

## GEOCHEMICAL STUDIES OF RESERVOIR PROCESSES IN THE NCPA FIELD OF THE GEYSERS A PRELIMINARY REPORT

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### INTRODUCTION

A nearly-fieldwide accelerated decline in pressure and steam production occurred at The Geysers in the late 1980s. As a result of this crisis, the U. S. Dept. of Energy has begun a program to examine the reservoir processes at The Geysers in greater detail, with particular attention to understanding the sources of steam and gas and predicting changes in pressure, steam flow and gas content. As part of that program the Lawrence Berkeley Laboratory is supporting the study of the chemical composition of steam, and is modelling processes that affect the composition as well as the temperature, pressure and flow.

The chemistry of steam has been used to indicate the distribution of liquid and gases in the reservoir, and the sources of produced steam.<sup>5,7,17</sup> These studies involve calculation of temperature and fraction of steam in the feed to wells, and tracing compositions of steam originating from partial condensation of steam, evaporation of liquid, and mixing of steam sources. Steam sources now exploited include steam from the open fractures of the system, vaporized liquid from small fractures and the rock matrix, and fluids entering the reservoir from outside, including injected condensate and fluids from undrilled areas. In the next sections methods of tracing reservoir processes will be discussed and applied to the NCPA Geysers steam field.

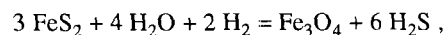
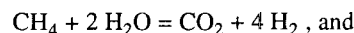
The Northern California Power Agency (NCPA) field is located in the southeastern part of The Geysers (Figure 1). The field is bounded to the north by Unocal and Calpine leases, to the southwest by the Big Sulfur Creek fault zone, in which low permeability limits steam production, and partially to the south and east by liquid-saturated boundaries. The engineering of the field and power plants and changes in pressure and gas contents of steam up to mid 1989 have been described by Eney et al.<sup>9</sup> From 1985, extensive collection and analyses of steam were made for gases and isotopes. The sampling and analysis program and composition changes to early 1987 were described by Klein and Eney.<sup>15</sup>

### TRACING USING GAS EQUILIBRIA

At equilibrium, concentrations of gases in reservoir steam and liquid are different because gases partition strongly into the steam. If reservoir liquid vaporizes during production and this steam mixes with original reservoir steam,

gas concentrations in the mixture will not correspond to equilibrium in either liquid or steam. By combining gas solubilities and equilibria for two reactions, both reservoir temperature and steam fraction, "y" equal to the fraction of original reservoir steam in the produced mixture (also called effective reservoir steam saturation), can be calculated. Methods for this calculation were described by Giggenbach<sup>12</sup> and D'Amore et al.<sup>7</sup>

The calculations used in this paper were described in detail in D'Amore and Truesdell.<sup>6</sup> The methane breakdown and pyrite-H<sub>2</sub>S reactions were chosen for the calculation. These reactions are



and the corresponding equilibrium expressions are

$$\text{KC} = \frac{P_{\text{H}_2}^4 P_{\text{CO}_2}}{P_{\text{CH}_4} P_{\text{H}_2\text{O}}^2}, \text{ and}$$

$$\text{KS} = \frac{P_{\text{H}_2\text{S}}^6}{P_{\text{H}_2}^2 P_{\text{H}_2\text{O}}^4},$$

where KC and KS are equilibrium constants and P indicates gas partial pressures. At equilibrium the wellhead steam composition is a function of the reservoir temperature and the fraction, y, of the original steam. These functions for the two reactions can be written as,

$$4 \log (\text{H}_2/\text{H}_2\text{O})_{\text{WH}} + \log (\text{CO}_2/\text{CH}_4)_{\text{WH}} \\ = \log \text{KC} - 2 \log P_{\text{H}_2\text{O}}$$

$$+ 4 \log A_{\text{H}_2} + \log (A_{\text{CO}_2}/A_{\text{CH}_4}), \text{ and}$$

$$3 \log (\text{H}_2\text{S}/\text{H}_2\text{O})_{\text{WH}} - \log (\text{H}_2/\text{H}_2\text{O})_{\text{WH}} \\ = \log \text{KS} + 3 \log A_{\text{H}_2\text{S}} - 2 \log A_{\text{H}_2},$$

where WH refers to wellhead analyses,  $A_i = y + (1-y)/B_i$  and  $B_i$  is the gas distribution constant,  $C_{\text{vapor}}/C_{\text{liquid}}$ .

