Geothermal Resources Council, TRANSACTIONS, Vol. 13, October 1989

RECHARGE OF GEOTHERMAL FLUIDS IN THE GREAT BASIN

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ABSTRACT

In August 1988, the Division of Earth Sciences, University of Nevada Las Vegas, began an investigation of geothermal fluid genesis in the Great Basin, Western United States. Currently, there are two theories that attempt to explain the nature and occurrence of geothermal fluids. Both theories rely on interpretation of stable light-isotope ratios of geothermal fluids and meteoric waters. The school of "contemporary recharge" argues that precipitation from elevations in excess of 2,500 meters have stable light-isotope ratios that are identical to those of geothermal springs and wells. This group concludes that geothermal resources are recharged by modern, high elevation precipitation.

An alternative theory is proposed by the school of "paleo-fluid recharge". This theory is based, in part, on pioneering paleo-climate studies by Dansgaard et. al. (1969) who, using continuous core from the Greenland Ice Sheet, identified a transition from modern, isotopically enriched meteoric water to paleo-, isotopically depleted water between 12,000 and 8,000 years BP.

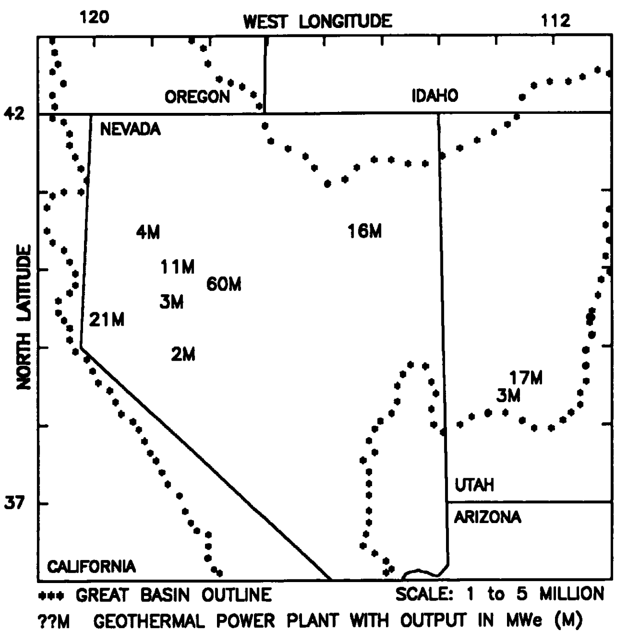
The purpose of this paper is to describe the elements of an investigation that is designed to assess the geologic and temporal framework required to support the hypothesis of paleo-fluid recharge of geothermal fluids. The investigation relies on interpretation of chemical and isotopic data from geothermal fluids, meteoric waters, and paleoclimate proxies such as glacial ice core and packrat midden studies. Interpretations are based on regional and systematic variations of stable light-isotopes within the Great Basin.

INTRODUCTION

The geothermal energy-producing potential of the Great Basin, Western United States, was long overlooked. White (1965) saw potential for development at only three sites in Nevada. The potential has today been upgraded dramatically. In 1979, high temperature (>150°C) hydrothermal systems were identified as having a potential to generate 3,000 MWe (megawatts of electricity) for 30 years, while moderate temperature (90°C to 150°C) heat content was estimated at 2.08 x 10^{18} Joules (Muffler, 1979). In addition, low temperature (<90°C) systems were estimated to hold a potential for 2,400 MWt (megawatts thermal energy) of beneficial heat for a period of thirty years (Reed, 1983) .

Geothermal resources within the Great Basin currently supply about 150 MWe of electric power (Figure 1) and have vast potential for further development. Lack of understanding of the source, rate

FIGURE 1: GENERAL LOCATION MAP FOR THE GREAT BASIN, WESTERN UNITED STATES SHOWING LOCATION OF GEOTHERMAL POWER PLANTS



and path of geothermal fluid recharge remains a risk to geothermal development and raises legal and institutional questions on development of geothermal (mineral) rights and water rights. The purpose of this research is to develop a conceptual, working and plausible model for paleo-recharge of geothermal systems and, eventually, to apply this information to the existing laws on water and mineral resource development in the State of Nevada.

