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STUDY OF NONCONDENSABLE GASES AT THE GEYSERS
FOR THE GEOTHERMAL TECHNOLOGY ORGANIZATION

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KEY WORDS
The Geysers, vapor-dominated, gases, HCl, magmatic, high-temperature reservoir, modeling

PROJECT OBJECTIVES
The concentration of non-condensable gases in Geysers steam is one of the most important factors in power plant design and one of the least predictable. Through better understanding of the origin of these gases it may be possible to improve predictions of their changes in concentration with time and well location. Recent changes in the flow and pressure of Geysers steam have been accompanied by large increases in gas concentrations in several areas of the field. This increase in gas may result from movement of high-gas steam from reservoir margins into lower-pressure central areas or from decrease in liquid vaporization, lowering the supply of low-gas steam to dilute gas in existing steam. Other possibilities include entry of higher-gas steam from deep high-temperature zones or production of gas from mineral reactions (buffers).

**Technical Objectives**
- Understand better the origin of The Geysers reservoir and the pre-exploitation chemical and isotopic characteristics through geochemical studies.
- Document the changes in distribution of isotopes and gases in The Geysers reservoir resulting from exploitation.
- Apply the methods of phase and reaction equilibrium to explain (and predict) changes in chemical and physical character of Geysers steam resulting from exploitation.
- Identify sources of steam that may extend the life of the field and predict the appearance of high gas, high HCl steam that could increase production costs.

**Expected Outcomes**
- Steam producers may be able to more confidently predict the rate of decline in steam flow, the future concentrations of non-condensable gases, and the possible appearance of corrosive HCl.

PROJECT BACKGROUND AND STATUS
A nearly field-wide accelerated decline in pressure and steam production occurred at The Geysers in the late 1980s. As a result of this crisis, the Department of Energy (DOE) has begun a program to examine...
the reservoir processes at The Geysers in order to better understand the sources of steam and noncondensable gas, and predict changes in pressure, steam flow and gas content. As part of that program the Lawrence Berkeley Laboratory started a study of the chemical compositions of steam at The Geysers, conceptual modeling, and mathematical modeling of the evolution of the thermodynamic structure, temperature, pressure, and steam compositions of The Geysers reservoir. This program has been continued, in part, through funding by the Geothermal Technology Organization.

In this study, the aspect of greatest near-term importance is the prediction of changes in noncondensable gas concentrations in steam. Removal of gas is necessary to achieve low pressures at the turbine exhaust and higher conversion efficiency. It is of great concern to the producers whether existing gas-handling equipment will be adequate for future gas concentrations. Inadequate capacity may cause plant shutdown. For a 100 MW geothermal power plant, each percent of gas increase costs about a million dollars in gas-handling equipment. The appearance of HCl gas in future steam is also of concern. Prevention of corrosion from this gas requires wellhead or downhole injection of caustic solution and adds to production costs. Both high gas and high HCl characterize steam from most of the high-temperature reservoir (HTR) of the NW Geysers. The possible existence of this reservoir under areas of the central and southern Geysers is of great concern.

APPROACH

The approach to the problem has involved: 1) compilation and interpretation of chemical and isotopic analyses of steam provided by field operators including NCPA, CCPA and Calpine (see complete names below); 2) construction of a conceptual model for the origin and present state of The Geysers reservoir; 3) Numerical modeling of critical parts of the conceptual model; and 4) The analysis of steam from typical wells throughout The Geysers for isotopes of noble gases and other elements that can trace steam origins and indicate the presence of a deep HTR (this part of the project is collaborative with Mack Kennedy of Lawrence Berkeley Laboratory (LBL) and is described elsewhere in this volume).