The equilibrium constants KC and KS and the pressure of saturated steam ( $P_{\text{H}_2\text{O}}$ ) are functions of temperature so the left-hand sides of the equations are written,

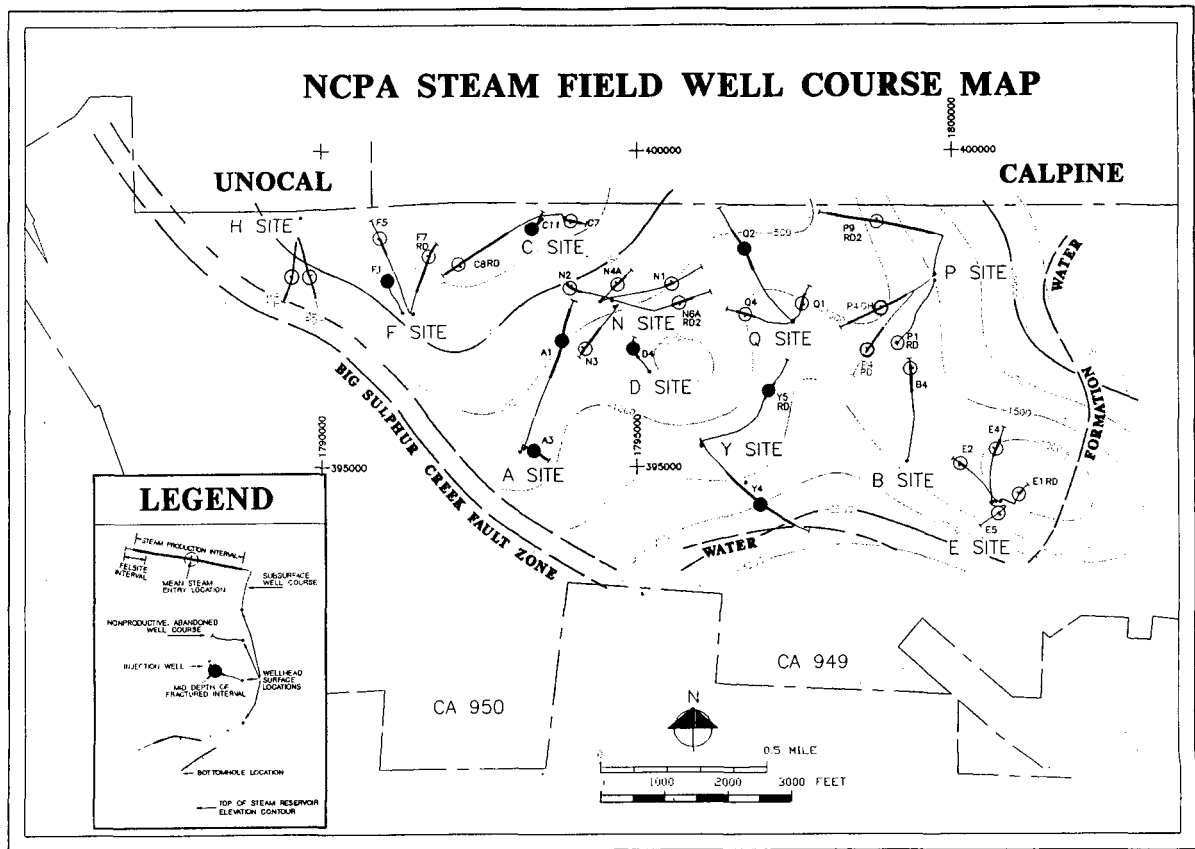


Figure 1. Map of the NCPA field showing locations of field boundaries, and selected well sites, well courses, mean steam entries and mean injection points (solid circles).

$$-15.35 - 3952/T + 4.635 \log T + 4 \log A_{H_2} + \log (A_{CO_2}/A_{CH_4})$$

$$6.23 - 6222/T - 0.412 \log T + 3 \log A_{H_2S} - \log A_{H_2},$$

with T in °K and  $A_i = y + (1-y)/B_i$  as before. Values of  $B_i$  are calculated from the data in Table 1.

Table 1. Equations for the distribution constant  $B_i$  (from<sup>12</sup>)

$$B_i = C_i + D_i t \text{ (t in } ^\circ\text{C)}$$

Gas	$C_i$	$D_i$
CO <sub>2</sub>	4.7695	-0.01096
H <sub>2</sub> S	4.0442	-0.00980
H <sub>2</sub>	5.9681	-0.01330
CH <sub>4</sub>	6.0810	-0.01388

On a grid drawn using these equations (Figure 2) the NCPA steam analyses indicate temperatures from about 210° to 265°C and steam fractions ("y" values) from about 0.005 to 0.25. Most steam analyses are between 225°C and 250°C, and 0.05 and 0.2 y. The indicated temperatures are reasonable. The original temperate at 2000 m depth was probably near 245°C<sup>16,19</sup> with somewhat lower temperatures expected as a result of exploitation. The calculated steam fraction values (5 to 20 weight % steam) indicate substantial liquid reserves.

