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A RESERVOIR ENGINEERING STUDY IN GABBRO ZONE (NORTHERN PART OF LARDERELLO FIELD)

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Gabbro zone, located north of the old geothermal field of Larderello, was explored after 1960 by several wells, as shown in Fig. 1.

The geology of the area can be summarized by grouping the different terrains into three main complexes as follows.

1. An upper complex, consisting of Neogenic deposits, and allochthonous flysch facies formations with ophiolites (Jurassic-Eocene). Because of its predominantly argillaceous nature, this complex is practically impermeable.

2. A discontinuous layer represented by brecciated carbonate rocks associated with evaporitic deposits (Trias), characterized by high secondary permeability.

3. A lower complex, consisting mainly of Triassic and Paleozoic metamorphic clastic formations (quartzites and phyllites). In this case too the permeability is tied to the existence of fractures.

Gabbro zone represents a structural high, separated from the culmination of the main Larderello-Castelnuovo structure.

On the E-NE side, this structure borders on an important direct fault which, on a regional scale, represents the western boundary of a large tectonic depression trending NW-SE (Era Graben).

On the north side of the Gabbro structure, the layer of Triassic breccias is lacking. This is probably one cause of the decrease in permeability observed in the northern marginal zone.

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Only a few wells were productive. The extension of research showed that the high productivity zone (G1, G3, G6, G9) is surrounded by dry or low productivity wells (Fig. 1). Therefore it can be said that the wells inside the circle in Fig. 1 are producing from a reservoir closed in on every side except that of the old Larderello area. In particular, 90% of production is concentrated in an area smaller than 1 km^2, including wells G1, G3, G6 and G9.

Other producing wells in this area are SD2, G7, SD4, G4, G8, 155. The non-commercial wells as, for example, SD4, G4, G8, have been shut-in since they were first drilled.

The producing wells deliver superheated steam at a well-head pressure between 5 and 8 ata (kg/cm^2a) and at a temperature of 230°C. This work sets out to analyze shut-in pressure and flow-rate declines. The first wells drilled north of Larderello area where N.155 and SV9 which, after their shut-in, reached the pressures of 25.8 and 25 ata, respectively, at well-head.

The small difference between the shut-in pressures of the two wells is not surprising considering their topographic position, which is along a line parallel to the area containing the producing wells of Larderello and Castelnuovo fields.

We can assume that the isobars of the drainage volume of Larderello-Castelnuovo wells lie parallel to the line joining wells SV9 and 155 and so the pressure gradient has its greatest value perpendicular to this line. These considerations are confirmed (Fig. 2) by the value (31 ata) of the shut-in pressure of Gabbro 1 well, drilled in 1962, which is about 5 ata more than the shut-in pressure of well 155 and also by shut-in pressures of wells G3 and SD2, drilled in 1963.

In that period the shut-in pressure in the old Larderello area was 8 ata and the flow-rate in Larderello field was 1500 t/h at a delivery pressure of about 5 ata.

It appears from these considerations that Gabbro zone is drained by the wells in old Larderello field.

The development of production in Gabbro zone is shown in Fig. 3 and the pressure decline in the closed wells is shown in Figs. 4 and 5.

The well-head pressure measurements for wells G4 and G8 are not completely reliable because their behavior is probably affected by the existence of liquid water inside the wells (Fig. 4).

However, an interference of G9 production on the pressure trend is apparent.

The pressure histories of SD2, G7 and G9 are available for a limited period of time.

Figure 5 shows that SD2 pressure history is affected by exploitation of G6 and G9.

We first of all tried applying the analysis methods used for gas reservoirs. As the available data are insufficient for defining a reliable average reservoir pressure history, shut-in pressures of the individual wells were plotted versus cumulative production of the entire zone (Figs 6 and 7). Considering the pressure values, well conditions and location, we can assume that the average pressure of the zone is higher than G8 pressure and lower than SD4 one. (As a matter of fact, well G6 has recently been shut-in for two days and its pressure reached 14.4 ata). Furthermore, in the final section all the curves appear to be parallel to one another. The extrapolations of these curves to 1 ata give an evaluation of steam reserves between 100 and 115 x 10^9 kg.

To obtain an alternative estimate of initial fluid in place, we analyzed the flow-rate decline curves.

