Geochemical characterization of geothermal systems in the Great Basin: Implications for exploration, exploitation, and environmental issues

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Abstract

The objective of this project is the development of a representative geochemical database for a comprehensive range of elemental and isotopic parameters (i.e. beyond the typical data suite) for a range of geothermal systems in the Great Basin. Development of this database is one of the first steps in understanding the nature of geothermal systems in the Great Basin. Of particular importance in the Great Basin is utilizing that database to classify geothermal systems so that similarities and differences among groups are elucidated and better predictive models assembled. The research proposed herein will increase utilization of geothermal resources by providing data that will be critical in developing exploration models and exploitation strategies for geothermal energy in the Great Basin. In addition, understanding the geochemical evolution of these various types of systems will provide important insights into the possible contributions of geothermal systems to groundwater chemistry and development of mitigation strategies for attendant environmental issues.

Background and project rationale

All geothermal systems are the result of penetration of meteoric fluids into the crust, heating of those fluids, and consequent buoyant upflow of the fluids. The heat engine for these systems in most areas of the world is considered to be igneous intrusions associated with active or very recent volcanic activity. In contrast, many, but not all, geothermal systems in the Great Basin are somewhat unique in that many of these systems are thought to be non-magmatic i.e. not associated with active igneous intrusion. Rather, the thermal energy driving non-magmatic systems is the result of the high geothermal gradient associated with the thinned and extending crust in the Great Basin.

The geochemical characteristics of geothermal systems associated with magmas has long been studied, and models have been developed for exploration for, and exploitation of, these systems. We have some understanding of the source of dissolved components in the fluids of most magmatic geothermal systems. In contrast, non-magmatic-type Great Basin geothermal systems have developed in areas where there is no active volcanism or (known) igneous intrusion, therefore the rocks through which these geothermal fluids pass may have highly variable composition. Consequently, non-magmatic geothermal fluids are likely to have variable compositions reflecting the rocks through which the fluids have traveled and are likely to be different in trace element chemistry from "typical" geothermal fluids from magmatic systems. It is particularly important to characterize non-magmatic systems as relatively few data exist for these types of system (in contrast to magmatic systems), and because many geothermal systems in the Great Basin will almost certainly be non-magmatic in character. An understanding of the origin and fluid chemical characteristics of these two (or more) types of geothermal system has important ramifications for developing targeted exploration strategies, designing efficient energy-extraction systems, and mitigating environmental issues.

Existing data and preliminary assessments

There are limited trace element geochemical data for geothermal systems in the Great Basin, but preliminary assessment of the extant data reveal some intriguing patterns. For example, high-temperature geothermal systems appear to have elevated As contents, when compared to lower-temperature systems (Figure 1). This suggests the possible utility of As content in fluids as an indicator of a higher-temperature (and therefore more energy-productive) system at depth. The cause of this correlation is unclear at present, but two possibilities are suggested: 1) high-T systems are associated in space with As-rich host rocks or magmas, and 2) high-T systems are more corrosive and leach the available As from any host rocks more efficiently.

