the Oak Springs formation, located on Rainier Mesa, NTS, in 1957 had temperature gradients ranging from 30 to 40°C/km, with a mean near 35°C/km. The variations in the gradients were accounted for by terrain and elevation effects.

An initial systematic thermal gradient study in the Yucca Mountain area was performed by Sass and others (1980) who analyzed temperature data from drill holes UE-25 a#1 and UE-25 a#3, completed in 1978. Temperature logs were completed by the U.S. Geological Survey in April, 1979. Hole UE-25 a#3 was drilled in the Calico Hills and contains a 600 m section dominated by thermal conduction, below which convection is noticeable. This hole was drilled through the Tertiary volcanic tuff and was completed in the Paleozoic basement of sedimentary rocks, primarily argillite. Both drill holes are located outside, but near, the Eureka Heat Flow Low which is defined as an area with <60 mWm^{-2} heat flow. Analysis of the profiles below the water table (greater than 450 m deep) indicate two different thermal regimes. Drill hole UE-25 a#1 had a temperature of 47°C at about 750 m; drill hole UE-25 a#3 had a temperature of only 35°C at the same depth. The heat flow in drill hole UE-25 a#1 is at least 30 mWm^{-2} less than the average for the Basin and Range (80 mWm^{-2}). They observed that the temperature profile of drill hole UE-25 a#1 was extremely disturbed by convection (moving water) in the volcanic tuff at a depth of 500 to 650 m. Sass and others (1980) concluded that the nearly three-fold difference in heat flow between the two holes, combined with the lower temperature in drill hole UE-25 a#1 over a lateral distance of only 20 km, "suggests the presence of a more deeply seated hydrothermal convection system with a net upward flow beneath the Calico Hills and a net downward flow beneath Yucca Mountain." This downward flow would make the existence of a geothermal resource below Yucca Mountain highly improbable.

In 1982, Sass and Lachenbruch analyzed temperature-depth data from 60 wells throughout the Yucca Mountain area in order to characterize the thermal regime. These measurements were completed in holes that were not intended for thermal gradient work. For most holes, temperature measurements above the static water level were taken in the air column, instead of in a water-filled tube as is the standard practice in the geothermal industry. The static water table in most holes exceeded 500 m below the well head, and measured temperatures below the static water level reflected moving (convecting) water, either in the formation or the well bore itself. The authors acknowledge that the data set did not "allow unambiguous interpretation of the heat flow." Systematic variations in temperature gradients without corresponding variations in thermal conductivity were evaluated and a preliminary interpretation of downward percolation of water in both the saturated and unsaturated zones was tested. The model suggests a fluid seepage velocity of about 8 mm/year and a circulation depth of 2.0 to 2.5 km.

Sass and others (1988) reported on repeated temperature logs from 18 geologic and hydrologic test wells at Yucca Mountain. Available lithologic logs from drill holes were evaluated here with the temperature-depth profiles (temperature logs) to provide additional understanding of the nature of the thermal regime in the Yucca Mountain area. In each of the following diagrams, data from lithologic logs were transferred by scaling the depth of the well and the formational contacts. The temperature log data were then transferred from published data at 50 m intervals to the corresponding lithologic log. Both data sets were plotted at a common scale to illustrate the relationship between measured temperatures, lithology, and, where known, fault contacts. All of the temperature logs were derived from Sass and others (1988). Lithologic log data are as follows: USW G-2 and UE-25 b#1H (Caporuscio and others, 1982); USW G-3 and USW G-4 (Anderson, 1984); and UE-25 p#1 (Carr and others, 1986). Because there are no chemical analyses associated with these wells, they are not included in the appendix or plates. Attribute data for these and similar wells can be found in the respective references.

Figure 36 shows the temperature and lithologic logs for USW G-2 drill hole, completed to a total depth of 1,250 m. The hole penetrates the static water level (SWL) at a depth of about 525 m and does not reach the Paleozoic rocks. The most obvious feature in the temperature profile is the straight line segment between 200 and 600 m, indicating a nearly conductive temperature gradient of about 25°C/km. Below that section, the gradient shows the kinds of hydrologic disturbances previously discussed (Sass and Lachenbruch, 1982). The isothermal section between 650 m and

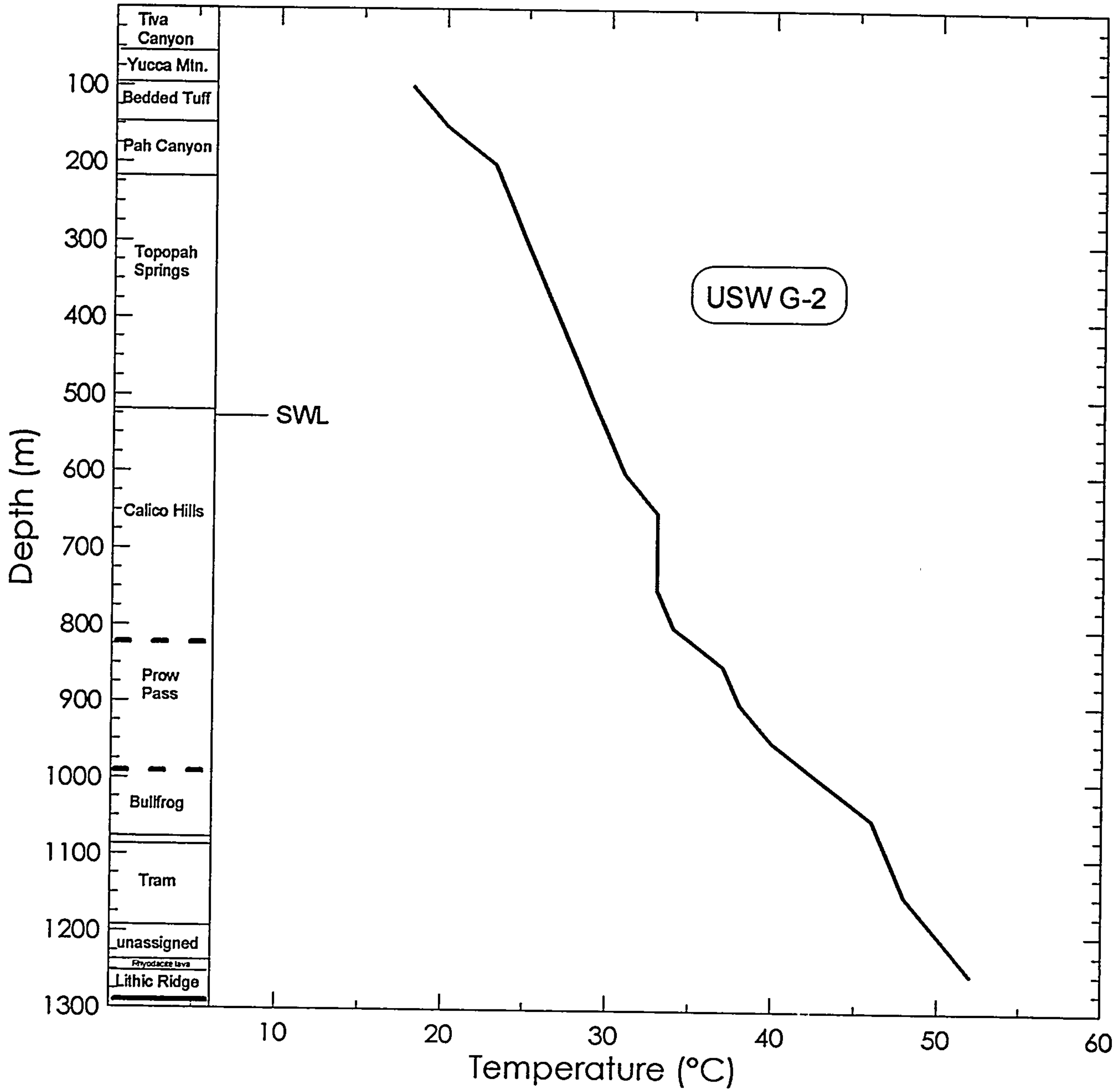


Figure 36. Temperature vs. depth profile and lithology for well USW G-2.

750 m appears to reflect convection within the Calico Hills sections, but there is no indication if it is related to lithology (porosity, dissolution vugs, etc.), a structure (fault zone, brecciation, etc.), or the well completion technique. Below 750 m, the profile shows a combination of convection and conduction, but there is considerable uncertainty in the details of all thermal gradient studies in the Yucca Mountain area. The maximum temperature at 1,250 m is 53°C.

The temperature and lithologic logs for USW G-3 drill hole, completed to a total depth of 1,300 m, entirely within the Tertiary volcanics are illustrated in Figure 37. The profile indicates slight variations in temperature throughout the profile. The most significant change occurs at the depth of the static water level (SWL) where the gradient changes from 25 to 20°C/km. The maximum temperature of 43°C occurs at total depth of 1,300 m.

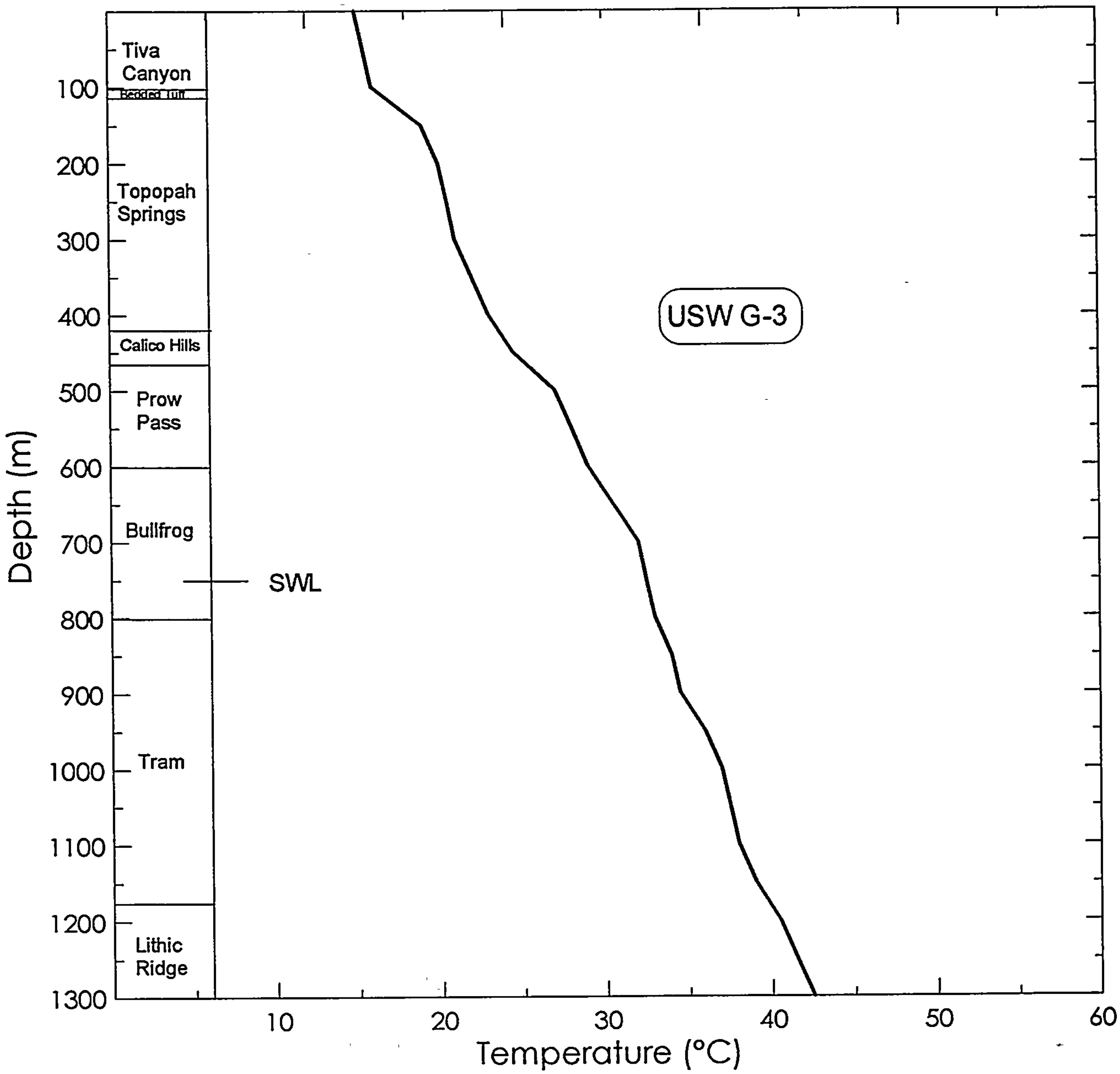


Figure 37. Temperature vs. depth profile and lithology for well USW G-3

Figure 38 shows the temperature and lithologic logs for USW G-4 drill hole, completed to a total depth of 900 m, all within the Tertiary volcanics. This profile is largely conductive above the water table and is partly conductive, partly convective below the water table. The maximum temperature of 35°C occurs at the maximum depth of 900 m.

The temperature and lithologic logs for UE-25 b#1H drill hole, completed to a total depth of 1,200 m, entirely within the Tertiary volcanics are shown in Figure 39. Temperature variations occur throughout the profile and there is little correlation to lithologic changes, although the isothermal section between 700 and 900 m does appear to be related to the Bullfrog Member. The maximum temperature of 42°C occurs at the maximum depth of 1,200 m.

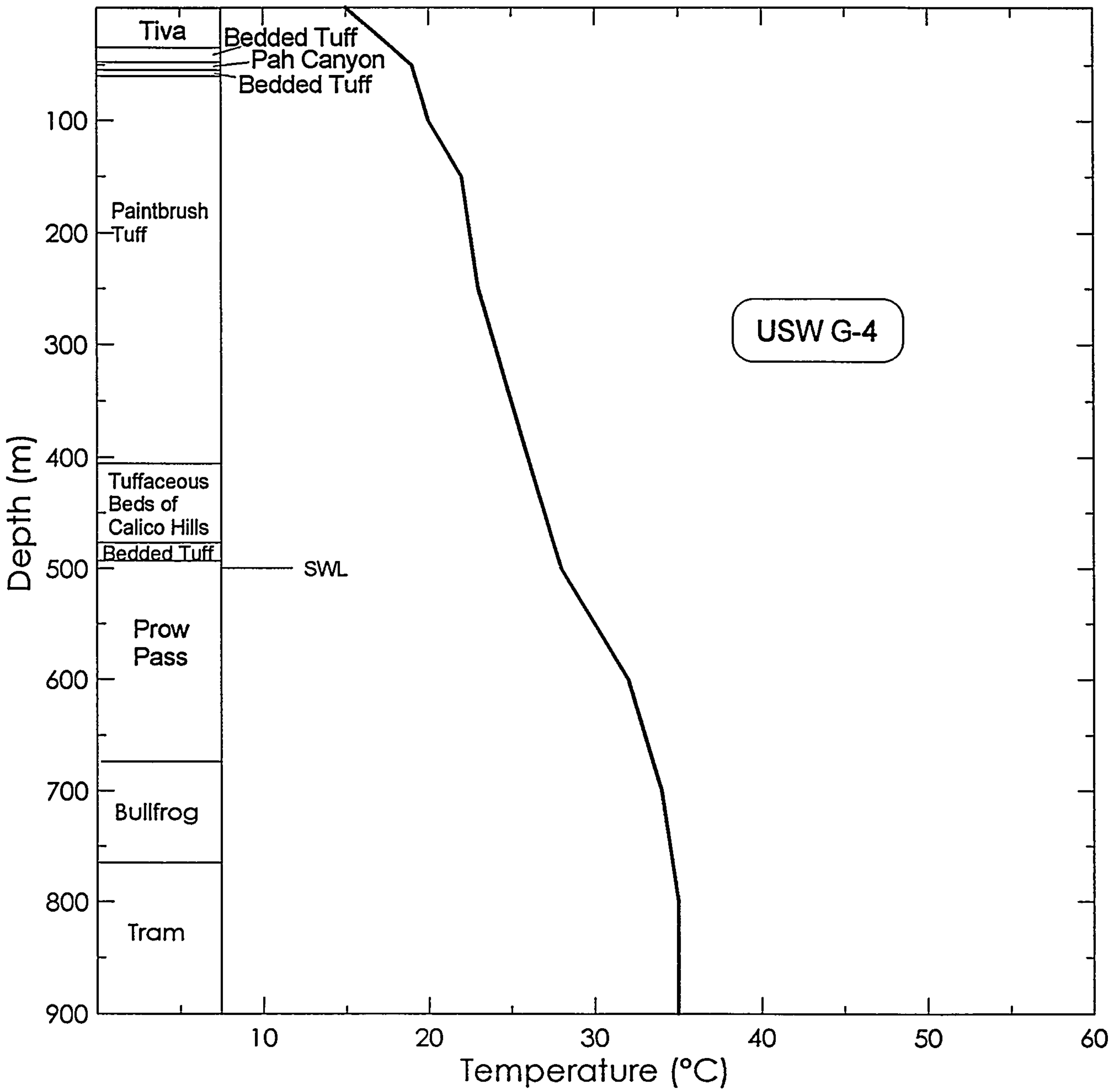


Figure 38. Temperature vs. depth profile and lithology for well USW G-4

The final profile (Figure 40) shows the temperature and lithologic logs for UE-25 p#1. This profile is the most complete and most complex because this well penetrates the entire Tertiary volcanic section as well as part of the Paleozoic carbonate aquifer below. Carr and others (1986) provide a summary of the geology and a lithologic log for drill hole UE-25 p#1, completed to a total depth of 1,805 m in May, 1983. The hole encountered Tertiary volcanic tuff and sedimentary rocks from 39 to 1,244 m. Snyder and Carr (1982), who accurately estimated the depth to basement using gravity data, suggested that the northward-trending gravity anomaly (the site of drill hole UE-25 p#1) was the signature of an uplifted block of high-density Paleozoic rocks, the Mississippian Eleana Formation. The bottom 550 m of the hole consisted of Silurian age Lone Mountain Dolomite. On the basis of conodont alteration indices (Epstein and others, 1977), the rocks in this

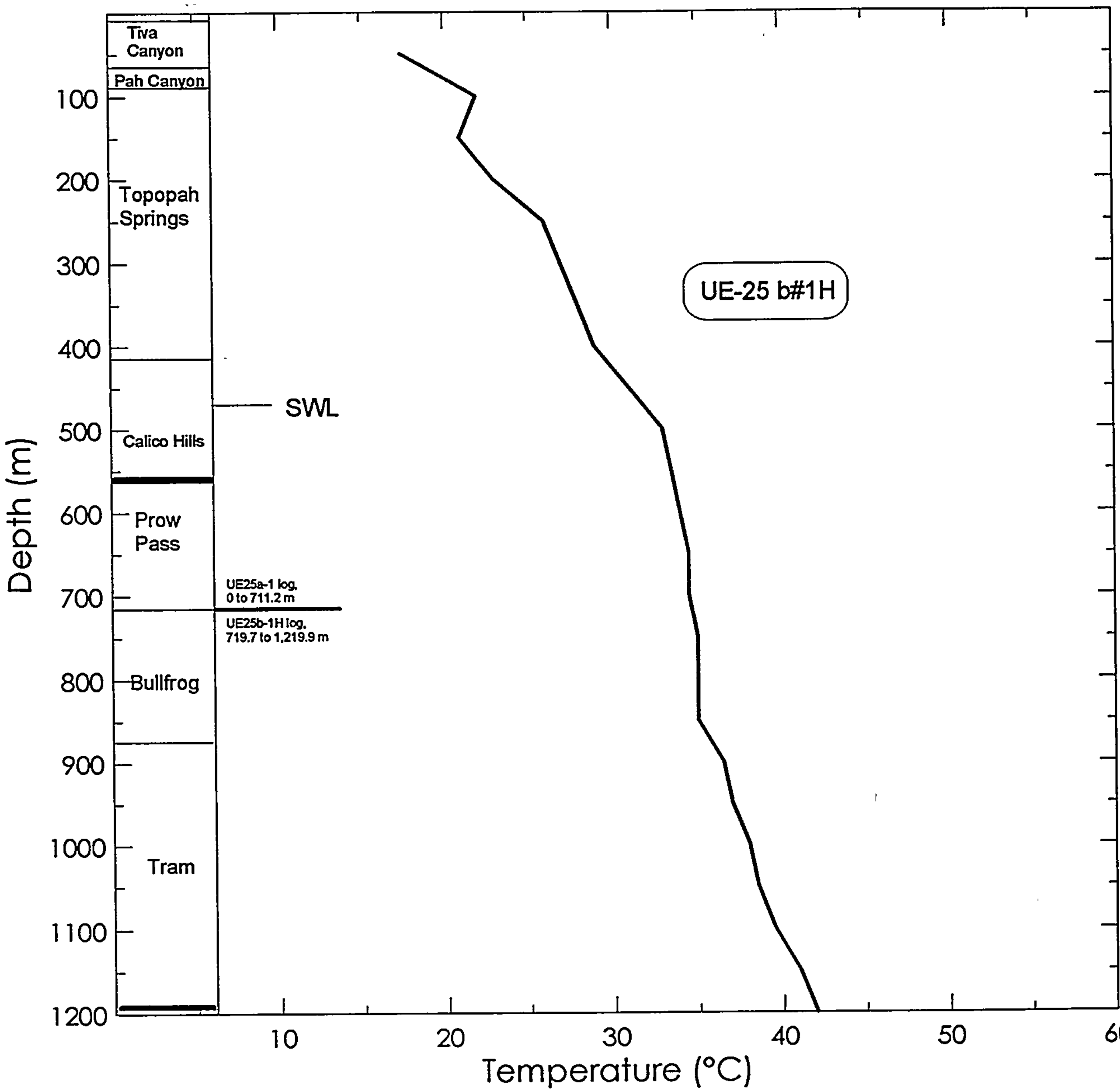


Figure 39. Temperature vs. depth profile and lithology for well UE-25 b#1H.

hole are believed to have never been above a maximum temp of 82°C, indicating that the temperature effects of the intrusive rocks were not registered in the Silurian rocks in the vicinity of the hole. The principal changes in the profile are associated with faults and fracture zones identified in the lithologic log. The maximum temperature in this well is 57°C. Unlike the four others described it does not occur at total depth, but rather occurs at a depth of 1,200 m, more than 600 m above the bottom of the hole. The maximum temperature occurs in association with a major fault zone and the top of the Lone Mountain Dolomite. The temperature profile is isothermal in this broad zone, but reverses at a depth of 1,400 m. The bottom hole temperature is 54°C.

