

HYDROGEOLOGIC AND HYDROGEOCHEMICAL ASSESSMENT OF GEOTHERMAL  
FLUIDS IN THE PYRAMID LAKE AREA, WASHOE COUNTRY, NEVADA

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ABSTRACT

This paper evaluates the hydrogeological and hydrogeochemical characteristics of the geothermal fluids in the Pyramid Lake area using data from existing published and unpublished reports on springs, shallow and deep wells in the area. Four geochemical provinces, namely, chloride, bicarbonate, sulfate and mixed chloride-bicarbonate have been identified. Chloride waters are found in known geothermal areas. Two subsurface water recharge zones which feed the shallow and deep geothermal systems are proposed. These are the Virginia Mountains and their Northern extension and the Fox and Lake Ranges. Tertiary and Quaternary faulting systems in these mountains and Ranges act as heat conduits for geothermal fluids. The Needle Rocks geothermal system is postulated to be deeper than the San Emidio system. A connection between the Needle Rocks system and the Pyramid and Anaho islands warm springs is not clear from this study because of lack of chemical data from these islands. More systematic measurements of static water levels, temperatures, well lithology, water chemistry and isotopes data are recommended to enable better understanding of the geothermal systems in the area.

INTRODUCTION

This study was carried out in summer 1991 as part of graduate study in regional groundwater flow system in the Pyramid Lake area. The area, north of Reno, Nevada was selected because of its naturally occurring hot springs, drilled geothermal areas at Empire/San Emidio and the Needle Rocks area and

because of continued interest by the local community and private investors to develop geothermal power stations in the area. The study included a review of the existing literature on Geothermal and groundwater flow systems of the area with special emphasis on the hydrogeochemistry of the waters, temperatures and study of hydrogeological parameters of the wells and interpretations of the data to develop a conceptual model. No computer modelling was done due to limited available time. Drs. W. Berry Lyons and E. (Britt) Jacobson acted as advisors to the author during the study.

PREVIOUS WORK

The majority of the literature on this area is on the paleoclimatology and geomorphology of the Quaternary Lake Lahontan. Reports by Glancy and Rush (1968) and by Van Denburgh, Lamke and Hughes (1973) cover surface and shallow groundwater resources of the northern and southern parts of the study area. Previous work on geothermal occurrences in the area is covered under the Northern Basin and Range Province reports by several researchers. Garside (1974) and Olmstead, et. al. (1975) have written on the hydrothermal systems in Nevada with some examples from the study area.

Garside and Schilling (1979) provide comprehensive data and map on thermal waters in Nevada which was updated by Purkey in 1990. Trexler, Flynn, Koenig and Ghush, Jr. (1983) updated their earlier map on Geothermal Resources of Nevada showing locations of the thermal areas. Trexler, 1990 (unpublished report) gives chemistry of the San Emidio geothermal area and has also worked on the detailed geology and faulting system of the same area (pers. comm.).

The geology of the area is well covered by Bonham, (1969).

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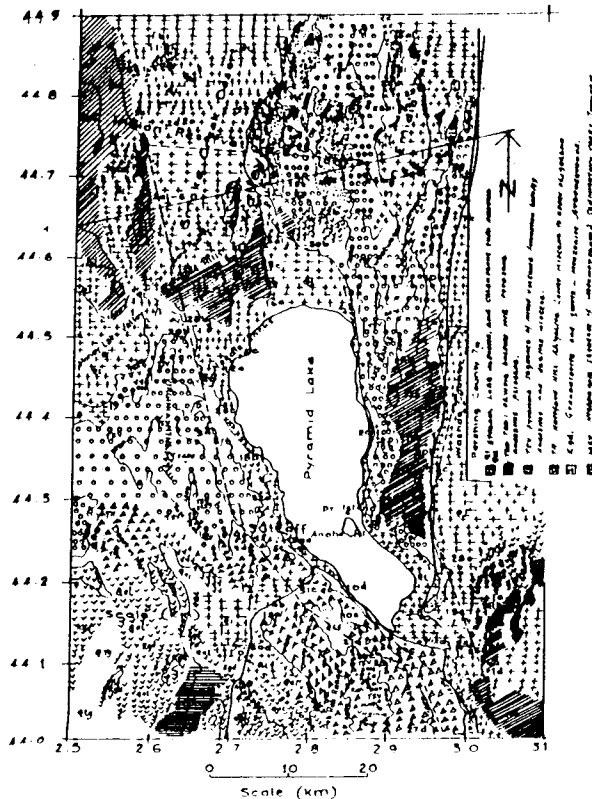


Fig.1 Generalized geology of the Pyramid Lake area.