The research program incorporates the Great Basin, emphasizing Nevada. Regional and systematic variations in stable light-isotopes of geothermal, nonthermal, and paleoclimate proxies are used to identify potential recharge area and mechanisms.

DATA COLLECTION

Data collection consisted of a compilation and assessment of existing data, and a fluid sampling program designed to fill data voids and incorporate data from newly completed geothermal wells.

Existing Data

An initial base of stable light-isotope data from the Great Basin was assembled through an extensive literature search. A computer search of GEOREF, CHEM ABSTRACTS AND POLLUTION ABSTRACTS used the following combination of key words: "Nevada" or "Utah" or "Great Basin" and "stable light-isotopes" or "deuterium" or "tritium" or "oxygen-18" and "geothermal" or "water". This data base was augmented by searching the publication lists of the Utah Geological and Mineral Survey, Nevada Bureau of Mines and Geology, Desert Research Institute (Reno, Nevada), California Division of Oil and Gas and the thesis collection of the University of Nevada Reno. To date, 40 references have been used to create a 1000+ point data base of stable light-isotope and geochemical values for thermal and non-thermal springs and wells from throughout the Great Basin. Unfortunately, some of the points are of limited use due to lack of supporting data such as sample temperature, collection date, or precise location.

Fluid Sampling Program

The focus of the fluid sampling program for this study was three-fold.

1) Fill voids in the assembled data base. Where a void was present, the hottest water available was sampled.

2) Duplicate samples for time-variant analysis. Hot springs with an extensive history of investigation were chosen for resampling.

3) Deep geothermal production wells through the industry-cooperative program. Deep geothermal fluids will be compared to nearby hot springs.

Distribution of the samples analysis budget was 16 for tritium, 48 each for bulk chemical, deuterium and oxygen-18, and 10 for *d*14C/*d*13C age dating. The bulk of these analyses has not yet been received and hence is not considered in this report.

PALEOCLIMATE WORK AND HISTORICAL RECHARGE SCHEMES

Initial hypotheses concerning geothermal recharge in the Great Basin were based on the similarity between the stable light-isotope content of geothermal fluids and the modern stable lightisotope content of range-top precipitation. The findings supported the contention of recharge by modern precipitation through immediate infiltration at elevations in excess of 2,500 meters. The questions of infiltration mechanism and the unrealistically high fluid flow rates required (meters to tens of meters per day) that are necessary to circulate fluids to a depth of six to seven kilometers (Lachenbruch and Sass, 1977) were never adequately addressed (Welch, 1981).

In an unrelated study, Dansgaard (1969) analyzed Greenland ice cores and showed a major enrichment occurred in stable light-isotopes of precipitation at the end of the Pleistocene ice ages, approximately 10,000 years BP. The study revealed a depletion in oxygen-18 of 10 to 12$^{o}/_{oo}$ (per mil) and of deuterium by approximately 100$^{o}/_{oo}$ relative to modern values. Dansgaard (1969) also demonstrated that the depletion was a worldwide phenomenon related to the colder, wetter climate. Applying the depletion to precipitation in the Great Basin, the elevation of Pleistocene precipitation with stable light-isotope content similar to that of modern range-top precipitation would have been considerably lower, probably near the basin floors (1,500 to 2,000 meters).

FLUID AGE AND STABLE LIGHT-ISOTOPE RATIOS

Paleo-carbon age dates and stable light-isotope data from three sources, non-thermal fluids, geothermal fluids and packrat middens, are utilized in this study.