Figure 3 shows the changes in calculated temperature for each year from 1985 to 1990 along a W-E cross-section of the field with well locations projected on a W-E line. The general locations of groups of wells are shown at the top (compare with Figure 1). Where there were several analyses for a year, the results of the calculations were averaged. The calculations show a range of temperatures for each group of wells of from 20 to 40 (or more) °C. The order to see yearly changes and variations along the section, a power series fit of temperatures for each year was calcu-

lated. Except for 1985, the results show that there is a general tendency for mean calculated temperatures in the center of the field (F to Q wells) to be near 235°C, with higher temperatures for P and E wells and lower temperatures for H wells. The high temperatures indicated in 1985 may be an artifact.

Fitted "y" values vary more widely (Figure 4). The 1985 y values are low across the middle of the field and very low at the western edge. Y values at both east and west edges of the field were low initially, but increased with time more rapidly than in the center. Y values were nearly constant in 1985-86, but increased in 1987-88. The high y values and increase in y at the margins of the field reflect high and increasing gas concentrations.

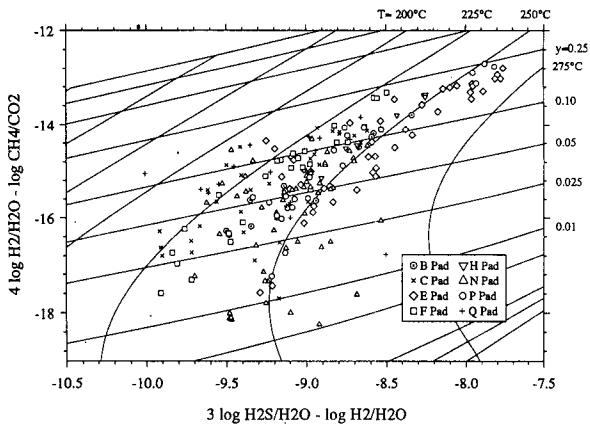


Figure 2. Part of the y-t "grid" diagram for CH<sub>4</sub>-CO<sub>2</sub>-H<sub>2</sub> and pyrite-magnetite-H<sub>2</sub>S reactions showing effective vapor saturation, y, and temperature for selected NCPA steam samples collected from 1985 to 1990.

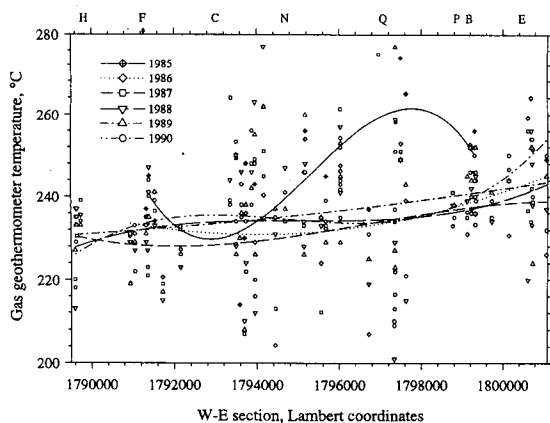


Figure 3. W-E cross-section of the NCPA field showing calculated gas geothermometer temperatures for yearly steam samples and curves fitted to each year's data.

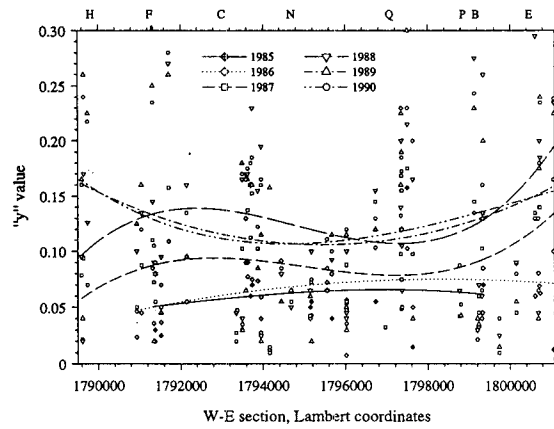


Figure 4. Calculated y values for yearly steam samples presented as in Figure 3.

### TRACING USING GAS CONCENTRATIONS

Calculated y values are closely related to total gas concentrations because the balance of original steam (gas rich) to vaporized liquid (gas poor), as measured by y, determines in most cases the concentration of total gas in the mixture. However if the high-gas steam originates separately from the low-gas steam then the changes in the gas concentrations may give a clearer picture of reservoir processes.

Total gas concentrations (as mole fractions) are shown for the section in Figure 5. These values show less scatter than temperatures and y values and vary distinctly with time and position in the field. Large increases occurred at the field margins after 1985, with smaller increases in the center of the field after 1987. These changes can be better seen in Figures 6 and 7 which show changes with time of the gas concentration of wells at the margins (H, P, B and E wells) and center (all others except N wells) of the field. Gas concentrations in steam from N wells is lower and more variable as a result of intense nearby injection (Figure 8). (Injection well locations are shown as filled circles on Figure 1.) These figures show that gas concentrations in almost all steam analyses decreased or were constant until mid-1987 and increased markedly from 1987 to late 1989 or 1990.