### GEOLOGICAL SETTING

Figure 1 shows the generalized geology of the study area adapted from Bonham, (1969). The oldest rocks are the basement Jurassic meta-sedimentary Nightingale Sequence (Msr) found in Fox Range and Northern Lake Range at elevations about 1200 meters above Pyramid Lake. Medium to coarse-grained granodiorite and quartz monzonite plutonic rocks of Cretaceous age intrude the Nightingale Sequence and also occur to the extreme southwestern part of the study area.

The oldest of the Tertiary formations are the Oligocene/Miocene Hartford Hill Rhyolite (Th) to the southwest of Pyramid Lake. Miocene basalt, andesite and dacite flows called the Pyramid Lake sequence are found on the Virginia Mountains to the west and in the Lake Range to the east extending northwards to Fox Range. During the Pliocene Epoch extensive basalt flows associated with intrusive dikes derived from fissures occurred in the Terraced hills, Black Mountain, and Red Rock Hills northwest of Pyramid Lake (Tba).

On the eastern slopes of the Lake Range, these basalts are found in association with pyroxene andesites (Tab).

The Smoke Creek Desert, San Emidio Desert, Honey Lake Valley, Truckee Valley, the area between Terrace hills and Pyramid Lake, and around the shores of the lake are largely covered by Pleistocene lake deposits (Q1) of silt, clay gravels and calcareous tuffa. Stream valleys and some hill slopes are covered by young recent stream and eolian deposits (Qal) (Bonham, 1969). Most of the wells drilled in the area discharge water from these two Quaternary aquifer formations.

### HYDROGEOLOGIC CONDITIONS

Hydrogeological data from 61 shallow and deep wells in the area were examined. Most of the wells (50) are less than 100 meters deep and about 67% of them have some record of static water levels.

A mean specific capacity of 3.8 lps/m was calculated from twelve wells around San Emidio Desert and the town of Nixon. These wells produce water from recent lake and stream deposits. Lack of proper data for computation of aquifer parameters such as hydraulic conductivity, transmissivity and storativity greatly limited more meaningful model conceptualization.

A composite piezometric surfaces map from available water levels data mainly from the drillers' reports was constructed (Fig 2).

Two possible recharge areas occur to the southwest along the Virginia Mountains, and to the north in the Fox Range area.

The contours indicate subsurface flows towards the Pyramid Lake from the two recharge zones and towards the San Emidio/Empire geothermal areas.

Static water levels around Nixon town show haphazard spatial variations which made it difficult to draw potentiometric contours. The static water levels seem to parallel the NE-SW Nightingale Mountains faulting system to the southeast of the study area. More water level measurements are required to facilitate the interpretation of ground water behaviour in the area.

Data on the well lithology and aquifer formation is limited. Glancy, et. al (1967) and Van Denburgh, et. al. (1973)

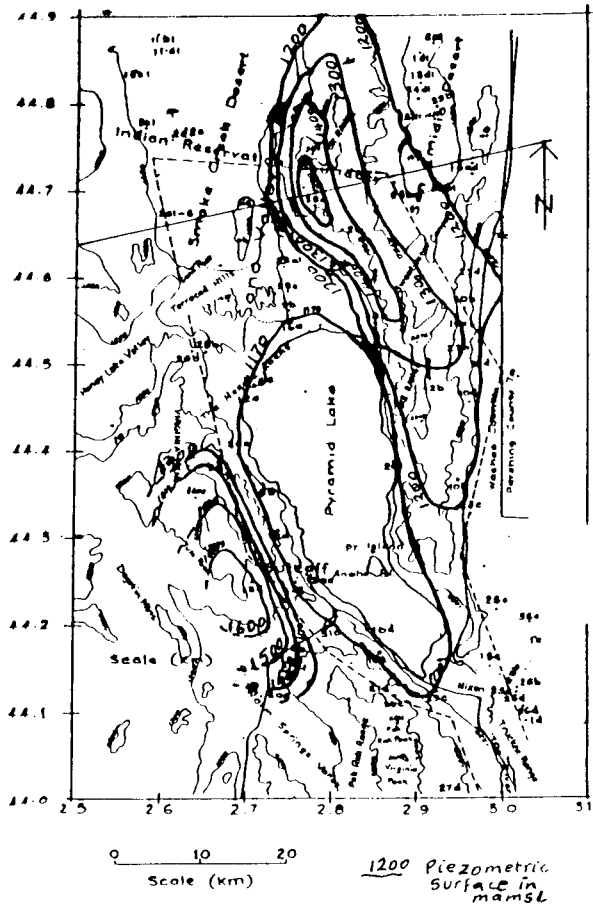


Fig.2 Composit piezometric surfaces map of the Pyramid Lake.