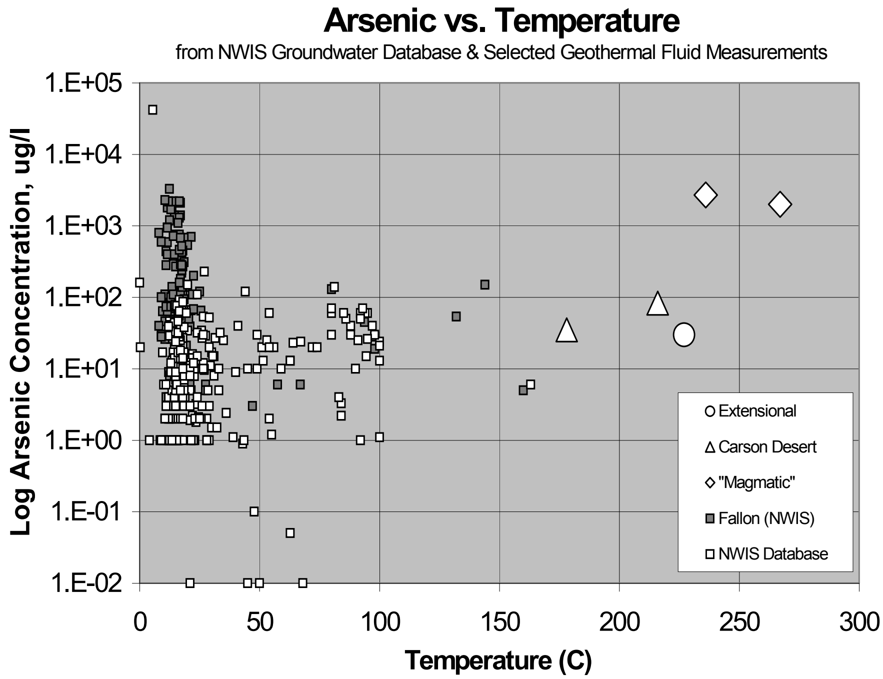

Figure 1. Plot of water temperature vs. As content for several geothermal systems (shown with large symbols) and regional groundwaters (shown with small symbols). Higher temperature systems appear to have higher As than lower temperature systems.

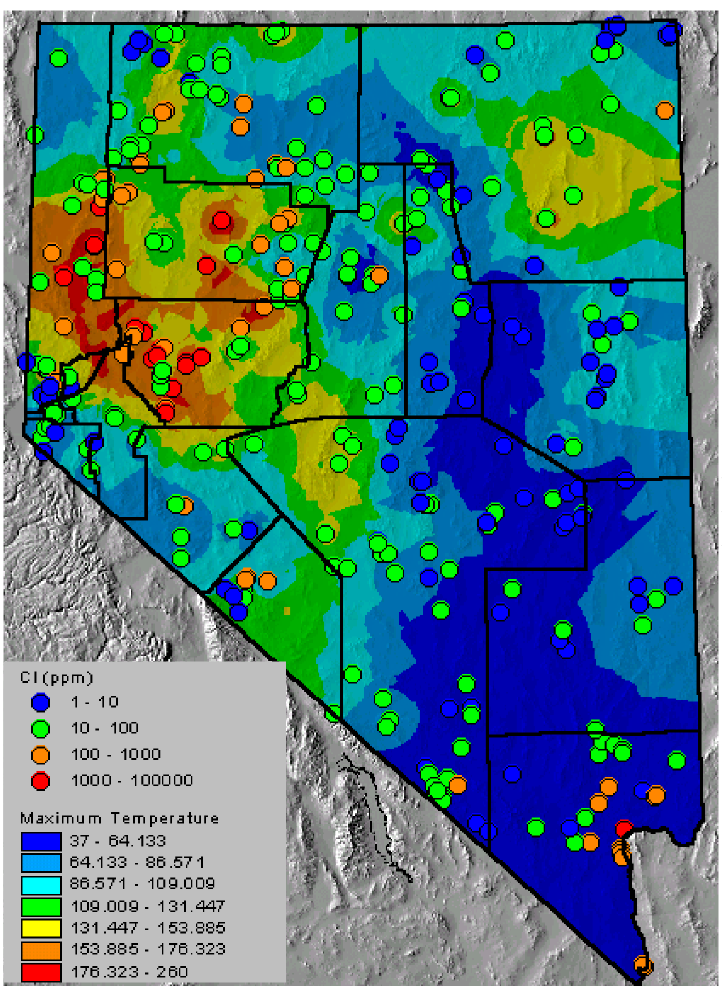

Figure 2. Map of Nevada showing maximum temperatures in geothermal wells (contoured, warmer colors are hotter wells) compared to chloride content in wells (dots, warmer colors are higher-chloride wells).

