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EFFECTS OF NATURAL RECHARGE ON GAS COMPOSITION IN THE LARDERELLO - CASTELNUOVO AREA

Franco D'Amore*, Romano Celati*, Claudio Calore*, Rino Bertrami**

*CNR-Istituto Internazionale per le Ricerche Geotermiche
PISA, Italy

**ENEL-Unità Nazionale Geotermica
PISA, Italy

ABSTRACT

A study of the temporal behaviour of gas composition in the Larderello-Castelnuovo area shows that this behaviour varies, depending on whether the wells are affected or not by natural recharge. Where no natural recharge exists, gas composition seems to be governed by chemical equilibria. The recharge water, and the steam it produces, mix with the fluid already existing in the reservoir. At Larderello (far from absorption areas) the gas composition resulting from this mixing does not undergo further changes by chemical reactions. This is due either to a lack of reactivity where there is no liquid phase or to an ineffective fluid-rock interaction. At Castelnuovo (close to absorption areas) the H_2S and CH_4 contents in the gas have gradually decreased with the increase in recharge effects. The decrease in H_2S can be attributed to dissolution in liquid water and oxidation. Various hypotheses have been forwarded for the methane. The correlation existing between CH_4 and N_2 concentrations, even when the methane decreases in the areas affected by recharge, suggests that CH_4 may be governed by more than just the Fisher-Tropsch reaction.

INTRODUCTION

In an earlier paper (Calore et al.,1982) the spatial and temporal variations in gas/steam ratio and the isotopic composition of the steam were studied in the Larderello-Castelnuovo area. This study showed that fluid composition in these zones of the field is mainly controlled by a mixing between the fluid originally present in the reservoir and recent meteoric waters. The areas affected by natural recharge were also gradually expanding. This paper deals with the variation in uncondensable gas composition in the area affected by natural recharge. A comparison is also made with fluid composition in areas unaffected by this phenomenon.

FLUID COMPOSITION IN THE LARDERELLO-CASTELNUOVO AREA

H_2 and H_2S concentrations in the uncondensable gas are plotted in Figs.1 and 2 versus gas/steam ratio. The evolution with time of gas/steam ratio is different in the wells unaffected by recharge (D'Amore & Truesdell, 1979; D'Amore et al.,1981; D'Amore et al.,1982) compared to wells affected by this phenomenon (Calore et al.,1982). In the latter case the typical trend exhibits strong decreases in gas/steam ratio within a relatively short time, accompanied by a shift in $\delta^{18}O$ towards more negative values and, in many cases, by the appearance or increase of the tritium content in the steam. This behaviour has been attributed to a mixing between the steam originally present in the reservoir and the steam formed by the vaporization of the recharge water containing tritium, with very negative $\delta^{18}O$ and almost no gas.

In the zones unaffected by recharge of recent meteoric waters, the H_2 and H_2S contents in the steam (Figs.1 and 2) vary inversely with the gas/steam ratio (D'Amore et al.,1982). The bands shown in these Figures include the Larderello wells with estimated reservoir temperatures in the 240°-260°C range. The trend is the same for different wells and for each single well in different periods, whether the gas/steam ratio increases or decreases.

In the wells affected by recharge, the percentage of H_2 in the uncondensable gas remains more or less constant with the decrease in gas/steam ratio, both at Larderello and Castelnuovo. This means that the H_2/H_2O ratio varies proportionally with the gas/H_2O ratio, as if the original steam was simply diluted by a gas-free vapour. The H_2S content in the uncondensable gas exhibits a different trend at Larderello from that at Castelnuovo. In the former area it remains

