GEOTHERMAL CHEMISTRY/EXPLORATION INVESTIGATIONS AT DIXIE VALLEY, NEVADA

Fraser Goff
Los Alamos National Laboratory
505-667-8060

Cathy J. Janik
U.S. Geological Survey
650-329-5213

Deborah Bergfeld and Dale Counce
Los Alamos National Laboratory
505-667-1812

Carol J. Bruton and Gregory Nimz
Lawrence Livermore National Laboratory
510-423-1936

ABSTRACT

Dixie Valley geothermal field has continuously produced electric power since 1988. At the request of Oxbow Geothermal Corp. and the U.S. Department of Energy, we have organized an inter-agency team of investigators to examine several topics of concern regarding management and behavior of the resource. These topics include scaling of the injection system, recharge of the reservoir, geochemical monitoring of the reservoir, and development of increased fumarolic activity north of the power plant.

INTRODUCTION

The Dixie Valley geothermal system is located in west-central Nevada between the Stillwater and Clan Alpine ranges (Fig. 1) and produces electricity from a 62 MWe double-flash power plant that began operations in 1988. Fluids are produced from depths of 2450 to 3050 m at an average temperature of about 250°C. The plant and geothermal wells are owned and operated by Oxbow Geothermal Corp. The geologic setting of the field was most recently described by Lutz et al. (1997).

During FY97 we began an inter-agency collaboration to investigate scaling in injection pipelines and wells. In FY98 we expanded this collaboration to evaluate recharge sources and ages of the geothermal sy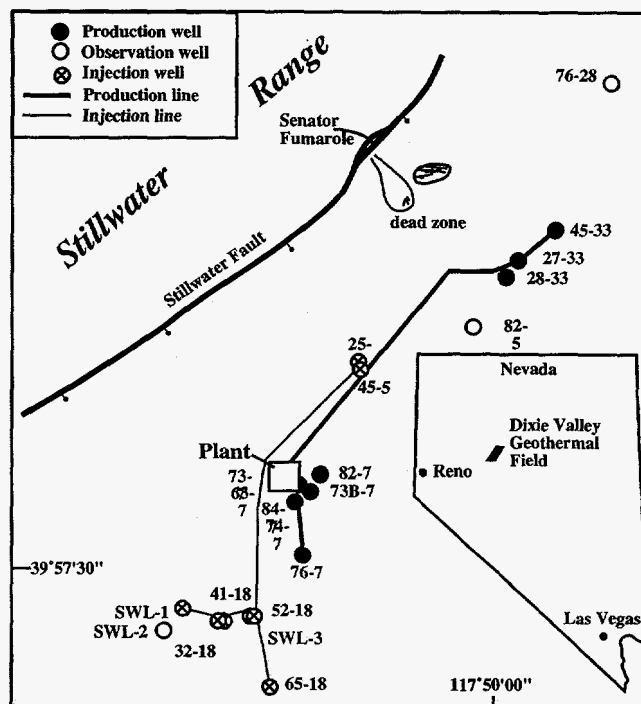stem, to monitor geochemical changes in production fluids, and to investigate time-series changes in CO_2 flux and temperature distribution on the recently discovered "dead zone." The object of this contribution is to summarize the status of these tasks.

SCALE FORMATION

Carbonate scaling in Dixie Valley production wells was described by Benoit (1987). Silica scaling in pipelines and

Figure 1. Map showing location of Dixie Valley geothermal system, Nevada.

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injector wells downstream of the power plant has been a problem for a number of years. Some initial investigations were previously carried out by Oxbow to determine the nature of the scale. A team from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Energy & Geoscience Institute was created at the request of Oxbow to address the scaling issue.

A report on the initial results of this effort was presented in early FY98 (Bruton et al., 1997). Several questions were considered:

* What is the source and composition of the scale that forms and how can it be controlled?

* Will scale form if reinjection is supplemented with local groundwater to maintain reservoir pressure?

* Will reinjection damage the reservoir over time?

Chemical and XRD analyses of scales from the Oxbow test bed revealed that they were composed primarily of amorphous silica with minor to trace amounts of quartz, calcite, magnetite, goethite, and clays. A variety of deposits from pipelines in the field shows that they may contain pebble-size clasts of reservoir lithologies cemented primarily by opaline silica, minor calcite and rare greenish, clay-like material.

Very detailed chemical analyses were made of shallow domestic water, production brines and gases, spent fluids from the power plant, and fluids in various sectors of the injection lines. Included were field extractions and analyses of ionized and total Al and of pH/Eh from all waters to determine mineral speciation and phase equilibria under various conditions of heating and mixing. Calculations showed that the injection fluids were saturated with amorphous silica and other phases, consistent with scale formation.