Carbon Age Dates

Two types of samples were collected for dating; water and carbonate scale. The water samples were treated with NaOH and SrCl to form a $SrCO_3$ precipitate, which was submitted for analysis. Carbonate scale was collected from geothermal production wells at Dixie Valley and Desert Peak. The scale precipitates at the flash point in the well and must be periodically removed to prevent well closure. Though the scale is a modern feature, it should represent the age of the fluids from which it precipitated. Carbonate scale dates will provide a good cross-check on the $SrCO_3$ precipitate dates.

Plots of radio-carbon age vs. deuterium for sites in northern and southern Nevada (Figure 2A) both indicate a direct correlation between deuterium depletion and age of fluid. The southern Nevada data (Figure 2B) are largely from shallow wells with moderate temperature (~30°C) waters. The three data sets are geographically close and show similar plots. The northern Nevada data (Figure 2C) are from three widely separated basins and demonstrate that thermal fluids (Dixie Valley and some Moana) tend to be much older than non-thermal fluids (Fallon). Moderate temperature fluids (some Moana) are of intermediate age and are likely a product of mixing.

Precipitation and Groundwater

Two principal storm tracks provide contemporary precipitation to the Great Basin. The first storm track has a northern latitude isotope signature, originates in the eastern Pacific, and travels to the region via the Gulf of Alaska. The second storm track is from the South Pacific. It has a tropical origin and isotopic signature and tracks into the region from the southwest.

Stable light-isotope values of precipitation vary systematically on the basis of latitude, distance inland, elevation, temperature and season (Faure, 1986). The multivariate nature of the changes in stable light-isotope concentrations makes meaningful monitoring of precipitation content difficult without a regionally extensive sampling network. However, non-thermal (<20°) shallow groundwater should provide a representative sampling of mean local precipitation, mitigating seasonal and single-storm effects. Mifflin (1968) described an extensive system of interbasin flow in Nevada, mixing waters from different basins and concealing individual basin signatures. This undesired effect can be avoided by sampling only non-thermal springs discharging in the ranges above the basins, prior to mixing. The samples should then represent contemporary local mean meteoric water.

A contoured plot of deuterium content of non-thermal springs in the Great Basin is provided as Figure 3A. The northern Great Basin displays a west to east deuterium depletion reflecting precipitation from the northern storm track, while the southern Great Basin shows a south to north depletion reflecting precipitation from the southern storm track. The northern region is clearly more depleted in deuterium than the southern region owing to the increased depletion of stable light-isotopes with increasing latitude. A plot of deuterium content of thermal (>75°C) springs and wells (Figure 3B) shows a similar depletion pattern.

Subtracting the plot of non-thermal springs from thermal waters (Figure 3C) allows easy comparison of the two populations. Areas where the non-thermal water is more depleted than the thermal water (positive values) are rare and limited to western Nevada. This area appears to coincide with the persistent location of Pleistocene Lake Lahontan, suggesting isotopically enriched lake waters entered the geothermal recharge system. Alternatively, this could be a result of an orographic effect of the Sierra Nevada Mountain Range. In general, the thermal waters show a depletion of approximately 6‰ to 10‰ throughout the Great Basin. Assuming the non-thermal springs represent contemporary precipitation and the thermal fluids represent Pleistocene meteoric waters, this supports the contention of a depletion in stable light-isotope content of Pleistocene precipitation. In a few areas, particularly the extreme east and south, the plots are adversely influenced by a sparsity of data points and should be viewed accordingly.

Packrat Middens

Middens are stratified deposits of organic material collected by generations of packrats and preserved with dried, semi-crystalline urine. Twigs, leaves or fecal pellets removed from a midden provide a proxy for the meteoric fluids that supported the plants gathered and consumed by packrats. Since the packrats scavenging range is very limited (10 to 20 meters), the middens can be used to establish an elevation scale against which stable light-isotope content of Pleistocene precipitation can be calibrated. Deuterium vs age plots of middens from Siegel (1983) show excellent correlation with the oxygen-18 vs age plots of Dansgaard (1969) (Figure 4). A researcher at the Desert Research Institute has agreed to provide dated packrat midden samples from northern Nevada to further this study.