Assuming the following rate and pressure decline equations:

$$Q = C(\overline{P}^2 - P^2)^n \qquad (1)$$

$$\overline{P} = P_i - KQ_{ex} \qquad (2)$$

$$K = P_i / Q_{tot} \qquad (3)$$

Q	=	flow-rate	kg/h
$\overline{P}$	=	reservoir average pressure	ata
P	=	flowing pressure	ata
P_i	=	initial reservoir pressure	ata
Q_{ex}	=	steam produced	kg
Q_{tot}	=	initial steam in place	kg

we obtain,

$$(Q/Q_1)^{1/n} = \frac{1-A^2}{1-B^2} - \frac{2R-R^2}{1-B^2} \qquad (4)$$

$A = P/P_i$

$B = P_1/P_i \qquad R = Q_{ex}/Q_{tot}$

Q_1, P_1 are Q and P at $t = 0$

To obtain this equation, C and n are supposed to remain constant throughout the production period. The values of n were taken from the back-pressure tests performed a short time after the wells blew out.

To establish whether equation (4) describes the temporal evolution of flow-rate in the wells examined, we plotted the actual values of $(Q/Q_1)^{1/n}$ versus time.

The diagram $(Q/Q_1)^{1/n}$ appearing in the figure is due to the fact that delivery pressures were considerably lowered during short periods.

The best value for Q_{tot} was chosen.

A 10% Q_{tot} variation is easily detected by this method.

Diagram $\ln(Q/Q_1)^{1/n}$ versus Pnt shows that production in wells G6 and G9 clearly interferes with the previously producing wells.

The interference effects change the drainage volumes of a well so that C is no longer constant and the equations no longer valid. Better results will probably be gained by varying C and n according to suitable criteria.

In order to obtain an evaluation of Q_{tot} and an indication of the effect of a variation in n, the analysis was repeated using n values covering all the possible range.

The sum of Q_{tot} for all the wells in the area is $70 \cdot 10^9$ kg, assuming $n = 0.5$, whereas, using the maximum value $n = 1$ for all the wells, ΣQ_{tot} becomes $130 \cdot 10^9$ kg.

Thus an evaluation of the initial steam-in-place gives:

pressure decline analysis : $100 \div 115 \times 10^9$ kg

flow-rate decline analysis: $70 \div 130 \times 10^9$ kg

These values are in sufficient agreement, considering the limits of the methods employed. However, assuming that the reservoir was initially filled with steam (specific volume of 0.07 m^3/kg) and considering a porosity of 5%, the bulk volume should be 100 km^3. Since the area concerned covers 7 km^2, the reservoir depth should be 14 km.

From the last consideration, the hypothesis of a closed gas reservoir, as assumed for the analysis, does not seem to work in our case, especially in view of the fact that an unknown amount of fluid is flowing from this area towards the old Larderello zone.

Some sort of water recharge, a feeding from deep subvertical fractures, or the initial presence of liquid and steam simultaneously in the reservoir, must be admitted.