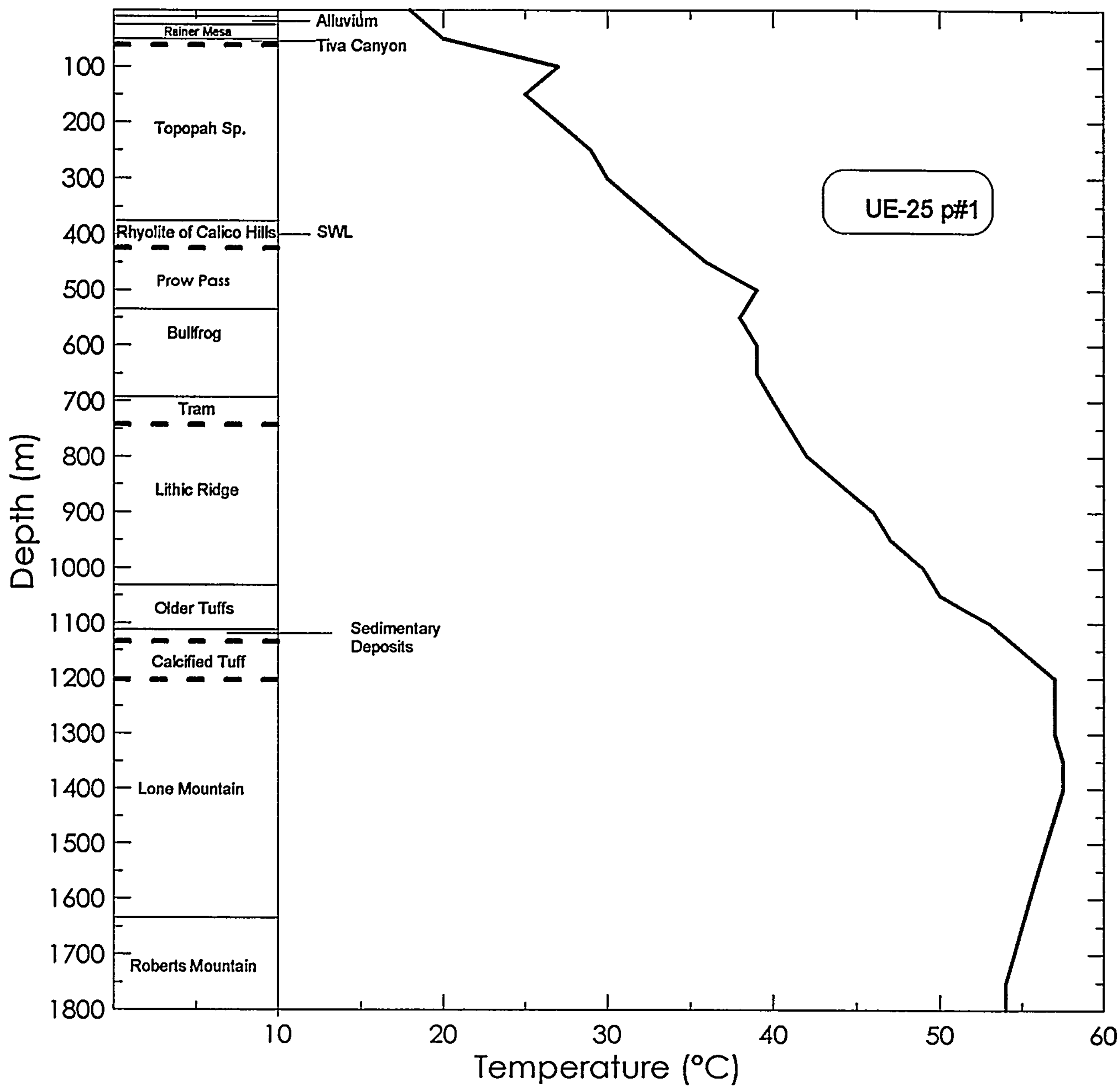


Figure 40. Temperature vs. depth profile and lithology for well UE-25 p#1.

The profile from UE-25 p#1 is described as having a complex thermal regime below the water table, the apparent result of lateral and vertical water flow (Sass and others, 1988). The isothermal nature of the profile at 1,200 to 1,400 m is indicative of a well-mixed, liquid-saturated reservoir that is typical of many geothermal reservoirs. This occurs within what is believed to be the subsurface continuation of the Fran Ridge Fault. Below the fault zone, there is a significant temperature reversal, suggesting that the thermal waters are restricted to the fault zone.

These temperature and lithologic logs illustrate the nature of the geothermal resources, including the temperature, depth, and structural and stratigraphic controls. They are deep (400 to 500 m), low-temperature (<60°C), and appear to be structurally controlled (restricted to fault zones).

Heat Flow

Heat flow evaluations of the NTS and the Yucca Mountain area have been completed in conjunction with thermal gradient studies (Sass and others, 1980; Sass and Lachenbruch, 1982; Lachenbruch and others, 1987; and Sass and others, 1988). Sass and others (1971) defined the Battle Mountain Heat Flow High (BMH) and the Eureka Heat Flow Low (EL) (Figure 3) and were among the first to recognize that the thermal and hydrologic regimes at the Yucca Mountain area are closely related. Heat flow in the BMH exceeds 104 mWm^{-2}, while heat flow in the EL is below 63 mWm^{-2} and has been measured as low as 31 mWm^{-2}. Based on the observation that hydrologic disturbances were widespread in test wells throughout the Yucca Mountain area, Sass and others (1971) reasoned that water and water movement are probably masking and altering the thermal regime. They also concluded that the thermal regime could not be modeled without taking into account the effects of water movement.

The EL has been described as a heat sink comparable in size and magnitude to the magmatic-hydrothermal heat flow high at Yellowstone, Wyoming (Lachenbruch and Sass, 1977). It is attributed to interbasin flow of water in the regional Paleozoic carbonate aquifer. It is a hydrologic feature that is believed to reflect lateral water flow at depths of 3 to 4 km.

The thermal regime at Yucca Mountain has been described as "a series of relatively shallow hydrologic perturbances both regional and local, superimposed on a "normal" (65 to 95 mWm^{-2}) Basin and Range Heat Flow. A part of the Yucca Mountain study area is located within the EL. On a local scale, the heat flow in the unsaturated zone varies systematically as a function of thickness and temperature at the base of the unsaturated zone.

Hydrology

The entire study area has been the site of intensive hydrologic investigations related either to the NTS (Winograd and Thordarson 1975), the Yucca Mountain Project (Waddell and others, 1984), or the regional carbonate aquifer (Mifflin, 1968). Hydrologic studies comprise the vast majority of investigations of this area and a complete description of every contribution is beyond the scope of this report. The principal categories include comprehensive analyses of the geology and hydrology (for example, Blankennagel and Weir, 1973; Hunt and others, 1966; Malmberg and Eakin, 1962; and Robinson and Beetem, 1966). Extensive data on rock permeability and hydrologic data from individual wells throughout the study area are contained in a variety of reports (for example, Anderson, 1992; Arteaga, 1987; Barton and others, 1993; and Bentley, 1984). In addition, the water levels in most wells have been routinely monitored (for example, Boucher, 1994a and 1994b; Doty and Thordarson, 1983; and Lehman and others, 1990). Hydrologic modeling studies of the entire area include paleo-recharge studies (Claassen, 1985 and 1986), paleo-discharge studies (Quade, 1986 and 1994; and Quade and others, 1995), and mathematical models of the present day hydrologic system (Byer, 1991; Czarnecki and Waddell, 1984; Dressel, 1992; Feeney, 1987; and Fridrich and others, 1994). The importance of hydrology to a geothermal resource assessment is the depth and temperatures of the fluid and the productivity of the reservoir rock.

Although there are some differences in the details of the investigations, some generalizations can be made. The first is observational in nature; there are no significant surface water features in the Yucca Mountain area. Surface flow, where it occurs, is restricted to springs in the Oasis Valley west of Yucca Mountain and in the Ash Meadows area to the south. The springs in both areas are low-temperature geothermal springs that emanate from fault-structures in the Paleozoic carbonate rocks.

The second generalization is that the hydrology in the Yucca Mountain area is dominated by the regional groundwater system, which occurs largely in the Paleozoic carbonate rocks. Flow paths, velocities, and gradients are controlled by regional permeability, rock properties, fracture distribution, and recharge.

Winograd and Thordarson (1975) divided the south-central Great Basin area into 10 hydrogeologic units. The three that control the regional movement of groundwater are listed in Table 5. The regional movement of water is controlled by variations in fracture transmissivity and by the structural juxtaposition of the aquifer and the lower clastic aquitard. Water circulates freely to depths of 500 m beneath the top of the aquifer and up to 1,300 m below the surface.

Table 5. Hydrogeologic units that control regional groundwater movement (Winograd and Thordarson, 1975).

Hydrologic Unit	Transmissivity (gal/day/ft)
Tuff Aquifer	<200
Lower clastic aquatard,	<1000
Lower carbonate aquifer	1,000 to 900,000
(In all units, interstitial permeability is negligible.)	

The most prominent feature in the groundwater hydrology is the steep hydrologic gradient (shown in Figures 29 and 30) mapped by Wadell and others (1984), which is recognized as a decline of about 300 m in some areas over a distance of less than 2 km. Fridrich and others (1994) provide a thorough discussion of this feature in terms of the hydrology, geophysics, and structural geology. They show that the large gradient is part of a larger hydrogeologic domain that extends nearly 100 km to the north. In the vicinity of Yucca Mountain, the gradient is shown to be coincident with the occurrence of a northeast-trending gravity low (Snyder and Carr, 1982) and the Eureka heat flow low (Sass and others, 1988).

Figure 41 shows the relationship between the hydraulic gradient, the gravity data, and the heat flow. The contours of the potentiometric surface appear to parallel the gravity contours from the CCA to the northeast corner of the NTS for a distance of about 40 km. Superimposed is the outline of the heat flow low (Sass and others, 1988) which roughly overlies the two gradients. The heat flow low has been interpreted as an area of downward moving groundwater (downwelling). Fridrich and others (1994) interpret the gravity low as a northeast-trending buried graben. The hydraulic gradient is interpreted as the drop in the potentiometric surface resulting from groundwater infiltration along a permeable basement fault contact into the underlying Paleozoic carbonate aquifer (Fridrich and others, 1994). This interpretation is consistent with the explanation for the low heat flow (Sass and others, 1988). The only anomaly that therefore appears in an otherwise flat-lying potentiometric surface is related to groundwater downwelling. Active geothermal systems in the Great Basin are characterized by artesian (upwelling) conditions in the vicinity of faults and fractures, which is not observed in this area.

Fluid Recharge

Grove and others (1969) determined that groundwater from the NTS ranges in age from modern to 23 ka and speculated that surface water probably recharged this groundwater 12 ka to 20 ka. In the Amargosa Desert, Claassen (1985) determined that groundwater was recharged primarily by overland flow of snow melt in stream channels during the late Pleistocene. White and Chuma (1987) used stable isotopes and radiocarbon ages to delineate possible recharge areas and flow rates for groundwater systems in the Oasis Valley - Forty Mile Canyon basins in southern Nevada. Various

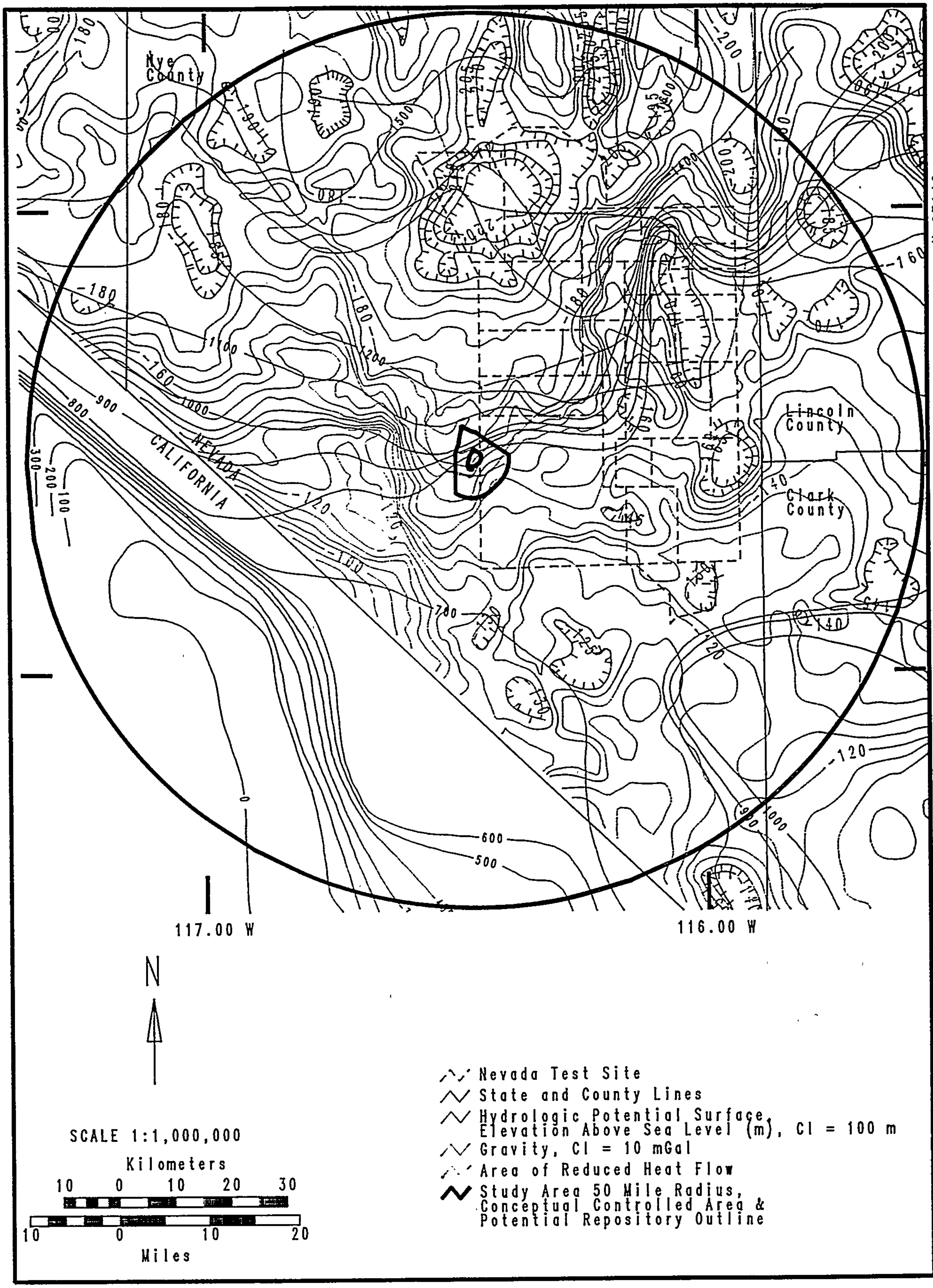


Figure 41. Water level elevations, regional Bouguer gravity, and area of reduced heat flow of Sass and others (1988).

corrections were applied and the calculated ages ranged from 3 to 12 ka. Lyles and Hess (1988) used a combination of ion, stable light-isotope, and radiocarbon ages to delineate the extent of the Las Vegas Shear Zone in southern Nevada. Geochemical traverses, both parallel to and across the zone, identified a range of fluid ages from 2.5 to 12.5 ka.

COMPARATIVE EVALUATION OF GEOTHERMAL FEATURES AT YUCCA MOUNTAIN

The economic exploitation of geothermal resources depends on the co-location of a viable geothermal resource and a prospective market for the product, either electricity or direct use. In theory, there are four kinds of geothermal resources that are suitable for electric power generation: hydrothermal, geopressured, hot dry rock, and magma. Currently, all commercial geothermal electric power generation comes from two types of hydrothermal resources; vapor dominated (steam) and liquid dominated (hot water).

The Lindal diagram (Figure 42) is widely used in the geothermal industry as a yardstick of temperatures required for a variety of applications, including direct use and electric power production (Gudmundsson and others, 1985). On the basis of the temperatures measured in various wells throughout the Yucca Mountain study area, potential conventional applications include animal husbandry, greenhousing, mushroom growing, therapeutic and recreational bathing, soil warming, swimming pools, biodegradation, year-round mining, de-icing, and fish farming (aquaculture).

Electric Power Production

In the Great Basin physiographic province, presently operating geothermal power plants include single flash, dual flash, binary, and hybrid power plants (Figure 5). Benoit and Butler (1983) showed that measured temperatures in producing geothermal wells range from 148 to 271°C at depths from 324 to 1,862 m. The maximum measured temperature reported for a non-producing well was 205°C at a depth of 2,981 m. Table 6 lists the most recent information on geothermal power plants throughout the Great Basin, including installed capacity, reservoir temperature, well depths, and sources of data. Temperature and depth data are graphically displayed for 16 operational power

Table 6. Statistics from geothermal power plants in the Great Basin.

Field	Number of Wells	Depth (m)	Temp. (°C)	Capacity (MWe)	Reference
Beowawe	3	2,100	216	16	Benoit and Butler, 1983
Bradys	8	1,500	212	20	Benoit and Butler, 1983
Coso	75	405	337	260	Benoit, 1994
Cove Fort	21	355	178	10	Huttrer, 1992
Desert Peak	2	2,000	208	10	Faulder and Johnson, 1987
Dixie Valley	9	2,981	267	60	Benoit, 1994
Empire	3	549	148	5	Edmiston and Benoit, 1985
Fish Lake	3	2,500	157	0	Benoit, 1994
Mammoth	14	200	178	40	Benoit, 1994
Roosevelt	10	2,250	271	23	Faulder, 1994
Rye Patch	1	2,500	205	0	Edmiston and Benoit, 1985
Salt Wells	1	2,000	160	0	Edmiston and Benoit, 1985
Soda Lake	4	1,300	204	23	Benoit, 1994
Steamboat (B)	15	500	160	47	Benoit, 1994
Steamboat (F)	3	929	228	13	Benoit and Butler, 1983
Stillwater	5	1,000	160	13	Benoit, 1994
Wabuska	2	120	108	1	Benoit, 1994

(B) = Binary Plant, (F) = Flash Plant

plants and 3 non-commercial sites (Figure 43). Data for well UE-20f (121°C at a depth of 3,740 m), which is the well with the highest measured temperature in the study area, are also plotted. The measured temperature is within the range for binary power production, but the depth exceeds even the deepest, high-temperature geothermal production wells in the Great Basin. Commercial success is defined on the basis of plants that receive sufficient revenue from the sale of electricity to cover all expenses, such as salaries, maintenance, royalty, taxes, and all financial obligations. The three sites shown as non-commercial all represent substantial capital investment, but development was stopped when the sites were found incapable of supporting a commercially viable project. It should be noted that temperatures of the non-commercial sites were greater and well depths were less than the UE-20f well. This essentially rules out UE-20f as a commercially viable geothermal power plant site.