Simulation of the heating of shallow domestic groundwater from 34°C (collection temperature) to 250°C (reservoir temperature) indicated that carbonates, sulfates, and Mg-silicates will precipitate if this fluid is used

for re-injection but that the potential for silica precipitation will decrease. Mixing of power plant injectate with reservoir waters is a more complicated issue (Fig. 2). Bruton et al. (1997) simplified the simulations into near and far wellbore cases. Near the wellbore, temperatures and salinities decrease as cool injection water dilutes the reservoir fluid. Silica saturation decreases but carbonate saturation increases as the injection fluid is progressively diluted. Away from the wellbore, temperatures and salinities rise as injection water mixes with reservoir fluids. Silica saturation decreases as the proportion
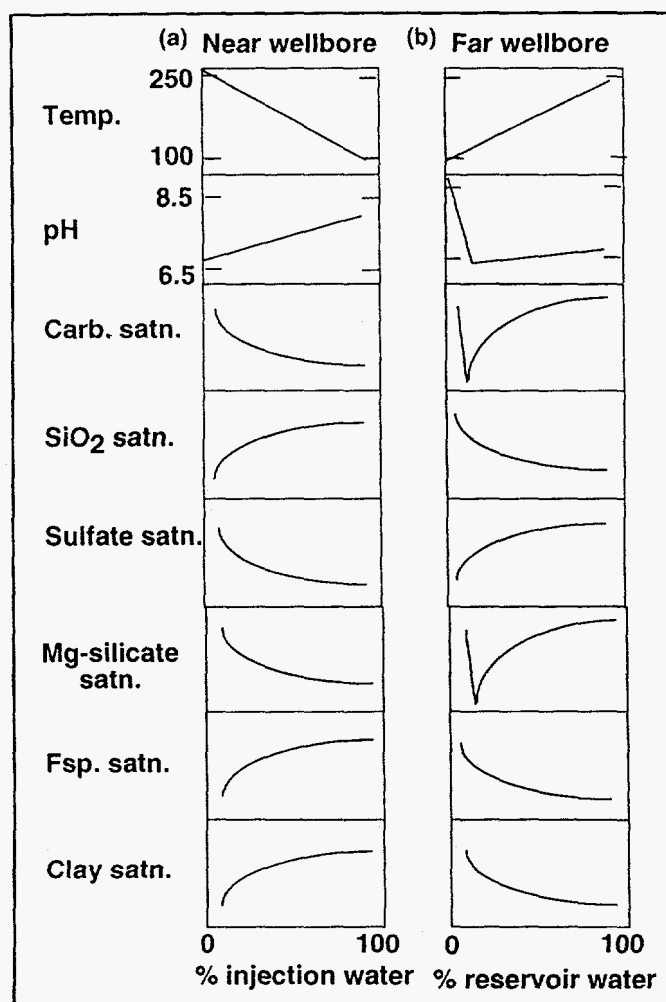
Figure 2. Summary of chemical-mineral trends during gradual mixing of (a) injectate into reservoir fluid and (b) reservoir fluid into injectate. Abbreviations: Carb. = carbonates, satn. = saturation, SiO_2 = silica polymorphs, Mg-silicate = Mg-bearing silicates, Fsp = feldspar (from Bruton et al., 1997).

of reservoir fluid increases. The far wellbore scenario is more sensitive to pH variations caused by more complicated precipitation responses from carbonates and Mg-silicates.

SYSTEM RECHARGE

Since exploitation began in 1988, the Dixie Valley geothermal reservoir has experienced a systematic decline of water levels and pressures in production wells. This has created a need to more thoroughly evaluate such processes as recharge to the geothermal system. We are presently collaborating on a combined chemical and isotopic study of regional springs and aquifers to help understand where recharge fluids primarily come from and to constrain how fast recharge occurs. The isotope studies will include analyses of deuterium/oxygen-18, tritium, carbon-13, carbon-14, chlorine-36, and strontium 87/86 in regional waters and production fluids.

Sampling for this task began in November 1997 so a complete data set has not yet been obtained.

