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GEOCHEMICAL EVIDENCE OF NATURAL RECHARGE IN LARDERELLO AND CASTELNUOVO AREAS (+)

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ABSTRACT

The spatial variations of the isotopic composition of the fluid in Castelnuovo and the southern zone of Larderello were, in the early 1970s, interpreted as the effects of a natural recharge.

It was subsequently noted that this distribution might be the result of the condensation process, at least in areas with no tritium. In order to further investigate this problem a study was undertaken of the spatial and temporal variations in the gas/steam ratio and in the isotopic composition.

Preliminary interpretation of the results of this study confirms that the evolution of fluid composition in this area is due to a mixing between the fluid originally present in the reservoir and recent meteoric waters. The area affected by natural recharge is, moreover, in continual expansion.

INTRODUCTION

The areal distribution of the chemical and isotopic composition of the fluid in the Larderello geothermal field is considered to be governed prevalently by some physical processes occurring in the reservoir, such as steam condensation, vaporization of liquid water and recharge from lateral aquifers (Celati et al., 1973; Panichi et al., 1974; Petracco and Squarci, 1976; D'Amore et al., 1977; Truesdell and Nehring, 1978; Mazor, 1978; D'Amore and Truesdell, 1979; Calore et al., 1980; D'Amore et al., 1981).

D'Amore and Truesdell (1979) observed that the spatial variations in isotopic composition and in some chemical species, in the northern area of the Larderello field, could be ascribed to a lateral flow of steam from central boiling or upflow zones towards the margins of the system. During this movement the steam undergoes a progressive condensation, with enrichment in the more volatile chemical components, depletion in the more soluble, and simultaneous depletion in ^{18}O.

With regard to the south and south-eastern areas of the Larderello field, Celati et al. (1973) and Panichi et al. (1974) suggested that the tritium present in some peripheral wells, and the relatively more negative $\delta^{18}O$ values spread over a wide zone of the field near absorption areas, were due to a mixing between steam of deep origin and steam deriving from recent meteoric waters. Although the influence of recharge was evident in the wells with high tritium contents, the isotopic data alone did not suffice to distinguish between a mixing and condensation model (D'Amore and Truesdell, 1979).

During the period 1980-82 this problem was further investigated by systematic isotopic analysis of samples from the Larderello and Castelnuovo areas, and by study of the spatial and temporal variations in both the gas/steam ratio and isotopic composition.

TEMPORAL VARIATIONS IN $\delta^{18}O$, TRITIUM AND GAS/STEAM RATIO

Figures 1 and 2 show the areal distribution of $\delta^{18}O$ and gas/steam ratio in the periods 1968-72 and 1978-82, for Castelnuovo area and the southern part of the Larderello area. The following considerations can be made:
- the areas with the most negative $\delta^{18}O$ values generally have the lowest gas/steam ratios;
- the gas/steam ratio and $\delta^{18}O$ have decreased greatly during the last 10 years in these same areas. Taking the curves of 10 and 20 l STP/kg

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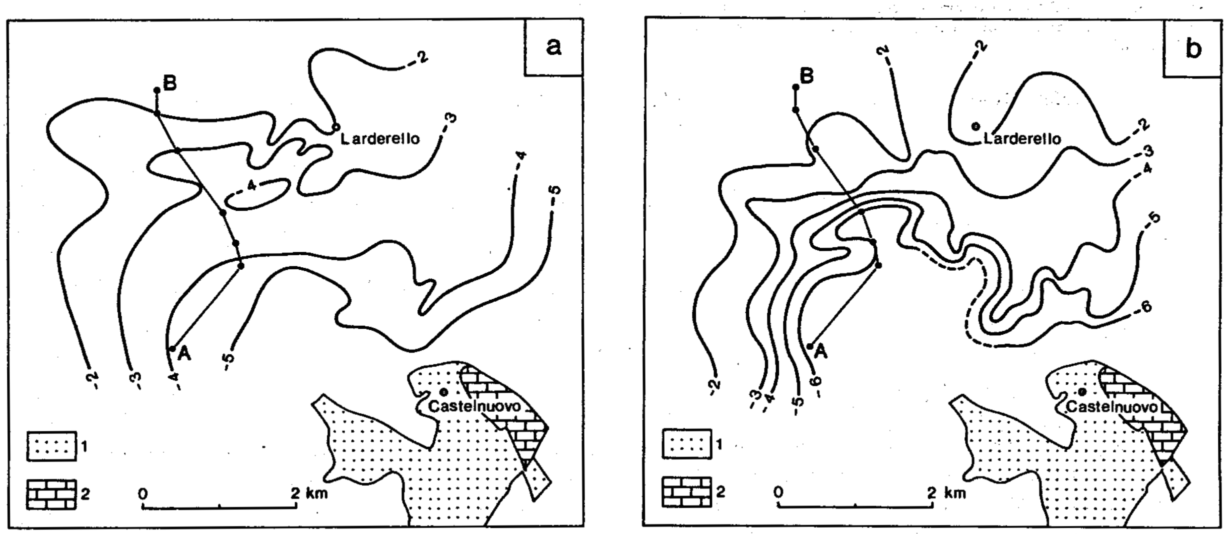