	°C		
saturated steam	200 -		
	190 -		Conventional Power Production
	180 -	Evaporation of highly concentrated solutions	
		Refrigeration by ammonia absorption	
		Digestion in paper pulp	
	170 -	Heavy water via hydrogen sulfide process	
		Drying of diatomaceous earth	
	160 -	Drying of fish meal	
		Drying of timber	
	150 -	Alumna via Bayer's process	
	140 -	Drying farm products at high rates	
		Canning of food	
	130 -	Evaporation in sugar refining	
		Extraction of salts by evaporation and crystallization	
		Fresh water by distillation	
hot water	120 -	Most mullet-effect evaporation. Concentration of saline solution	
	110 -	Drying and curing of light aggregate cement slabs	
	100 -	Drying of organic materials, seaweed's, grass, vegetables, etc.	
		Washing and drying of wool	
	90 -	Drying of stock fish	
		Intense de-icing operations	
	80 -	Space heating (buildings and greenhouses)	
	70 -	Refrigeration (lower temperature limits)	
	60 -	Animal husbandry	
		Greenhouses by combined space and hotbed heating	
	50 -	Mushroom growing	
		Balneology	
	40 -	Soil Warming	
	30 -	Swimming pools, biodegradation, fermentation	
		Warm water for year-round mining in cold climates	
		De-icing	
	20 -	Hatching of fish. Fish farming	

Figure 42. The Lindal diagram depicting the application temperature for several types of geothermal energy uses.

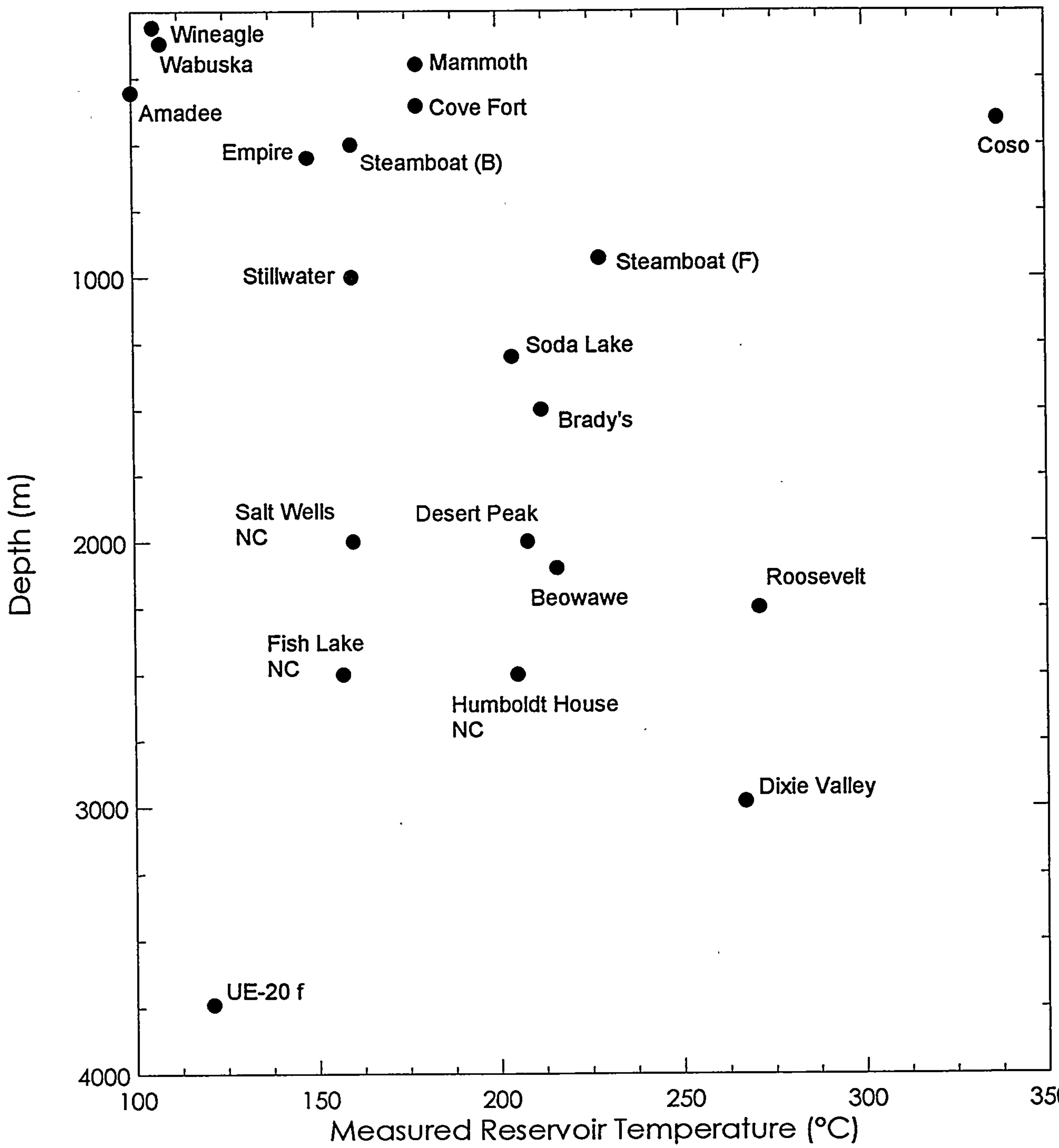


Figure 43. Comparison of depth vs. measured reservoir temperature between commercial and non-commercial geothermal sites and the hottest well near Yucca Mountain.

Experimental power plants include Hot Dry Rock (HDR), Kalina Cycle, and geopressured power plants. The temperatures reported for the only HDR site in the United States exceed 245°C in artificially fractured granite at depths that range from 3,500 to 3,750 m (Brown, 1995). The geological environment required for geopressured resources includes rapid sediment deposition and subsidence associated with coastal processes. In addition, the heat source is believed to be associated with either salt domes or large hydrocarbon traps, neither of which are believed to exist in the study area. The only remaining experimental electric power plant is the Kalina Cycle, which is a binary power plant that utilizes ammonia gas as the working fluid. The scheduled site for a test of the Kalina Cycle power plant is Steamboat Hot Springs, in northern Nevada. Temperatures there range from 175 to 200°C, at depths that range from 300 to 1,000 m. These conditions have not been reported, nor are they likely to exist, in the Yucca Mountain study area.

The evaluation of resources for electric power production and direct utilization considers only current economics and technology. On the basis of the historical development of geothermal energy and competing resources in the Great Basin, it likely that these values will persist into the foreseeable future.

Direct Utilization

Direct utilization technologies are those that use the thermal energy with no conversion to electricity, and several examples were listed above. The locations of the principal direct-use geothermal developments are shown in Figure 6. Examples of existing and potential operations within the Great Basin exploiting direct-use include the following sites.

Great Basin Direct-Use Projects

Round Mountain Gold

The Round Mountain Gold Corporation gold mine is located in Big Smoky Valley, approximately 13 km from Darrough's Hot Springs, Nye County, central Nevada. Geothermal fluids are produced from two wells at a temperature of 82°C at an average flow rate of 70 l/s. The wells are completed in fractured ash-flow tuffs to a depth of about 300 m. Thermal fluids (340 ppm TDS) are pumped to a surface heat exchanger and are used to heat a cyanide solution, which is used to leach gold and silver from the low-grade ore. All produced geothermal fluids are injected into a 322 m deep well located 1,220 m north-northwest of the production wells (Trexler and others, 1990).

Moana Geothermal Area (Reno)

The Moana geothermal area, located in southwest Reno, Nevada, is the largest, single low- to intermediate-temperature geothermal resource in Nevada employed for direct-use applications. Approximately 300 homes and businesses are geothermally heated. Temperatures in the area range from 35 to 102°C at depths of 30 to 300 m. The primary reservoir rock is the Kate Peak andesite, a Tertiary volcanic lahar that has excellent permeability within the narrow fault zones that bisect the area. The Kate Peak Formation is overlain by impermeable Tertiary lake sediments and alluvium (Flynn and Ghusn, 1984).

The largest development in the Moana area is the Warren Estates - Manzanita Estates, a privately owned and operated residential geothermal district heating system. The system has operated for ten years and presently services 95 homes. Geothermal energy is used to heat homes, domestic water, spas, swimming pools, and greenhouses. Two production wells completed at the intersection of two faults to a depth of about 240 m provide fluids, pumped at a rate of 15 to 25 l/s at a temperature of 95°C (McKay and others, 1995).

San Emidio Desert - Integrated Ingredient's Food Dehydration Plant

The Gunion dehydration plant uses geothermal fluids at a temperature of 152°C to dehydrate 20,000 to 30,000 kg per day of garlic and onions. The plant is located in the San Emidio KGRA in northern Washoe County, 144 km north-northeast of Reno, Nevada. Three geothermal wells drilled to depths ranging from 150 to 540 m produce fluids ranging in temperature from 130 to 153°C (Trexler and others, 1995).

Duckwater (Big Warm Springs)

These artesian springs are located on the Shoshone Indian Reservation at Duckwater, northern Nye County, Nevada. Dilute (358 ppm TDS) thermal fluids at a temperature of 35°C from Big Warm Springs are diverted to a series of concrete raceways, each of which supports a population of about 2,000 catfish. The fish grow rapidly in the warm water and are harvested at a size of 0.6 kg within six months (Cowan, 1988).

Wabuska Hot Spring

Located in Lyon County, Nevada, approximately 15 miles north of Yerington, geothermal fluids are produced from wells completed to a depth of 300 m or less at temperatures that range from 99 to 108°C. The geothermal fluids are a mixed sodium chloride-sodium sulfate type and contain approximately 1,200 ppm TDS (Garside and Schilling, 1979). Wabuska is the site of the first geothermal power plant in Nevada and presently produces 2 MWe of electric power by the binary conversion method. In the past, geothermal fluids have been used in alcohol fermentation, greenhouses, and aquaculture, including tropical fish and exotic amphibians. The facility was also used to raise spirolina (blue-green algae) on an experimental basis in the early 1980's (Cowan, 1988).

Brady's Hot Springs

The Brady's Hot Springs area is located 80 km east of Reno in Churchill County, Nevada. Historically, springs flowed at an estimated rate of about 1.5 l/s, but since geothermal wells were drilled in the late 1950's and early 1960's, the flow has ceased. Wells in the area range in depth from 104 to 2,235 m with temperatures up to 214°C (Garside and Schilling, 1979). In 1978 a geothermal dehydration plant was constructed at the site using fluids at a temperature of 132°C from a well located about 400 m from the plant. Fluids at Brady's are sodium chloride in composition and have a TDS of > 2,400 ppm (Lund, 1982).

Elko

The City of Elko is located in Elko County in northeastern Nevada. Elko Hot Springs (56°C) are located 1 km southwest of the City of Elko and two geothermal space heating districts are located in the city. The Elko Heat Company produces geothermal fluids at a temperature of 82°C from a well completed to a depth of 259 m. The well intersects a northeast-trending fault zone and has an artesian flow of 30 l/s (Meeks and Lattin, 1982).

The second space heating system has been operated by the Elko County School District since 1986. The geothermal well that supplies water at a temperature of 88°C is completed to a depth of 600 m. The system uses heat exchangers to supply hot water to 13 school buildings, a convention center, the county hospital, city offices, and the swimming pool (Anonymous, 1986).

Sarcobatus Flat - Beatty

Several warm springs and wells are located in Beatty, southern Nye County, Nevada, and north of the town along U.S. Highway 95. Five springs flow from alluvium near outcrops of silicified, opalized and moderately argillized welded tuff at Hick's Hot Spring. One spring, flowing at a temperature of 43°C, supplies bathing pools and related facilities. The municipal water supply is obtained from Beatty Springs, a group of six springs that issue from alluvium 0.6 km north of the town. Reportedly, the springs discharge 6 to 12 l/s of 44°C water (Garside and Schilling, 1979).

Amargosa Desert

Warm springs and shallow wells are distributed over the southern third of the Amargosa Desert, southern Nye County, Nevada, with reported temperatures of 34°C or less. Spring temperatures range from approximately 24 to 34°C at Ash Meadows (Garside and Schilling, 1979). Currently, the water is used only for irrigation purposes. Use of the water is limited by Federal regulations related to the endangered species act to protect the habitat of the Desert Pupfish found at Devil's Hole in Death Valley National Monument (Westenburg, 1993).

Honey Lake

Geothermal fluids are used to pre-heat boiler make-up water for a wood chip burning 30 MWe power plant operated by HL Power in Lassen County, northeastern California. The plant has been in operation since 1989 (A. Goldsmith, personal communication, 1995).

Yucca Mountain Area Potential

Two wells were selected as representative of the Yucca Mountain area based on the relatively elevated temperatures, and on reliable depth and flow rate data. The temperature and depth parameters of the other wells in the area are similar to the two selected and do not provide any significant departures from the interpretation.

Test well F was drilled as a water supply well for the Nevada Test Site in area 27 (then area 410) in 1961 to a depth of 570 m; flow rate was estimated to be 327 m^3/day (West and Garber, 1961). By 1963, the well had been deepened to a total depth of 1,037 m (Carroll, 1963) with a reported down hole temperature of 72°C. Well USW H-4 was drilled on the northwest side of Yucca Mountain to a total depth of 1,219 m with a bottom hole temperature of 41°C (Sass and Lachenbruch, 1982) and an estimated flow rate of 1,500 m^3/day (Whitfield and others, 1984).

In order to determine the applicability of the study area for direct use application, a comparative evaluation of the important resource parameters and logistical requirements was made. The basis for this comparison is that any development that is based on an economic venture must compete successfully with all other options available, including other geothermal areas.

The temperature and depth of the commercial direct use projects in the Great Basin are compared (Figure 44) to the temperature and depth data of five representative wells in the study area. The data show that, with the exception of the Honey Lake Project, all of the Yucca Mountain wells are considerably deeper than the commercial projects. The temperatures of the Yucca Mountain wells are comparable with surface thermal waters used for recreation and aquaculture in other locations in southern Nevada. This simple comparison suggests that the fluids are not commercially viable when compared with existing operations, however a more rigorous comparison is presented below.

Several direct use geothermal evaluation techniques have been developed (Trexler and others, 1979; McClain, 1980; and Bloomquist and others, 1985) that use parameters in 3 broad categories: resources, engineering, and environmental and institutional factors. Each category is further divided into sub-categories and each is assigned a numerical value based on temperature, depth, water quality, infrastructure demands, and environmental sensitivity.

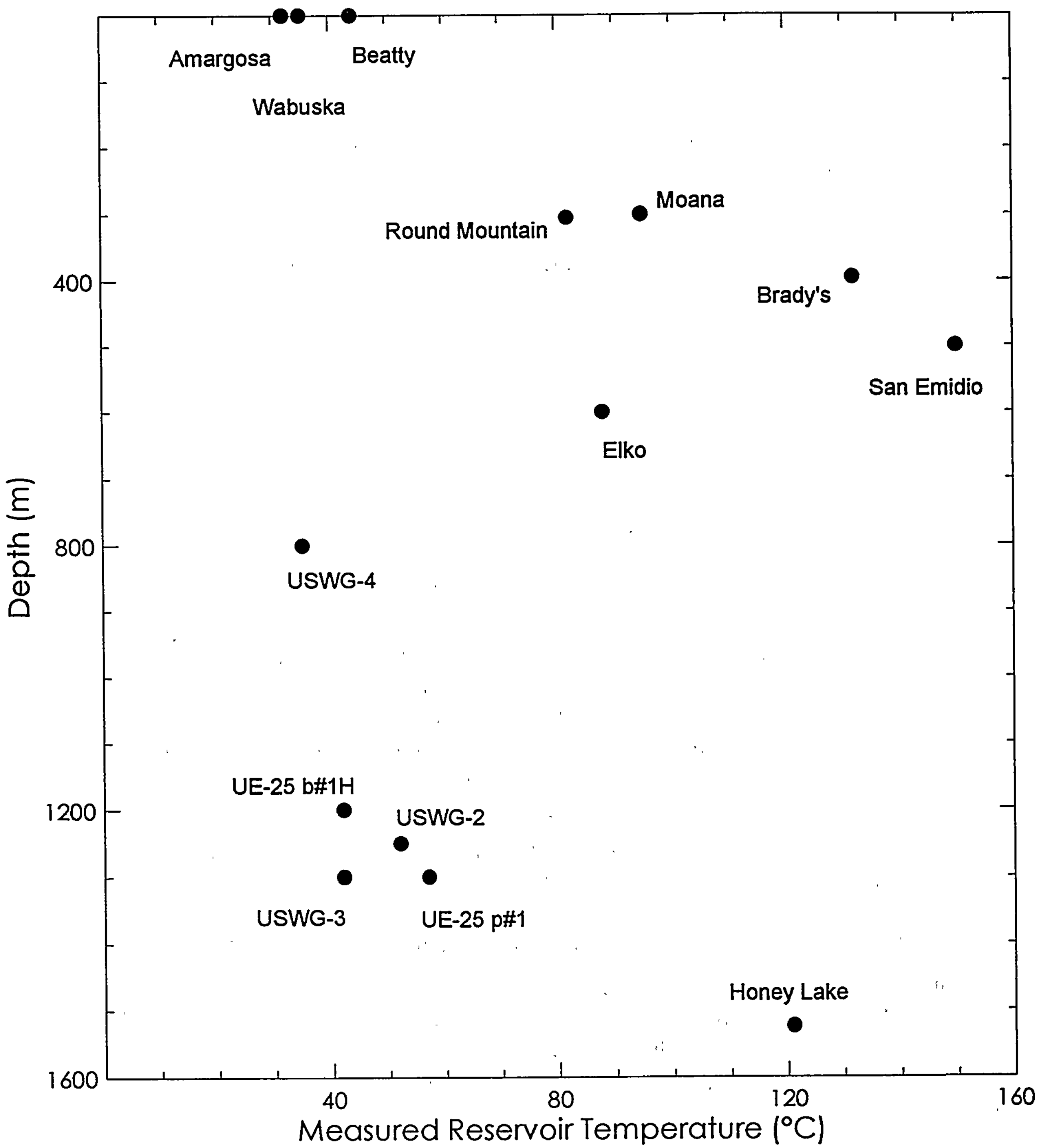


Figure 44. Comparison of depth vs. measured reservoir temperature between direct-use geothermal project sites and warm wells near Yucca Mountain.

The model used in this study is patterned after the model developed by Trexler and others (1979) because it was specific to geothermal resources of the Great Basin. The ranking system uses a simple function called the Probability Function (PF) based on the probability of development potential and defined as follows:

$$PF = \sum RiWFi$$

where: Ri = Rank of the i^{th} parameter ($3^0 - 3^i$)
WFi = Weighting Factor of the i^{th} Parameter (0,1,2)

This simple evaluation scheme is generally applicable and sufficiently flexible to allow for future data input or a change in the priority of resource requirements. It also produces a semi-quantitative basis for comparison of undeveloped thermal fluids at Yucca Mountain with known developed geothermal resources areas to the north.

The chosen parameters are sorted from most to least important, then assigned an "i" value. The least important parameter receives a '0', increasing by 1 up to the most important. The rank (Ri) of the parameters is listed in terms of decreasing powers of 3, which preserves the established order of importance. The first parameter can never be "over-ruled" by the sum of the subsequent parameters. Weighting factors, ranging in value from 0 to 2, are used to indicate the "desirability" of each parameter for each separate case. The least desirable value of 0 is assigned to values for the parameters that, for example, are the lowest temperature, the deepest resource, or located within rocks that have poor permeability. Conversely, the most desirable value of 2 is, for example, assigned to high-temperature, shallow, permeable resources.