A second interesting correlation exists between areas of higher-T geothermal systems and chloride content (Figure 2). It is unclear whether this correlation is a function of temperature or host rocks. Geothermal systems developed in magmatic terranes (i.e. dominated by igneous host rocks) generally have chloride contents in the range of 10^3 -10^4 ppm (Henley, 1984) whereas those developed in other types of host rocks can have highly variable chloride contents (e.g. Salton Sea, ~19,000 ppm Cl; Henley, 1984). Many of the sub-basins of the Great Basin contain evaporite minerals which could be contributing to the elevated Cl. Additional geochemical data (such as B, Li and Br in this case) are needed to assess this possibility.

Isotopic data for various active and fossil geothermal environments in the Great Basin also may provide insights into fluid sources and pathways. Vikre (2000) presented S isotope data for a number of active and fossil geothermal systems in western Nevada. When combined with trace element data, such as As, Sb, Cu, Se, and Te, there were some clear differences in the various styles of geothermal systems. The use of discriminant analysis, with multiple trace elements, should provide important insights into the origin and nature of different geothermal systems across the Great Basin.

Proposed work

It is proposed to assemble and augment representative geochemical and geological data on fluid compositions for a wide variety of geothermal systems in the Great Basin region. These chemical data will be integrated into a geographical information system (GIS) to more fully explore relationships between the chemistry of fluids and other features known to correlate with geothermal systems. One goal is to generate predictive maps outlining areas where certain types of fluid chemistries are most likely to occur. These maps could be used to predict, for example, areas where carbonate scaling is likely to present a problem during geothermal energy production (such as systems developed in carbonate-bearing rocks), and areas where high concentrations of arsenic and other metals might occur in groundwaters. An example of the latter is the recently-described As problem in the Fallon area. Preliminary indications are that geothermal systems (known and/or hidden) may be contributing to elevated As levels in the local aquifer(s).

The research proposed herein is designed to provide the first comprehensive comparison of the geochemistry of magmatic-related geothermal systems to non-magmatic-related geothermal systems. This database will provide the basis for further research that will have important implications for the understanding of the two (or more?) types of geothermal systems including such issues as:

1. what geochemical techniques might be utilized to locate these systems;
2. what are the likely sizes, lifetimes, and stage-of-life of these systems;
3. how can the systems be managed to optimize energy extraction (e.g. scaling issues, reinjection issues);
4. what local/regional environmental impacts are likely and how can those impacts be minimized; and
5. where, how, and why these systems form (spatial distribution and unique geochemical indicators of geothermal processes).

Analytical work will be undertaken in the ICP-MS and Stable Isotope laboratory at the University of Nevada, Reno. For most trace elements except those found at sub-ppb concentrations, ICP-MS is the analytical method of choice. For elements of sub-ppb concentrations, upgrading of the elements can be done using a ferric hydroxide or mixed ester technique (Wood, 2002). Stable isotope measurements (primarily S but also H, O, C, N) will be done by precipitation of $BaSO_4$ from geothermal fluids and analysis by elemental analyzer - continuous flow mass spectrometry in the Nevada Stable Isotope Lab at UNR. Other stable isotopes will be analyzed using conventional established techniques.

Significance and future work

The proposed research will form the basis for continuing research into the understanding of the nature of geothermal systems in the Great Basin. Following are four additional research projects that will be developed in future years as follow-on to the present project.

1. *Complete characterization of three (or more?) types of geothermal systems found in the Great Basin*. Our present understanding suggests that there may be three distinct types of systems: basaltic magma-driven, rhyolite magma-driven, and non-magmatic. Understanding the geologic and geochemical

environment of each of these three types will be important in understanding the spatial distribution of these different types of systems. It will be important to understand the relationship of fluid geochemistry to wallrocks; how does major element chemistry affect solubility of trace elements and characteristics of geothermal fluids in general? Because of the diversity of rock types hosting geothermal systems in the Great Basin, the Great Basin is one of the few places in the world where such research can be undertaken. In addition, for development of new resources, fluid chemistry will provide some important insights into which type of system underlies a surface manifestation. This ultimately may have important ramifications for how that system is put into production.