Steam may exist in areas beyond the margins of the drilled field. These areas, initially rejected because of high gas or low productivity, eventually contribute to the total steam produced in neighboring wells. Steam at the reservoir margins is distinct chemically from steam in the center. In the SE Geysers and in several areas of Larderello there is a characteristic pattern of steam composition in which water soluble salts (e.g. B) are more concentrated in steam from the center of the field and water insoluble gases (e.g. CO<sub>2</sub>) are more concentrated at the margins.<sup>5,21</sup> Oxygen-18 is more soluble in water than oxygen-16 and is depleted in marginal steam. These patterns are produced by natural state (pre exploitation) lateral steam flow with partial con-

densation as heat is lost by conduction to the surface. This can be described chemically as a Rayleigh or open system process which the concentration of a component is a function of the amount of steam condensed and the relative solubility of the component in steam and water. The equation for this process is<sup>5</sup>

$$C/C_0 = (m/m_0) (1/K - 1),$$

where at any point  $C/C_0$  is the ratio of a component concentration to its original concentration,  $m/m_0$  is the fraction of steam condensed and  $K$  is the distribution coefficient of the component between steam and water ( $C_s/C_w$ ). The same equation for isotope notation is<sup>5</sup>

$$\delta - \delta_0 = 1000 [ (m/m_0) (\alpha - 1) - 1 ],$$

with  $\delta$  and  $\delta_0$  the present and original isotopic compositions (in permil) and  $\alpha$ , the fractionation factor between water and steam.

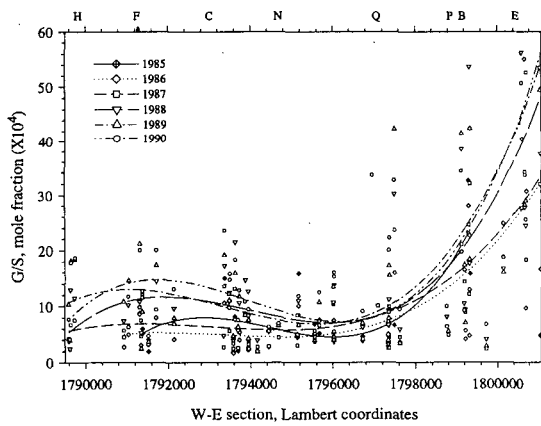


Figure 5. Gas to steam mole fractions presented as in Figure 3.

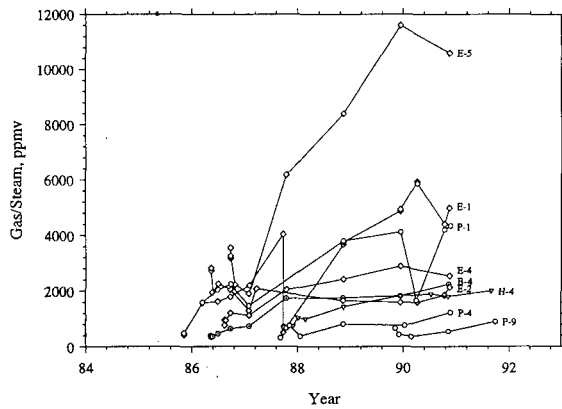


Figure 6. Changes with time of gas concentrations (in ppm by volume) for steam at the margins of the NCPA field (H, P, B and E wells).

The most easily demonstrated effects of this condensation process in the NCPA field are enrichment of marginal steam in gas ( $CO_2$ ) and depletion in oxygen-18. Later discussion of isotopic compositions describes the lower  $^{18}O$  composition of steam from H and E wells on the field margins.

High gas at the E, S and W margins of the field is shown in Eney et al.<sup>8</sup> The increase of gas generally and for wells near reservoir margins can be seen in Figures 5-8 in which the total gas is shown for the period from 1985 to 1991. These figures show gas contents for wells that may show influence of migration of marginal steam (B, E, H and P wells) or vaporization of injectate (N wells), or possibly influences from both process (C, F, and Q wells).

Steam from E and P wells clearly shows the effect of mixture with marginal steam (Figure 6). These wells (except E-1) produce the highest initial (1986) gas contents and (except E-2) have increased in gas with time generally

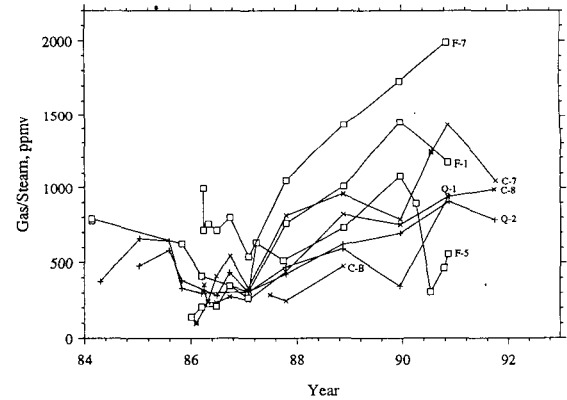


Figure 7. Changes in gas concentrations for steam from wells in the central NCPA field (except N wells).