Several parameters could be used for defining the potential of the resource, including physical and chemical characteristics of the resource, demographics and accessibility to both the resource and materials required in the process (for example, onions for dehydration). For this study, three applications were considered: industrial process heating, space heating (residential and commercial), and aquaculture.

In the Great Basin, examples of industrial processes that use geothermal heat include food dehydration and cyanide heap leaching. Both processes require high volumes of intermediate-temperature fluids to be effective. The ranking parameters and weighting factors for industrial processes are listed in Table 7.

The results of the evaluation for industrial processes are listed in Table 8. The maximum score for this model is 80 points. The food dehydration plants located at Brady's Hot Springs and in the San Emidio Desert have scores of 74 and 76 respectively. The Wabuska resource presently has no installed industrial process, but scored 77 for potential applications of the resource. The Round Mountain area supports a geothermally enhanced cyanide heap leaching process and scores 53. Well F (NTS) and well USW H-4 (Yucca Mountain), selected as representative of the thermal waters in the vicinity of Yucca Mountain, score only 29 and 32 respectively. The thermal fluids at Beatty and Amargosa, although low-temperature, have good accessibility, shallow depth, and high transmissivity, and score 53, suggesting they have as much potential for application as the Round Mountain resource.

Table 7. Ranking parameters and weighting factors for industrial processes.

Parameter	Units	i	Rank (Ri) 3^i	Weighting Factors (WFi) 0	1	2
Temperature	°C	3	27	<40	41 to 100	>100
Resource depth	m	2	9	>1000	501 to 1000	<500
Productivity	m^3/day	1	3	<12.4	12.4 to 124	>124
Location	km	0	1	>15	5 to 15	<5

Table 8. Ranking results for industrial process.

Parameter	Temperature	Depth	Productivity	Location	Sum
Rank =	27	9	3	1	
Empire	2	2	1	1	
Value	54	18	3	1	76
Bradys	2	2	0	2	
Value	54	18	0	2	74
Wabuska	2	2	1	2	
Value	54	18	3	2	77
Round Mountain	1	2	2	2	
Value	27	18	6	2	53
Beatty	1	2	2	2	
Value	27	18	6	2	53
Amargosa	1	2	2	2	
Value	27	18	6	2	53
Well F	1	0	0	2	
Value	27	0	0	2	29
USW H-4	1	0	1	2	
Value	27	0	3	2	32

Location relates the resource to residential or commercial buildings available for space heating applications (Table 9). Depth and temperature are self explanatory; shallow, high-temperatures are more desirable than deep, low-temperatures. Areal extent relates to the size of the resource, which determines the number of wells that can be drilled for fluid production and injection. Again, the maximum score is 80 points. Reno and Elko both have various residential and commercial space heating systems, district and municipal, and both score 80. Well F on the NTS and USW H-4 at Yucca Mountain score 8 and 5 respectively. On the other hand, the Beatty and Amargosa areas scored 77 and 50 respectively, indicating a much higher potential for development than the Yucca Mountain area. The results of the evaluation for space heating are listed in Table 10.

The final direct use application considered in this evaluation is aquaculture (Table 11), which is the use of geothermal fluids to grow aquatic species. Catfish, tropical fish, and freshwater prawns have all been grown in geothermal waters in Nevada.

Depth is considered the most important factor for aquaculture because surface flow is essential for the successful operation of the facility. Facilities at Hobo, Hinds, and Duckwater were built downstream from existing thermal springs, thus eliminating the need for pumping. The Wabuska operation relied on the discharge from an existing geothermal power plant, but had sufficient

Table 9. Ranking parameters and weighting factors for space heating.

Parameter	Units	i	Rank (Ri) 3^i	Weighting Factors (WFi) 0	1	2
Location	km	3	27	>2	1 to 2	<1
Resource depth	m	2	9	>300	100 to 300	<100
Temperature	°C	1	3	<30	31 to 60	>60
Areal Extent	km^2	0	1	<1	1 to 2	>2

Table 10. Ranking results for space heating.

Parameter	Location	Depth	Temperature	Areal Extent	Sum
Rank =	27	9	3	1	
Reno	2	2	2	2	
Value	54	18	6	2	80
Elko	2	2	2	2	
Value	54	18	6	2	80
Beatty	2	2	1	2	
Value	54	18	3	2	77
Amargosa	1	2	1	2	
Value	27	18	3	2	50
Well F	0	0	2	2	
Value	0	0	6	2	8
USW H-4	0	0	1	2	
Value	0	0	3	2	5

Table 11. Ranking parameters and weighting factors for aquaculture.

Parameter	Units	i	Rank (Ri)	Weighting Factors (WFi)		
			3^i	0	1	2
Resource Depth	m	3	27	>300	1 to 300	<1
Location	km	2	9	>2	1 to 2	<1
Flow Rate	l/s	1	3	<3.2	3.2 to 12.8	>12.8
Temperature	°C	0	1	<15 or >40	30 to 40	15 to 30

reservoir storage to support the operation when pumps were off. Water chemistry is not considered critical in this evaluation for several reasons. First, most of the thermal springs throughout the Great Basin consist of dilute, near-neutral pH waters that supports a variety of aquatic life. Second, if the water is not of adequate quality to support the desired aquatic habitat, the rest of the evaluation is moot. Third, if it does not meet that standard, the water will have to be chemically treated to support the habitat, resulting in additional costs. The results of the evaluation for aquaculture are listed in Table 12.

Figure 45 illustrates the temperature and depth relationships for two "thermal" wells in the Yucca Mountain area, a well completed in the Warren Estates geothermal field, and a well completed in the Desert Peak geothermal field (Benoit and others, 1982) and effectively demonstrates the very low thermal gradient at Yucca Mountain in comparison to the thermal gradient found at a commercially viable resource.

This evaluation indicates that, compared to developed and undeveloped geothermal resources in Nevada, there is little to no potential for development of the resources in the Yucca Mountain area for electric power production, industrial applications, space heating, or aquacultural applications. There is some potential for such development in the Amargosa and Beatty areas, but to date, there has been only minor development of the spring for recreational purposes. This evaluation is consistent with the views of Bell and Larson (1982).

Table 12. Ranking results for aquaculture.

Parameter	Depth	Location	Flow	Temperature	Sum
Rank	27	9	3	1	
Hobo	2	2	0	1	
Value	54	18	0	1	73
Duckwater	2	2	2	1	
Value	54	18	6	1	78
Wabuska	2	2	2	0	
Value	54	18	6	0	78
Beatty	2	2	2	1	
Value	54	18	6	1	79
Amargosa	2	2	2	2	
Value	54	18	6	2	80
Well F	0	2	2	0	
Value	0	18	6	0	24
Well H4	0	0	2	0	
Value	0	0	6	0	6

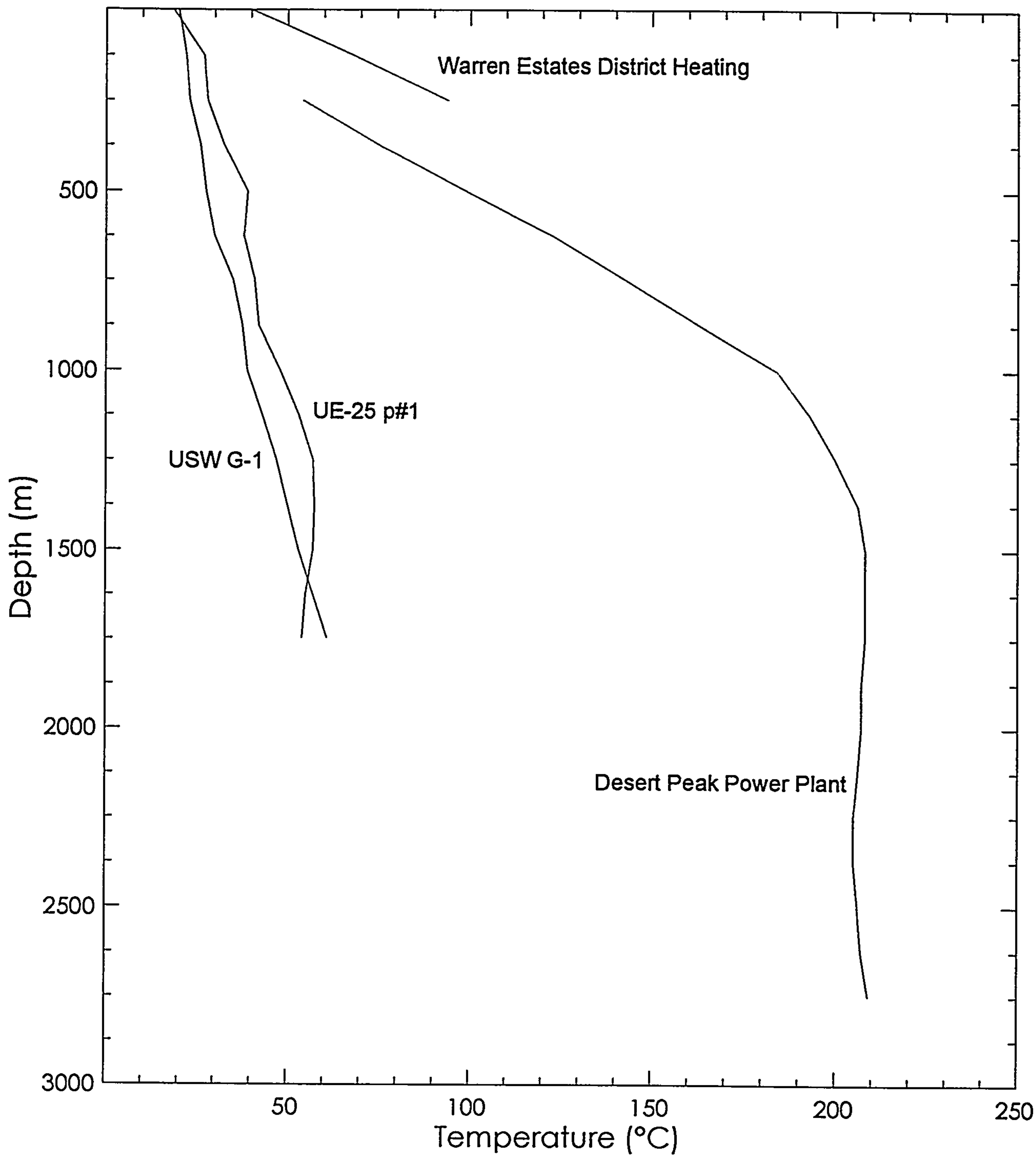


Figure 45. Comparison of temperature vs depth profiles from a geothermal power plant well and a direct-use project in northern Nevada, and two hot wells in the Yucca Mountain area.

SUMMARY AND CONCLUSIONS

A comprehensive analysis of the substantial volume of existing geological, geophysical, geochemical, and drilling data in the Yucca Mountain area demonstrates that low-temperature geothermal fluids occur beneath the potential repository at depths in excess of 450 m. These fluids are similar to surface geothermal waters in the Beatty - Oasis Valley area and the Amargosa Desert. Compared with data from existing, developed and undeveloped geothermal sites in the northern Great Basin and from conventional potential applications, we conclude that, presently, there is no potential for development of any of the thermal fluids in the study area other than the small-scale recreational developments that exist in the region. Specifically excluded from potential development, now and well into the foreseeable future, are geothermal electric power plants, space heating (commercial or residential), and known industrial process heating. These conclusions are based on graphic and numerical comparisons of thermal fluids that best represent the Yucca Mountain area. Table 13 summarizes the characteristics used by the U.S. Geological Survey in their classification of lands deemed valuable for the prospects of geothermal development and compares them with the Yucca Mountain study area. The evaluation clearly indicates that there is no potential for geothermal development in this area.

From a regional perspective, the Yucca Mountain area is located adjacent to a large area of anomalously low heat flow. The area shares some of the characteristics of the northern Great Basin: a deep basement consisting of Paleozoic sedimentary and Mesozoic intrusive rocks overlain in large part by Tertiary volcanic rocks; northwest-trending basement structures parallel to the Walker Lane and north-trending faults that parallel Basin and Range structures; and recent extrusive volcanic rocks. The Yucca Mountain area lacks the geophysical and geochemical characteristics found in the eastern and western margins of the Great Basin and in the Battle Mountain Heat Flow High, where geothermal development is widespread. Chemical geothermometers of groundwaters strongly suggest that only low-temperature ($25 \leq T < 90°C$) waters occur in and adjacent to Yucca Mountain, and only at depths in excess of 400 m. The analysis failed to identify any thermal anomalies other than the negative heat flow low described in the text. Recent volcanic intrusive and extrusive rocks are not considered likely targets for subsequent geothermal exploration programs because of their small volume and lack of thermal energy. Likewise, gravity and magnetic surveys do not provide any indication of anomalous thermal activity. The absence of a geothermal anomaly and the extreme depth to low-temperature fluids essentially rules out geothermal exploration or development on a commercial scale in the Yucca Mountain area.

Table 13. Evaluation of geothermal characteristics from within the Yucca Mountain Study Area.

Characteristic		Yucca Mountain Area	
Na/K anomaly	Non-thermal	Geothermal discoveries	None nearby
Siliceous sinter	None present	Temperature gradient	Low, below average
High silica water	Non-thermal	Porosity/permeability	Deep carbonate aquifer
Recent volcanism	Small, isolated	Geophysical anomalies	Non-thermal
Geysers, fumaroles, and hot springs	None present	Competitive interests	None nearby

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APPENDIX 1

Compilation of Geochemical database

In compiling the geochemical data, five separate databases were searched and edited: (1) the DOE-supplied Yucca Mountain Site Characterization database (DOE database), (2) a database compiled by D. Perfect (Perfect and others, 1994) for the Yucca Mountain and Death Valley Regions (Perfect database), (3) data from the STORET database (EPA) using EarthInfo (1993) commercial software (STORET database), (4) an internal database compiled by T. Flynn at the Harry Reid Center, University of Nevada, Las Vegas (UNLV; Flynn database), (5) and the U.S.G.S GEOTHERM database (GEOTHERM database).

GEOTHERM is an acronym for a U.S. Geological Survey (U.S.G.S.) computerized information system designed to maintain data on the geology, geochemistry, and hydrology of geothermal sites primarily within the United States (Swanson, 1977; Teshin and others, 1979; Bliss, 1983a). The system was first proposed in 1974, and was maintained until 1983. When the GEOTHERM database was taken off line, a number of products were published or made available to preserve the data. These include basic data for thermal springs and wells on a state-by-state basis (for Nevada see Bliss, 1983a) and a listing of each record on a state-by-state basis as microfiche (for Nevada, see Bliss, 1983b). The GEOTHERM database was also filed with the National Technical Information Service (NTIS) as digital data. A 9-track one-half inch reel-to-reel tape in ASCII format of this GEOTHERM database was provided to the Nevada Bureau of Mines and Geology (NBMG) by Howard Ross at the University of Utah Research Institute (UURI). This tape, containing 8,082 records, was originally from NTIS. GEOTHERM contained 1,367 records for Nevada when it was taken off-line in 1983. The majority of these records are from the published sources used to compile Appendix 1 of Garside and Schilling (1979). Unpublished site data and analyses from the files of D.E. White (U.S.G.S.) make up a significant section of the database. About 75% of this GEOTHERM data were added to the original database during 1978 and 1979 by personnel at the NBMG as part of the U.S. Department of Energy State-Coupled Program (see Trexler and others, 1979). In addition to the entry of new data and the editing and verifying of existing data in GEOTHERM, the longitude and latitude locations of springs and wells were determined by plotting them on 1:250,000-scale maps and hand digitization (Trexler and others, 1979). New chemical analyses done during this period were added to GEOTHERM.

The first database evaluated was the Perfect database because it was the largest, and apparently the most comprehensive for the area. All databases were manipulated using the spreadsheet program Excel. Several versions of database files were saved throughout the project in order that sequential files would be available to check previous calculations and to serve as back-ups in case of loss of more recent data files or other errors. The procedures used to manipulate the Perfect database served as a template for manipulation of all other databases and these procedures are described in this appendix.

The original Perfect compiled database contained 3,733 records. Records which were not within the latitude and longitude range of 36°02′ and 37°54′, and 117°25′ 114°49′ were removed, resulting in 2,974 records. All of Perfect's "-" signs indicating "less than" were changed to "<", and all < signs are read by Excel as equal to zero when summation calculations are made.

Total dissolved solids (TDS) were calculated by summing all major and trace element analyses for a record. Charge balances were calculated for all records. Cation sum was calculated as follows:

$$\Sigma cat = \frac{Ca}{20.04} + \frac{Mg}{12.15} + \frac{Na}{22.99} + \frac{K}{39.098} + \frac{Ba}{68.665} + \frac{Fe}{18.616} + \frac{Mn}{18.313} + \frac{Li}{6.941}.$$

The anion sum is calculated as follows:

$$\Sigma an = \frac{Cl}{35.435} + \frac{B}{77.617} + \frac{F}{18.998} + \frac{HCO3}{61.006} + \frac{CO3}{60.008} + \frac{SO4}{48.025}.$$

Balances are calculated from the following:

$$\frac{(\Sigma cat - \Sigma an)}{(\Sigma cat + \Sigma an)}.$$

The above calculations were done in the file perf-c1.xls.

The perf-c1.xls file was saved to perf-c2.xls and further manipulated. In this file, deletions were made of some analyses with poor charge balances or entries where there were not sufficient numbers of analyses to calculate any geothermometers. If there were enough data to calculate even one geothermometer, the analysis was retained in the database. If the record had a poor charge balance, the record was retained in the database if (1) SiO_2 > 20 mg/l, or (2) temperature > 25°C. The average Beatty air temperature is 59°F (15°C) (Nichols, 1987). All samples with temperatures >10°C above the average annual mean temperature were retained in the database. A new file (perf-c3.xls) was saved part way through this procedure in order to have an incremental backup.

The database was sorted by charge balance, and all records with a balance >10% (aside from the exceptions noted above) were deleted from the database. The database was then sorted by Na/K, and all records with values of ≤1 were eliminated from the data set. This filtering was conducted because, in natural waters, Na is almost always more abundant than K, and any analysis with Na/K ≤1 is not reliable and it can not be determined if the Na or the K value is in error. Because nearly all geothermometers require accurate Na and/or K values, these records with Na/K ≤1 could not be expected to provide realistic geothermometer temperatures. Thirty-one records had acceptable balances, but their Na/K ratio was ≤1, and hence the records were deleted. After these deletions, there were 2,129 records remaining. All records previously mentioned as having been deleted from the database are retained in their entirety in the file perf-del.xls.

Next, the records were again sorted by balance in order to identify which analyses were poor, or for which no cation or anion analyses were available but which had an elevated SiO_2 (>20 mg/l) content or temperature (>25°C). For these records, the major and trace element chemistry were deleted from the record because it was impossible to determine the reliability of the analyses and because use of the data would result in unreliable geothermometer temperatures. The records which were altered in this manner are retained in their entirety in the file perf-si.xls. The altered data file is saved in perf-c4.xls. All surface water analyses were removed from perf-c4.xls and put into file perf-sur.xls. The resulting database file was placed in perf-c5.xls.

EarthInfo data were selected for the region within the latitude and longitude range of 36°02′ and 37°54′, and 117°25′ 114°49′. These analyses were compared with the Perfect database entries, and all duplicate analyses were deleted from the EarthInfo data set. Next, all surface waters, effluent samples, etc., were deleted from the EarthInfo data set. The resulting file was saved as a STATION file (yuc-1(STATION)). The database was searched for all chemical parameters which were reported in the Perfect database, focusing on dissolved, rather than total, element concentrations. Data were dumped in groups of 10 to an ANALYSIS file which contained all analyses for the indicated parameters (e.g., Cl, F, etc.) on the entire CD. In order to obtain only those data for the stations of interest near Yucca Mountain, the ANALYSIS file was filtered with the STATIONS file developed previously. This filtering required approximately 6 hours of processing time for a file of 10 chemical parameters to be formed.