recognized three major aquifers in the area. These are:

- (1) Younger alluvium made of unconsolidated sedimentary deposits with variable permeability found around lake shores and valleys.
- (2) Older alluvium made of unconsolidated and semi-consolidated sedimentary deposits of high to low permeability found mainly on flat plains and valleys. The majority of the wells are located in this aquifer type.
- (3) Consolidated rocks largely having little or no interstitial permeability. These are mainly intrusive igneous and metamorphic rocks. Less wells are located in this formation than in the older alluvium formation.

## GEOCHEMICAL CHARACTERISTICS OF THE FLUIDS

### Chemical Provinces

The chemical composition of waters from 30 shallow groundwater and deep geothermal wells and from warm and cold springs was evaluated and  $\text{HCO}_3 + \text{CO}_3 - \text{Cl} - \text{SO}_4$  and  $\text{Ca} - \text{Na} + \text{K} - \text{Mg}$  trilinear diagrams drawn to examine the possibility of classifying the fluids. Most of the spring fluids and all those from wells plotted above 50% of  $\text{Na} + \text{K}$  rendering no good classification from the cation plot. The anion plot gives four possible fluid chemical provinces as shown in Figure 3.

- (a) Chloride-rich waters mostly from hot wells and springs and Pyramid Lake.
- (b) Bicarbonate rich waters mostly from springs and some cold wells.
- (c) Mixed waters, from wells and one spring.
- (d) Sulfate-rich waters, from one well, spring and Truckee River.

General geographical distribution of the above water provinces are shown in Figure 4. Bicarbonate waters are the least mineralized using the specific conductance,  $\text{Na} + \text{K}$  and  $\text{Ca} + \text{Mg}$  concentrations as a measure. All the waters have pH between 7 and 10 with the mean at 7.8.

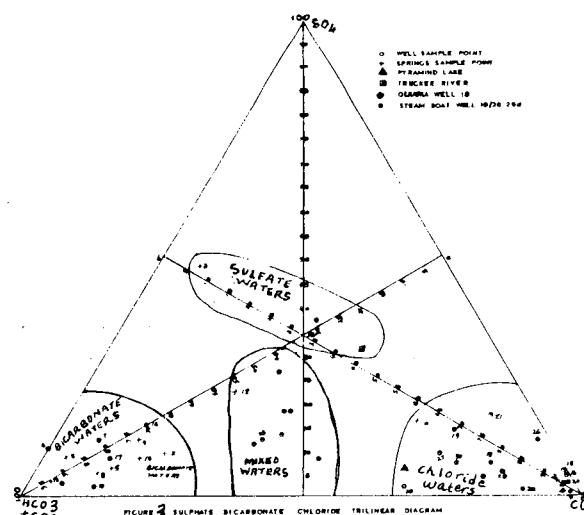


Fig.3 Sulphate bicarbonate chloride trilinear diagram

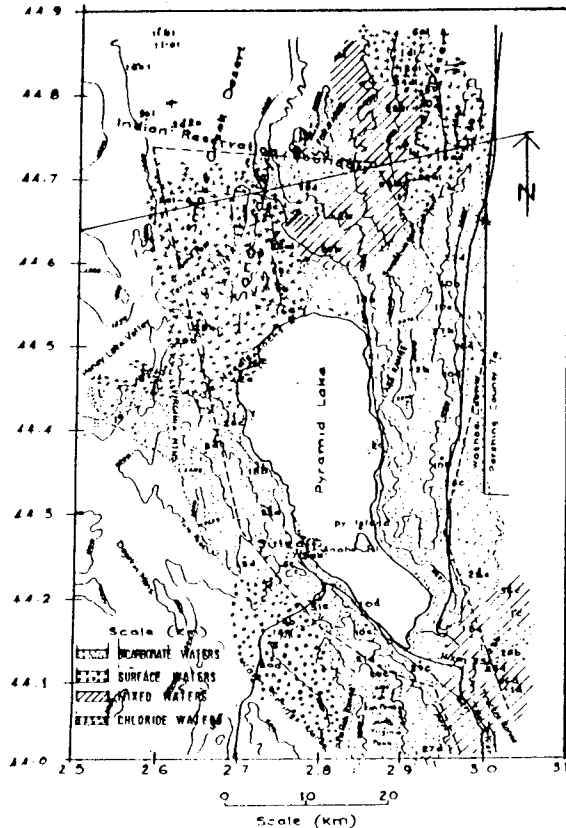


Fig.4 Geochemical classification of the Pyramid Lake areas subsurface waters

Chemical Geothermometers

A large number of water chemistry analyses obtained from the area give no SiO<sub>2</sub> concentrations. Most of the early analyses do not separate Na and K concentrations. This is a major drawback in attempting to compute chemical geothermometers where concentrations of Na, K, Ca, Mg and SiO<sub>2</sub> are required.