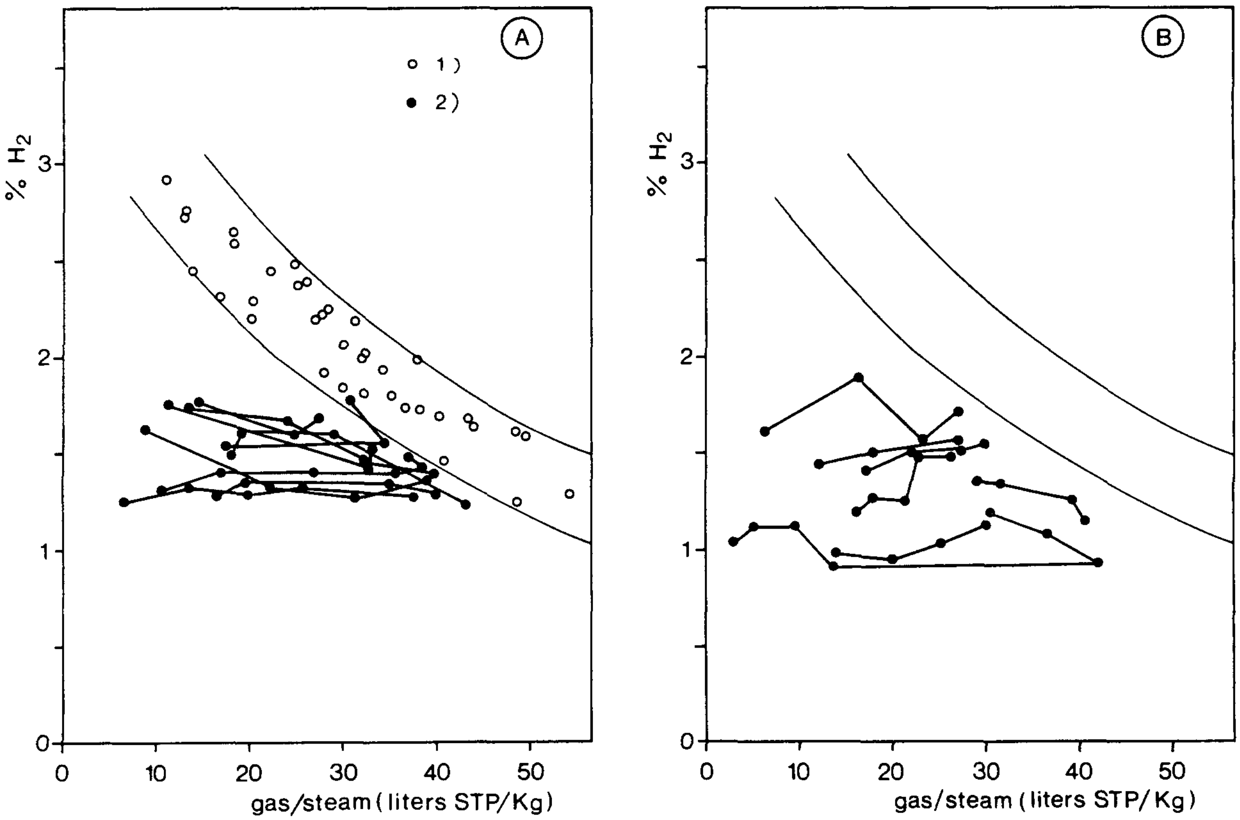

Figure 1. H_2 (molar percent in the uncondensable gas) versus gas/steam ratio. A) Larderello area; B) Castelnuovo area. 1)wells unaffected by recharge; 2)wells affected by recharge. The band in Fig. 1A is shown in Fig.1B for comparison.

practically constant, whereas in the latter it shows a strong decrease with the decrease in gas/steam ratio. Figure 3 shows the zone of the field for which there is no evidence of recharge effects and the zones, affected by recharge, where the H_2S content remains constant (Larderello) or decreases (Castelnuovo).

The percentage of CH_4 in the uncondensable gas shows no correlation with the gas/steam ratio in the areas unaffected by recharge (Table 1); on the other hand, its areal distribution in that area is well defined, and similar temporal trends are shown by groups of neighbouring wells. Figure 4 illustrates the CH_4 trend in the Larderello area before recharge had any effect on the zone. The Castelnuovo area is excluded from this map as there were not enough data available to define any temporal behaviour before the effects of recharge. Two zones can be distinguished in Fig.4 in which the CH_4 molar percentage remained constant with time, at values of 0.2-0.5 and 1-2 respectively. In the intermediate zone the %CH_4 increased considerably (as much as 100%) before recharge effects became evident.

In the Castelnuovo area the methane content in the gas showed a well-defined areal distribution during the period 1940-1950. It increased regularly from about 0.1 on the southernmost margin to 1-1.5 on the northern margin.

Recharge produced a general strong decrease in the CH_4/gas ratio at Castelnuovo (Table 2).At Larderello the most conspicuous decreases caused by recharge occurred in the wells that initially had the highest percentages of CH_4, whereas in the wells with the lowest initial values the latter remain constant or decrease very little. It is difficult to distinguish any trend in the case of the lowest values, however, as the analytical errors are of the same order of magnitude as the variations.

A general correlation was noted throughout the whole Larderello field between CH_4 and N_2.This correlation is shown by D'Amore et al.(1983). Figure 5 shows that this correlation holds even when %CH_4 decreases in the wells affected by recharge.