Except for the notations made below, the other databases were processed in the same manner in which the Perfect database was altered. Duplicate analyses (identical site name, site location, and sample date) between the various databases were deleted from the Flynn, DOE, STORET and GEOTHERM databases. Note that it was later found that some sites with different names and/or different latitudes and longitudes were also believed to be duplicate samples, and were deleted from geothermometer databases later in the procedure. This was likely the result of previous authors obtaining the same data and modifying the name and/or coordinates to fit their unique format. The name format was also standardized in this step so samples from the same location would have the same name. The changes are recorded in file yuc-chg.xls, which is a comparison of the names in master.xls and all-fnl.xls. All-fnl.xls was used to create the GIS coverage for groundwater chemistry. The same procedure was applied to the maximum geothermometer file geo-max3.xls. File max-chg.xls is a comparison of geo-max3.xls and max5_fnl.xls, which was used to produce the maximum geothermometer GIS coverage.

All of the databases were re-arranged so that their columns would be in the exact order needed for later merging. Charge balances were calculated for the analyses in the remaining four files. The units on the Li, Sr, Mo, Mn, and V analyses were not consistent in the DOE database file. For instance, the Li values ranged from 0.04 to 410, and presumably the smaller values are in mg/l, whereas the larger values are in µg/L, yet this was not noted in the original database. Where possible, these values were checked with other analyses at the same site which appeared in the other databases. For instance the USW H-4 analysis in the DOE database was 130, but it was 0.13 mg/l in the Perfect database. Similarly, the Willow Spring NV analysis was 5 in the DOE database, whereas it was 0.005 mg/l for Li in the Perfect database. Many other values could not be verified, yet it was assumed that the large values for Li, Sr, Mo, Mn, and V were actually reported in µg/L rather than mg/l, and hence the reported values in the DOE database were divided by 1,000. The corrections made are noted in Table 14. Some of these corrected analyses were ultimately deleted and do not appear in the final database.

STORET trace elements were reported in µg/L; and all values were converted to mg/l. In addition, STORET entries are not numeric, but are entered as text. These values were changed to numeric values. "Punch" symbols were located in front of all values in the GEOTHERM columns, so the numbers could not be directly read as numeric values. All columns were parsed so that the numeric values could be physically separated from the punch symbols, and then all punch symbol columns were deleted. A "<" symbol which is not followed by a number in the GEOTHERM data indicates that the particular element was not detected.

Based on charge balances, records were deleted from each of the databases. Deleted records from the DOE database were placed in the file labeled doe-del.xls. Deleted records from the Flynn database were placed in the file labeled flyn-del.xls. Deleted records from the STORET database were placed in the file labeled stor-del.xls. Deleted records from the GEOTHERM database were placed in the file labeled geo-del.xls. When the charge balance was poor, but SiO_2 values were in excess of 20 mg/l, the major and trace element chemical data were deleted from the databases. However, the entire chemical analysis was retained in a separate file (i.e., doe-si.xls, flynn-si.xls, geo-si.xls, stor-si.xls).

Table 14. Changes made to trace element entries in the DOE database converting presumably µg/l to mg/l. Original entry is followed by modification in parentheses ( ).

	Blue Point Spring	Grapevine #1	Grapevine #3	Nevares Spring	Saratoga Spring	Staininger Spring	#9
Ba:	22 (0.022)			42 (0.042)	15 (0.015)		
B:							
Br:							
Cu:							
Fe:				4 (0.004)			
I:							
Li:		200 (0.2)	210 (0.21)	160 (0.16)	410 (0.41)	120 (0.12)	13 (0.13)
Mo:		12 (0.012)	12 (0.012)	18 (0.018)	24 (0.024)	10 (0.01)	
Mn:		10 (0.01)	10 (0.01)	4 (0.004)		1 (0.001)	26.7 (0.027)
Sr:	5,300 (5.3)	570 (5.7)	660 (0.66)	1,100 (1.1)		7 (0.007)	
V:		3.8 (0.0038)	3.9 (0.0039)		30 (0.03)	9.4 (0.0094)	
Zn:				4 (0.004)			

	USW H-1	USW H-1	USW H-4	Virgin Spring	Willow Spring	Woodcamp Spring
Ba:				51 (0.051)	96 (0.096)	
B:					30 (0.03)	
Br:					41 (0.041)	
Cu:				2 (.002)		
Fe:					6 (0.006)	
I:					1 (0.001)	
Li:	40 (0.04)	40 (0.04)	130 (0.13)	68 (0.068)	5 (0.005)	30 (0.03)
Mo:				10 (0.01)		1 (0.001)
Mn:				5 (0.005)	2 (0.002)	1 (0.001)
Sr:	5 (0.005)	20 (0.02)			84 (0.084)	20 (0.02)
V:						2.3 (0.0023)
Zn:				4 (0.004)		

The specific conductance (SC; µmhos/cm) data in the DOE database are predominantly field measured values. However, in some cases a lab value was reported, and a field value was not. In these cases, the laboratory SC was copied into the field SC column and a comment was placed in the comments column stating the SC value was measured in the laboratory. In the majority of cases, the reported pH was a field measured pH in the DOE database. However, in three instances, there were no field measured pH's but there were lab measured pH's. In these cases, the laboratory pH was copied into the field pH column and a comment was placed in the comments column stating the pH value was measured in the laboratory.

Several of the entries in the DOE database had missing or apparently incorrect latitudes and longitudes. Table 15 lists the site name, the DOE reported latitude, the latitude reported in the Perfect database, comments and the action taken on the entry in the DOE database. The format of the latitude and longitude of the data sets differed, so all were changed to one format.

Database	Example Latitude	Example Longitude	Example Date
Flynn	36.374	116.273	06 64 (month and year in separate columns)
DOE	36 50 32	116 26 54	1/18/82
GEOTHERM	36-35.45 N	115-51.13 W	1944/08/30
Perfect	362627	1164949	820422
STORET	36:03:03	114:59:36	19860929

Latitude and longitude were converted to decimal degrees in all databases, and the format of all dates was transformed to mm/dd/yy. In order to convert the latitude and longitude of the Perfect file, a UNIX awk program was used to separate the values so that 362627 1164949 would be converted to 36 26 27 116 49 49. The awk program is:

```
{
        printf("%s %s %s  %s %s %s\n",\
                substr($1,1,2),substr($1,3,2),substr($1,5,2),\
                substr($2,1,3),substr($2,4,2),substr($2,6,2))
}
```

and it was invoked in the following manner:

```
awk -f lat_long.awk < input > output .
```

Using the 'vi' text editor in UNIX, a global search and replace for a space was conducted, replacing the single spaces with a ":". The file was then imported to an Excel spreadsheet and the lines were parsed such that each separate entry (36, 26, 27, etc.) was placed in separate columns. The seconds column was divided by 60 (seconds/minute) and added to the minutes column. This new minutes column was then divided by 60 (min/degree) and added to the degree column to obtain decimal degrees. Similarly, the values in the DOE and STORET databases were parsed, and the divisions by 60 and additions to subsequent columns were also performed to obtain decimal degrees. The values in the GEOTHERM database were similarly converted. The data were parsed in an Excel spreadsheet such that degrees and decimal minutes appeared in separate columns. The decimal minutes were divided by 60 and added to the degrees column.

The date fields were transformed in a similar manner. The date in the GEOTHERM file was parsed into columns in Excel, resulting in columns for year, month, and day. The number 1,900 was subtracted from the year column and the month, day and year columns were concatenated with '/' between each value. The Flynn year and month were reported in separate columns, and they were subsequently concatenated by month/day/year, with all day values being equal to zero because no data for day appear in the Flynn database. The STORET date field could not be parsed, and hence spaces were added between year, month, and day using the UNIX text editor vi. The date was then combined as it was in the GEOTHERM database. Because the Perfect file is considerably longer than the STORET file, a UNIX awk program was written to separate the field values into separate columns for year, month and day, and these were subsequently concatenated and separated by "/". The awk program used to conduct this manipulation is:

Table 15. Comparison of latitude and longitude values between the maximum geothermometer and the minimum geothermometer files.

	Maximum Geothermometer File		Database & Year	Minimum Geothermometer File		Database & Year	Action Taken
Similar Names and Similar Latitudes and Longitudes:							
Name	Crystal Spring			Crystal Pool			
Lat/Long	36.4183	116.3300	G-1971	36.4183	116.3217	G-1929	AD
Name	Deer Creek Spring #2			Deer Creek Spring #1			
Lat/Long	36.3075	115.6269	P-1985	36.3075	115.6369	P-1987	AD
Name	Grapevine Spring			Grapevine #1			
Lat/Long	37.0240	117.3840	F-1989	37.0231	117.3839	D-1993	AS-2
Name	Grapevine Spring			Grapevine Spring S10 E58 16BB			
Lat/Long	36.3011	115.4903	P-1980	36.3008	115.4903	P-1985	AS-2
Name	Indian Springs NWNW 14-16S-56E			Indian Spring-2			
Lat/Long	36.5647	115.6686	P-1966	36.5650	115.6683	P-1986	AS-2
Name	Longstreet Spring NENWNE 22-17S-50E Nye			Longstreet Spring			
Lat/Long	36.4678	116.3250	P-1966	36.4667	116.3250	G-1962	AS-1
Name	LVVWD #15A S20 E61 30DC			LVVWD #15A			
Lat/Long	36.1739	115.1872	P-1982	36.1753	115.1897	P-1986	AS-2
Name	Paiute Indian Reservation S18 E59 04DB			Paiute Indian Reservation Well			
Lat/Long	36.3506	115.3481	P-1986	36.3506	115.3425	P-1982	AS-1
Name	Parent Spring			Parent Springs			
Lat/Long	36.4650	116.3183	G-1962	36.4642	116.3183	G-no date	AS-1
Name	Raycraft Well			"Raycraft, J.M. Well"			
Lat/Long	36.2000	115.9889	G-1946	36.2092	115.9883	F-1916	AS-1
Name	Rogers Spring SENWNE 15-17S-50E Nye Co			Rodgers Spring			
Lat/Long	36.4778	116.3222	P-1966	36.4783	116.3233	G-1971	AS-2
Name	S16 E51 27BAA Amargosa Tracer Hole #3			S16 E51 27BAA Amargosa Tracer Well 2			
Lat/Long	36.5369	116.2272	P-1966	36.5369	116.2269	P-1971	AS-2
Name	Stocks Mill and Supply S21 E60 21DDD1			Stocks Mill and Supply Co. Well			
Lat/Long	36.1014	115.2628	S-1982	36.1019	115.2628	P-1986	AS-2
Name	Tule Springs Park Well NENWNE 9-19S-60E			Tule Spring State Park Well			
Lat/Long	36.3206	115.2653	P-1968	36.3206	115.2667	P-1985	AS-2
Name	Tunnel U12t.03 U.G. #1 7+18 .01 work drift			Tunnel U-12t.03 UG#1 Rainier Mesa			
Lat/Long	37.2181	116.1806	P-1973	37.2181	116.1803	P-1972	AS-1
Name	U.G. Campbell Well (#4)			U.G. Campbell Well			
Lat/Long	36.0917	115.0867	G-1944	36.0903	115.0872	G-1944	AS-1
Name	U20a-2			U20a-2 N907395 E571439 Pahute Mesa			
Lat/Long	37.2430	116.2410	F-1966	37.2428	116.4211	P-1971	AD
Name	UE-20e Pahute Mesa			UE-20e#1 Pahute Mesa			
Lat/Long	37.3172	116.4569	P-1964	37.3169	116.4569	P-1966	AS-2
Name	UE-25p#1			UE-25P-1 Yucca Mtn			
Lat/Long	36.8272	116.4222	D-1983	36.8272	116.4225	P-1983	AS-1
Name	UE20h			UE20h N918015 E567747 Pahute Mesa			
Lat/Long	37.2720	116.4340	F-1965	37.2717	116.4339	P-1965	AS-2
Name	Unnamed Well			Unnamed Well			
Lat/Long	36.4267	116.2817	G-1961	36.4267	116.2883	G-1972	AD

Table 15, continued.

	Maximum Geothermometer File		Database & Year	Minimum Geothermometer File		Database & Year	Action Taken
Name	Unnamed Well			Unnamed Well			
Lat/Long	36.4283	116.2667	G-1972	36.4283	116.2650	G-1972	AS-1
Same Names and Similar Latitudes and Longitudes:							
Name	230 S E	230 S E					
Lat/Long	36.5536	116.5069	P-1972	36.5717	116.4617	P-1972	AD
Name	Alkali Hot Springs			Alkali Hot Springs			
Lat/Long	37.8267	117.3400	G-1957	37.8247	117.3367	G-no date	AS -1
Name	Amargosa Desert Area			Amargosa Desert Area			
Lat/Long	36.4908	116.3342	G-no date	36.7517	116.4283	G-1958	AS-2
Name	Badwater Spring			Badwater Spring			
Lat/Long	36.2314	116.7667	P-no date	36.2161	116.7642	P-1959	AS-2
Name	Captain Jack Spring			Captain Jack Spring			
Lat/Long	37.1722	116.1583	P-1959	37.1722	116.1697	P-1991	AS-2
Name	Cold Creek Spring			Cold Creek Spring			
Lat/Long	36.4139	115.7389	P-1987	36.4117	115.7433	P-no date	AS-1
Name	Davis Ranch Spring			Davis Ranch Spring			
Lat/Long	36.3983	116.3050	G-1962	36.4083	116.3100	G-1971	AS-2
Name	Hiko Spring			Hiko Spring			
Lat/Long	37.5867	115.2300	G-1912	37.6094	115.2117	P-1912	AS-2
Name	J.K. Houssels Well			J.K. Houssels Well			
Lat/Long	36.0667	115.1118	G-1943	36.0633	115.1117	G-no date	AS-1
Name	Oak Spring			Oak Spring			
Lat/Long	37.2447	116.0725	P-1958	37.2450	116.2390	F-1958	AS-1
Name	Ray Thomas Well			Ray Thomas Well			
Lat/Long	36.2000	115.9883	G-1945	36.1983	115.9800	G-1946	AS-2
Name	Scruggs Spring			Scruggs Spring			
Lat/Long	36.4340	116.3090	F-1972	36.4317	116.3067	G-1972	AS-2
Name	Sec 10 T21S R53E			Sec 10 T21S R53E			
Lat/Long	36.1383	116.0008	P-1992	36.1383	116.0011	P-1992	AS-2
Name	Sec 11 T21S R53E			Sec 11 T21S R53E			
Lat/Long	36.1383	115.9833	P-1992	36.1400	115.9833	P-1992	AS-1
Name	Sec 14 T21S R53E			Sec 14 T21S R53E			
Lat/Long	36.1242	115.9833	P-1992	36.1383	115.9833	P-1992	AS-2
Name	Sec 18 T21S R54E			Sec 18 T21S R54E			
Lat/Long	36.1250	115.9478	P-1991	36.1233	115.9483	P-1992	AS-2
Name	Test Well 10			Test Well 10			
Lat/Long	36.5933	115.8533	F-1964	36.5919	115.8511	P-no date	AS-1
Similar Names and Identical Latitudes and Longitudes:							
Name	Indian Spring Sewage Co #1 N660000 E795000			Indian Springs N665000 E796000			
Lat/Long	36.5583	115.6611	P-1968	36.5583	115.6611	P-1968	R-1
Different Names and Identical Latitudes and Longitudes							
Name	10S/47-30DCC			Sarcobatus Flt/Oasis Vy S10/47-30d1			
Lat/Long	37.0333	116.7583	P-1967	37.0333	116.7583	P-1962	R-2

Table 15, continued.

	Maximum Geothermometer File		Database & Year	Minimum Geothermometer File		Database & Year	Action Taken
Name	230 S17 E49 11BC 1			Well (Mecca Club) NENW 11-17S-49E			
Lat/Long	36.4933	116.4208	P-1974	36.4933	116.4208	P-1970	R-2
Name	Davis Ranch Spring			Unnamed Well			
Lat/Long	36.3983	116.3050	G-1962	36.3983	116.3050	G-1967	AD
Name	Tunnel Drift B Sta 175 in B-2b			Tunnel U-12b Shaft 07 NTS			
Lat/Long	37.1947	116.2008	P-1973	37.1947	116.2008	P-1961	R-2
Name	Unnamed Spring			Indian Rock Spring			
Lat/Long	36.3983	116.2700	G-1962	36.3983	116.2700	G-1962	R-2
Name	Well NE22-20S-52E 6 M W of Pahrump			Well (Field # 16604) NE 22-20S-52E			
Lat/Long	36.2044	116.1025	P-no date	36.2044	116.1025	P-1959	R-1
Name	Well SM13			Well SMB			
Lat/Long	36.4842	116.3233	F-1970	36.4842	116.3233	G-1970	R-1
Name	Well NW 19-15S-50E Nye Co			Lathrop Wells NW			
Lat/Long	36.6383	116.3975	P-1959	36.6383	116.3975	P-1959	R-2

"Database abbreviations: P = Perfect, F = Flynn, D = DOE, G = GEOTHERM, and S = STORET"

Action Taken:

R-1 = Renamed the entries with the name appearing in the first name listed here.

R-2 = Renamed the entries with the name appearing in the second name listed here.

AS = The two entries are assumed the same, and one Lat/Long pair is selected for both. One entry is placed in the maximum geothermometer file, and the other is placed in the minimum geothermometer file.

AS-1 Indicates the first Lat/Long pair is selected, and;

AS-2 Indicates the second Lat/Long pair is selected.

AD = The two entries are assumed to be different locations and both are put in the maximum geothermometer temperature file.

```
{
        printf("%s %s %s\n",\
                substr($1,1,2),substr($1,3,2),substr($1,5,2))
}
```

and it was invoked in the following manner:

```
awk -f date.awk < input > output .
```

The column order of all five databases were re-arranged in order that they would be identical to one another, thus allowing direct merging of the databases. Not all data fields were labeled identically. For instance, in the original GEOTHERM file a number listed as GEORECORD appeared in the file, and this was assumed to be the same as the site ID. The data labels in the Perfect database were selected, and those corresponding ones in the other databases were renamed. A Data Reference column was added to each database to indicate from which database the record originated. If the original database also listed a reference for the data source, the two were added together such that the original data source was followed by a '-' and the first letter of the database name (e.g., WNP-F indicates the data was retrieved from the Flynn database, and the original data came from Winograd and Pearson, 1976). The original references noted in the Flynn database are listed below.

712	Blankennagel and Weir (1973)	LYL	Lyles and Hess (1988)
BOU	Boughton (1986)	MAT	Matuska (1989)
BSN	Benson and others (1983)	WHT	White and Chuma (1987)
CLA	Claassen (1985)	WNF	Winograd and Freidman (1972)
GAR	Garside and Schilling (1979)	WNP	Winograd and Pearson (1976)
GFG	Flynn and Buchanan (1990)		

Once all five databases were manipulated as indicated above, and their columns were ordered in an identical manner, the databases were merged into one file which was labeled master.xls.

This file was subsequently saved as master1.xls and reduced in size by selecting the best analysis for each individual sample location based on charge balances. Hence, only one analysis from each location was sought for incorporation into this file. The file was first sorted by name, and all names with the same Lat/Long were evaluated for the best analysis. The file was subsequently sorted by Lat/Long for the event where an identical sample site occurs, yet was named differently in different databases. These same Lat/Long values were then also evaluated based on their charge balances.

The isotope file was constructed in a similar manner as the chemistry file previously discussed in detail (i.e., Lat/Long and dates were converted, etc.). All isotope analyses in the combined data set appear in file isotope.xls. A second file was constructed for use in GIS and is called isot-gis.xls. This differs from the first file in that all duplicate analyses are deleted, and only one analysis appears for each sample location. The selection of which one to retain in the database was based on which record had the greater number of isotope analyses. If the number of analyses was equal, the one which was sampled most recently was selected for retention in the database. Prior to making the deletions, the file was checked for well elevation and total depth. If these values appeared for one site location, but were not recorded at the same site for other analyses, the values were copied into the record with the missing values. This addition is reasonable because elevation and well depth do not vary between sample collection times.

Geothermometer files

Once all of the databases were manipulated and combined into one master database, geothermometers were calculated for all analyses using a standard suite of chemical geothermometers to estimate equilibration temperatures within the reservoirs. The geothermometers selected for use in this work are as follows: quartz - no steam loss, quartz - maximum steam loss, chalcedony, a-cristobalite, b-cristobalite, amorphous silica (Fournier and Potter, 1982; after Fournier and Rowe, 1966; and White and others, 1956); Na-K (Fournier, 1979); Na-K (Truesdell, 1976); Na-K-Ca (Fournier and Truesdell, 1973); Mg correction to the Na-K-Ca geothermometer (Fournier and Potter, 1979); Na-Li (Fouillac and Michard, 1981); and Na-K-Mg-Ca geoindicators (Giggenbach, 1988). A summary of chemical geothermometers and their application can be found in Mariner and Willey (1976), Fournier and others (1974), and Truesdell (1976).