However, there is correlation between high aquifer temperatures with chloride-rich fluids especially around San Emidio.

The three geothermal wells of the Needle Rocks have measured downhole temperatures although they had not equilibrated and are all below the indicated average subsurface geochemical temperatures of 140 C even from the deepest well #1 which is 1807 meters deep. In the San Emidio area, the maximum down-hole temperature measured at 590 meters is 148 C in the Philips Petroleum Co. Well # 29/13-16ad giving a temperature gradient of over 200 C per km. If this temperature is

extrapolated downward, the indicated 190 C geochemical reservoir temperature would be reached around 750 meters.

The subsurface temperatures as indicated by geochemical geothermometry show that the two known geothermal areas in the study area, namely, the Needle Rocks and San Emidio have moderate reservoir temperatures sufficient for binary system power generation. Furthermore, it can be inferred that the Needle Rocks system has lower temperatures and deeper reservoir than the San Emidio one. Wells may have to be drilled deeper than 1500 meters at the Needle Rocks while at San Emidio, the deeper reservoir should be within 750 meters depth. Geochemical temperatures from wells 24d1 and 25d1 north of San Emidio show a northward drop in temperatures indicating possible northward flow of water and cooling of geothermal fluids.

Stable Isotopes Data

Five isotope data was available from the areas shown hereunder:-

Name	d 0	dD
Needle Rocks Well #1	-6.33	-106.5
M.K. Steward Prod. Well #1. 21(1)	-11.99	-107.4
Ditto, Irrig. Well	-14.86	-115.5
San Emidio Hot Springs (29/23-9/16)	-11.73	-106.6
San Emidio	-14.24	-110.2

Flynn and Buchanan (1990) found that the best fit meteoric line for the Great Basin is:

$$dD = 7.55d_0 - 0.5$$

which they took to be the same as the global meteoric water line for practical purposes.

The five data points were plotted on the meteoric water line graph (Fig. 5). They all show oxygen-18 shift. The hot Needle Rocks geysering well has the largest shift (+8%) while the San Emidio geothermal well and hot spring have a + 2% oxygen-18 shift. The San Emidio cold springs and irrigation well show negligible shift. The higher oxygen-18 concentrations at the Needle Rocks corroborate the earlier stated

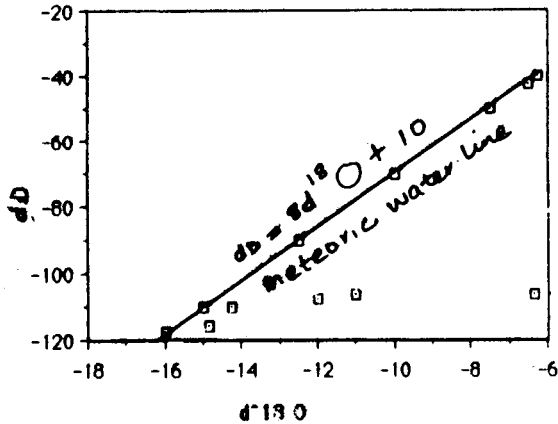


Fig.5 Deuterium vs. oxygen-18 isotope diagram

fact that it is deeper seated and most likely undergone more water-rock reactions and longer residence time than the San Emidio system. With such limited data, it may not be prudent to draw many conclusions. More isotope data are required to be able to relate the isotope values to the recharge and hydrothermal reactions of the fluids in this area. Furthermore, there are no data at all on isotopes in the study area south of the Needle Rocks to enable overall interpretation of isotope variations in the area.

MIXING MODEL

Figures 3 and 4 show the four water provinces in the study area. Mixed waters are found to the North and South Eastern. The mixed waters in the Nixon town area may be derived from mixing of bicarbonate and deeper waters or due to evolution of bicarbonate waters via evaporation and water-rock reactions.

The mixed water north of San Emidio may be due to mixing between hot chloride richer waters with bicarbonate regional waters. Trexler (1990) has proposed 3:1 mixing between shallow waters and geothermal waters using TDS concentrations. Very few TDS data are available from the area and it is difficult to extend this conclusion further, but does not appear a plausible mixing model.