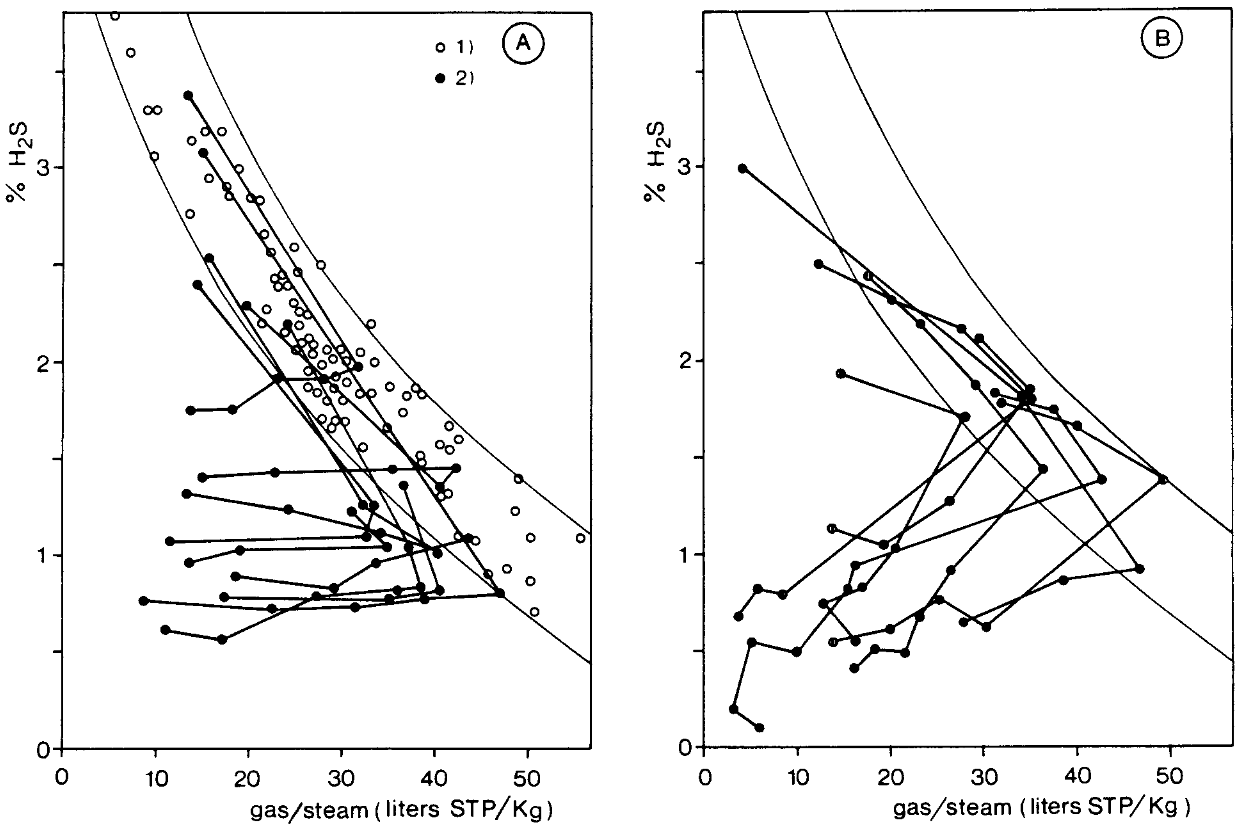

Figure 2. H_2S (molar percent in the uncondensable gas) versus gas/steam ratio. See Fig.1 for symbols.

DISCUSSION

Fluid composition in zones unaffected by recharge

According to the conceptual model of D'Amore & Truesdell (1979), different parts of the reservoir with different fluid compositions and liquid saturations can be distinguished in a vapour-dominated system. Temporal variations in the gas/steam ratio have been explained by the fact that expansion of the drainage volume is accompanied by a temporal variation in the contribution to production of various zones of the reservoir. D'Amore et al.(1982) have shown that H_2 and H_2S contents in the fluid are governed by the following two equilibria in adequate redox conditions (oxygen and sulphur fugacity):

$$H_2O = H_2 + \frac{1}{2}O_2 \qquad (1)$$

$$H_2S = H_2 + \frac{1}{2}S_2 \qquad (2)$$

Equations (11) and (17) in D'Amore et al.(1982) have been modified, for oxygen fugacity, according to D'Amore & Gianelli (1984):

$$\log f_{O_2} = -3.808 - 13708.3/T - 2.075 \times 10^6/T^2 \qquad (3a)$$

and, for sulphur fugacity, according to the following empirical correlation (valid for the Larderello field):

$$\log f_{S_2} = 5.706 - 9767/T \qquad (3b)$$

These equations can be rewritten as:

$$\log\left(\frac{n_{H_2}}{n_{H_2O}}\right)_{WH} = \log\left(\frac{n_{H_2}}{n_{gas}}\right)_{WH} + \log\left(\frac{n_{gas}}{n_{H_2O}}\right)_{WH}$$

$$= 4.556 - 5922/T + 1.038 \times 10^6/T^2 + \log\left(y + \frac{1-y}{B_{H_2}}\right) \qquad (4)$$

$$\log\left(\frac{n_{H_2S}}{n_{H_2O}}\right)_{WH} = \log\left(\frac{n_{H_2S}}{n_{gas}}\right)_{WH} + \log\left(\frac{n_{gas}}{n_{H_2O}}\right)_{WH}$$

$$= 7.539 - 6410.75/T - 0.79 \log T + 1.038 \times 10^6/T^2 + \log\left(y + \frac{1-y}{B_{H_2S}}\right) \qquad (5)$$