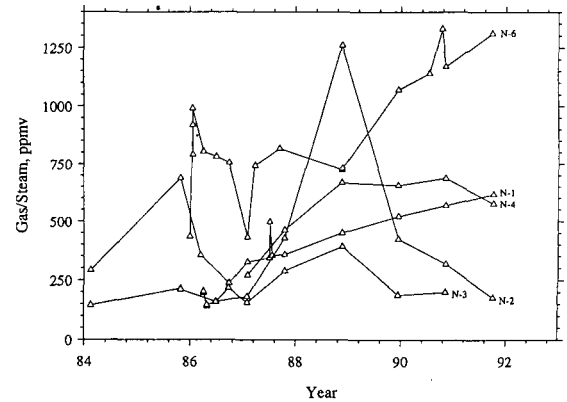


Figure 8. Changes in gas concentrations for steam from N wells.

starting in 1987. Wells E-5, E-1 and P-1 produce the highest gas of the field (to 12000 ppmv) and are nearest to the field margin. Steam from well H-4 on the western margin, which (along with E well steam) was originally low in  $\delta^{18}\text{O}$ , has moderately high gas relative to most wells but much lower than for E wells.

Steam from C, F, and Q wells has somewhat higher gas contents than that from N wells and much lower gas than steam from field margins (Figure 7). Most steam in this group shows large increase in gas after early 1987, similar to that for marginal steam. Some steam from C and F wells increased greatly in  $\delta\text{D}$  during the 1989-90 injection experiment in the low pressure area in which most condensate was injected into well C-11. This experiment probably produced the drop in gas (along with increases in  $\delta\text{D}$ ) observed in F-1 and F-5 steam after 1989 and later in C-7. The decrease in gas content of most steam before 1987 is probably due to dilution of reservoir steam by the continued vaporisation of reservoir liquid. In 1987 this process stopped or slowed markedly and gas content of steam increased.

Steam from N wells has the lowest gas of the NCPA field (Figure 8). This is probably due both to the position of N wells at the center of the field and to gas dilution from vaporization of injectate. Well N-6 steam has shown a rapid increase in gas (but only to 1260 ppmv) and may receive less injection steam. Steam from wells N-1 through N-4 generally has gas contents below 750 ppmv, and has not shown rapid increase in gas. These wells are evidently receiving enough injectate to stabilise gas contents of the produced steam.

### TRACING USING ISOTOPES

Isotopes have been frequently used in tracing injection return in steam fields. Studies of injection in a low pressure area of the SE Geysers shared by NCPA, Calpine and Unocal have demonstrated substantial increases in steam flow and reservoir pressure.<sup>10</sup> Isotopic data were used as tracers in this and other studies to estimate the quantity of steam generated from evaporation of injected condensate.<sup>17,1,2,4,11</sup>

Steam condensate from cooling towers is enriched in oxygen-18 and deuterium because these isotopes fractionate strongly into liquid at lower temperatures. This fractionation is an open system or Rayleigh process and follows the equation

$$\delta = \delta_0 + 1000 \left( \frac{m}{m_0} \right) \left( \frac{1}{\alpha} - 1 \right),$$

in which  $\delta_0$  and  $\delta$  are the initial and final isotope compositions,  $m/m_0$  is the fraction of condensate remaining after evaporation and  $\alpha$  is the fractionation factor. The derivation of this equation follows that given for steam condensation in D'Amore and Truesdell.<sup>5</sup> At NCPA cooling towers there is about 30% liquid remaining after evaporation at an average temperature of 70°C, and the expected  $\delta\text{D}$  change of the condensate is +50 permil, close to the observed difference between produced steam and injectate.

Isotope changes for other temperature and residual liquid fractions are given in Table 2.

Table 2. Change in  $\delta\text{D}$  for open-system, isothermal evaporation at temperatures from 40 to 100°C and fractions of residual liquid from 0.5 to 0.2.