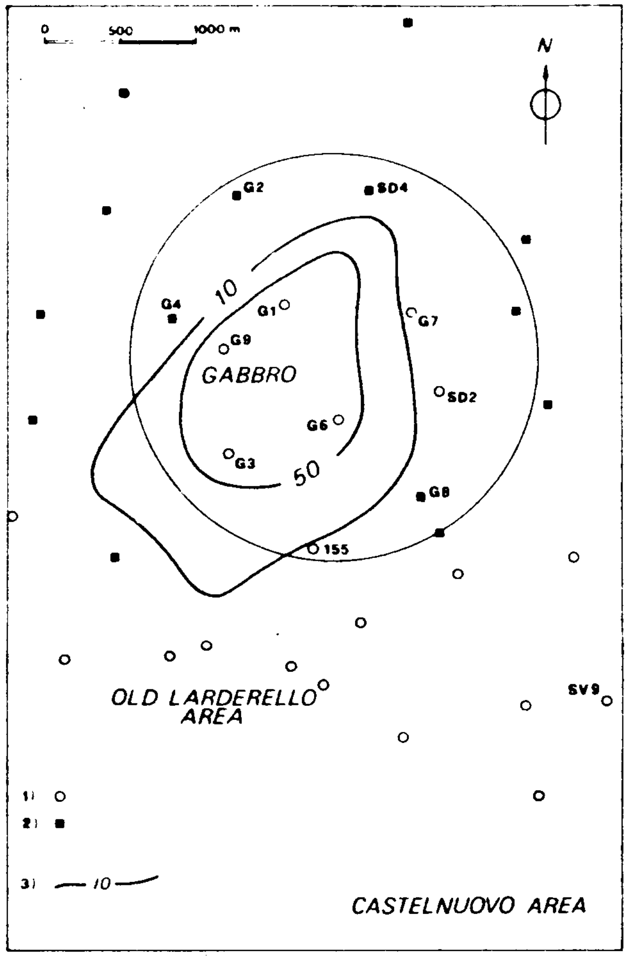

Fig. 1 - Location of the wells in Larderello field. Gabbro zone lies within the circle.

1: producing wells.
2: dry or non-commercial wells.
3: Kh contours (Darcy m).

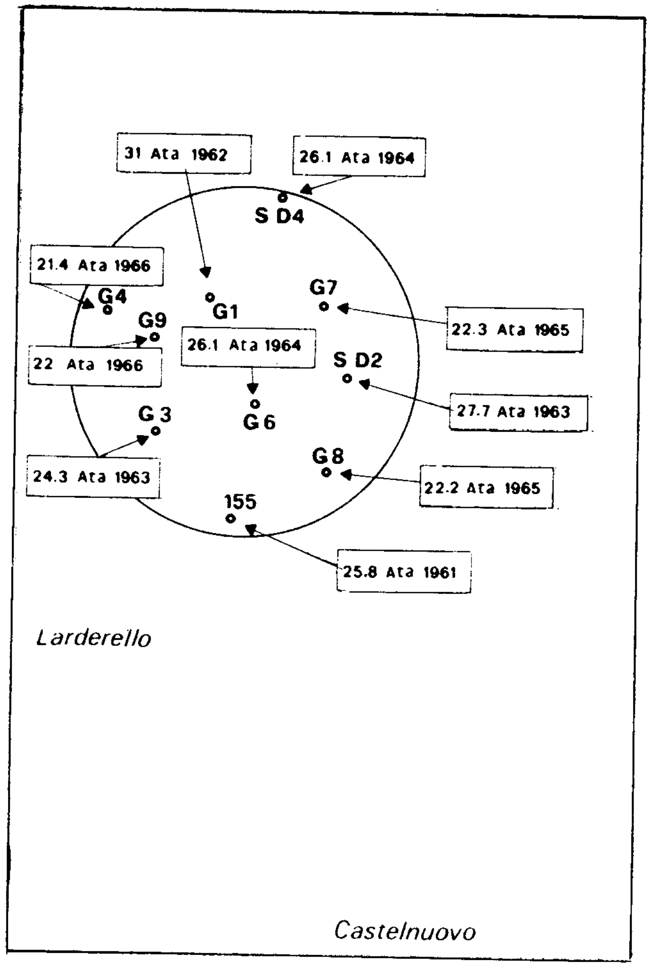

Fig. 2 - Initial shut-in pressures of the wells drilled in Gabbro zone.