Figure 1. Areal distribution of $\delta^{18}O$ in the Castelnuovo and southern Larderello areas. a) data of 1968-72 period; b) data of 1978-82 period; A-B) section represented in Fig.3; 1) outcrop of "macigno" sandstone; 2) outcrop of prevalently brecciated dolostones.

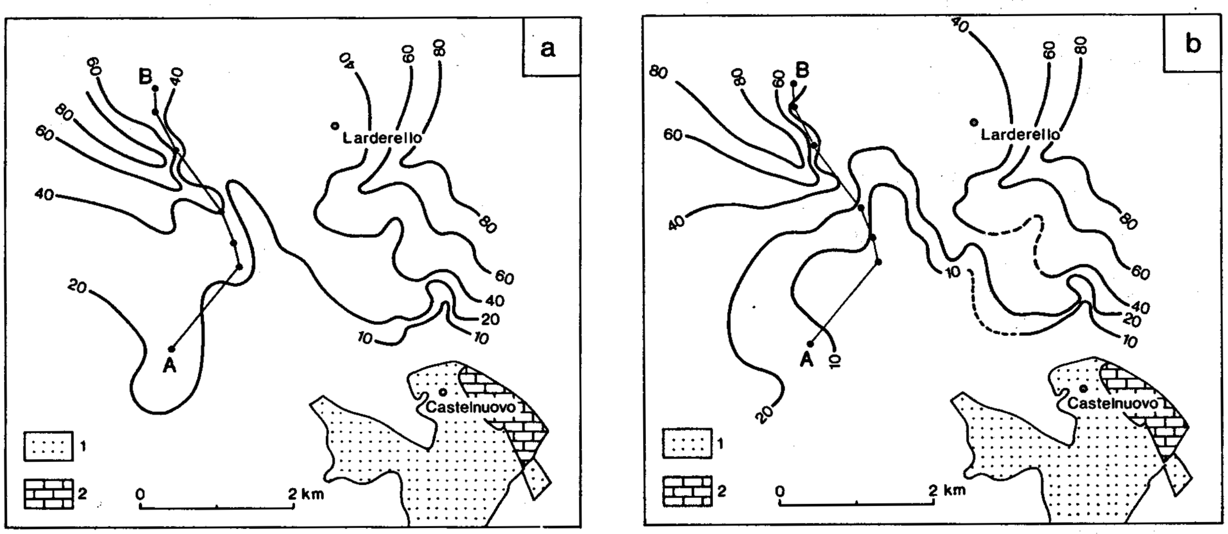

Figure 2. Areal distribution of the gas/steam ratio in the Castelnuovo and southern Larderello areas. For legend see Fig.1.

as reference for the gas/steam ratio, and the -5 and -6 curves for $\delta^{18}O$, it is evident that the maximum variations occur prevalently along a S-N and a SE-NW direction;

- the variations in the same period were not as conspicuous in the areas already characterized by high gas content and relatively more positive $\delta^{18}O$ values.

The temporal variations in $\delta^{18}O$ and gas/steam ratio are more evident in Fig.3, which shows the trends for the two periods in question along the section A-B (Figs.1,2), which passes through wells having gas/steam and $\delta^{18}O$ data for both periods.