Liquid Fraction	Temperature °C			
	40	60	80	100
0.5	42	32	25	19
0.4	56	42	33	25
0.3	74	56	44	34
0.2	100	76	59	45

The effects of evaporation on the injected condensate and the results of mixing steam from vaporized condensate with reservoir steam are shown in Figures 9 and 10 in which steam isotope compositions for 1985-86 are compared with those for 1990. In 1985-86, some N and A wells were affected by condensate injection, while in 1990 this effect was felt strongly by F, C and N wells with a small effect for most other wells. F and C wells were intensively sampled during the injection experiment in the low pressure area (LPA)<sup>10</sup> and the results are prominent in the 1990 data (Figure 10). In 1990 only wells far from injection wells (some E and H wells) retained their original isotope compositions. A small number of 1990 steam samples from several areas show  $\delta\text{D}$  compositions lower than any in 1985-86. This could only be explained by entry of shallow, low-temperature (<220°C) steam or (less likely) deep, high-temperature liquid.

In Figures 11 and 12 changes in isotopic compositions (omitting the data for F and C wells from the LPA injection experiment) are shown on the cross-section used earlier. The fitted lines show the same increase in heavy isotopes in the east-central field after the 1989 start of the LPA injection experiment as in Figure 10. Except for this change (and an initial high  $\delta\text{D}$  analysis at the east margin)  $\delta\text{D}$  values are very similar across the field. This is not true of  $\delta^{18}\text{O}$  values which show (save one number) lighter oxygen at the field margins before the LPA experiment with an increase in  $\delta^{18}\text{O}$  in the west-central field for 1989 and 1990, similar to that observed for  $\delta\text{D}$ .

### DISCUSSION

As we have seen the gas and isotope chemistry of produced steam is far from uniform even in a restricted volume of the reservoir. The composition is affected by many factors. Differences in permeability, local existence of gas pockets or perched liquid and the pattern of fracture connection can cause neighboring wells to produce steam of different compositions. This study attempts to separate local effects from general influences by viewing the data across the field and over a period of time. The fits of the trend lines to the data are far from perfect but present a reasonably consistent picture.

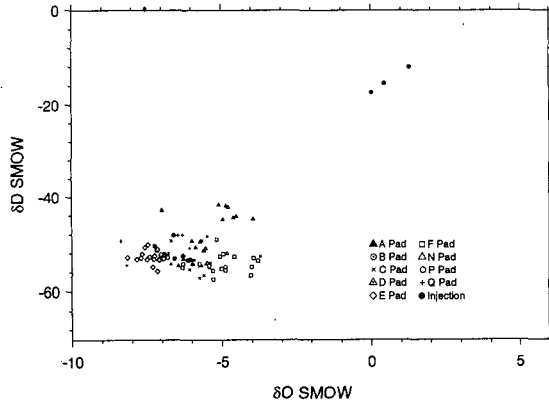


Figure 9. Isotope diagram showing values of  $\delta^{18}\text{O}$  and  $\delta\text{D}$  (in permil SMOW) for 1985-86 NCPA steam samples.

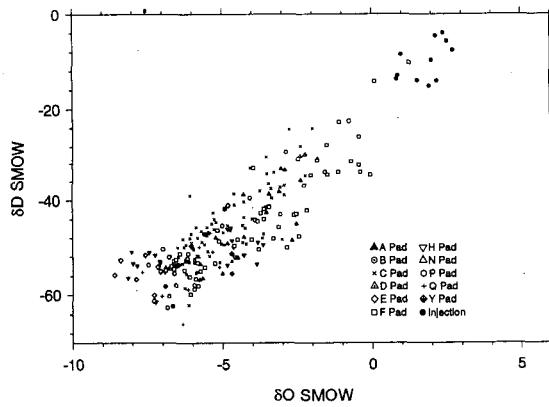


Figure 10. Isotope diagram (as Fig. 9) for 1990 NCPA steam samples.

The main influences on the gas and isotope compositions of steam from the NCPA field include: 1) original (pre-exploitation) gradients produced by the lateral movement of steam, resulting in the presence of high-gas steam at field margins; 2) injection of steam condensate which vaporizes and mixes with reservoir steam to dilute gases; and 3) a decrease in the availability of liquid in the reservoir which has decreased pressures and flows and increased gas.

Natural state gradients in gas and isotope chemistry result from lateral movement of steam from an upflow zone in the west-central part toward zones of condensation mainly to the south and east, with a smaller flow to the west. This movement was accompanied by partial condensation of steam along the flow path causing the residual steam to be enriched in gas and depleted in oxygen-18. This process was described for Larderello by D'Amore and Truesdell.<sup>5</sup> The resulting zones of condensation at the field margins contain sub-commercial quantities of high-gas steam. As pressures decrease during production, the marginal steam

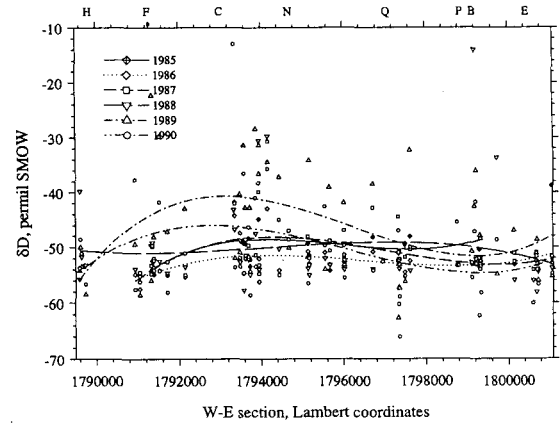


Figure 11. W-E cross-section of the NCPA field showing  $\delta\text{D}$  compositions of yearly steam samples and curves fitted to each year's points.