The Na-K-Ca geothermometer, for the $\beta = 1/3$ and $\beta = 4/3$ scenarios (Fournier and Truesdell, 1973), was calculated for all records. If the $\beta = 4/3$ calculated temperature is <100°C, then the $\beta = 1/3$ calculation is considered unreliable and it is assumed that the waters equilibrated at a temperature of <100°C. In addition, if the function $\log(Ca^{0.5}/Na) + 2.06$ is negative, then the $\beta = 1/3$ value is used to obtain the temperature.

Using spreadsheet calculations, an 'if' statement was written to sort through the $\beta = 1/3$ or $4/3$ values and compile a single column with the appropriate geothermometer temperature. Most values are <100°C, and many values are <0 indicating unreliable estimates. Next the Mg-correction to the Na-K-Ca geothermometer (Fournier and Potter, 1979) was used to screen the data further. A series of "if" statements were used in the spreadsheet to determine if it was appropriate to apply the Mg-correction to the geothermometer. If the calculated temperature was <70°C, the Mg-correction was not applied. A factor, R, was computed (R={Mg/(Mg+Ca+K)} X 100 in equivalents), after Fournier and Potter (1979), to determine if corrections to the Na-K-Ca geothermometer should be made and to determine if the waters come from relatively cool reservoirs. For instance, if R>50, the sampled waters are assumed to originate from a relatively cool environment at a temperature close to the measured water temperature. None of the samples in the database had R> 50, and all had R<1.0. If R<0.5, the Mg-correction was not applied, and a significant number of analyses in this database had R<0.5. If 0.5<R<5, equation (2) of Fournier and Potter (1979) was used for the Mg-correction, and this temperature was subtracted from the appropriate $\beta = 1/3$ or $4/3$ value. Based on the above requirements, the Mg-correction was applied to only a small percentage of the analyses (i.e., most had temperatures <100°C and R<0.5). Of those with R>0.5, minimal changes to the calculated temperatures were made with the Mg-correction in most cases. For instance, Mclean Spring had a calculated $\beta = 4/3$ temperature of 142.91°C, and a $\beta = 1/3$ of 633.11°C and the Mg-corrected temperature to the $\beta = 1/3$ value was only 0.58°C. However, in other cases where temperatures were between 70 and 100°C, the Mg-correction resulted in completely unrealistic results (Saratoga Spring had a calculated $\beta = 4/3$ temperature of 90.36°C, and a corrected temperature of -430°C). Therefore, an additional 'if' statement was included in the spreadsheet in which the uncorrected value was maintained in the final tally if the temperature was <100°C, and the Mg-correction was applied if the temperature was >100°C.

Some of the data in the geothermometer file had poor (>±10%) charge balances but were retained in the data set because of elevated SiO_2 or measured temperatures. In these cases, the cation geothermometers were deleted from the file because their values were not reliable, and the entry for the site was retained solely for the purpose of retaining the elevated temperature value and/or estimating the subsurface temperature based on the SiO_2 content of the water. Two files were subsequently made from the main geothermometer file: one for the minimum calculated geothermometer temperature, and one for the maximum. The minimum and maximum temperatures were selected based on the chalcedony geothermometer because the indicated reservoir waters are <200°C, and the chalcedony temperatures are believed to be more realistic at lower (<190°C) temperatures than is the quartz geothermometer. Interpretation of quartz geothermometers for temperatures <190°C is ambiguous because chalcedony appears to control the solubility of silica in some areas, whereas quartz does in others (Fournier, 1991). When there were no SiO_2 data, the minimum and maximum temperatures were selected based on the Na-K geothermometer. When only one analysis was available at a particular location, the geothermometer values were retained and placed in the file containing the maximum calculated geothermometer temperatures at the sites containing more than one analysis.

The geothermometer files were subsequently streamlined by removing all chemical analyses and by deleting all geothermometer entries which were not calculated in the spreadsheet due to insufficient amounts of data (i.e., #NUM and #DIV/0 entries). These #NUM and #DIV/0 entries were replaced with blank fields in order to reduce file size and to simplify future calculations and analysis of the data.

After the maximum and minimum geothermometer files were formed, they were compared by site name and latitude and longitude to assure that the same site in each file was associated with the same location (latitude and longitude). This verification was performed at this step for the following reason. A considerable number of duplicate entries were removed from the original data sets during selection of the maximum and minimum geothermometer values. Because it was known that many analyses would be removed from the final geothermometer data set, comparison of locations from apparently duplicate sample sites was conducted later in this procedure to avoid time spent verifying locations for analyses which would ultimately be deleted from the final files.

The results of the comparison of the maximum and minimum calculated geothermometer temperature files appears in Table 15. The discrepancies are grouped by (1) similar name and similar latitude and longitude values, (2) same name and similar latitude and longitude values, (3) similar name and identical latitude and longitude values, and (4) different name and identical latitude and longitude values between the two files. The original database from which the entry was obtained is listed for each entry, as well as the year of sample collection (i.e., G-1971 indicate the entry originated from the GEOTHERM file and was collected in 1971). The last column indicates the action taken to resolve the discrepancies. If the entries were assumed to be different locations (AD) then the one in the minimum geothermometer temperature file was copied to the maximum geothermometer temperature file given that the entry was the only one for the site. If the entries from the two files were assumed to be the same site (AS), then the entries were retained in their respective files and the latitude and longitude values changed in one of the files so that the locations would be identical. An AS-1 notation indicates the latitude and longitude from the first entry (maximum geothermometer file) was used in both files, whereas an AS-2 notation indicates the latitude and longitude from the second entry (minimum geothermometer file) was used in both files. The latitude and longitude values were chosen as follows. The Lat/Long values associated with the most recent date of sample collection were given preference, assuming that more recent sample may have been more carefully located. If one of the entries had no listed date, it was assumed that this entry was incomplete and less reliable, and the Lat/Long was selected from the entry containing a date. If both entries had the same collection year, then one of the Lat/Long values was arbitrarily selected. When sites had identical Lat/Long and different names, the more descriptive name was retained in both files.

Files on 4mm Tape

All files saved incrementally were TARed from a Sun SparcLX workstation to an 8 mm data tape. These files are archived for QA purposes to allow verification of the data. Final data files used in the work described in this report are also TARed onto the same 8 mm tape. Most files are in an Excel version 4.0 format, and have also been saved as a tab delimited text file. Hence, perf-c2.xls and perf-c2.txt contain the same information, yet the first is in a Microsoft Excel spreadsheet, and the second is in a tab delimited text file. Note, the perf-c1.xlw workbook could not be saved to a text file. Files dumped from the STORET database had an original file format of DBase (.dbf), and these were also saved as tab delimited text files. Following is a listing of the descriptions of the incremental files followed by the file size.

Perfect Database

(TAR from /yucca/data/perf/)

Major Element Chemistry from Perfect Database: :

perf-c1.xlw, 3.78 Mb
perf-c2.xls and .txt, 3.69 Mb and 1.08 Mb
perf-c3.xls and .txt, 2.97 Mb and 892 Kb
perf-c4.xls and .txt, 2.85 Mb and 870 Kb
perf-c5.xls and .txt, 2.83 Mb and 861 Kb

Surface water analyses from Perfect database.
perf-sur.xls and .txt, 72 Kb and 21 Kb

Analyses from Perfect database with poor charge balance but elevated temperatures or SiO_2 contents. These analyses were retained in the final Perfect database, but with their major element analyses deleted.
perf-si.xls and .txt, 243 Kb and 66 Kb

Other analyses deleted from the perf-del database were placed in another file.
perf-del.xls and .txt, 1.14 Mb and 301 Kb

Stable and radio-isotope analyses from the Perfect database.
isochem.wk3 and .xlw, 4.65 Mb and 4.19 Mb
yuc-isot.xlw, 1.6 Mb isot-p.xls and .txt, 211 Kb, and 113 Kb

STORET Database

(TAR from /yucca/data/storet/)

Major and trace element analyses retrieved from the STORET database. Several Dbase files (yucca*.xls) were dumped from STORET in order that they could be more rapidly processed in PCFile. These were then combined with the station information to form the storet*.xls files.

yucca1.dbf and .txt, 342 Kb and 318 Kb
yucca2.dbf and .txt, 180 Kb and 161 Kb
yucca3.dbf and .txt, 67 Kb and 64 Kb
yucca4.dbf and .txt, 63 Kb and 60 Kb
yucca5.dbf and .txt, 117 Kb and 116 Kb
yucca6.dbf and .txt, 88 Kb and 82 Kb
stations.dbf and .txt, 175 Kb and 123 Kb
storet.xls and .txt, 79 Kb and 39 Kb
storeta.xls and .txt, 82 Kb and 41 Kb
storet1.xls and .txt, 80 Kb and 46 Kb
storet2.xls and .txt, 376 Kb and 92 Kb
storet3.xls and .txt, 67 Kb and 26 Kb
storet4.xls and .txt, 73 Kb and 27 Kb

Analyses from the STORET database with poor charge balance but elevated temperatures or SiO_2 contents. These analyses were retained in the final STORET database, but with their major element analyses deleted.
stor-si.xls and .txt, 23 Kb and 5 Kb

Analyses deleted from the STORET database due to poor charge balances.
stor-del.xls and .txt, 81 Kb and 18 Kb

Isotope analyses retrieved from STORET are located in the following file.
isot-s.xls and .txt, 39 Kb and 14 Kb

GEOTHERM Database

(TAR from /yucca/data/geoth/)

Analyses retrieved from the U.S.G.S. GEOTHERM database.

geotherm.dbf and .txt, 3.21 Mb and 629 Kb
geoth-y1.xls and .txt, 193 Kb and 120 Kb
geoth-y2.xls and .txt, 149 Kb and 94 Kb
geoth-y3.xls and .txt, 139 Kb and 86 Kb
geoth-y4.xls and .txt, 111 Kb and 71 Kb
geoth-y5.xls and .txt, 183 Kb and 75 Kb
geoth-y6.xls and .txt, 119 Kb and 64 Kb

Analyses from the GEOTHERM database with poor charge balance but elevated temperatures or SiO_2 contents. These analyses were retained in the final GEOTHERM database, but with their major element analyses deleted.

geo-si.xls and .txt, 119 Kb and 31 Kb

Other analyses deleted from the GEOTHERM data file appear in another file,
geot-del.xls and .txt, 62 Kb and 17 Kb

DOE Database

(TAR from /yucca/data/doe/)

Major element analyses obtained from the DOE maintained database.

doe_maj.xls and .txt, 42 Kb and 17 Kb
doe2.xls and .txt, 56 Kb and 30 Kb
doe4.xls and .txt, 66 Kb and 20 Kb
doe_maj1.xls and .txt, 71 Kb and 38 Kb
doe3.xls and .txt, 112 Kb and 35 Kb
doe5.xls and .txt, 40 Kb and 20 Kb

Trace element chemical analyses obtained from the DOE maintained database.
doe_trc.xls and .txt, 34 Kb and 14 Kb

Isotope analyses obtained from the DOE maintained database.
doe_isot.xls and .txt, 16 Kb and 6 Kb

Analyses from DOE database with poor charge balance but elevated temperatures or SiO_2 contents. These analyses were retained in the final DOE database, but with their major element analyses deleted.

doe-si.xls and .txt, 53 Kb and 16 Kb

Analyses deleted from the DOE database due to poor charge balances.
doe-del.xls and .txt, 54 Kb and 16 Kb

Flynn Database

(TAR from /yucca/data/fly/)

Chemical analyses from the Flynn database.

fly-orig.xls and .txt, 229 Kb and 49 Kb
flynn.xls and .txt, 229 Kb and 49 Kb
flynn2.xls and .txt, 318 Kb and 53 Kb
flynn3.xls and .txt, 258 Kb and 41 Kb
flynn4.xls and .txt, 213 Kb and 47 Kb

Analyses from the Flynn database with poor charge balance but elevated temperatures or SiO_2 contents. These analyses were retained in the final Flynn database, but with their major element analyses deleted.

flyn-si.xls and .txt, 48 Kb and 7 Kb

Analyses deleted from the Flynn database due to poor charge balances:
flyn-del.xls and .txt, 75 Kb and 11 Kb

Isotope analyses from the Flynn database appear in the following file.
isot-f.xls and .txt, 65 Kb and 17 Kb

Geothermometer Files

(TAR from /yucca/data/geotherm/)

Geothermometers calculated from all sites in the chemical analysis file (master1.xls), including duplicate sampling dates for individual sites. This file includes all chemical analyses used in the geothermometer calculations.

geoth-1.xls and .txt, 5.7 Mb and 955 Kb

When no chalcedony geothermometer temperature was available for a site, the Na-K-Ca geothermometer was consulted. If the estimated temperature and the measured temperature were <25°C, then the entry was placed in a file.

nontherm.xls and .txt, 101 Kb and 25 Kb

The geoth-1.xls file was copied to two separate files. The first was the file containing the maximum geothermometer value at each site.

max-new.xls and .txt, 676 Kb and 178 Kb   max5_fnl.xls and .txt, 511 Kb and 136 Kb

The second file formed from the geoth-1.xls file was the file containing the minimum geothermometer value from each site.

min-new.xls and .txt, 285 Kb and 83 Kb   min2_fnl.xls and .txt, 108 Kb and 25 Kb

All entries with maximum collection temperatures of <25°C and for which the chalcedony geothermometer temperature was less than or equal to the sample collection temperature were deleted from the maximum geothermometer file. If the maximum measured temperature was <25°C, and the chalcedony geothermometer temperature was within 7°C of the measured temperature, the entry was also deleted from the maximum geothermometer file. These entries were then placed in the following file.

geot-del.xls and .txt, 62 Kb and 17 Kb

If the maximum measured sample temperature was >25°C and the geothermometer temperature was either <25°C or within ±7°C of the measured temperature, then the entries were deleted from the maximum geothermometer file and retained in the following file.

geoth-25.xls and .txt, 80 Kb and 22 Kb

(TAR from /yucca/data/geotherm/delete/)

Deletions and site name changes made to the maximum geothermometer file prior to conversion to a PC Arc/Info coverage are listed in the following file.

max-chg.xls and .txt, 79 Kb and 183 Kb

Combined Database

(TAR from /yucca/data/chem/)

The incrementally saved chemistry files for the combined database are as follows.

master.xls and .txt, 3.0 Mb and 775 Kb   all-fnl.xls and .txt, 1.17 Mb and 294 Kb
master1.xls and .txt, 1.38 Mb and 359 Kb

(TAR from /yucca/data/chem/delete/)

Deletions and site name changes made to the combined database prior to conversion to a PC Arc/Info coverage are listed in the following file.

yuc-chg.xls and .txt, 95 Kb and 201 Kb

The final, combined files for chemical analyses, isotope analyses and minimum and maximum geothermometers based on chalcedony are named as follows (TAR from /yucca/final/).

Chemistry	all-fnl.xls and .txt	1.17 Mb and 294 Kb
Isotope	isotope.xls and .txt	280 Kb and 100 Kb
GIS Isotope	isot-gis.xls and .txt	168 Kb and 60 Kb
Maximum Geothermometer	max5_fnl.xls and .txt	511 Kb and 136 Kb
Minimum Geothermometer	min2_fnl.xls and .txt	108 Kb and 25 Kb

The total size of all files listed in this appendix is 60.7 Mb.

APPENDIX 2

GIS Coverage Summary

Several new and existing coverages were used to provide administrative or boundary information that does not affect interpretation, and for that reason metadata is not provided for these coverages. A summary of these coverages and their source is provided in Table 16.

Other GIS coverages used in this study were either created from data collected for this study, previously created for other studies, or modified from coverages obtained from EG&G Energy Measurements Division (EG&G, 1993). All coverages were manipulated using PC Arc/Info v3.4.1 at the Division of Earth Sciences, University of Nevada, Las Vegas. A metadata page for each data coverage which affects interpretation, which describes the steps involved in their creation or modification and their source, follows. The metadata pages are provided in alphabetical order based on the coverage name as listed in Table 1.

Data Availability

Copies of this report and the data in the appendices may be obtained through the Yucca Mountain Site Characterization Project Technical Data Base.

Table 16. Summary of administrative boundary GIS coverages used in the preparation of this report.

Coverage Name	Coverage Description	Data Reference	Coverage Name	Coverage Description	Data Reference
CAKGR	California's KGRAs	3	USCOU	County lines, Western U.S.	1
GBBOU	Great Basin outline	2	UTKGR	Utah's KGRAs	2
GBCOU	County lines, Great Basin	1	YM50M	50 mile radius study area	2
NVKGR	Nevada's KGRAs	2	YMCCA	Conceptual Controlled Area	1
ORKGR	Oregon's KGRAs	2	YMPRO	Potential Repository Outline	1
TSBOU	Nevada Test Site boundary	1			

1 EG&G Energy Measurements Division 2 University of Nevada Las Vegas, Division of Earth Sciences
3 California Division of Mines and Geology

GIS METADATA, UNLV - Earth Sciences

FAULTS
GBFLT

Coverage Name: GBFLT
Coverage Dir: \USGSFLT\SPC\
Location: Great Basin
Description: Faults compiled from State maps.

SOURCE

Data Source: USGS - Reno field office data coverage GBFAULTS
Series:
Material: Paper
Scale: 1:500,000 (NV, OR, UT, ID), 1:750,000 (CA)
Projection: State map projection
Publication Date:
Comments: Coverage obtained from USGS in ARC/INFO EXPORT format. IMPORTed to PC ARC/INFO with a UTM projection, GBFAULT.

DIGITIZING INFO

Initial Date: N/A
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision:

Tics:				
	LONG: **LAT:**	**LONG:** **LAT:**	**LONG:** **LAT:**	**LONG:** **LAT:**
SPC	**1 X:** 2145891.0000	**2 X:** -1211430.0000	**3 X:** -997135.3000	**4 X:** 1939860.0000
ZONE 4626	**Y:** -257393.5000	**Y:** -253849.8000	**Y:** 3222357.0000	**Y:** 3218541.0000

Comments: Coverage projected from UTM meters to State Plane Coordinates.

Digitizing Parameters: **ED:** **SD:** **WE:** **GRAI:** **SNAPT:**

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ UTM
UNITS METERS
ZONE 11
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
09AUG	SPC	PROJECT to spc

DATE	FILE	ACTION

Coverage Name: GBGWC
Coverage Dir: \WATER\GWCHEM\
Location: Great Basin
Description: Temperature of thermal wells and springs throughout the Great Basin.

SOURCE

Data Source: UNLV - Earth Sciences data file GEOCHEM.XLS, collected from numerous sources.
Series:
Material: Digital Coordinates (spreadsheet)
Scale:
Projection:
Publication Date:
Comments:

DIGITIZING INFO

Initial Date: 06NOV95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POINT
Precision:

Tics:	**LONG:** 111.5950	**LONG:** 121.9260	**LONG:** 111.5950	**LONG:** 121.9260
	LAT: 32.8090	**LAT:** 32.8090	**LAT:** 46.4110	**LAT:** 46.4110
SPC	**1 X:** 2059061.0000	**2 X:** -1116818.0000	**3 X:** 1779187.0000	**4 X:** -826514.9000
ZONE 4626	**Y:** -668801.2000	**Y:** -665972.1000	**Y:** 4288956.0000	**Y:** 4292055.0000

Comments: Coverage was generated from lat/long coordinates in data file GEOCHEM.XLS.

Digitizing Parameters: **ED:** .03 **SD:** .03 **WE:** .03 **GRAI:** .05 **SNAPT:** CLOSEST

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
06NOV	BD2	BUILD
06NOV	AT3	ATTRIBUTE
06NOV	PR4	PROJECT from lat/long to SPC
06NOV	ED5	EDIT to filter areas of dense points
07NOV	BD6	BUILD POINT
13NOV	CP7	CLIP to Great Basin outline
13NOV	BD8	BUILD POINT

DATE	FILE	ACTION

Coverage Name: GBHFL
Coverage Dir: \GEOLOGY\HEATFLOW
Location: Great Basin (Nevada, Utah, California, Oregon, Idaho)
Description: Battle Mountain heat flow high and Eureka heat flow low outlines.

