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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 ongoing 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. This research is designed to 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. Preliminary data suggest that there are differences in the trace element geochemistry of magmatically-driven systems when compared to extensional systems (those that are just driven by elevated geothermal gradients). Once understood in the context of Great Basin geothermal systems, such differences can be utilized to more effectively explore for, assess the potential of, and develop exploitation strategies for these two types of systems.

Introduction

Most 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 volcanism. In contrast, many, but not all, geothermal systems in the Great Basin are somewhat unique in that they are thought to be non-magmatic, i.e., not associated with active igneous intrustion. 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 (Wisian, *et. al.*, 1999).

The geochemical characteristics of geothermal systems associated with magmas have 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, particularly of trace components. 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 important to characterize non-magmatic systems because few data exist for these types of systems. An understanding of the origin and fluid chemical characteristics of these two (or more) types of geothermal systems has important ramifications for developing targeted exploration strategies, designing efficient energy-extraction systems, and mitigating environmental issues.

Existing Data and Preliminary Assessments

In spite of limited data, preliminary assessment reveals some intriguing patterns. For example, high-temperature geothermal systems appear to have elevated As concentrations, when compared to lower-temperature systems (Figure 1). This suggests the possible utility of As concentrations in fluids as an indicator of a higher-temperature (and therefore more energy-productive)

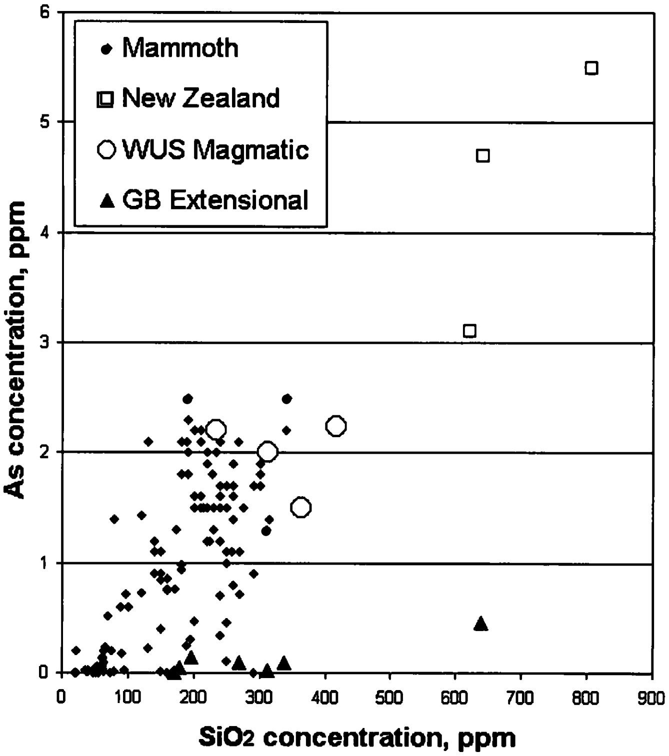

Figure 1. Plot of As content of geothermal fluids vs. ppm SiO2 (as a proxy for maximum temperature) for a variety of geothermal systems. GB = Great Basin; WUS = Western US. The WUS Magmatic group includes data from Steamboat NV; Roosevelt, UT; Yellowstone, WY; and Shasta, CA. All systems except those included as GB extensional are considered to be magmatic.

system at depth. The cause of this correlation is unclear at present, but two possibilities are suggested: 1) high-temperature systems are associated in space with As-rich host rocks or magmas, and 2) high-temperature systems are more corrosive and leach the available As from host rocks more efficiently. In addition, the slope of the As-temperature relationship between the magmatic and extensional systems appear to be different, with magmatic systems having considerably more As than extensional systems. This suggests that trace element chemistry, such as As may be useful in discriminating between the two types of systems, and further suggests that Steamboat Springs is, in fact, a system driven by magmatism.

A second interesting correlation exists between areas of higher-temperature 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.

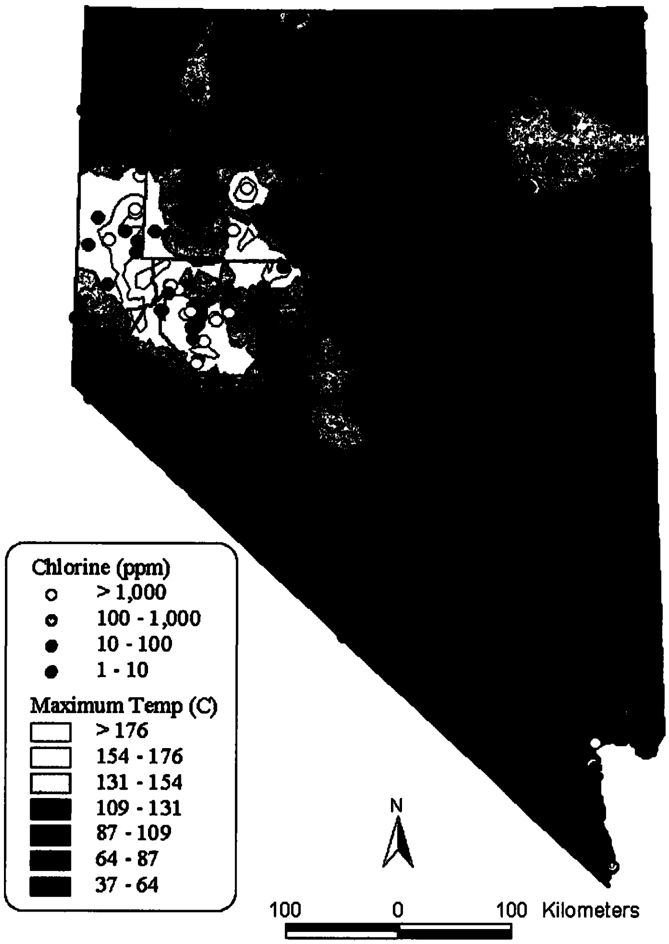

Figure 2. Map of Nevada showing maximum temperatures in geothermal wells (contoured, whiter colors are hotter areas) compared to chloride content in wells (dots, whiter colors are higher-chloride wells).

Isotopic data for 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, several different styles of geothermal systems become apparent. 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.

Ongoing Work

Sampling is continuing with the objective of assembling and augmenting representative geochemical and geological data on fluid compositions for a wide variety of geothermal systems in the Great Basin region. 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. Geothermal systems, known and/or hidden, may be contributing to elevated As levels in the local aquifer(s).

Analytical work is being undertaken in the ICP-MS and Stable Isotope Laboratories at the University of Nevada, Reno (UNR). For most trace elements except those found at sub-ppb concentrations, ICP-MS is the analytical method of choice. Elements at sub-ppb concentrations, such as the rare earth elements, will be analyzed in a second round of sampling. Concentration of the elements is planned using a ferric hydroxide or mixed ester technique (Wood, 2002) to allow for measurement at the levels achievable using the ICP-MS. Stable isotope measurements (primarily S but also H, O, C, N) are being done by standard techniques, primarily using elemental analyzer - continuous flow mass spectrometry in the Nevada Stable Isotope Lab at UNR.

These chemical data are being 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. The database containing representative existing (publicly-accessible) and newly-generated data for all geothermal systems in the Great Basin is under construction at the Great Basin Center for Geothermal Energy website: http://www.unr.edu/geothermal/

Significance and Future Work

The data being generated are 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 do these systems form?

Summary

The goal of this research has been, and continues to be, 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. Preliminary data suggest it is possible to discriminate between higher-temperature and lower-temperature systems, and between magmatically-driven and extensional geothermal systems. 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 and water-quality issues.

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