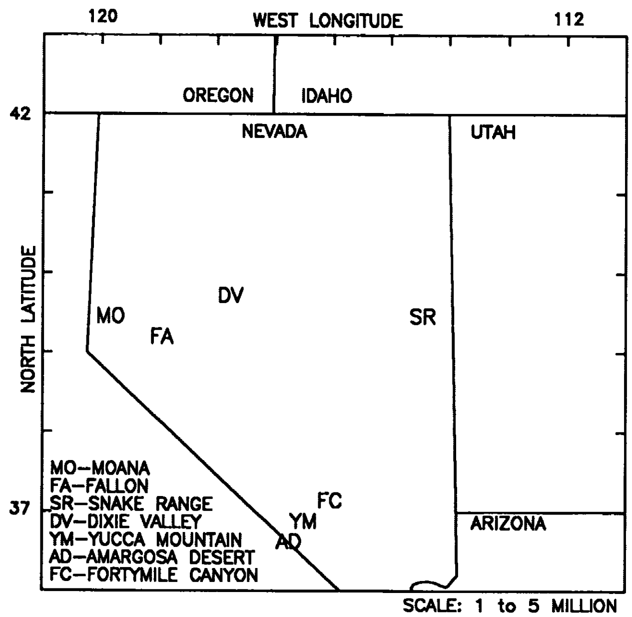
FIGURE 2:

A) RADIOCARBON AGE VS DEUTERIUM, DATA LOCATIONS

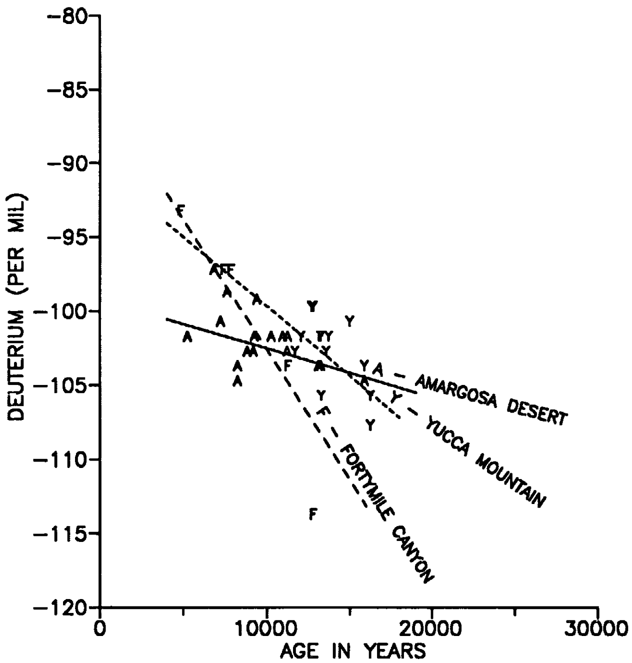
B) RADIOCARBON-AGE VS DEUTERIUM, SOUTHERN NEVADA

C) RADIOCARBON-AGE VS DEUTERIUM, NORTHERN NEVADA

2A LOCATIONS FOR FIGURES 1B, 1C AND 3



2B LOCATIONS IN SOUTHERN NEVADA AT 36.5 DEGREES LATITUDE



2C LOCATIONS IN NORTHERN NEVADA AT 39.5 DEGREES LATITUDE

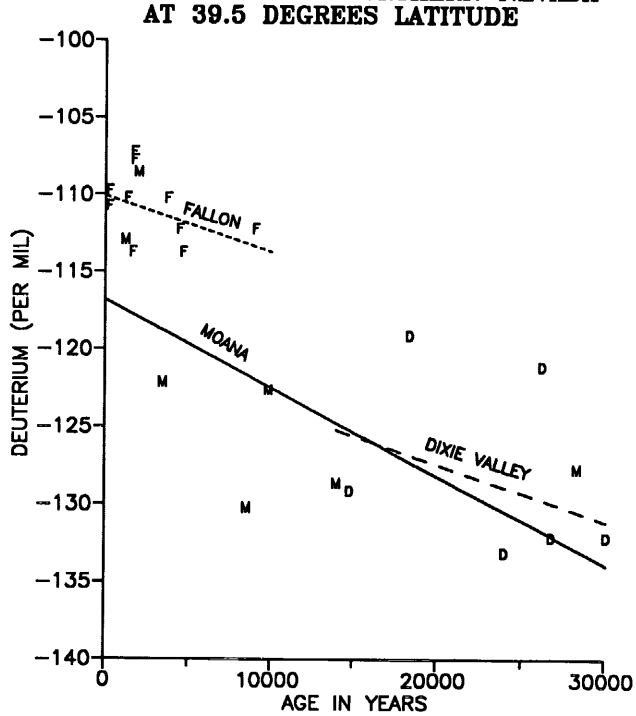
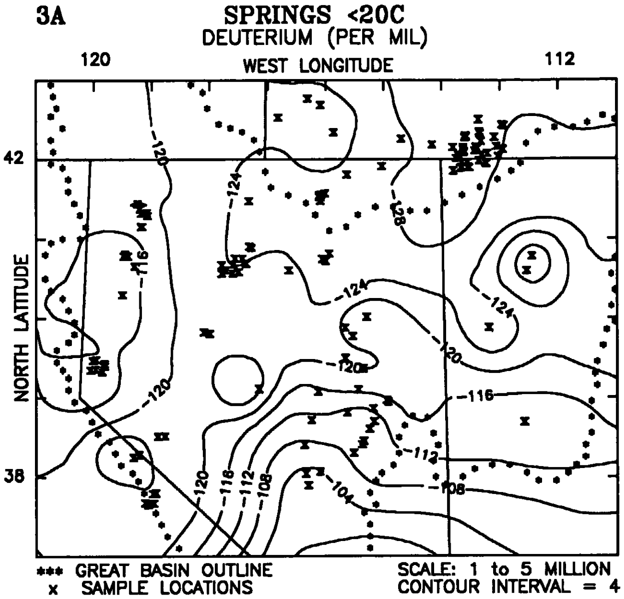


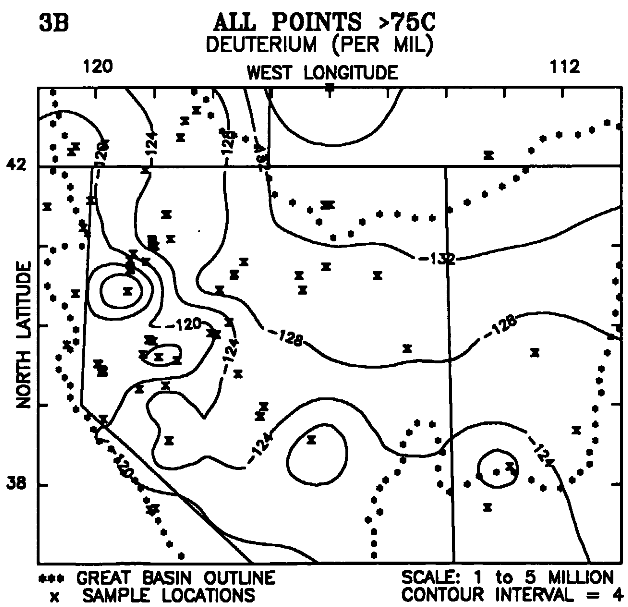
FIGURE 3:

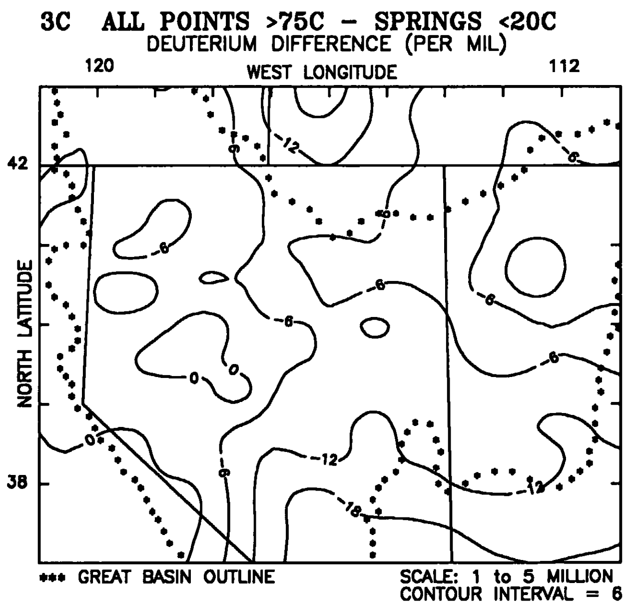
A) CONTOUR MAP OF DEUTERIUM CONTENT OF NON-THERMAL SPRINGS

B) CONTOUR MAP OF DEUTERIUM CONTENT OF THERMAL SPRINGS AMD WELLS

C) DIFFERENCE BETWEEN A) AND B)







LAKE LAHONTAN HIGH-STANDS AND NEW RECHARGE SCHEMES

Geothermal fluids from the Great Basin have apparent ages dating from late Pleistocene, 40ka to 10ka. During this time the basins of Western Nevada were submerged beneath Lake Lahontan from 25ka to 10ka (Benson and Thompson, 1987, Thompson et al, 1986). A chart showing the variations in the level of Lake Lahontan is provided in Figure 5. Note the correlation between the high stand at 13ka (Fig. 5) and depleted isotope values of the same age in Figure 4.

A lake surrounded by a high water table and supplied by a homogeneous, anisotropic aquifer system will experience inflow from all sides. The presence of a high-permeability zone beneath the lake will significantly change the potentiometric field (Fetter, 1980) and alter the hydraulic gradient allowing leakage to occur through the lake bottom. Applying the latter scenario to the Great Basin, shattered rock along range-bounding faults could provide a high-permeability zone for fluid flow. Leakage from the lakes into the submerged alluvial fans would mix with groundwater supplied by run-off from the ranges. This mixture would then migrate vertically through the high-permeability zone provided by the range-bounding faults. The range-front faults therefore act as conduits for deep recharge of geothermal fluids. The presence of the pluvial/glacial lakes almost certainly had a positive effect on recharge of deep geothermal systems.

Certain thermodynamic properties of molecules, including vapor pressure, are dependent upon the mass of their constituent atoms (Faure, 1986). Since surface water is constantly evaporating it becomes more enriched in the heavier isotopes of oxygen and hydrogen. The lighter molecules, having a higher vapor pressure, are preferentially evaporated. Lakes therefore are normally isotopically more enriched than their inflow. The similarity in the stable light-isotope values between contemporary and Pleistocene fluids in Western Nevada could thus be explained by assigning a substantial portion of the recharge to lake water. A mixture of isotopically enriched lake water and depleted meteoric water could resemble contemporary precipitation.

Geothermal fluids from Eastern Nevada are isotopically depleted compared to those from Western Nevada and to contemporary precipitation. Since late Pleistocene lakes were not as prevalent in Eastern Nevada, the bulk of geothermal fluid recharge was derived from the meteoric waters of the colder, wetter Pleistocene climate. Range-bounding faults remain the likely conduit for deep geothermal recharge.