SOURCE

Data Source: Sass and others, 1982, Preliminary interpretation of thermal data from the Nevada Test Site
Series: USGS OFR 82-973
Material: Paper map, 8.5 x 11
Scale: 1:1,000,000
Projection: GEOG
Publication Date: 1982
Comments:

DIGITIZING INFO

Initial Date: 08NOV95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY
Precision:

Tics:	**LONG**: 120.000	**LONG**: 114.000	**LONG**: 114.000	**LONG**: 120.000
	LAT: 42.000	**LAT**: 42.000	**LAT**: 37.000	**LAT**: 39.000
SPC	**1 X**: -406053.8000	**2 X**: 1224827.0000	**3 X**: 1278773.0000	**4 X**: -447397.8000
ZONE 4626	**Y**: 2657672.0000	**Y**: 2651316.0000	**Y**: 829877.0000	**Y**: 1564554.0000

Comments:

Digitizing Parameters: **ED**: .03 **SD**: .03 **WE**: .03 **GRAI**: .05 **SNAPT**: CLOSEST

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
O8NOV	CN2	CLEAN
O8NOV	TR3	TRANSFORM RMS Error (input,output) = (0.5863029E-02, 4687.108)
O8NOV	AT4	ATTRIBUTE

DATE	FILE	ACTION

GIS METADATA, UNLV - Earth Sciences

Coverage Name: NTSPR
Coverage Dir: \NTS\HYDROL\
Location: Nevada Test Site
Description: Springs and wells in the vicinity of the Nevada Test Site.

SOURCE

Data Source: UNLV - Earth Sciences data file GEOCHEM.XLS, collected from numerous sources.
Series:
Material: Digital coordinates
Scale:
Projection:
Publication Date:
Comments:

DIGITIZING INFO

Initial Date: 17OCT 94
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POINT
Precision:

Tics:	**LONG:** 116.8459	**LONG:** 115.5578	**LONG:** 116.8485	**LONG:** 115.5419
	LAT: 36.2537	**LAT:** 36.2487	**LAT:** 37.3499	**LAT:** 37.3447
SPC	**1 X:** 447148.0000	**2 X:** 826972.0000	**3 X:** 447148.0000	**4 X:** 826972.0000
ZONE 4626	**Y:** 547337.0000	**Y:** 547337.0000	**Y:** 946404.0000	**Y:** 946404.0000

Comments: Coverage was generated from lat/long coordinates in data file GEOCHEM.XLS.

Digitizing Parameters: **ED:** .03 **SD:** .03 **WE:** .03 **GRAI:** .05 **SNAPT:** CLOSEST

Projection Parameters: \SML-OP\DDSPC.SML

INPUT	OUTPUT
PROJ GEOG	PROJECTION STATEPLANE
UNITS DD	UNITS FEET
QUADRANT NW	ZONE 4626
PARAM	PARAMETERS
	END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
17OCT	CN2	CLEAN
17OCT	ED3	EDIT
17OCT	BD4	BUILD
17OCT	AT5	ATTRIBUTE
17OCT	PR6	PROJECT to spc
17OCT	ED7	EDIT to remove points out of study area.

DATE	FILE	ACTION

Coverage Name: RGGRV
Coverage Dir: \GRAVITY\REGIONAL
Location: Yucca Mountain Region, Goldfield to Pahrump
Description:

SOURCE

Data Source: USGS Map 94A Bouger Gravity Anomaly Map of Nevada
Series:
Material: Folded Paper Map
Scale: 1:750,000
Projection: GEOG
Publication Date: 1988
Comments: 5 Mgal contour map of State, reduction density = 2.67g/cm^3

DIGITIZING INFO

Initial Date: 03OCT95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: LINE
Precision:

Tics:	**LONG:** 117.000	**LONG:** 116.000	**LONG:** 116.000	**LONG:** 117.000
	LAT: 38.000	**LAT:** 38.000	**LAT:** 36.000	**LAT:** 36.000
SPC	**1 X:** 403952.5000	**2 X:** 692095.8000	**3 X:** 697194.4000	**4 X:** 401403.3000
ZONE 4626	**Y:** 1183223.0000	**Y:** 1183739.0000	**Y:** 455617.0000	**Y:** 455111.3000

Comments: RMS on TRANSFORM high. TIC's 3 and 4 were picked from hand drawn Lat. and Long. lines projected to intersecting points. Medium was folded paper at a small scale (1:750,000). A digitizing error of 1/100' = 628'.

Digitizing Parameters: **ED:** .03 **SD:** .01 **WE:** .01 **GRAI:** .03 **SNAPT:** CLOSEST
Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE FILE ACTION

03OCT CN2 CLEAN
03OCT ED3 EDIT
03OCT BD4 BUILD
03OCT AT5 ATTRIBUTE
03OCT TR6 TRANSFORM RMS Error (input,output) = (0.1611929E-01, 1015.885)
25OCT ED7 EDIT arcs collapsed during transform
25OCT CN8 CLEAN
25OCT ED9 EDIT remove arcs illegible at scale
25OCT BDA BUILD
25OCT ATB ATTRIBUTE edits
25OCT BDC BUILD

DATE FILE ACTION

Coverage Name: RGMAG
Coverage Dir: \AEROMAG\REGIONAL
Location: Yucca Mountain Area
Description: General regional Aeromag data at 100 Gamma contours

SOURCE

Data Source: Aeromagnetic Map of Nevada: Color Coded Intensities
Series: GP-922
Material: Folded Paper Map
Scale: 1:1,000,000
Projection: GEOG
Publication Date: 1978
Comments:

DIGITIZING INFO

Initial Date: 26SEP95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY, LINE
Precision:

Tics:	**LONG:** 117	**LONG:** 116	**LONG:** 116	**LONG:** 117
	LAT: 38	**LAT:** 38	**LAT:** 36	**LAT:** 36
SPC	**1 X:** 403952.5	**2 X:** 692095.8	**3 X:** 697194.4	**4 X:** 401403.3
ZONE 4626	**Y:** 1183223.0	**Y:** 1183739.0	**Y:** 455617.0	**Y:** 455111.3

Comments:RMS on TRANSFORM high. TIC's 3 and 4 were picked from hand drawn Lat. and Long. lines projected to intersecting points. Medium was folded paper at a small scale (1:1,000,000). A digitizing error of 1/100' = 628'.

Digitizing Parameters: **ED:** .03 **SD:** .01 **WE:** .01 **GRAI:** .03 **SNAPT:** CLOSEST
Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
26SEP	CN2	CLEAN
26SEP	ED3	EDIT
26SEP	BD4	BUILD POLY,LINE
26SEP	AT5	ATTRIBUTE
26SEP	AT5	SPLINE, should have been done at ED3
26SEP	AT5	BUILD after spline
27SEP	TR6	TRANSFORM RMS Error (input,output) = (0.9075943E-02, 761.2736)
25OCT	ED7	EDIT arcs collapsed during transform
25OCT	BD8	BUILD POLY,LINE
25OCT	AT9	ATTRIBUTE edits
25OCT	BDA	BUILD POLY,LINE

DATE FILE ACTION

Coverage Name: YMALL
Coverage Dir: \YUCCA\WATER\
Location: YUCCA MOUNTAIN AREA, 50-75 MILE RADIUS
Description: NBMG master list of geochemistry

SOURCE

Data Source: Lisa Shevenell, NBMG, modified by Paul Buchanan, DES.
Series:
Material: Excel spreadsheet, \GENERAL\YUCCA\SHEETS\NBMG-ORG\MASTER.XLS, modified to ..\NBMG-MOD\ALL\ALL-CULL.XLS.
Scale: NA
Projection: GEOG
Publication Date: 19
Comments: Data provided by L. Shevenell in an Excel spreadsheet, ranges from 114.5-118 longitude, 35.5-38 latitude. Spreadsheet underwent extensive modification as duplicates were removed and SITE_NAME standardized.

DIGITIZING INFO

Initial Date: 06JUN95, COVERAGE YMALLGN1 was generated from spreadsheet data, not digitized.
25JUL95, COVERAGE YMALLGN1 re-generated from modified spreadsheet data, original deleted.
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision: POINT

Tics:	**LONG:** 114°30'	**LONG:** 118°00'	**LONG:** 118°00'	**LONG:** 114°30'
	LAT: 38°00'	**LAT:** 38°00'	**LAT:** 35°30'	**LAT:** 35°30'
SPC	**1 X:** 115802.1	**2 X:** 1124344.0	**3 X:** 1144949.0	**4 X:** 103127.9
ZONE 4626	**Y:** 1185804.0	**Y:** 1190321.0	**Y:** 280037.5	**Y:** 275636.0

Comments: An empty coverage was created with the CREATE command, {tic_bnd_cover}=YMMAPTIC. Data coordinates provided in DD and placed in file \YUCCA\DATFILES\YMALLGN1.CSV, then projected to SCP using PROJECT, {sml_file}=DDSPC.SML, and placed in file \YUCCA\DATFILES\YMALLPR1.SPC. This file then used to GENERATE points into the coverage.

Digitizing Parameters: **ED:** NA **SD:** NA **WE:** NA **GRAI:** NA **SNAPT:** NA
Projection Parameters: \YUCCA\SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	ACTION
25JUL	BD4 BUILD for POINT
25JUL	AT5, JOINITEM to attach .DBF file from spreadsheet

DATE	ACTION
05OCT	COVERAGE transferred to NGMG with EXPORT to attribute with elevations, returned as YMTALL90
18OCT TR6	COPYCOV used to copy YMTALL90

Coverage Name: YMGRV
Coverage Dir: \YUCCA\GRAVITY\XXX\
Location: YUCCA MOUNTAIN - BARE MOUNTAIN AREA
Description: Residual gravity survey reduced at 2.0 g/cm, east half before APPEND, entire coverage after..

SOURCE

Data Source: USGS OFR 82-701
Series:
Material: Folded Paper Map
Scale: 1:48,000
Projection: GEOG
Publication Date: 1982
Comments:

DIGITIZING INFO

Initial Date: 04AUG95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY, LINE
Precision:

Tics:	**LONG:** 116°45' **LAT:** 37°00'	**LONG:** 116°30' **LAT:** 37°00'	**LONG:** 116°15' **LAT:** 36°37.5
SPC ZONE 4626	**1 X:** 475665.8 **Y:** 818976.6	**2 X:** 548668.4 **Y:** 819008.5	**3 X:** 621671.3 **Y:** 819232.1
Tics:	**LONG:** 116°45' **LAT:** 37°00'	**LONG:** 116°30' **LAT:** 37°00'	**LONG:** 116°15' **LAT:** 36°37.5'
SPC	**6 X:** 475546.8 **Y:** 682460.6	**5 X:** 548906.4 **Y:** 682496.4	**4 X:** 622266.2 **Y:** 682715.1

Comments: Map digitized in two halves, and appended as YMGRVAP7. West half digitized as YMGR2, with all specifications identical to this one. YMGR2 uses TICs 1, 2, 5, and 6. YMGRV uses TICs 2, 3, 4, and 5.

Digitizing Parameters: **ED:** .03 **SD:** .03 **WE:** .03 **GRAI:** .05 **SNAPT:** CLOSEST
Projection Parameters: \YUCCA\SML-OP\DDSPC.SML

INPUT	OUTPUT
PROJ GEOG	PROJECTION STATEPLANE
UNITS DD	UNITS FEET
QUADRANT NW	ZONE 4626
PARAM	PARAMETERS
	END

SUBSEQUENT MANIPULATIONS

DATE FILE ACTION

03OCT CN2 CLEAN
04AUG CN2 CLEAN
04AUG ED3 EDIT
04AUG BD4 BUILD
04AUG AT5 ATTRIBUTE
04AUG TR6 TRANSFORM RMS Error
(input,output) = (0.1488674E-01, 59.84183)
04AUG AP7 APPEND YMGR2
04AUG BD8 BUILD APPENDed coverages
04AUG ED9 EDIT to remove dangles from APPEND
04AUG BDA BUILD

DATE FILE ACTION

Coverage Name: YMGR2
Coverage Dir: \YUCCA\GRAVITY\XXX\
Location: YUCCA MOUNTAIN - BARE MOUNTAIN AREA
Description: Residual gravity survey reduced at 2.0 g/cm, west half.

SOURCE

Data Source: USGS OFR 82-701
Series:
Material: Folded Paper Map
Scale: 1:48,000
Projection: GEOG
Publication Date: 1982
Comments:

DIGITIZING INFO

Initial Date: 04AUG95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY, LINE
Precision:

Tics:	**LONG:** 116°45'	**LONG:** 116°30'	**LONG:** 116°45'	**LONG:** 116°30'
	LAT: 37°00'	**LAT:** 37°00'	**LAT:** 37°00'	**LAT:** 37°00'
SPC	**1 X:** 475665.8	**2 X:** 548668.4	**6 X:** 475546.8	**5 X:** 548906.4
ZONE 4626	**Y:** 818976.6	**Y:** 819008.5	**Y:** 682460.6	**Y:** 682496.4

Comments: West half of Yucca Mountain gravity map, uses TIC numbers 1, 2, 5,and 6. APPENDed to YMGRVTR6 to create YMGRVAP7.

Digitizing Parameters: **ED:** .03 **SD:** .03 **WE:** .03 **GRAI:** .05 **SNAPT:** CLOSEST
Projection Parameters: \YUCCA\SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE FILE ACTION

03OCT CN2 CLEAN
04AUG CN2 CLEAN
04AUG ED3 EDIT
04AUG BD4 BUILD
04AUG AT5 ATTRIBUTE
04AUG TR6 TRANSFORM RMS Error
(input,output) = (0.2396742E-02, 9.63783)

DATE FILE ACTION

Coverage Name: YMHFL
Coverage Dir: \GEOLOGY\HEATFLOW
Location: Yucca Mountain
Description: Extension of the Eureka heat flow low into the Yucca Mountain area.

SOURCE

Data Source: Sass and others, 1988, Temperature, thermal conductivity, and heat flow near Yucca Mountain, Nevada
Series: USGS OFR 88-649
Material: Paper map, 8.5 x 11
Scale: 1:500,000
Projection: GEOG
Publication Date: 1988
Comments:

DIGITIZING INFO

Initial Date: 08NOV95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY
Precision:
Tics: **LONG:** 116.7667 **LONG:** 115.8000
LAT: 37.5000 **LAT:** 37.5000
SPC **1 X:** 470981.4000 **2 X:**
751410.6000**3 X:** 754724.9000 **4 X:** 470598.9000
ZONE 4626 **Y:** 1001016.0000 **Y:**
1002158.0000 **Y:** 638092.5000 **Y:** 6369
Comments:
Digitizing Parameters: **ED:** .03 **SD:** .03
Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
O8NOV	CN2	CLEAN
08NOV	ED3	EDIT
08NOV	BD4	BUILD
08NOV	AT4	ATTRIBUTE
O8NOV	TR6	TRANSFORM RMS Error (input,output) = (0.9644565E-00, 427.2318)
08NOV	BD7	BUILD

DATE	FILE	ACTION

Coverage Name: YMMAX
Coverage Dir: \YUCCA\WATER\
Location: YUCCA MOUNTAIN AREA, 50-75 MILE RADIUS
Description: NBMG list of maximum chalcedony geothermometer data.

SOURCE

Data Source: Lisa Shevenell, NBMG, modified by Paul Buchanan, DES.
Series:
Material: Excel spreadsheet, \GENERAL\YUCCA\SHEETS\NBMG-ORG\MAX5.XLS,
modified to ..\NBMG-MOD\ALL\MAX5CULL.XLS.
Scale: NA
Projection: GEOG
Publication Date: 19
Comments: Data provided by L. Shevenell in an Excel spreadsheet, ranges from 114.5-118 longitude, 35.5-38 latitude. Spreadsheet underwent extensive modification as duplicates were removed and SITE_NAME standardized.

DIGITIZING INFO

Initial Date: 06JUN95, COVERAGE was generated from spreadsheet data, not digitized.
25JUL95, COVERAGE re-generated from modified spreadsheet data, original deleted.
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision: POINT

Tics:	**LONG**: 114°30'	**LONG**: 118°00'	**LONG**: 118°00'	**LONG**: 114°30'
	LAT: 38°00'	**LAT**: 38°00'	**LAT**: 35°30'	**LAT**: 35°30'
SPC	**1 X**: 115802.1	**2 X**: 1124344.0	**3 X**: 1144949.0	**4 X**: 103127.9
ZONE 4626	**Y**: 1185804.0	**Y**: 1190321.0	**Y**: 280037.5	**Y**: 275636.0

Comments: An empty coverage was created with the CREATE command, {tic_bnd_cover}=YMMAPTIC. Data coordinates provided in DD and placed in file \YUCCA\DATFILES\YMALLGN1.CSV, then projected to SCP using PROJECT, {sml_file}=DDSPC.SML, and placed in file \YUCCA\DATFILES\YMALLPR1.SPC. This file then used to GENERATE points into the coverage.

Digitizing Parameters: **ED**: NA **SD**: NA **WE**: NA **GRAI**: NA **SNAPT**: NA
Projection Parameters: \YUCCA\SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	ACTION
25JUL	BD4 BUILD for POINT
25JUL	AT5 JOINITEM to attach .DBF file from spreadsheet.
05OCT	COVERAGE transferred to NGMGwith EXPORT command to attribute with elevations, returned as YMTMAX90

DATE	ACTION

Coverage Name: YMPOT
Coverage Dir: \WATER\POTEN\
Location: Yucca Mountain area
Description: Potentiometric surface

SOURCE

Data Source: EG&G Energy Measurements Coverage POTEND
Series: USGS OFR 84-4267
Material:
Scale: 1:500,000
Projection:
Publication Date: 1984
Comments: Coverage obtained from EG&G in ARC/INFO EXPORT format. IMPORTed to PC ARC/INFO with a long/lat projection, YMPOTIM1.

DIGITIZING INFO

Initial Date: N/A
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision:

Tics:	**LONG:** 118.0000	**LONG:** 114.7500	**LONG:** 118.000	**LONG:** 115.0000
	LAT: 37.500	**LAT:** 37.5000	**LAT:** 36.0000	**LAT:** 36.0000
SPC	**X:** 113207.8000	**X:** 1056028.0000	**X:** 105602.9000	**X:** 993004.1000
ZONE 4626	**Y:** 1003741.0000	**Y:** 1006664.0000	**Y:** 457640.3000	**Y:** 459158.0000

Comments:

Digitizing Parameters: **ED:** **SD:** **WE:** **GRAI:** **SNAPT:**

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
28SEP	PR2	PROJECT to spc
09OCT	BD4	BUILD
09OCT	AT5	ATTRIBUTE
19OCT	RB6	REBOX to reduce extent

DATE	FILE	ACTION

Coverage Name: YMSBF
Coverage Dir: \GEOLOGY\SBFAULTS\
Location: Yucca Mountain CCA
Description: Large-scale fault mapping

SOURCE

Data Source: EG&G Energy Measurements Coverage SBFAULTD, from Scott and Bonk (1984)
Series: USGS OFR 84-494
Material:
Scale: 1:12,000
Projection:
Publication Date: 1984
Comments: Coverage obtained from EG&G in ARC/INFO EXPORT format. IMPORTed to PC ARC/INFO with a long/lat projection, YMSBFIM1.

DIGITIZING INFO

Initial Date: N/A
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision:

Tics:	**LONG:** 116.5000	**LONG:** 116.4167	**LONG:** 116.5000	**LONG:** 116.4167
	LAT: 36.9167	**LAT:** 36.9167	**LAT:** 36.7917	**LAT:** 36.7917
SPC	**X:** 548721.5000	**X:** 573071.8000	**X:** 548800.9000	**X:** 573190.9000
ZONE 4626	**Y:** 788672.7000	**Y:** 788725.9000	**Y:** 743167.0000	**Y:** 743220.1000

Comments:

Digitizing Parameters: **ED:** **SD:** **WE:** **GRAI:** **SNAPT:**

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
	PR2	PROJECT to spc
	ED3	EDIT to remove extraneous arcs such as strike and dip symbols, etc. Also remove undesired fault types based on EG&G "CODE" attribute. Retain Fault (CODE:10), Concealed Fault (30), Concealed Fault (35), and Fault Scarp (50). Number of arcs reduced from 5,642 to 1,663.
	BD4	BUILD
	CP5	CLIP to eliminate extraneous TICs.