Figure 3 is a plot of deuterium vs. oxygen-18 for over 50 fluid samples collected in 1997. The gray cloud shows the range of 24 regional meteoric waters from Dixie Valley, the Stillwater Range, and the Clan Alpine Range that do not show any isotopic modifications due to evaporation or rock- water exchange. These waters form a trend that we refer to as the Dixie Valley meteoric water line (DMWL) and this trend is shifted by about +1 ‰ in oxygen-18 relative to the world meteoric water line (WMWL, Craig, 1961). The equation for the DMWL is $\delta D = 7.42 \, \delta^{18}O - 8.91$ (n = 24, r = 0.91). A similar shift was found by Goff et al. (1994) for background waters in the Railroad Valley and Pine Valley regions, Nevada (SE and E of Dixie Valley). A slope of 7.55 was determined for cold springs throughout the Great Basin by Flynn and Buchanan (1993).
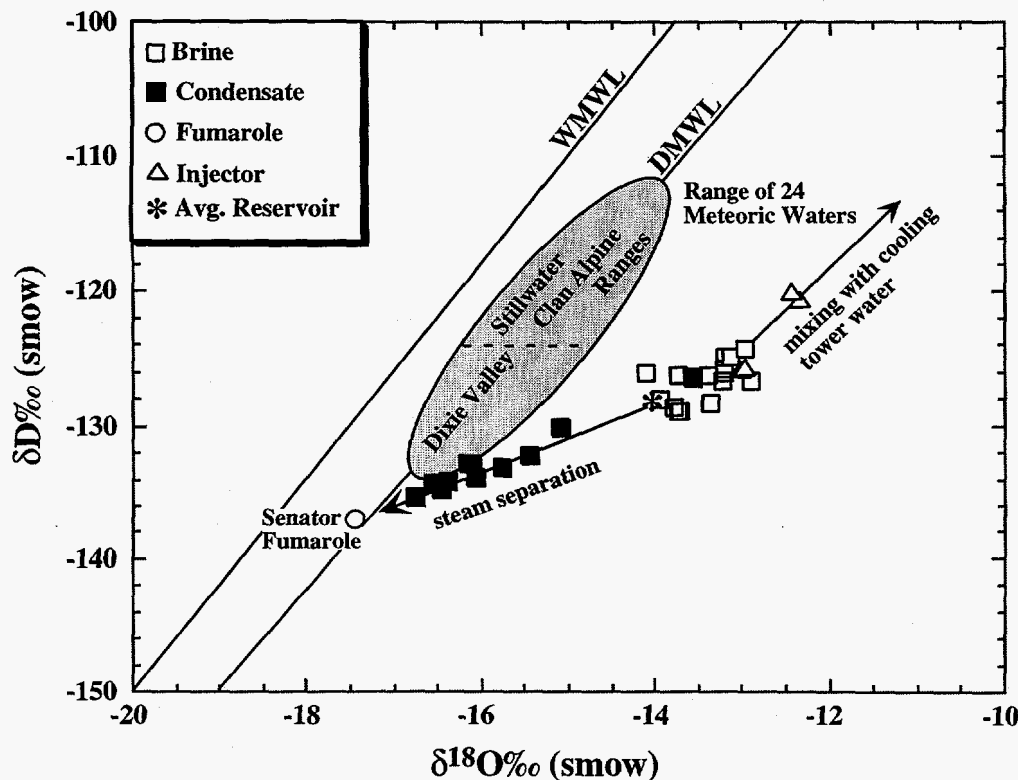

Figure 3. Plot of δD vs. δ^{18}O for various production fluids and regional waters in the Dixie Valley geothermal system and adjacent ranges.

Of the 24 meteoric waters represented by the gray cloud, 10 issue from the floor of Dixie Valley and their isotope compositions fall within the most depleted sector of the cloud (Fig. 1). Fourteen of the remaining 24 waters issue in the Stillwater and Clan Alpine ranges and 13 of these have isotope values that are enriched compared to those in Dixie Valley. Normally, the reverse relation would be expected because waters precipitated at higher elevation (such as in a mountain environment) would have isotope values that are more depleted than those in adjacent basins (Hoefs, 1973; Vuataz and Goff, 1986). The implication is that waters in Dixie Valley were either recharged at elevations higher than those we collected in the ranges or originated from an earlier time when precipitation was isotopically different. Flynn and Buchanan (1993) noted similar isotope relations between thermal and nonthermal waters and stated that most geothermal fluids in the Great Basin were recharged in the Pleistocene, 10 to 30 ka.

Dixie Valley production fluids form two major clusters of residual brines and steam condensates. Steam produced in the separators (~165°C) has isotope values that are depleted relative to residual brine. The average isotopic composition of the reconstructed reservoir fluid (~250°C) is about -130 ‰ (δD) and -14 ‰ ($\delta^{18}O$). The oxygen-18 value is shifted about +2.3 ‰ relative to the DMWL, a characteristic best explained by high-temperature rock-water isotopic exchange in the reservoir (Hoefs, 1973). Some injection fluids are isotopically enriched relative to residual brines because they are mixed with highly evaporated water from the cooling towers of the power plant (Bruton et al., 1997). In contrast, Senator Fumarole (97°C), which issues from a strand of the Stillwater Fault north of the power plant, is isotopically depleted compared to separator condensates and appears to be derived from Dixie Valley reservoir fluids by boiling at ~180°C (Henley et al., 1987).