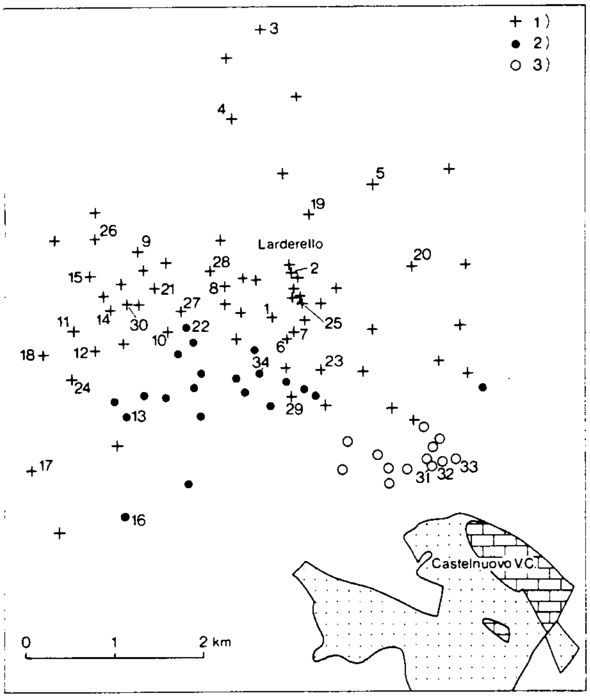

Figure 3. Location of wells with different evolution of $\%H_2S$ in the uncondensable gas. 1) Wells unaffected by recharge; 2) wells affected by recharge, with constant $\%H_2S$; 3) wells affected by recharge, with decreasing $\%H_2S$.

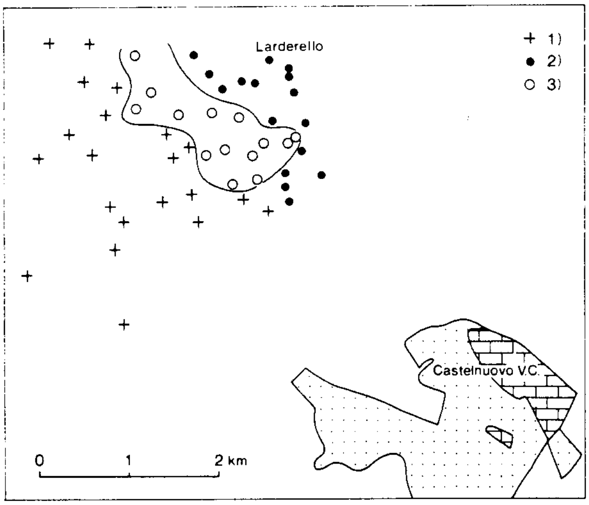

Figure 4. Areal distribution and temporal evolution of CH_4 (molar percent in the uncondensable gas) for the Larderello wells before recharge effects became evident. 1) $\%CH_4$ constant in the range 0.2-0.5; 2) $\%CH_4$ constant in the range 1-2; 3) $\%CH_4$ increasing with time towards values of 1-2.

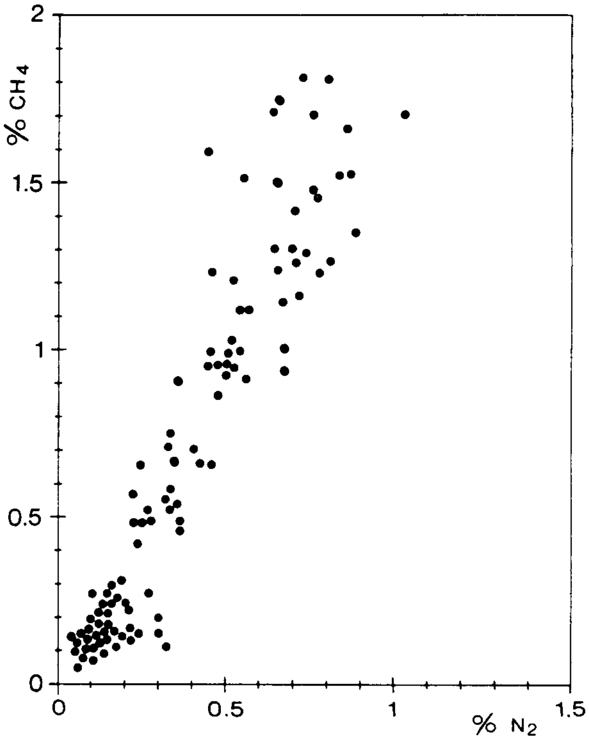

Figure 5. Correlation between $\%CH_4$ and $\%N_2$ in the uncondensable gas from nine wells affected by natural recharge.

where n is the number of moles, T is temperature in °K, B_i is the distribution coefficient of the species i between steam and liquid water, and y is the molar fraction of steam in the steam-water mixture in the reservoir. These equations are valid in the following conditions (D'Amore & Celati, 1983):

- the fluid produced comes from one two-phase source in chemical and phase equilibrium;
- the two-phase fluid present in the reservoir is transferred to the well with no chemical reactions and no gain or loss of mass, although it may undergo phase changes (liquid boiling).