DATE	FILE	ACTION

Coverage Name: YMSGE
Coverage Dir: \YUCCA\GEOLOGY\YMSGE
Location: Yucca Mountain area, ~ 100mi x 100mi
Description:

SOURCE

Data Source: EG&G coverage GEOLSDD, scanned from USGS/NBMG State Geological Map. YMSGE copied from NVSGEBD4.
Series:
Material: Folded Paper Map
Scale: 1:500,000
Projection: GEOG
Publication Date: 1978
Comments: Scanned coverage includes faults and cultural linear features. Arcs were added by EG&G personnel to reduce the size of polygons for import from A/I to pc A/I.

DIGITIZING INFO

Initial Date: not digitized
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POLY, LINE
Precision:

Tics:	**LONG:** 117.356	**LONG:** 115.633	**LONG:** 115.651	**LONG:** 117.344
	LAT: 37.495	**LAT:** 37.493	**LAT:** 36.120	**LAT:** 36.122
SPC	**1 X:** 300000.0000	**2 X:** 800000.0000	**3 X:** 800000.0000	**4 X:** 300000.0000
ZONE 4626	**Y:** 1000000.0000	**Y:** 1000000.0000	**Y:** 500000.0000	**Y:** 500000.0000

Comments:

Editing Parameters: **ED:** 50 **SD:** 25 **WE:** **GRAI:** **SNAPT:** CLOSEST
Projection Parameters: N/A

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
31AUG	ED1	COPYCOV from NVSGEBD4, manually EDIT to YM50MBD4 study area, close polygons.
31AUG	CN2	CLEAN
31AUG	CP3	CLIP with YMCLIP50
31AUG	ED4	LABEL unlabeled polygons
31AUG	BD5	BUILD
31AUG	DS6	DISSOLVE to remove faults and other unwanted arcs, combine like polygons.
31AUG	AT7	ATTRIBUTE with ERA item (PC,PZ, etc.)
31AUG	BD8	BUILD

DATE	FILE	ACTION

Coverage Name: YMTRV
Coverage Dir: \WATER\TRAVER\
Location: Yucca Mountain area
Description: Location of areas with travertine spring deposits

SOURCE

Data Source: Larry Garside, NBMG, locations identified for this report.
Series:
Material: Digital coordinates (spreadsheet)
Scale:
Projection:
Publication Date:
Comments:

DIGITIZING INFO

Initial Date: 06NOV95
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology: POINT
Precision:

Tics:	**LONG:** 116.0990	**LONG:** 116.8989	**LONG:** 116.0990	**LONG:** 116.8989
	LAT: 35.5587	**LAT:** 35.5587	**LAT:** 36.8447	**LAT:** 36.8447
SPC	**1 X:** 668841.4000	**2 X:** 430926.3000	**3 X:** 666102.1000	**4 X:** 432046.9000
ZONE 4626	**Y:** 294805.4000	**Y:** 294400.4000	**Y:** 762922.4000	**Y:** 762511.6000

Comments: Coverage was generated from lat/long coordinates in data file TRAVER.XLS.

Digitizing Parameters: **ED:** .03 **SD:** .03 **WE:** .03 **GRAI:** .05 **SNAPT:** CLOSEST

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
06NOV	BD2	BUILD
06NOV	PR3	PROJECT from lat/long to spc

DATE	FILE	ACTION

Coverage Name: YMVOL
Coverage Dir: \GEOLOGY\VOLCNTR\
Location: Yucca Mountain area
Description: Miocene - Quaternary volcanic centers

SOURCE

Data Source: EG&G Energy Measurements Coverage VOLCTR, Scherschel and Bowker, 1992
Series: LANL EES-13-LV-07-92-13
Material:
Scale: 1:950,400
Projection:
Publication Date: 1992
Comments: Coverage obtained from EG&G in ARC/INFO EXPORT format. IMPORTed to PC ARC/INFO with a long/lat projection, YMVOLIM1.

DIGITIZING INFO

Initial Date: N/A
Checked By:
GIS Sytem: PC A/I 3.4.1
Topology:
Precision:

Tics:	**LONG:** -115.8383	**LONG:** -115.8310	**LONG:** -117.0410	**LONG:** -117.0443
	LAT: 36.6872	**LAT:** 37.3606	**LAT:** 36.6895	**LAT:** 37.3630
SPC	**1 X:** 742880.5000	**2 X:** 742867.9000	**3 X:** 390247.6000	**4 X:** 390254.4000
ZONE 4626	**Y:** 706149.6000	**Y:** 951340.6000	**Y:** 706148.1000	**Y:** 951340.8000

Comments:

Digitizing Parameters: **ED:** **SD:** **WE:** **GRAI:** **SNAPT:**

Projection Parameters: \SML-OP\DDSPC.SML

INPUT
PROJ GEOG
UNITS DD
QUADRANT NW
PARAM

OUTPUT
PROJECTION STATEPLANE
UNITS FEET
ZONE 4626
PARAMETERS
END

SUBSEQUENT MANIPULATIONS

DATE	FILE	ACTION
	PR2	PROJECT to spc
	BD4	BUILD

DATE	FILE	ACTION

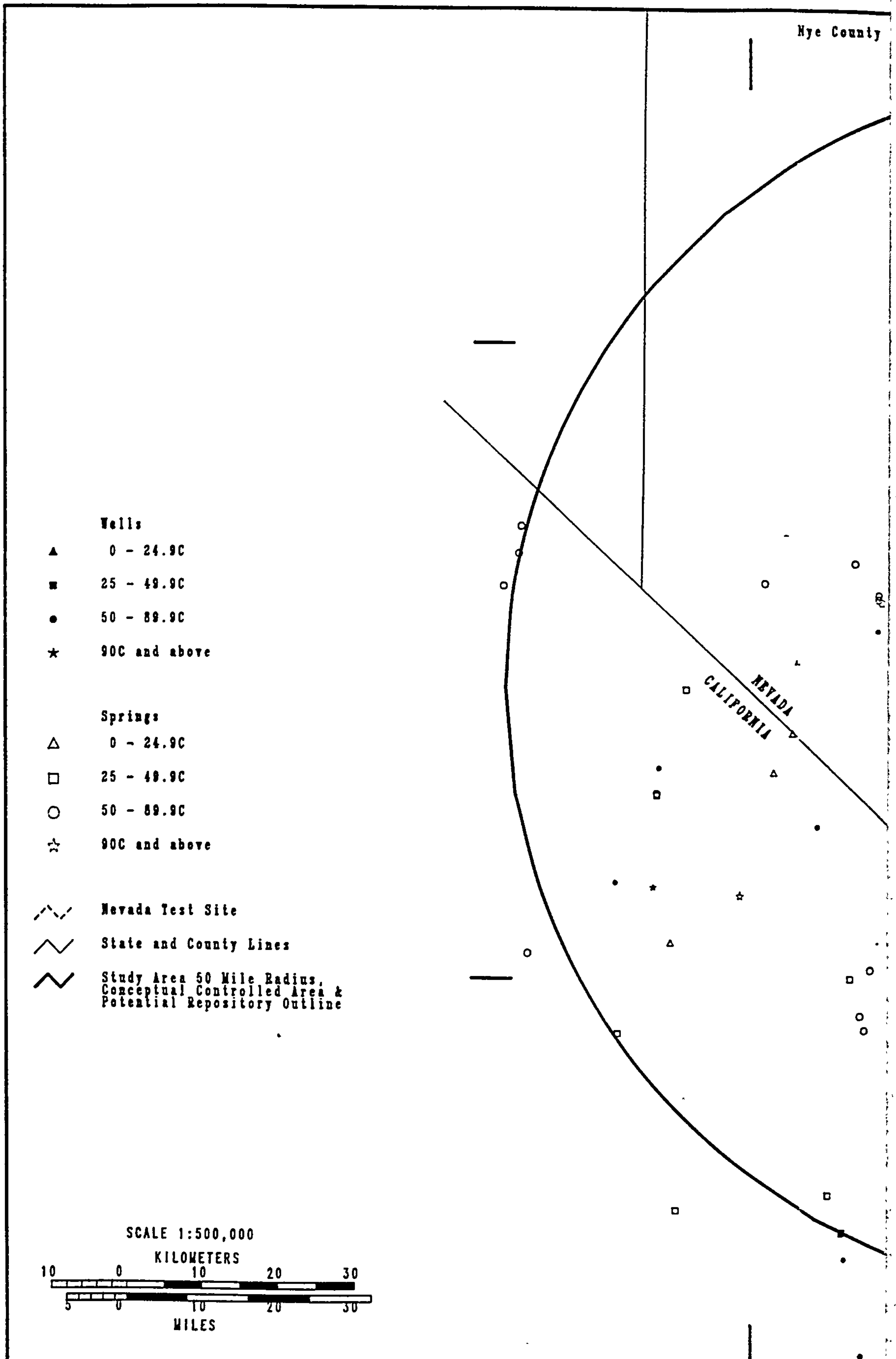
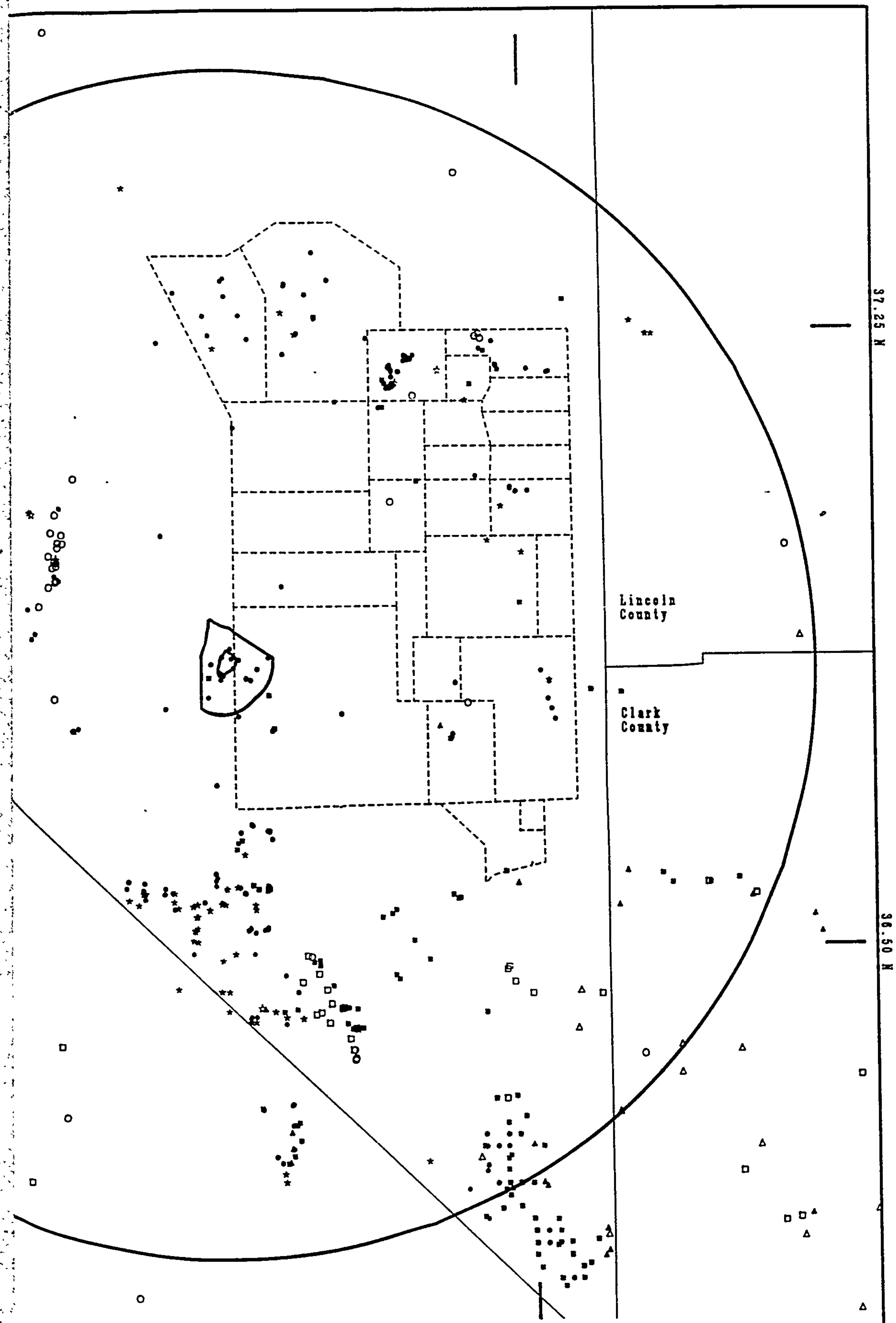


Plate 2: Well and spring chalcedony geothermometer temperatures (C



) and locations, Yucca Mountain and vicinity.

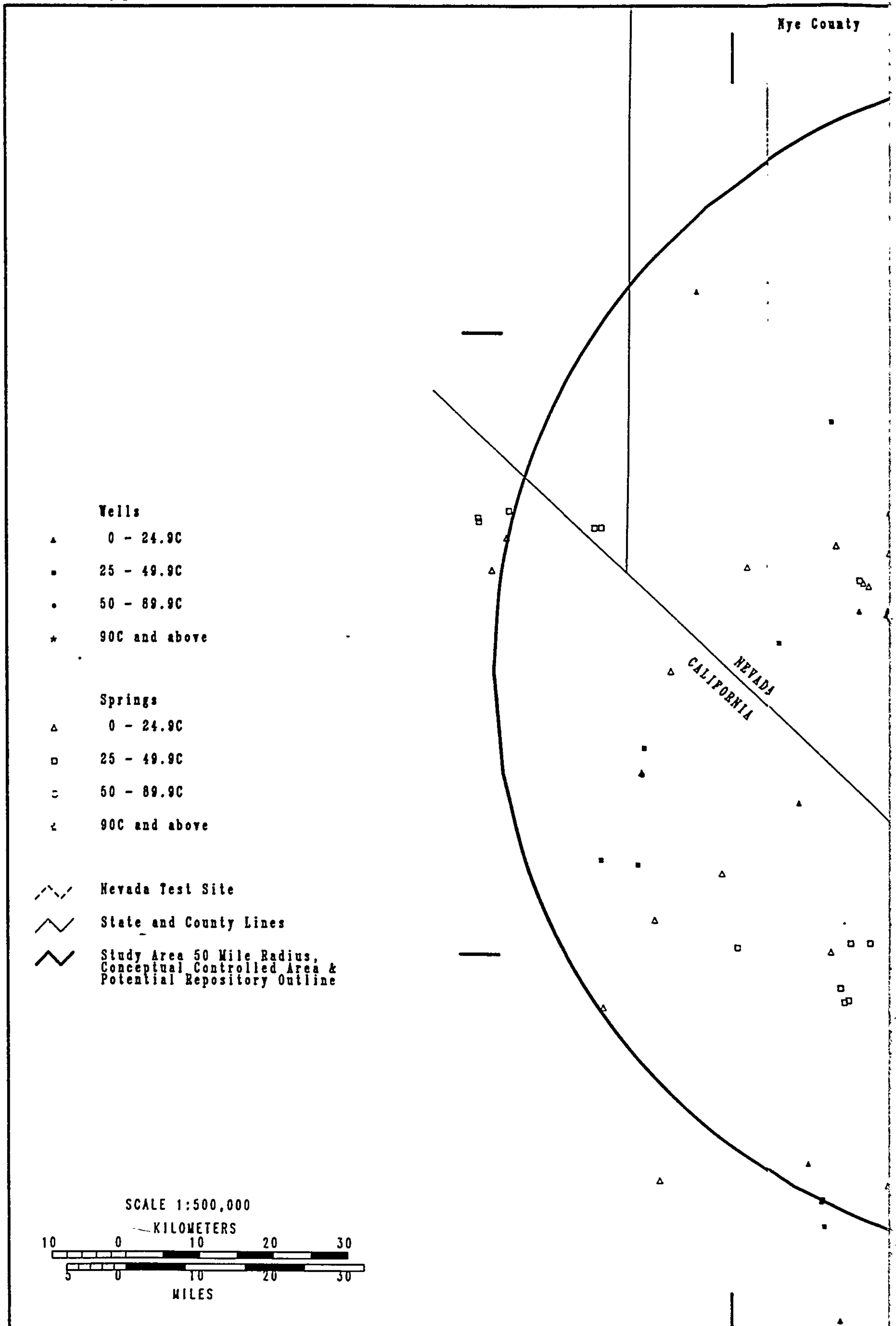
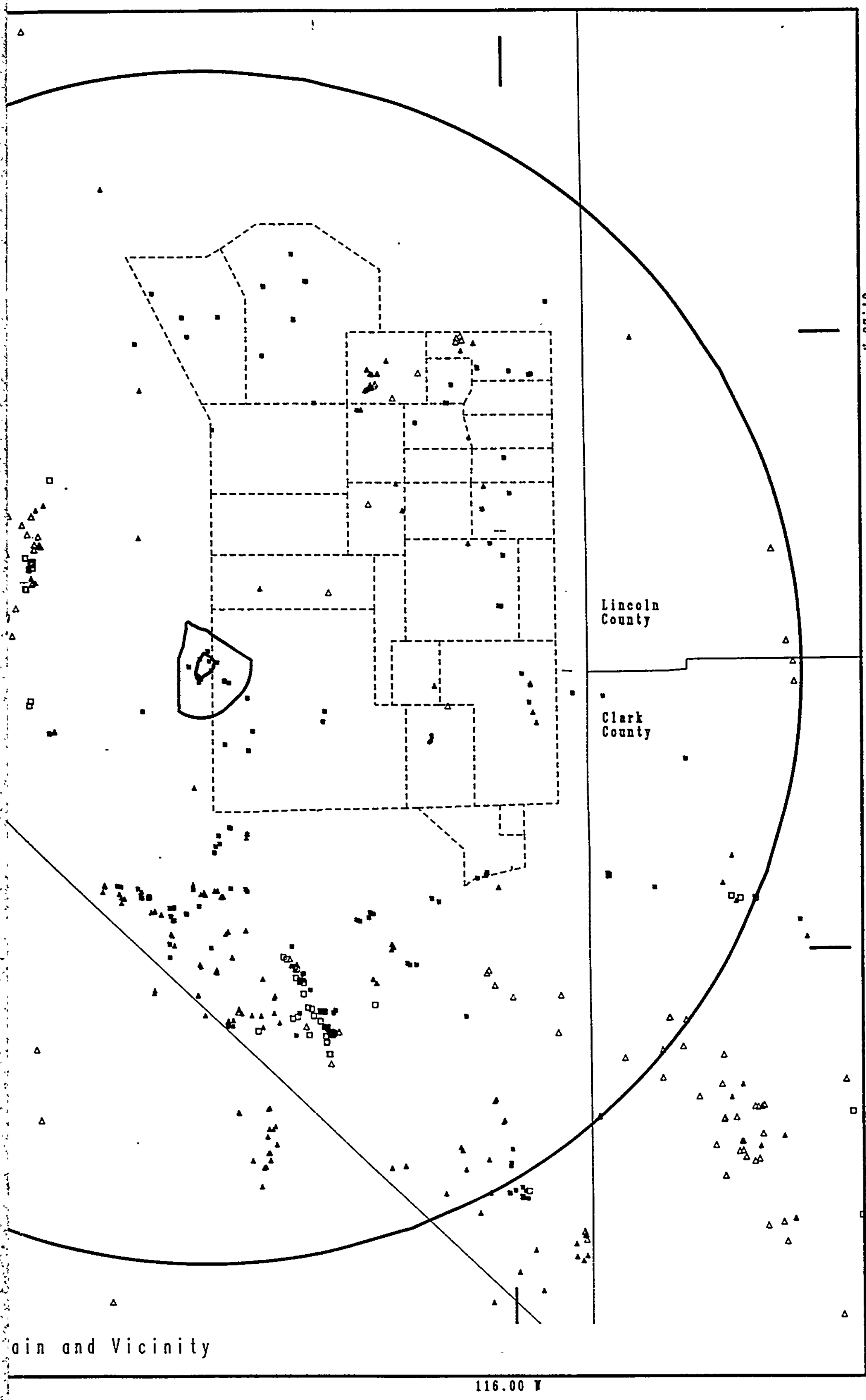


PLATE 1: Well and Spring Temperatures (C) and Locations, Yucca Mount

117.00 W


Lincoln County
Clark County
37.25 N
36.50 N
116.00 W
ain and Vicinity