If we accept that the average deuterium value of Dixie Valley reservoir water is about -130 ‰, it would appear that the reservoir does not contain fluids resembling those presently precipitated in the ranges. Tritium in reservoir fluids that were analyzed in 1996 contain ≤0.12 T.U. Using a well-mixed reservoir model (Shevenell and Goff, 1995), the maximum mean residence times of these fluids would be ≥10 ka. Additional tritium and future carbon-14 analyses should provide a much better handle on the age and recharge of Dixie Valley geothermal fluids.

MONITORING

Tracer tests conducted since 1989 have shown that there is some breakthrough of injection fluids into production wells of the geothermal reservoir (Adams et al., 1993). In addition, analysis of noncondensible gases have shown systematic decreases in CO_2 and H_2S during the first six years of power plant operation (Benoit and Hirtz, 1994).

Geochemical data obtained by our group in November 1997 was limited to just two production separators whereas data obtained in November 1998 included the entire geothermal field. At this time we can't make reliable statements regarding temporal changes in reservoir composition. As additional sample suites are collected, we will compare our analyses with early analyses provided by Oxbow to see if changes have occurred (do) due to fluid removal, pressure decline, reinjection procedures, and other reservoir processes (i.e., Mariner and Janik, 1995).

DEAD ZONE

Areas of weak to intense fumarolic activity are interspersed along the NNE-trending Stillwater fault zone. These locations are characterized by gas and soil temperatures ≤97°C, localized alteration of the surrounding rock units, and precipitation of sulfur, jarosite and other sublimate minerals around the vents. Coincident with the decline in reservoir levels and fluid pressures has been an increase in the size and vigor of a fumarole field on the northwestern border of the geothermal system near the Senator fumarole (Fig. 1). In 1997 dramatic changes occurred around the alluvial fan that extends east from

the fumaroles. These changes include partial to total die off of woody shrubs and formation of an area of steaming ground fractures at the base of the fan. This general area is now referred to as the "dead zone." Another group of dry fractures occurs in the basin northeast of the dead zone.

The two sets of ground fractures are noticeably different in character. Dead zone fractures (steaming ground) are associated with high temperatures, dead vegetation, moist soil, and formation of a soil crust. Basin soil fractures (dry cracks) have no thermal signature but are more laterally extensive and deeper than surface fractures in the dead zone. These fractures were first noticed in 1996 and visual observations suggest that they are growing with time.

Measurements of diffuse soil CO_2 flux are being used in volcanic and geothermal environments to provide information on transient processes (Farrar et al., 1995). We measured soil CO_2 flux along regularly spaced traverses within, across, and bordering the dead zone. Additional traverses were located around the area of dry ~~using a LI-COR brand infrared CO_2 gas analyzer in a closed loop with an accumulation chamber. This system delivers a well-mixed measured soil CO_2 flux along regularly spaced traverses within, across, and~~ cracks. CO_2 concentrations were obtained gas sample from the chamber to the analyzer and back at the rate of one sample per second. This instrument can measure very low CO_2 concentrations (signal noise is below 0.2 ppm) with an accuracy of ±2 ppm at high CO_2 concentrations (1000 ppm). For the purposes of this study flux is reported as grams of CO_2 per m^2 per day. Data is contoured using a software package that applies kriging statistics to determine a minimum error-variance estimate of the flux for unsampled locations. The contouring eliminates extremely high flux values from the resulting map (Fig. 4).