Figure 4 shows some typical trends in gas/steam ratio, along with the available $\delta^{18}O$ data, for some wells in the study area of the field. The trend for one well (W6) showing no notable variations in either gas/steam ratio or $\delta^{18}O$ is given for comparison. The different

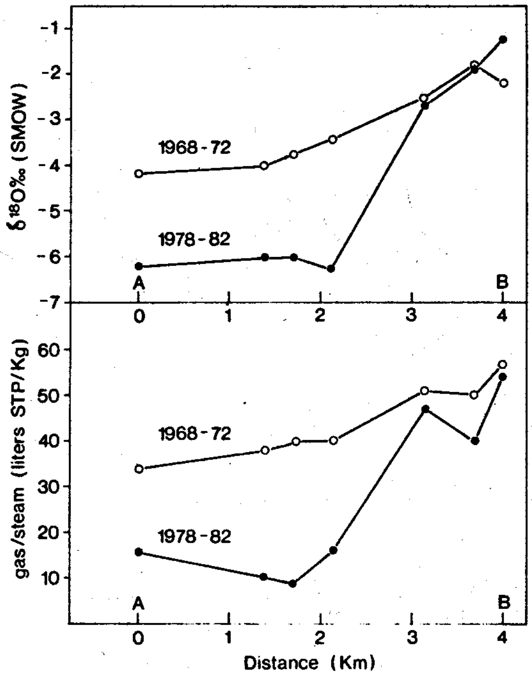

Figure 3. Trend of $\delta^{18}O$ and gas/steam ratio, along the section A-B (Figs.1,2), in the periods 1968-72 and 1978-82.

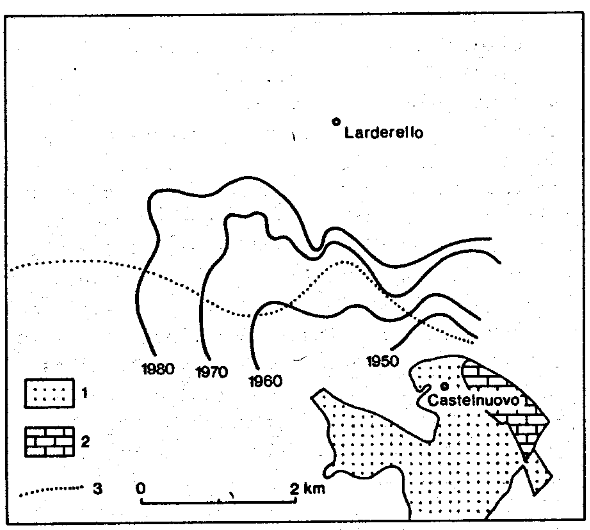

Figure 5. Dates on which a sharp decrease in the gas/steam ratio occurred. 1) and 2) as in Fig.1; 3) boundary of the "macigno" sandstone beneath the flysch cover.

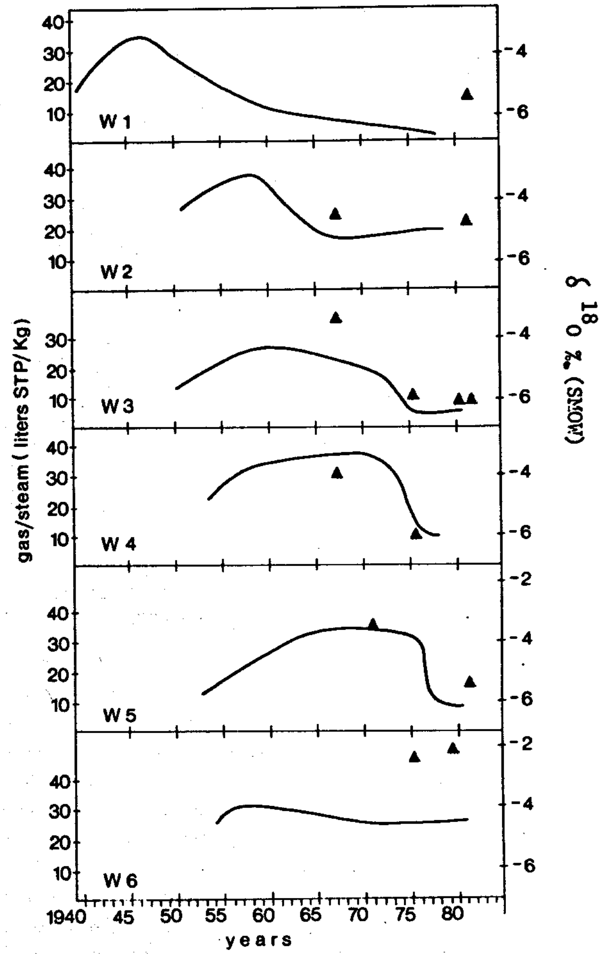

Figure 4. Temporal evolution of the gas/steam ratio (line) and $\delta^{18}O$ (triangles) for some wells in Castelnuovo and Larderello areas.

dates on which the gas/steam ratio decreases correspond to different geographic positions of the wells. The sequence W1 to W6 in Fig.4 corresponds to well locations running SE to NW, indicating that the decrease in gas/steam ratio advances in that direction with time; this phenomenon is more evident in Fig.5, which shows the zones that have gradually become affected from 1950 on.