From the above equations it follows that the H_2 and H_2S concentrations in the gas vary inversely with the gas/steam ratio (for constant T and y), and increase as a function of T and y. The field data shown in Figs. 1 and 2 are clustered within relatively narrow bands for two reasons:

a) the selected wells have rather uniform reservoir temperatures;
b) all other conditions being equal (temperature, fluid composition in the steam phase, etc.), the gas/steam ratio increases with y.

Table 1 gives fluid composition for some wells at Larderello during a period in which their gas/steam ratio remained more or less constant. Also shown are estimated reservoir temperatures based on production data and in-hole logs. In order to verify whether eqs.(4) and (5), at these temperatures, are consistent with fluid analyses, we calculated y for each well from eqs.(4) and (5) (y_H and y_S). The y values obtained are plausible, and there is usually a satisfactory agreement between the y values from these two equations.

As regards CH_4, assuming that the Fisher-Tropsch reaction

$$CO_2 + 4H_2 = CH_4 + 2H_2O \qquad (6)$$

is in equilibrium in a two-phase system, and that the hypotheses made for eqs.(4) and (5) are valid, then:

$$\log\left(\frac{n_{CH_4}}{n_{gas}}\right)_{WH} = \log\left(\frac{n_{CO_2}}{n_{gas}}\right)_{WH} + 4\log\left(\frac{n_{H_2}}{n_{H_2O}}\right)_{WH} + 0.26 + 5227/T - 4\log\left(y + \frac{1-y}{B_{H_2}}\right) - \log\left(y + \frac{1-y}{B_{CO_2}}\right) + \log\left(y + \frac{1-y}{B_{CH_4}}\right) \qquad (7)$$

Equation (7) does not satisfactorily explain the variations in CH_4/gas ratio observed in the area. According to the y values calculated from eq.(7) (y_{FT} in Table 1) the low CH_4/gas ratios should be tied to high y values. The y values obtained from eq.(7) in this case are, however, systematically higher than those obtained from eqs.(4) and (5). Note that eqs.(4), (5) and (7) are valid only for one two-phase source of fluid. Following the model of D'Amore & Truesdell (1979), however, the fluid may come from various zones of the reservoir with possibly different fluid compositions and physical characteristics. The y value obtained when assuming a single source is still meaningful in the case of various sources, if the latter have the same temperature and steam phase composition. In this case the calculated term $y + \frac{(1-y)}{B}$ represents the weighted average of these terms of the various sources.

The correlation between CH_4 and N_2 at Larderello cannot be explained by considering reaction (6) as the only possible equilibrium controlling methane concentration. If at least some of the methane derives from the products of decomposition of organic nitrogenous compounds (C, N_2, H_2), on the other hand, then CH_4 and N_2 could be linked together in the same chemical reaction. D'Amore et al.(1983) have considered the reaction:

$$C + \frac{1}{2}N_2 + 7/2\ H_2 = CH_4 + NH_3 \qquad (8)$$

In the same hypotheses on chemical equilibria and the boiling process formulated for reactions (1),(2) and (6), we obtain:

$$\log\left(\frac{n_{NH_3}}{n_{H_2O}}\right)_{WH} + \log\left(\frac{n_{CH_4}}{n_{H_2O}}\right)_{WH} - \frac{7}{2}\log\left(\frac{n_{H_2}}{n_{H_2O}}\right)_{WH} - \frac{1}{2}\log\left(\frac{n_{N_2}}{n_{H_2O}}\right)_{WH} = 0.14 + 2737.5/T + \log\left(y + \frac{1-y}{B_{NH_3}}\right) + \log\left(y + \frac{1-y}{B_{CH_4}}\right) - \frac{7}{2}\log\left(y + \frac{1-y}{B_{H_2}}\right) - \frac{1}{2}\log\left(y + \frac{1-y}{B_{N_2}}\right) \qquad (9)$$

The y values calculated from eq.(9) for the field data (y_{CN} in Table 1) are generally in good agreement with those calculated from the H_2 and H_2S concentrations (eqs.(4) and (5)).

The temporal increases in CH_4/gas ratio observed at Larderello occurred in a zone lying between the central zone of Larderello, with a relatively high CH_4/gas ratio, and the south-western zone, with a low CH_4/gas ratio. Since several sources at varying depths contribute to fluid production, we may assume that the contribution from the deepest sources gradually increased with time in the zone with an increasing CH_4/gas ratio. Fluid composition thus gradually came closer to that in the adjacent central zone, where the contribution from depth was already quite large (D'Amore & Truesdell, 1979).

Fluid composition in the zones affected by recharge

At Larderello the constant values of H_2 and H_2S (Figs.1A, 2A) are indicative of a mixing in the steam phase with no further changes due to chemical reactions.