2. *Duration and stage-of-life of geothermal systems*. Optimal development of geothermal energy sources requires that we understand the life cycle of those systems. Young systems are likely to have abundant fracture and primary permeability, whereas older systems may have plugged pores and require different techniques of energy extraction. Young systems may be expanding whereas older systems are likely to be contracting. Each of these variants will require careful assessment of reservoir properties so that development can be properly planned. To date, there have been few studies of the life span of geothermal systems, although there are indirect data available suggesting that most geothermal systems are significantly less than 1 my old (although multiple systems may occupy a similar spatial location at different times: cf. Arehart et al., 2002; Moore et al., 2000). Modern geochronometric techniques are beginning to provide some new tools with which some limits on the age and duration of active geothermal systems might be elucidated. Most of these geochronological studies have been undertaken on igneous-related systems; the non-magmatic systems of the Great Basin offer us the opportunity to examine a different type of system. Clearly, duration data on non-magmatic systems will be important in developing effective exploitation strategies. Also in the Great Basin are many fossil geothermal systems that may yield insight into the duration of non-magmatic systems (see #5 below).
3. *Local environmental impacts of geothermal systems*. An understanding of the geochemistry of geothermal systems in the Great Basin is critical to determining which types of geothermal systems are likely to cause what environmental (e.g. toxic trace elements such as As or Se) and production (carbonate/silicate scaling) issues. A complete geochemical database is the first step in fluid flow modeling (both physical and chemical) that will elucidate the potential problems associated with development of any given system. There are significant implications for developing clean systems vs dirty systems, in terms of environmental mitigation strategies and reinjection strategies. For example, systems containing high levels of toxic metals may be a significant issue should those systems be developed for direct uses such as balneology or agriculture (e.g. uptake of trace elements in plants or fish).
4. *Regional environmental impacts of geothermal systems*. On a larger scale, geothermal systems can be significant contributors to regional aquifers. An important test case requiring investigation is the Carson Desert area (Fallon) where high As concentrations affect the potability of groundwater. Several different geothermal systems may provide inputs to the regional groundwater in the Fallon area. Characterization of each of these systems is necessary to understand their potential role in groundwater chemistry. Are there different types of geothermal systems in Fallon area, and are they contributing in different manners? We might approach this question using element ratios as fingerprints for individual geothermal systems. The use of ratios or other complex measures is important because they are less likely to be affected by dilution problems.
5. *Geothermal systems through time in the Great Basin*. The Great Basin has been the locus of active geothermal activity for at least the past 150 million years. By developing criteria for understanding and categorizing active geothermal systems (#1 above) it will ultimately be possible to extend this database to fossil geothermal systems in the region. Development of a model for fossil systems will better allow us to understand the relationship between tectonic and magmatic processes and geothermal system development. These fossil systems will provide some important opportunities, then, to help assess the overall duration of different styles of geothermal system (#2 above), ultimately providing important insights into the longevity of the active systems in the Great Basin.

Deliverables

Deliverables will include a GIS database containing representative existing (publicly-accessible) and newly-generated data for all geothermal systems in the Great Basin. In addition to the available data in the public domain, additional analyses of geothermal fluids for non-routine elements will be undertaken and incorporated into the database. A preliminary report summarizing our findings will be presented at the GRC meeting (September 30, 2002) and a paper submitted for publication upon completion of the project.

Summary

The goal of this project is compilation and augmentation of a *comprehensive* geochemical database for a wide range of elemental and isotopic parameters as one of the first steps in understanding the variety and nature of geothermal systems in the Great Basin. Such data, and the models derived from them, will be useful in developing exploration models and exploitation strategies for geothermal energy in the Great Basin. In addition, understanding the geochemical evolution of these various types of systems will provide important insights into the possible contributions of geothermal systems to groundwater chemistry and attendant environmental issues.

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