Proceedings Seventh Workshop Geothermal Reservoir Engineering
Stanford, December 1981. SGP-TR-55.

TEMPORAL EVOLUTION OF THE COMPOSITION OF THE FLUID FROM SERRAZZANO ZONE (LARDERELLO)

Franco D'Amore, Claudio Calore and Romano Celati

Istituto Internazionale per le Ricerche Geotermiche (CNR)
Via del Buongusto 1,
56100 Pisa, Italy

Abstract A temporal evolution in fluid composition has been noted during exploitation of the Serrazzano geothermal area, on the northwestern margin of the Larderello field. Strong variations have been recorded in the contents of NH_3, H_3BO_3, HCl and the uncondensable gases. The largest variations were recorded in the 1955-70 period, when new boreholes were being drilled.

One possible explanation of these changes may lie in the fact that the fluid discharged from the wells comes from diverse sources and that exploitation has gradually modified the contribution from each of these sources.

Introduction During the last few years there has been an increase in interest in time and space variations of fluid composition in vapour-dominated fields. The studies of fluid composition at Larderello and The Geysers have already shown interesting possibilities of the application of geochemical methods in field development and reservoir engineering (Celati et al.,1973; Panichi et al.,1974; D'Amore et al.,1977; Truesdell et al.,1977; Truesdell and Nehring, 1978; Mazor, 1978; D'Amore and Truesdell,1979; Calore et al.,1980).

The long production histories of Larderello reveal different trends of fluid composition in different areas of the field, both as regards space distribution and time evolution. Space distribution appears to be controlled by two major phenomena: 1) mixing of original reservoir fluid with recharge waters and 2) gradual condensation of steam flowing from vaporization zones towards the field boundaries.

Time variations observed in some old wells of the central area of Larderello have been interpreted as the consequences of changes in the contribution of different steam sources to fluid production (D'Amore and Truesdell,1979).

Serrazzano area, where space distribution appears to be controlled by steam condensation (Calore et al.,1980) has now been studied from the point of view of evolution of fluid composition during about 40 years of production.

This paper describes the first attempt at defining a conceptual model of Serrazzano reservoir capable of explaining the observed fluid composition history. We assume that, during exploitation, different steam sources contribute, to varying degrees, to fluid production.

Evolution of steam composition at Serrazzano
We consider a limited zone, including the old densely drilled area and the productive wells north of it (Fig.1). The geological features are well known (Calore et al.,1980).