RESEARCH RESULTS

Extensive study was made of steam compositions from the Northern California Power Agency (NCPA) field of the SE Geysers. In this field, near the southern margin of The Geysers reservoir, a relatively rapid decrease of reservoir pressure occurred in the period between 1985 and 1990. Initial gas concentrations were low in the middle of the field but increased sharply to the east and south. Gas concentrations in steam not affected by condensate injection had generally decreased from the start of production to 1987, but increased sharply in 1988 and have continued to increase. Gas remained low only in areas of strong injection. Initially $^{18}$O and D in steam were fairly uniform across the field except for a decrease of $^{18}$O in the east toward a condensation boundary. After 1987 both isotopes increased sharply in the center of the field in response to increased total injection of evaporated condensate. These observations are interpreted to indicate that most liquid water (except that adsorbed or held in small pores far from fractures) was depleted by 1987. The loss of liquid caused the rapid decline in pressure in the central part of the reservoir. The increase in gas also resulted from loss of liquid because dilution of existing steam with low-gas steam from vaporized liquid ceased and, possibly more important, high gas steam from undrilled reservoir margins was drawn into the wells. The changes in gas and isotopes after 1987 indicate that an increasing fraction of steam production is from vaporized injectate and margin steam.
The Geysers conceptual model (abbreviated in Truesdell et al., 1993) lead to an examination of the conditions under which a two-phase vapor-dominated reservoir can lie above and be in pressure continuity with a high-temperature steam-only reservoir. The model (Figure 1) and earlier studies (Truesdell, 1991) indicate that all parts of The Geysers reservoir were formed by downward penetration of the vapor-dominated reservoir into hot, fractured, vapor-saturated rock formed by igneous intrusion ("heat mining"). In the NW Geysers the interface between normal and high-temperature reservoirs occurs at relatively shallow, drillable depths because of limited recharge of liquid. Numerical modeling (Lai et al., 1994) showed that the balance of heat input and overall liquid saturation was critical to the reservoir structure and that with 75% or greater steam saturation, two-phase conditions overlie high-temperature superheated vapor. These conditions would be expected if limited amounts of liquid water were introduced into a high-temperature, dry reservoir. Although this cooling process is probably common adjacent to igneous intrusions, the unusually low intrinsic permeability of the Franciscan greywacke and the presence of open fractures from earlier intrusions created the extraordinary Geysers reservoir.

Ongoing studies collaborative with Mack Kennedy of LBL (Kennedy and Truesdell, 1994 and this volume) have confirmed several other parts of the conceptual model. The high total gas and the nearly pure magmatic noble gases in the HTR of the NW Geysers indicate that the heat mining process hypothesized in the model is more probable than the boildown of a liquid-dominated reservoir. A boildown process would necessarily produce low-gas steam with an atmospheric noble gas signature related to the source of recharge. In addition the observed sharp gradients in gas compositions within the HTR suggest that large scale convection does not occur. This results from the lack of an underlying liquid zone. The patterns of gases and isotopes found in the central and southern Geysers (but not in the NW) indicated that partial condensation of laterally flowing steam must have occurred with condensate returning to central boiling zones in a liquid saturated layer (Figure 1).

FUTURE PLANS

The joint project with LBL involving collection and analysis of steam samples for isotopes of noble gases will be extended throughout The Geysers. This study is contingent on enough funding to keep the isotope laboratory operating. The next phase of this study will be crucial to discovering if high-temperature reservoirs similar to that of the NW Geysers extend under central and southern areas. This study will also be extended to include analyses of carbon isotopes in CO₂ and CH₄ which provide durable indications of gas formation temperatures. The methods applied to the NCPA reservoir are now being applied to the larger and more central Calpine area (Figure 2). Collaboration with Franco D’Amore (IIRG, Pisa) will involve applying new gas reaction models to Geysers Gases. Work with Jill Haizlip to interpret gas compositions at inlets to PG&E power plants will continue. As the present GTO grant is nearly finished, an extension or other funding will be sought. Extension of this project would complement ongoing noble gas isotope studies (Kennedy and Truesdell, this volume).
## INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

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<tr>
<th>Organization(s)</th>
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<tbody>
<tr>
<td>Northern California Power Agency</td>
<td>Interpretation of gas analyses; location of HTR</td>
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<td>Central California Power Agency</td>
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<tr>
<td>Calpine Corp</td>
<td>Detection of HTR gases; prediction of gas changes</td>
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<tr>
<td>Pacific Gas and Electric Co.</td>
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## REFERENCES


## CONTACTS

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Figure 1. Conceptual model of The Geysers reservoir showing the relation of the central and SE, where the vapor-dominated reservoir was developed earlier by heat mining from high-temperature fractured rock and supports large-scale convection, and the NW, where the more recently developed reservoir is thinner, major convection is absent, and wells penetrate the underlying hot, vapor-saturated rock.

Figure 2. Changes in well flow and reservoir gas/steam, y values and liquid saturation for Calpine well DV-3 from start of production to 1993. This well produced initially from the central two-phase reservoir then increasingly from high-gas margins of the field. Note accelerated changes in 1987.