Figure 6 is a comparison of the areal distribution of the tritium content of the steam during the two survey periods. The following considerations can be made:

- the areal distribution is qualitatively similar in both periods;

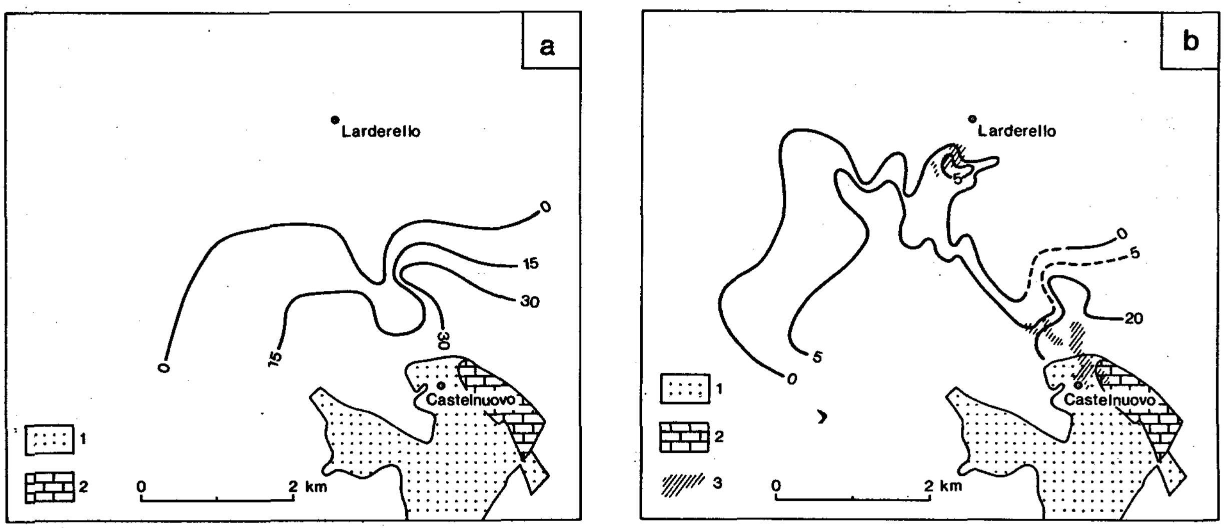

Figure 6. Areal distribution of tritium in the Castelnuovo and southern Larderello areas. a)data of 1968-72 period; b)data of 1978-82 period; 1) and 2) as in Fig.1, 3) natural manifestations.

- the densely drilled area of Castelnuovo has still the highest tritium concentrations even though the absolute values have all shown a decrease. The latter can be ascribed to a depletion of the tritium content of the rainwater (tritium content is now less than half of the 1970 value);
- the area whose steam contains tritium has widened considerably. The largest increases still occur along the same directions observed for $\delta^{18}O$ and gas/steam ratio. In the 1978-82 period, moreover, a relative maximum can be observed in the densely drilled zone of Larderello.

DISCUSSION

Significant tritium concentrations, that were once a characteristic of the more peripheral zones only, can now be found in many wells a few kilometres from the infiltration areas. This fact indicates a contribution of recent waters to production over a wide zone of the field. The maximum tritium values are found in the Castelnuovo area and are probably caused by the proximity of the productive wells to the infiltration area. The largest tritium content at Castelnuovo is observed in front of a small outcrop of carbonate rocks of much higher permeability than the surrounding sandstone. The relative maximum in tritium content in the central area of Larderello could be related to the presence of old manifestations in this area, now exhausted because of exploitation. The area of the manifestations may nowadays act as an infiltration area for surface meteoric waters, as the cover is not totally impermeable.