FIGURE 4: PALEO-CLIMATE DATA FROM GREENLAND AND THE SNAKE RANGE

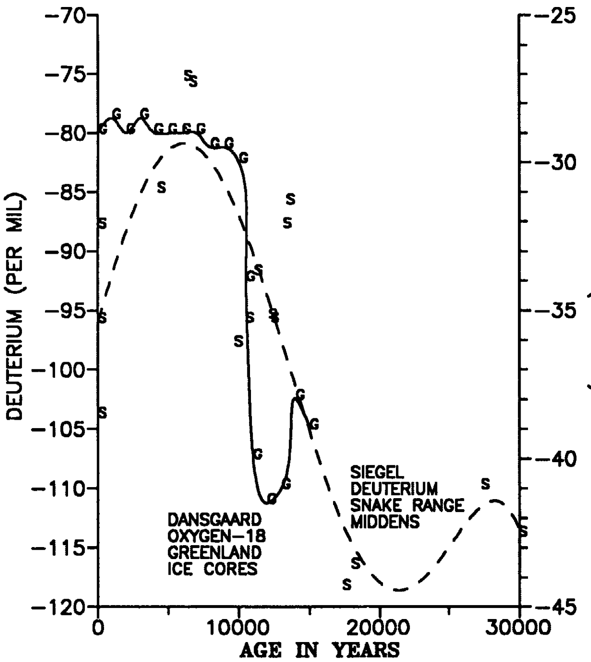
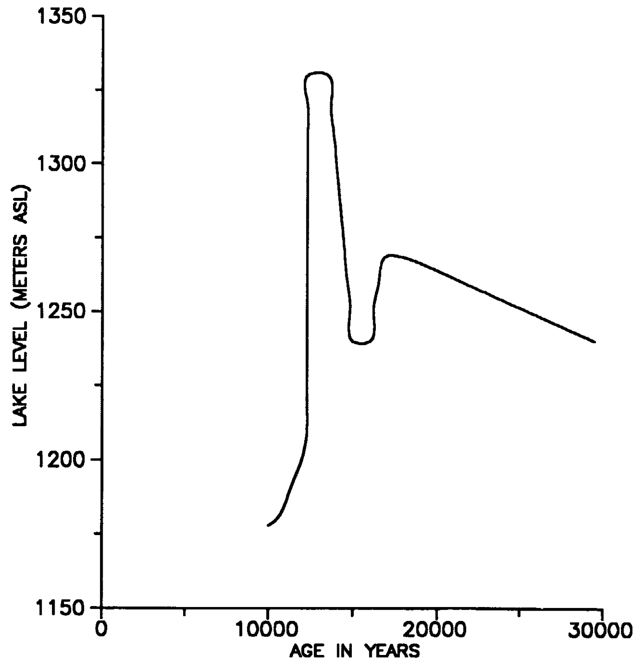


FIGURE 5: PLEISTOCENE HIGHSTANDS OF LAKE LAHONTAN, WESTERN NEVADA FROM BENSON AND THOMPSON (1987)



CONCLUSION

Isotope ratios of non-thermal (contemporary) fluids and thermal (older) fluids vary systematically throughout the Great Basin. Contemporary precipitation falling at elevations in excess of 2,500 meters has isotopic signatures similar to geothermal fluids, but would require unrealistically high flow rates to complete the cycle from range-top to resource to basin.

The apparent late Pleistocene age of nearly all geothermal fluids strongly supports a paleo-recharge scheme. This contention is supported by the isotopically depleted nature of the geothermal fluids compared to contemporary meteoric water. Range-bounding faults provide a plausible conduit for recharge of deep geothermal systems. In Western Nevada, Pleistocene lakes appear to have made a substantial contribution to the recharge, isotopically enriching the geothermal fluids. The influence of Pleistocene lakes on recharge in Eastern Nevada is not evident, suggesting recharge is a local phenomenon.

ACKNOWLEDGEMENTS

This work is funded by the United States Department of Energy, Idaho Operations Office, grant #DE-FG07-88ID 12784. Additional support for this paper was received from the Nevada Section of the Geothermal Resources Council and the Nevada geothermal industry.

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