The Pyramid Lake has a specific conductance of 8400 micro-mhos/cm. Mixing 70% of the lake water with 30% of the shallow groundwater yields fluids of similar conductance as that of the Needle Rocks geothermal fluids. This may be the likely source of the fluids until more data is available.

CONCEPTUAL MODEL

Figure 6 shows the proposed hydrothermal conceptual model for the San Emidio and Needle Rocks geothermal systems. The cross section line is shown on Figures 2 and 4.

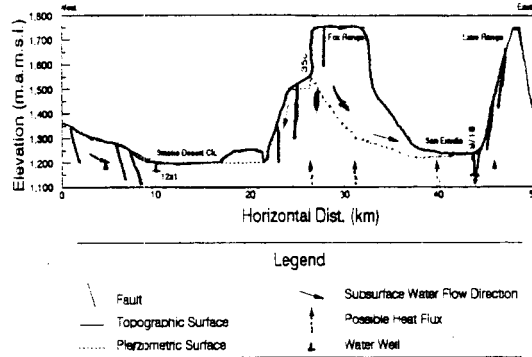


Fig.6 Proposed conceptual flow model of the Smoke Creek/San Emidio area

The study area lies within the transitional zone between the Basin and Range Provinces and the Sierra Nevada where regional structural control is by the Walker Lane faulting system. The youngest volcanic activity recorded from rocks in the area is at least 2 million years (Bonham, 1969).

This was mainly intrusive dike basalt flows derived from fissures and some andesites (Bonham, 1969). Any heat generated by this activity may not be waning away. Faulting activity has, however, continued into the Pleistocene and perhaps Holocene (Bonham, 1969). Regional high heat flow in the Basin and Range Province combined with these locally intense activities may cause the heat anomaly in the area. Most of the faulting is in Virginia Mountains and their northern extension, Terraced Hills, Fox Range and Lake Range (Bonham, 1969) and most likely act as conduits for deep, hot geothermal fluids.

The piezometric surface map (Fig. 2) shows two possible recharge zones in the Fox Range to the northeast and the Virginia Mountains and their northward extension on the west. The general subsurface water flow is from the western divide eastward towards Pyramid Lake and Smoke Creek Desert. Flows from the Fox Range are westward into the Smoke Creek Desert and east and north-eastward towards San Emidio. A westerly flow component from Northern Lake Range into San Emidio is also possible but data to support this may need to be collected further east of the study area.

It is postulated that the Needle Rocks geothermal area could be obtaining its recharge water from the northwestern mountains, Sano Valley and downward percolating water from Pyramid Lake. San Emidio geothermal fluids flow northwards from the geothermometry evidence. This is supported by the general groundwater flow from Fox Range towards San Emidio (Figure 2) assuming that the deep geothermal fluids rise through faults and laterally mix with shallow waters flowing in the same direction.

The heat source from the Needle Rocks and San Emidio Desert geothermal areas may be associated with the Walker Lane faulting system and the regional high heat flow, but localized to higher gradients in these areas. Strong fault system to the northwest and intercrossing of NW-SW, N-S and NW-SE faulting systems over Sand Pass and Terraced Hills may have caused localized high heat gradients and increased hydrothermal reactions resulting in hot chloride fluids seen in the northwest. Similarly, faulting in the Fox and Northern Lake Range is proposed as forming the flow paths for the hot fluids and the development of chloride fluids in the San Emidio area.

The NW-SE trending faults from Terraced Hills most likely continue under Pyramid Lake to Pyramid and Anaho Islands causing the warm springs reported on these islands.

#### DISCUSSION AND CONCLUSIONS

Hydrogeochemistry shows four chemical water provinces with the chloride waters associated with waters of the Needle Rocks and San Emidio geothermal systems. Statistical correlation of the ionic concentrations against conservative chloride ion is poor maybe due to poor sampling and analysis or both. The high oxygen-18 shift at the Needle Rocks may be due to evaporation and longer residence time of the fluids in this area. More evenly distributed isotope data from the area are necessary before detailed interpretation can be made.

Figure 6 gives the preliminary conceptual model of the geothermal systems in the area. More temperature measurements and chemical data plus a closer look at the local tectonic setting of the geothermal systems are necessary to further develop this model. The heat sources may be either below the Ranges themselves or more shifted and localized below or near the two known hot fluid areas at San Emidio and Needle Rocks.

Elaborate modelling was not done due to time limitations and quality of the available data. This work should hopefully encourage more detailed work on these interesting geothermal systems and the flow model of the groundwater by other researchers.

Geochemical geothermometry interpretation is also limited by the availability and distribution of the data.

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