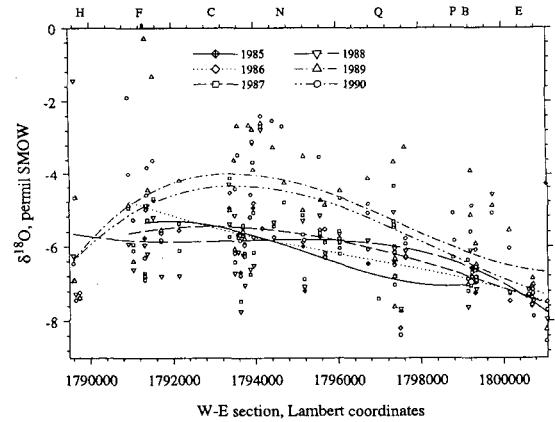


Figure 12. Yearly  $\delta^{18}\text{O}$  steam compositions presented as in Figure 11.

is drawn into producing zones causing an increase in gas concentrations. This effect may produce similar results to the general decrease of steam from vaporized liquid.

The second main influence on steam compositions is the injection of condensate in the center of the field. Injection greatly increases heavy isotope (D and  $^{18}\text{O}$ ) contents of steam fed in part from vaporization of the injectate. Injection has also lowered the content of gas in the center of the field, but this effect has been overshadowed by the general change in steam origins discussed next.

The third and most important influence on steam compositions is the sudden decrease in 1987 of the amount of steam formed by vaporization of liquid water in the reservoir. This is most clearly seen in the change in the gas concentration of steam from individual wells (Figures 6 and 7). Before 1987 steam from most central wells contained less than 1000 ppmv, and wells at the eastern margin contained less than 3000 ppmv. In early 1987, gas contents increased rapidly from minimum values to

maxima in 1990 (2 to 6 times greater). This change is also apparent in the increase of  $\gamma$  values after 1987 (Figure 4). The decrease in vaporization of easily available liquid in the reservoir has caused rapid decreases in pressure and steam flow throughout most of The Geysers field. This has important consequences for the continued productivity of the entire field and deserves further discussion.

From simple volumetric calculations it can be shown that the main source of steam from vapor-dominated reservoirs is the vaporization of liquid.<sup>14</sup> But although its presence is certain, the location and mobility of reservoir liquid is still a matter of debate. Static bottom-hole pressure and temperature conditions at The Geysers were initially close to saturation values based on data for pure steam and water.<sup>22,19</sup> This indicates that initial reservoir liquid in equilibrium with steam was thermodynamically equivalent to pure bulk liquid, neither highly saline nor bound to rock surfaces. Downhole static pressure measurements showed low "vaporstatic" gradients and surface heat flow was high even in the near absence of surface discharge.

These observations indicate that the reservoir contains steam and water, with steam flowing upwards in response to a pressure gradient caused by boiling at the bottom and condensation at the top, and liquid condensate flowing downwards by gravity. Thus the counterflow of steam and water acts as a "heat pipe".<sup>22</sup> The upward flow of steam must occur in large fractures but the location of liquid downflow is less certain. Liquid descent could occur in saturated matrix blocks, as liquid sheets on the surfaces of fractures or as a combination in which matrix flow is interrupted by fractures where sheet flow occurs. It is unlikely that downward flow of liquid is limited to matrix block porosity. Observed perched water and liquid in dead-end drill holes show that steam and bulk water coexist.<sup>20</sup>

Numerous modelling studies of mass and heat transfer in vapor-dominated reservoirs have demonstrated steam-water counterflow, but only Pruess and Narasimhan<sup>18</sup> indicate the location of liquid in the reservoir. These authors state that liquid is confined to matrix blocks because it will vaporize if it enters vertical fractures and cannot exist on fracture surfaces. This argument appears limited to very low-permeability rocks in which conductive heat flow is as rapid as fluid flow. For a natural system at equilibrium, thermodynamic arguments indicate that water in rock pores, water on fracture surfaces, and steam can coexist.

It seems likely that the 1987 increase in gas and decline in pressure and flow was due to a decrease in the availability of liquid water in the reservoir. Relating the production history of The Geysers to assumed distributions of reservoir steam and liquid is however difficult. Pressure could be maintained by producing steam from a large volume of interconnected fractures with minimal vaporization of liquid in each unit volume, or from a smaller production volume with extensive vaporization. Similarly, declining pressure could result from an increasing distance to the source of steam or from decreasing availability of nearby liquid.