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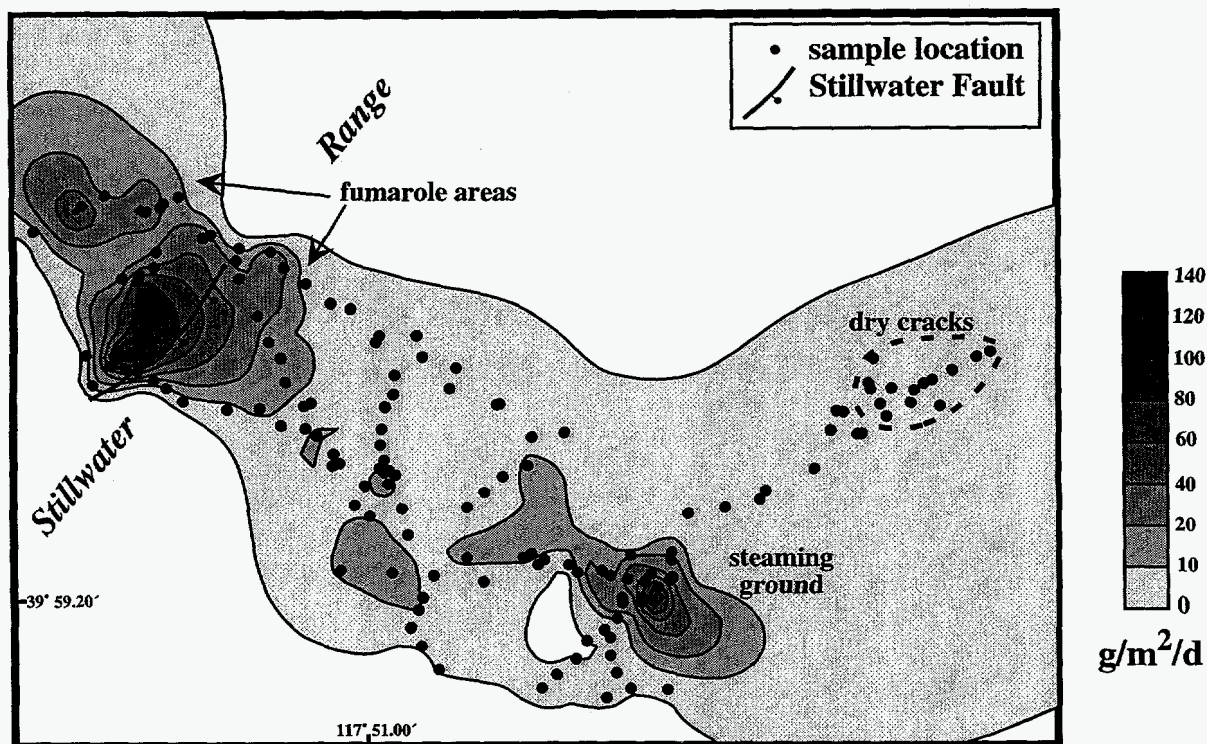

Figure 4. Map of contoured CO_2 flux over the dead zone and adjacent areas, Dixie Valley, Nevada. A contour map of soil temperature has a similar appearance. White regions lack sufficient data to be contoured.

The dry cracks area shows no CO_2 anomaly associated with ground fractures. Ambient CO_2 concentration at the soil surface is approximately 370 ppm and CO_2 flux across this area averages 1.8 $g/m^2/d$. CO_2 flux across the dry cracks area is comparable with other basin measurements located far away from steaming ground and essentially defines the local background flux.

It was not possible to obtain flux measurements directly over fumaroles because high CO_2 concentrations quickly exceeded the measurement capabilities of the analyzer. Maximum flux measurements of around 200 $g/m^2/d$ were obtained near fumaroles located along the Stillwater fault zone (Fig. 4). CO_2 flux rapidly decreases away from the fumaroles but all sample locations along a range front traverse yield a flux well above the local ambient value. Sample locations within the steaming ground area display elevated CO_2 concentrations and have flux magnitudes similar to those measured near fumaroles. Average flux for sample localities in this area is 52 $g/m^2/d$ with a maximum of 170 $g/m^2/d$ adjacent to fractures.

Four down-fan traverses in NW-SE and N-S orientations were performed to investigate flux trends away from the Stillwater fault zone. The traverses show a steep decline in CO_2 flux in a down-fan direction with the exception of the steaming cracks in the basin and a middle to lower fan region of elevated flux. This area is characterized by diffuse surface precipitates and moderate to high soil temperatures ranging between 24° to 59°C. The mid fan region helps to define a NW-SE striking zone of enhanced CO_2 emission that is bounded by the Senator fumarole field and the steaming cracks.

Results from this study indicate that ground fractures outside of the dead zone are not correlative with enhanced CO_2 flux. As such we feel that the dry cracks are not related to expansion of the fumarole field and are more likely related to another process, possibly subsidence within the basin.

In contrast, the steaming cracks at the base of the dead zone show soil temperatures and CO_2 flux similar to areas around the fumaroles. Although the causes of cracking are not understood, the steam must come from boiling of underlying geothermal reservoir fluids or from vaporization of shallow meteoric water that overlies the geothermal reservoir. Chemical and isotopic analyses of the steam suggest that it originates by the latter process. Another set of flux measurements will be obtained later this year to assess the rate of growth of the dead zone, if possible.

ACKNOWLEDGMENTS

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