The recharge water during its flow towards the centre of the field is assumed to be totally vaporized after a rather short distance. The steam produced in this way has probably a low gas content. During its flow within the field this 'recharge steam' mixes with the steam and gas rising from the deeper boiling zones, and the resulting fluid is, in part, extracted through the productive wells along this flow-path. The gradients observed in the gas/steam ratio and in isotopic composition (Calore et al.,1982) can be ascribed to this process. This gradual mixing process does not change the H_2 and H_2S concentrations in the gas, since these concentrations are almost uniform in the deep steam all along the flow-path, as indicated by the H_2 and H_2S concentrations observed before recharge effects became important in the area. This is not the case for methane, whose concentration was not uniform in the area. The lowest values occur in the southern zone, i.e. in the first part of the flow-path of the recharge fluid. Thus the mixing produced a decrease in CH_4 concentration in the gas of the wells furthest from the recharge areas, which had a high CH_4 content before mixing.

When an excess of water is present as steam in the fluid resulting from the mixing, the equilibria considered in the system unaffected by recharge generally no longer hold for the mixture. A new equilibrium is apparently not attained for H_2. This may be the result of the lack of a liquid phase, or of the limited rock volumes capable of interacting with the fluid: if the fluid flows prevalently through a small number of large fractures, then the contact surface will be small and the buffer capacity of the rock next to the walls of the fracture may be used up or covered. Note that in the latter case equilibrium (1) may be attained with no detectable change in $\%H_2$, but with an increase of f_{O_2}. The mixing produces a decrease in H_2/H_2O ratio with respect to the original fluid, and f_{O_2} may increase to a new equilibrium value by dissociation of a minimum amount of H_2O, being $f_{O_2} << f_{H_2}$. This hypothesis could be verified by independent determination of f_{O_2} (e.g. by CO/CO_2 ratio measurements). With regard to reaction (2), the dilution phenomenon does not affect the H_2/H_2S ratio in the gas, so that f_{S_2} should remain constant.

Reaction (6) in the steam phase, on the other hand, could produce important variations in gas composition, as the fluid contains appreciable quantities of all the species involved in this reaction. A decrease in H_2/H_2O ratio might lead to the decrease in CH_4/CO_2 ratio observed in several wells. However, reaction (6) does not explain the simultaneous decrease in N_2/gas ratio.

At Castelnuovo, which is the zone nearest the recharge area, fluid composition is probably affected by the presence of a large amount of liquid water in the reservoir.

H_2S is probably the gas component most affected by the presence of liquid, as it has a high solubility and can be quickly oxidized to HSO_4^-. Very young infiltration waters can be expected to retain a certain oxidizing capacity. Note that H_2S could equilibrate with HSO_4^- in the presence of $CaCO_3$ and $CaSO_4$ (with $0.7\%H_2S$ in the gas and a gas/steam ratio of 5 litres STP/kg as typical values of the area), with $\log f_{O_2} = -38.5$ at 200°C. This is still a very low value (the value expected in a water-rock equilibrium at the same temperature is $\log f_{O_2} = -42$).

There is no indication of any trend to restore the previous H_2/H_2O ratio in the fluid when the gas/steam ratio decreases, as the majority of the Castelnuovo data indicate an approximately constant concentration of H_2 in the gas. This does not exclude that eq.(1) re-equilibrates with a higher oxygen fugacity. Calculations made at the same f_{O_2} considered for H_2S oxidation reproduce the observed H_2/H_2O ratio with plausible low values of y.

More processes can be considered possibly responsible for the strong decrease in $\%CH_4$ in the gas.

1) Partial re-equilibration after mixing. At Castelnuovo the mixing of 'original steam' and recharge fluid occurs in the presence of a liquid phase which may facilitate chemical reactions. If reaction (6) takes place, the decreased H_2/H_2O ratio entails a strong decrease in $\%CH_4$ in the gas. However, once again reaction (6) cannot explain the simultaneous decrease in CH_4 and N_2. Equation (9), for fixed temperature and y can be re-written as:

$$\log\left(\frac{n_{CH_4}}{n_{gas}}\right)_{WH} = 7\log\left(\frac{n_{H_2}}{n_{gas}}\right)_{WH} - \log\left(\frac{n_{CH_4}}{n_{N_2}}\right)_{WH}$$

$$+ 4\log\left(\frac{n_{gas}}{n_{H_2O}}\right)_{WH} - 2\log\left(\frac{n_{NH_3}}{n_{gas}}\right)_{WH} + \text{const.}$$

In the study area n_{H_2}/n_{gas} and n_{CH_4}/n_{N_2} are more or less constant, so that n_{CH_4}/n_{gas} should decrease with an increase in n_{NH_3}/n_{gas} and a decrease in n_{gas}/n_{H_2O}. A strong increase in n_{NH_3}/n_{gas} and a decrease in gas/steam ratio have actually been observed at Castelnuovo.

A complete re-equilibration appears unlikely in the upper parts of the reservoir, considering the fast circulation of recharge water, the imperfect mixing and the short time available for chemical reactions.