The existence of well-defined chemical patterns inherited from the natural state in the long-exploited Larderello

field,<sup>5</sup> and in the geochemical results presented here suggest a local source of steam. In this view, rather than the exhaustion of a distant homogeneous source, the recent accelerated decline in pressure and flow at The Geysers resulted from the local disappearance of liquid held in easily accessible sites—liquid on surfaces of major fractures, in minor fractures opening upwards and perched liquid in structural traps. Continued production is from existing steam and vaporization of less-accessible reservoir liquid as well as from injected water, and possibly from under-exploited areas at the reservoir margins.

#### EXISTING STEAM AND LESS-ACCESSIBLE RESERVOIR LIQUID

Before 1987 much of the steam produced from The Geysers probably originated from vaporization of easily-accessible liquid. The fieldwide pressure decline after 1987 indicated that the amount of easily-accessible liquid had declined rapidly throughout the interconnected reservoir. Continued production is largely from existing steam and less-accessible liquid. This liquid is probably contained in limited matrix porosity (< 2% in Geysers graywacke; G.S. Bodvarsson, pers. com., 1992) and in small fractures of matrix blocks. The amount that this "matrix" liquid contributes to steam flow is indicated at least semi-quantitatively by the gas equilibria calculations (Figures 2-4). At the NCPA field vaporization of matrix liquid may still provide more than 75 or 80% of production from most wells. The rate at which the steam produced by vaporization of liquid within the matrix blocks can move to large fractures connecting to wells is limited by permeability. The Geysers cannot boil dry immediately (unlike a teakettle), but the rate of boiling may be limited. If the indication from gas geothermometry that most of present steam is from matrix blocks, then the amount of liquid water in the reservoir may be large but the production rate limited. This suggests that The Geysers will continue to be productive for a long time, but at a lower rate.

#### OTHER SOURCES OF STEAM

Pressure and flow declines at The Geysers are recognized as due to decrease in reservoir fluid rather than decrease in reservoir temperature or heat content.<sup>8,10</sup> In principle, near-original pressures and flows could be maintained if a quantity of liquid equal to the steam extracted could be recharged into the reservoir to preserve original liquid contents and distribution. However, water available for injection (at present essentially limited to surplus condensate from cooling towers) is inadequate to maintain reservoir liquid mass. Even if the quantity were sufficient, ideal redistribution of liquid in the reservoir is probably not possible until field pressures decline greatly. Injection of liquid into a reservoir produces local cooling. The now wet, but cooled, volume receiving the liquid can produce steam to the reservoir only if its steam pressure is higher than the reservoir pressure. If the local steam pressure is lower, then higher-pressure steam from the reservoir will condense in the cooled zones and, although a long term increase of reserve fluid occurs, the immediate effect will be a decrease in reservoir pressure and steam production.

However, if the reservoir has dried out and lost pressure, the effect of injection can be immediately beneficial. Although pressures have dropped substantially, rock temperatures are close to original values.<sup>8</sup> Liquid injected into the hot, under-pressured reservoir boils vigorously and an immediate increase in pressure and steam flow results. Injection of water into the low pressure area of the SE Geysers and the Valle Secolo area of central Larderello has demonstrated this effect.<sup>1,2,10</sup> Steam flow to wells increased greatly and it was shown from isotopic and gas compositions that nearly all water injected was produced as steam. Other factors that influence the expected benefits of injection have been discussed by Cappetti et al.<sup>3</sup> Injection of increased amounts of liquid piped from outside the field to augment condensate injection increases the necessity of understanding injection mechanisms.

Recovery of steam from outside the drilled field may not be a major source of steam but the high gas content of this steam may require changes in plant design and field management. Gas contents increase toward the margins of the field over most of the center and south Geysers.<sup>13,21</sup> In the development of The Geysers it was assumed that the margin of the field was indicated by the limit of productive wells and that steam was locally derived and would have more or less constant gas contents. As a result the gas handling abilities of power plants designed for conditions at the start of production may not be adequate for higher gas steam from field margins and that resulting from reservoir liquid decline. Now, when production from the central field has decreased, entry of marginal steam may be useful although changes in power plants will be necessary. In any case there is little choice. The rapid increases in gas in steam from wells near the field margins show that steam from the undrilled areas is being captured.

Finally it appears from the geochemical study that there will be continued long term production of steam from the NCPA field at a stable rate lower than the maximum observed in the 1980s. The field will also benefit immediately from injection in the lower-pressure, hot area in the west central part of the field. Contributions from marginal steam may require plant modification but will increase total steam production.

#### ACKNOWLEDGMENTS

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