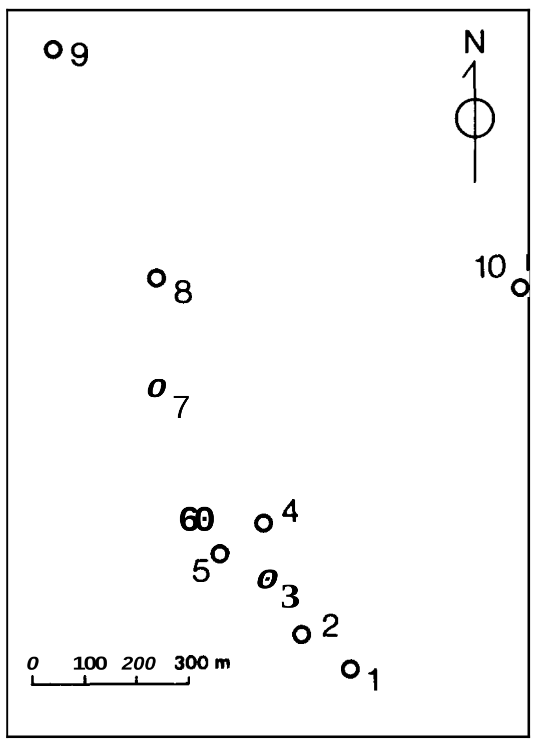

Figure 1 Producing wells in Serrazzano area

Wells nos.1 to 6 were drilled in the period

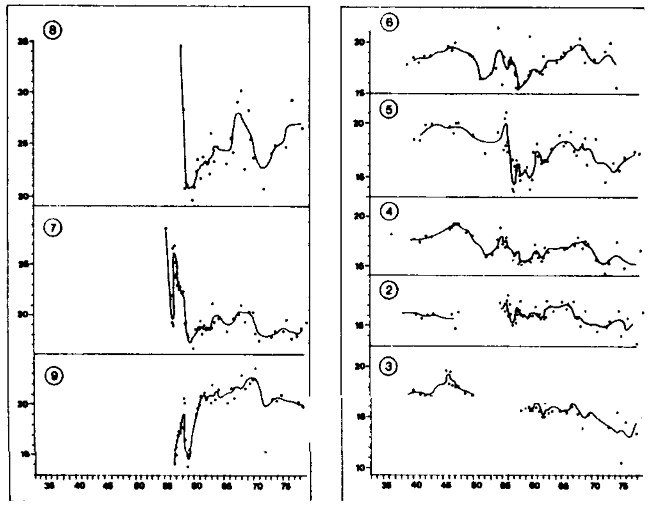

Figure 2 Gas/steam ratio in the steam of the producing wells of Serrazzano area (litres S.T.P./kg)

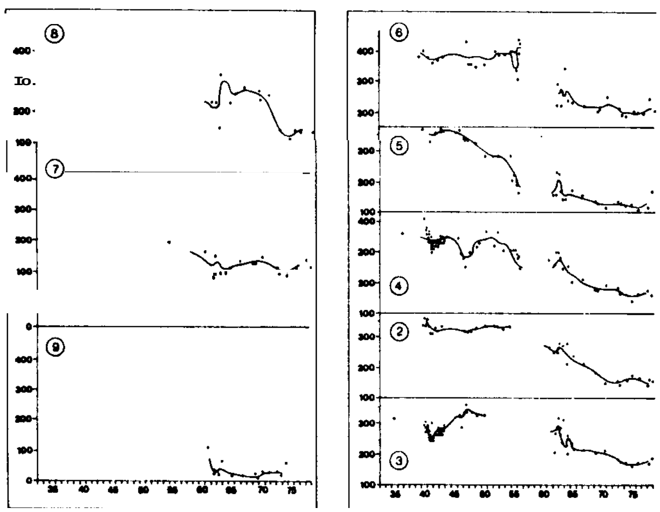

Figure 3 H_3BO_3 in the steam of the producing wells of Serrazzano area (ppm)

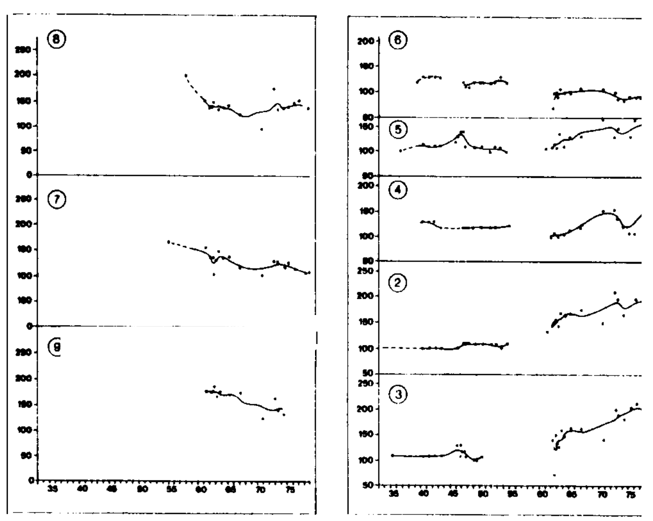

Figure 4 NH_3 in the steam of the producing wells of Serrazzano area (ppm)

1928-1941, with a very reduced spacing, close to surface manifestations.

From 1941 to 1954 no new wells were drilled in the area; wells 7,8 and 9 started production between 1954 and 1957 and well 10 in 1966.

The gas/steam ratio, boric acid and ammonia concentrations are generally available from 1940 on, while other chemical and isotopic analyses are relatively recent in this area.

Figures 2,3 and 4 show the changes with time of the gas/steam ratio and boron and ammonia in wells 2 to 9. Figure 5 shows the available Cl^- data for the wells in which its concentration was detectable.