2) Variations in flow pattern. The fluid variations observed at Castelnuovo during exploitation suggest lateral fluid flow from the outer towards the central area. Increased contribution from the south-west zone to production in the central area of Castelnuovo must lead to a decrease in CH_4 in the gas, with minor changes to H_2 and H_2S. In fact, the south-west zone is characterized by very low concentrations of CH_4 and N_2, and H_2 and H_2S concentrations similar to the central zone. This process could also explain the simultaneous variation in CH_4 and N_2.

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Table 1. Averages of gas/steam ratios and major gas analyses from steam samples from Larderello wells before any recharge effects. Compositions are in mole percent of total dry gas. NH_3 is in ppm in the steam condensate. y_H , y_S , y_{FT} and y_{CN} are the molar fractions of steam in the steam-water mixture in the reservoir, computed from eqs.(4),(5),(7) and (9) respectively.

Well	Years	T_{res} °C	Gas/steam litres STP/kg	%H_2	%H_2S	%CH_4	%N_2	%CO_2	NH_3 ppm	y_H	y_S	y_{FT}	y_{CN}
1	70-76	250	29.8 ± 1.7	1.96 ± 0.14	1.91 ± 0.11	1.42 ± 0.10	0.74 ± 0.09	94.12 ± 0.50	130 ± 8	0.44	0.53	0.49	0.44
2	70-76	250	31.0 ± 0.8	2.06 ± 0.11	2.02 ± 0.15	1.32 ± 0.13	0.69 ± 0.06	93.95 ± 0.44	119 ± 19	0.48	0.58	0.54	0.51
3	71-77	260	51.0 ± 1.6	1.53 ± 0.06	1.38 ± 0.11	0.69 ± 0.02	0.60 ± 0.08	95.79 ± 0.19	177 ± 13	0.50	0.53	0.71	0.62
4	71-76	260	38.1 ± 0.8	1.76 ± 0.07	1.48 ± 0.07	1.93 ± 0.07	1.28 ± 0.07	93.56 ± 0.21	172 ± 16	0.43	0.42	0.47	0.40
5	70-76	240	51.8 ± 1.6	1.42 ± 0.12	1.37 ± 0.08	0.88 ± 0.04	0.69 ± 0.07	95.66 ± 0.21	197 ± 30	0.65	0.81	0.78	0.60
6	71-76	260	39.7 ± 1.5	1.77 ± 0.09	1.97 ± 0.10	1.52 ± 0.07	0.83 ± 0.05	93.92 ± 0.21	123 ± 22	0.45	0.60	0.52	0.50
7	71-76	260	40.5 ± 0.6	1.72 ± 0.10	1.98 ± 0.16	1.52 ± 0.04	0.90 ± 0.10	93.76 ± 0.39	121 ± 6	0.45	0.62	0.52	0.51
8	70-76	270	21.6 ± 0.6	2.49 ± 0.10	2.58 ± 0.14	1.38 ± 0.09	0.69 ± 0.04	92.85 ± 0.15	105 ± 11	0.29	0.33	0.37	0.38
9	71-76	250	25.4 ± 1.2	2.40 ± 0.08	2.34 ± 0.13	1.25 ± 0.07	0.71 ± 0.04	93.28 ± 0.17	157 ± 9	0.46	0.55	0.53	0.46
10	70-75	250	44.2 ± 1.2	1.61 ± 0.06	1.00 ± 0.05	0.43 ± 0.05	0.23 ± 0.02	96.71 ± 0.15	151 ± 15	0.54	0.40	0.81	0.65
11	70-76	240	49.8 ± 1.1	1.34 ± 0.10	0.87 ± 0.06	0.36 ± 0.02	0.14 ± 0.01	97.29 ± 0.09	138 ± 15	0.59	0.48	0.89	0.65
12	71-76	240	52.4 ± 1.5	1.31 ± 0.06	0.86 ± 0.06	0.33 ± 0.02	0.16 ± 0.02	97.33 ± 0.09	131 ± 21	0.61	0.51	0.93	0.71
13	71-76	240	32.2 ± 1.1	1.40 ± 0.06	1.08 ± 0.05	0.32 ± 0.02	0.15 ± 0.03	97.06 ± 0.07	307 ± 18	0.40	0.39	0.62	0.30
14	71-76	250	73.5 ± 2.0	1.07 ± 0.07	0.51 ± 0.05	0.26 ± 0.03	0.13 ± 0.01	98.03 ± 0.05	178 ± 16	0.59	0.34	1.0	0.70
15	73-77	250	84.1 ± 3.3	0.98 ± 0.04	0.46 ± 0.03	0.30 ± 0.06	0.17 ± 0.02	98.09 ± 0.08	177 ± 7	0.62	0.35	1.0	0.72
16	71-75	230	33.9 ± 1.2	1.49 ± 0.10	1.03 ± 0.10	0.19 ± 0.01	0.08 ± 0.01	97.22 ± 0.13	485 ± 29	0.52	0.44	0.89	0.35
17	71-76	260	19.6 ± 0.6	2.21 ± 0.06	2.02 ± 0.10	0.42 ± 0.03	0.13 ± 0.01	95.21 ± 0.15	293 ± 18	0.28	0.29	0.44	0.24
18	71-76	240	44.3 ± 1.2	1.38 ± 0.06	0.92 ± 0.05	0.30 ± 0.01	0.14 ± 0.03	97.27 ± 0.10	166 ± 11	0.54	0.45	0.85	0.56
19	70-76	250	32.1 ± 1.8	1.99 ± 0.17	1.99 ± 0.14	1.37 ± 0.08	0.80 ± 0.04	93.76 ± 0.33	168 ± 31	0.48	0.59	0.54	0.45
20	70-76	240	89.3 ± 5.8	1.02 ± 0.18	1.00 ± 0.09	1.20 ± 0.07	0.93 ± 0.03	95.84 ± 0.28	165 ± 12	0.80	1.0	0.88	0.75
21	70-76	240	25.2 ± 0.9	2.31 ± 0.09	2.03 ± 0.08	1.02 ± 0.07	0.53 ± 0.04	94.08 ± 0.20	129 ± 10	0.52	0.57	0.59	0.52
22	70-76	250	19.4 ± 0.6	2.78 ± 0.19	2.09 ± 0.11	0.87 ± 0.04	0.39 ± 0.05	93.88 ± 0.20	121 ± 9	0.41	0.36	0.51	0.47
23	71-76	240	46.8 ± 2.6	1.69 ± 0.11	1.29 ± 0.05	0.97 ± 0.05	0.54 ± 0.05	95.43 ± 0.29	155 ± 6	0.70	0.69	0.81	0.71
24	71-76	240	27.8 ± 1.0	1.96 ± 0.05	1.78 ± 0.05	0.83 ± 0.04	0.38 ± 0.02	94.97 ± 0.22	117 ± 21	0.48	0.56	0.58	0.50
25	71-76	250	37.2 ± 2.5	1.71 ± 0.06	1.55 ± 0.06	0.97 ± 0.10	0.53 ± 0.06	95.24 ± 0.21	182 ± 15	0.48	0.54	0.59	0.45
26	70-76	250	46.0 ± 4.0	1.44 ± 0.10	0.98 ± 0.15	0.64 ± 0.05	0.36 ± 0.05	96.55 ± 0.20	172 ± 7	0.50	0.41	0.69	0.51
27	70-76	260	22.1 ± 0.5	2.56 ± 0.17	2.28 ± 0.09	1.11 ± 0.08	0.51 ± 0.04	93.54 ± 0.21	108 ± 14	0.36	0.38	0.46	0.45
28	71-76	250	30.3 ± 0.9	2.08 ± 0.19	1.69 ± 0.11	1.17 ± 0.03	0.62 ± 0.05	94.38 ± 0.34	152 ± 25	0.47	0.47	0.55	0.46
29	70-75	240	28.0 ± 0.5	2.51 ± 0.15	2.26 ± 0.11	1.68 ± 0.08	0.75 ± 0.16	92.78 ± 0.26	115 ± 12	0.62	0.72	0.63	0.63
30	71-76	270	26.3 ± 1.4	2.23 ± 0.15	1.84 ± 0.11	0.90 ± 0.03	0.47 ± 0.03	94.51 ± 0.23	153 ± 13	0.32	0.29	0.44	0.35