D'Amore and Truesdell (1979) discussed the temporal variations in gas/steam ratio observed in some wells of the central area of Larderello. The slow declines observed after 10-15 years of production, accompanied by the appearance and gradual increase of HCl, were attributed to an increased contribution to production from boiling of a brine. The declines in gas/steam ratio in the zone now under study differ in some important respects from those considered by D'Amore and Truesdell (1979). The variations are, in fact, usually much larger, occur in periods of a few years only and there is no concomitant appearance of HCl in the steam. Furthermore, the concentrations of H_3BO_3 and NH_3 remained constant as the gas content decreased in the wells studied by D'Amore and Truesdell (1979), whereas these concentrations generally decrease in the wells of the present study. Similar phenomena were also observed in the Larderello field in the areas affected by reinjection (Giovannoni et al.,1981; Cappetti et al., 1982).

The areal distribution of the gas/steam ratio, which decreases from the central zones of the field towards the recharge areas, and its evolution towards low values are compatible with a dilution of the gas in the original fluid, caused by a mixing with recent meteoric waters of negligible gas content. Figure 5 can then be interpreted as a gradual advance of the dilution front.

A simple mass balance of the gas was carried out for some wells, assuming a mixing between original steam, with a gas content equal to that of the steam produced before the effects of dilution became apparent, and a steam with no gas content. The contribution of recharge water results more than 50% in many wells in the study area.

Throughout the study area the dilution front has generally made the greatest progress in correspondence to zones of intense fracturation, tied to particular structural characteristics (Celati et al.,1973; Panichi et al., 1974; Celati et al.,1975). The zone most affected by recharge may also be tied to the presence of a "macigno" sandstone (Fig.5);the latter forms an aquifer overlying the carbonate reservoir and separated from it, discontinuously, by prevalently impermeable shales. The water seeps from the sandstone into the underlying reservoir wherever the shale layer is missing or densely fractured.

The rapidity of the observed variations supports the hypothesis that the current increase in contribution of recharge water to production is mainly the consequence of intense field exploitation (D'Amore and Truesdell, 1979; Calore et al.,1981).

Some lack of correlation between the distributions of the different variables can be referred to other phenomena that, along with recharge, control the present fluid composition in the zone. In the areas on the NE and NW margins of the study area some effects of the lateral flow and condensation described by D'Amore and Truesdell (1979) are still evident. Moreover, recharge has recently begun to affect wells producing fluids of different original composition, and undergoing an evolution tied to variations in the contribution from various steam sources (D'Amore and Truesdell, 1979). The stage reached in their evolution varies according to the duration of production.

The recharge model is adequate for interpreting the situation in the southern part of the field after a long period of production. Pre-exploitation conditions are not known, as drilling was extended to the peripheral areas after tens of years of exploitation in the older part of the field.

D'Amore and Truesdell (1979) noted that the water-calcite and water-feldspar isotopic equilibration rates are rather fast at the reservoir temperatures, whereas the recharge water takes a long time to reach zones with no tritium. In a porous medium, if the rock mass is much larger than the cumulative mass of interacting fluid, and the isotopic composition of the rock is uniform, then the water should equilibrate with the rock and no gradients should appear in the isotopic composition of the fluid.

In order to explain the gradients that did appear, D'Amore and Truesdell (1979) also considered the possibility that, in the period prior to field exploitation, condensation was also present in the area in question. On a geological time-scale this process could have produced $\delta^{18}O$ gradients in the reservoir rock. According to this hypothesis the recharge water, as it gradually flows from the marginal areas to the centre of the field, is now equilibrating with rocks whose $\delta^{18}O$ is progressively more positive. Even in this case, however, assuming a high mass ratio of rock to circulated recharge water, we cannot explain the rapid evolution of the $\delta^{18}O$ to increasingly more negative values.

We must then consider the factors capable of reducing the water-rock isotope exchange or the rock/recharge water ratio.

For the first case we could hypothesize that the circulation of the recharge water mostly takes place in low-temperature rocks and that its vaporization occurs within a rather short distance as it reaches the high-temperature reservoir, then flowing towards the central zones in the steam phase.

We could hypothesize for the second case that, during its circulation, most of the recharge water came into contact with a small part of the reservoir rock only. This could happen if the water were to flow prevalently through a limited number of fractures that also determine the preferential flow-paths.

Another possible concomitant phenomenon is that of a progressive vaporization of the recharge water during its circulation within the reservoir.

Research in future will be directed at further investigating these factors and at conducting isotopic analyses of samples of the reservoir rocks.

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