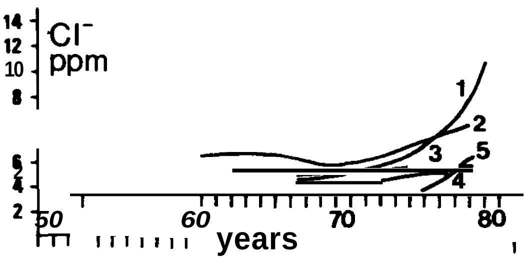

Figure 5 Cl^- (ppm) in the steam of the wells at Serrazzano. Wells not reported in the figure have undetectable Cl^- concentrations.

By smoothing the data some definite trends appear and in different wells show some correlation. Minor features are apparent in the gas/steam ratio only, as no boric acid and ammonia data are available for certain periods.

Discussion The study of space variations in fluid composition throughout Serrazzano area led to a conceptual model for this part of the field (Calore et al.,1980) that has now been tested to explain the time changes. A sketch of this model is shown in Fig.6.

A steam source is assumed to exist in a high temperature (about 270°C) zone east of the small area of our present study. This steam initially flowed towards the north, north-west boundaries, condensing on its way. The condensation should have been very effective near the 'cold walls' at the top of the reservoir and on the northern boundary, where there are low permeability formations, with the added probability of being cooled by a limited meteoric water infiltration through the ophiolitic

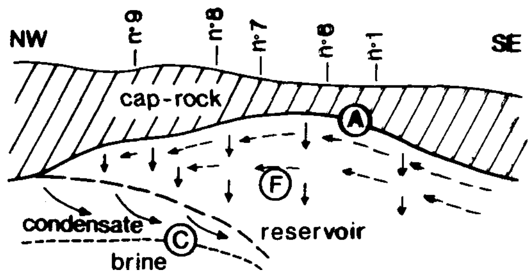

Figure 6 Conceptual model of Serrazzano reservoir.

rocks outcropping north of the study area. Along the vertical we can distinguish three different portions of the reservoir:
1) upper condensation zone, A, characterized by high fracture-derived permeability (Celati et al.,1975), high initial liquid saturation and a fluid very rich in boron and poor in ammonia and CO_2;
2) intermediate two-phase zone, F, with a lower permeability and low water saturation, capable of producing a fluid rich in CO_2 and NH_3 and poor in H_3BO_3;
3) lower liquid-saturated zone, C, whose existence is documented by the wells in the northern area and is inferred elsewhere; the liquid-two-phase boundary descends towards the south, so that the continuous liquid phase is close to the bottom of the wells in the northern part, gradually moving away as we move southwards.

We assume this liquid is made up of a high salinity water, surmounted by a layer of condensate, thinning from north to south; the effect of this condensate probably becomes negligible on the southern edge of the densely drilled zone.

Both in A and F, NH_3 and CO_2 gradually increase and H_3BO_3 decreases as we move towards the north. The deep liquid is assumed to be generally very poor in CO_2, boron and ammonia, but boron and ammonia increase towards the south where the brine contribution becomes significant.

Prior to 1954 only wells 1 to 6 were producing. During the second world war, from 1941 to 1946, when production probably decreased, some condensation occurred in the reservoir and the gas/steam ratio continually increased in wells 3 to 6. In 1946 production returned to normal and in a few years the fluid composition returned more or less to pre-war values:the gas accumulation was depleted and the condensate deposited vaporized. Boron and ammonia data are scarce for this period; however, a decrease in boron and a contemporaneous increase in ammonia are clear in a few wells.

Production in this period came mainly from the upper section **A** of the reservoir. Before 1954 the gas/steam ratio was increasing, probably due to an increase in the contribution to fluid production from section F and from the north. This trend was halted by the start of production in new wells (no.7 in 1954, no.9 in 1955, n0.8 in 1957). Production from these wells **was** more than total production from the wells producing previously in the area. There was a strong interference between the new and old wells as shown in Fig.7: reservoir pressure is not available for the period 1954-1957 but the sharp decrease in total flow-rate of wells 2, **4**, 5 and 6 clearly shows this interference.