Table 2. Variations in fluid composition with time for some wells affected by recharge

Well	Year	Gas/steam litres STP/kg	$\%H_2$	$\%H_2S$	$\%CH_4$	$\%N_2$	$\%CO_2$	NH_3 ppm
31	1948	35.4	1.60	2.80	1.16	0.68	93.76	180
	1965	9.4	1.70	0.82	0.19	0.13	97.16	144
	1982	2.5	1.34	0.49	0.07	0.10	98.00	119
32	1948	44.9	0.91	1.45	0.85	0.54	96.25	310
	1965	15.8	0.98	0.95	0.25	0.15	97.70	270
	1973	4.0	1.18	0.54	0.12	0.13	98.00	137
33	1948	49.6	0.74	1.40	0.76	0.50	96.60	370
	1966	26.0	1.12	0.77	0.30	0.13	97.69	283
	1979	18.0	1.01	0.56	0.25	0.16	98.01	186
34	1966	31.0	1.93	1.93	1.60	0.43	94.11	119
	1976	21.4	2.48	1.90	1.13	0.51	93.98	177
	1981	13.7	2.20	1.75	0.85	0.47	94.73	140
16	1973	34.5	1.32	1.12	0.20	0.10	97.27	468
	1978	18.9	1.67	1.10	0.07	0.03	97.12	408
	1981	13.5	1.55	0.97	0.06	0.05	97.35	350