The flow pattern in the reservoir was completely altered; the new wells exhibited a large and rapid decrease in gas/steam ratio and ammonia as they drained fluid from the south and the pressure decrease induced liquid boiling. The interference from the new wells brought on more boiling in the old zone too, and interrupted the previous flow of fluid from the north, so that a fast decrease also took place in the gas/steam ratio. The effects of the new wells were felt first in the upper zone **A**, due to its high permeability. Unfortunately boron and ammonia data are missing for this period.

The flow pattern continued to vary in the reservoir: the contribution from the two-phase intermediate zone F increased in all the wells, thus increasing the gas/steam ratio. The behaviour of the northern (nos.6,7,8 and 9) and southern (nos.1,2,3,4 and 5) wells differed in this period.

For the northern wells the two-phase zone F has a limited thickness, the deep,continuous liquid phase is close to the bottom of the wells and becomes rapidly the main source of the fluid produced. The steam generated at the top of the deep liquid phase is very poor in gas, boron and ammonia, so that the concentrations of all these components decrease in time.

For the central wells zone F eventually becomes the main source of fluid, with a minor contribution also from **C**. Thus, while boron decreases continuously in the period of decreasing A contribution, ammonia increases with the in-

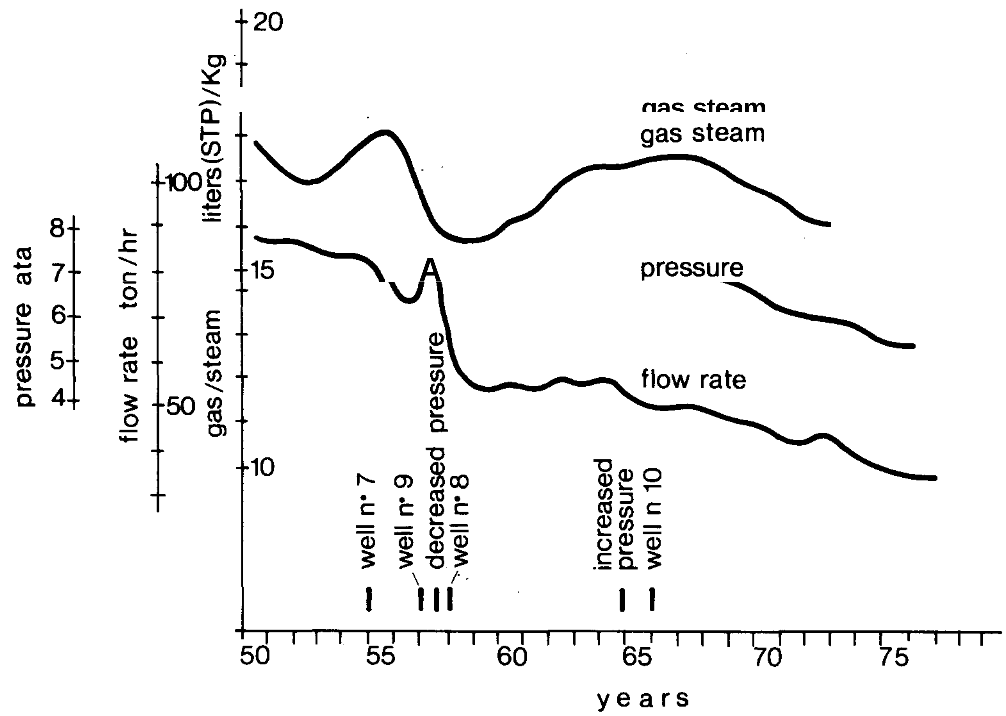

Figure 7 Total steam flow-rate and average gas/steam ratio of wells nos.2, 4, 5 and 6. Reservoir pressure and the date of starting production in new wells are also reported.

crease in contribution from F and C.

In the southernmost wells the contribution from the brine is responsible for the relatively high NH3 content and for the appearance or increase in Cl⁻.

These processes are accelerated by the entry into production of well 10 and its consequent interference to already producing wells. In Fig.7 this interference is apparent both in the trend of reservoir pressure (measured in a shut-in well) and in the production of the old wells: both start decreasing after a period of rough stabilization. The contribution of deep liquid continues to increase, with a decrease in the gas/steam ratio in the majority of the wells and essentially a levelling-off of boron and ammonia.

The three-sources model applied by D'Amore and Truesdell (1979) to some wells of the central area of Larderello has been applied to the wells at Serrazzano. This model assumes that three sources, A, F and C, each delivering a fluid of constant composition, contribute to the production of each well. The three sources differ from one well to another.

The chemical characteristics attributed to the fluid coming from the different sources (Table 1) and the variations in their relative contribution to well production were chosen so as to be consistent with the conceptual model just described and to give a good match of the geochemical history of Serrazzano. The space variations of the F sources are consistent with a process of condensation of steam flowing from ESE to NNW (Fig. 8).

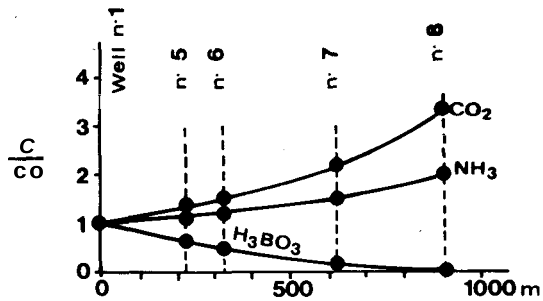

Figure 8 Space distribution of the assumed concentration changes of H_3BO_3, NH_3 and CO_2 in steam source F.

Figures 9 and 10 show the variations in time of the contributions from the different sources, along with the experilental data (dots) and model results (circles) for *two* wells characteristic of northern and southern zones.

These simple models roughly confirm the hypotheses outlined above. Obviously, these models are not completely adequate to describe the well behaviour in this area. In fact, they totally ignore horizontal flow of fluid in the reservoir. Strictly speaking, only a distributed parameter model would be capable of simulating this system adequately.

Table 1 Concentrations in the steam delivered by the sources A, F and C.

Well	Source	Gas/steam (litres STP/kg)	H_3BO_3 (ppm)	NH_3 (ppm)	HCl (ppm)
No.8	A	22.5	375	125	0
	F	75.0	20	400	0
	C	0.0	55	40	0
No.7	A	17.5	425	110	0
	F	52.0	40	300	0
	C	0.0	65	50	0
No.4	A	12.0	500	65	0
	F	30.0	120	230	0
	C	0.0	85	100	5
No.2	A	12.0	500	40	0
	F	22.5	170	200	0
	C	0.0	110	150	15

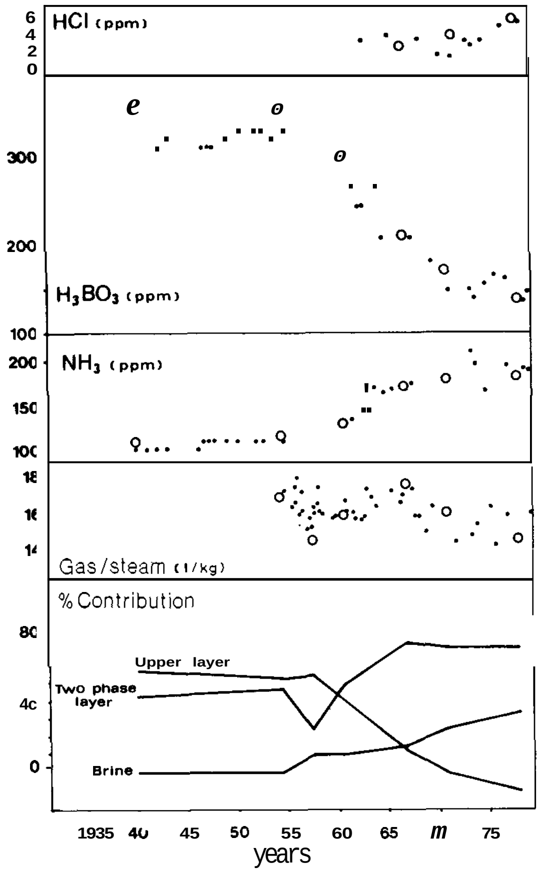

Figure 9 Matching of experimental data of well no.2 with a three-source model, and contribution of the three sources.

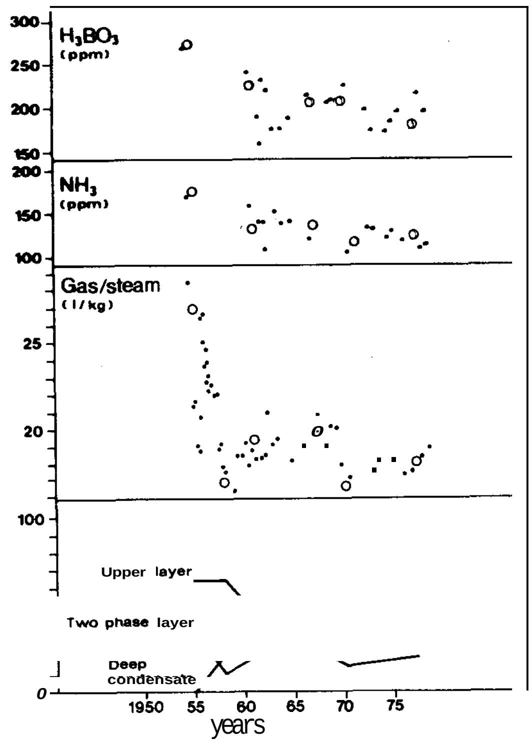

Figure 10 Matching of experimental data of well no.7 with a three-source model and contribution of the three sources.

References

Calore,C.,Celati,R.,D'Amore,F.,Squarci,P. and Truesdell,A.H. (1980),"A Geologic,Hydrologic and Geochemical Model of the Serrazzano Zone of the Larderello Geothermal Field". Proc.6th Workshop Geothermal Reservoir Engineering (H. J.Ramey,Jr. and P.Kruger,Eds.),Stanford,16-18 December,1980, 21-27.

Celati,R.,Noto,P.,Panichi,C.,Squarci,P. and Taffi,L. (1973), "Interactions between the Steam Reservoir and Surrounding Aquifers in the Larderello Geothermal Field".Geothermics, Vol.2-3/4,174-185.

Celati,R.,Neri,G.,Perusini,P. and Squarci,P. (1975), "An Attempt at Correlating **kh** Distribution with the Geological Structure of Larderello Geothermal Field". Geothermal Reservoir Engineering,Stanford,Geothermal Program, 15-17 December,1975, 37-41.

D'Amore,F.,Celati,R.,Ferrara,G.C. and Panichi, C. (1977),"Secondary Changes in the Chemical and Isotopic Composition of the Geothermal Fluids in Larderello Field".Geothermics,Vol.5, 153-163.

D'Amore,F. and Truesdell,A.H.(1979)"Models for Steam Chemistry at Larderello and The Geysers". Proc.5th Workshop Geothermal Reservoir Engineering,11-14 December,1979,283-297.

Mazor,E.(1978),"Noble Gases in a Section Across the Vapor-dominated Geothermal Field of Larderello,Italy".Pure and Applied Geophysics,Vol. 117,262-275.

Panichi,C.,Celati,R.,Noto,P.,Squarci,P.,Taffi, L. and Tongiorgi,E.(1974),"Oxygen and Hydrogen Isotope Studies of the Larderello (Italy) Geothermal System". In:Isotope Techniques in Groundwater Hydrology,1974.IAEA,Vienna,Vol.2, 3-28.

Truesdell,A.H.,Nehring,N.L. and Frye,G.A.(1977) "Steam Production at The Geysers,California, Comes from Liquid Water Near the Well-bottom". (Abs)Geol.Soc.Am.Abstracts with Programs,Vol.9, 1206.

Truesdell,A.H. and Nehring,N.L.(1978),"Gases and Water Isotopes in a Geochemical Section across the Larderello,Italy,Geothermal Field". PAGEOPH, V01.117, 276-289.