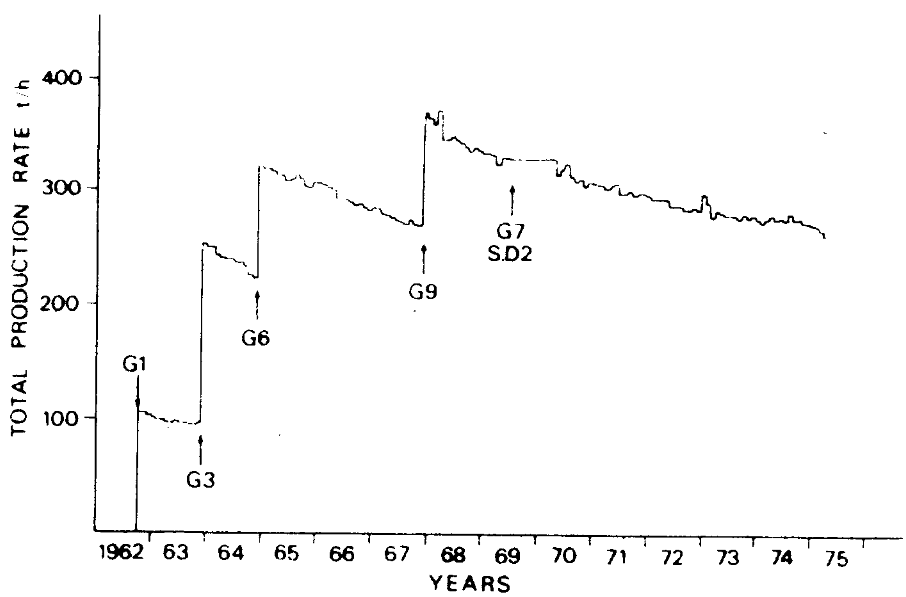

Fig. 3 - Total flow-rate of the wells in Gabbro zone during 1962-1975 period. Well No. 155 is not included.

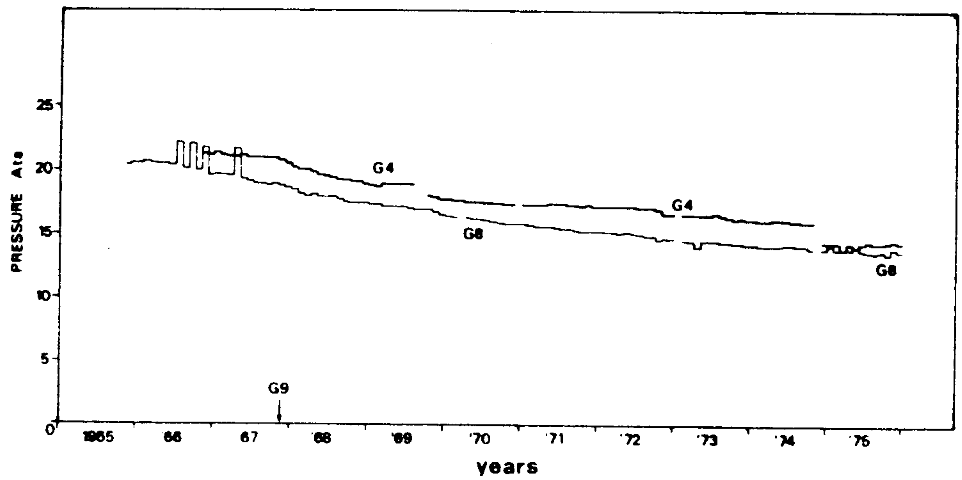

Fig. 4 - G4-G8 well-head shut-in pressures versus time.

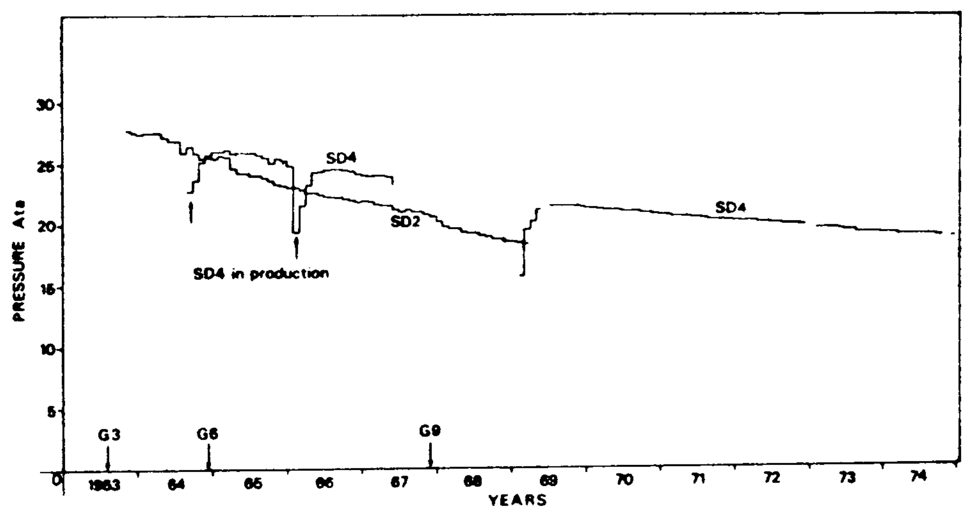

Fig. 5 - SD4 - SD2 well-head shut-in pressures versus time.

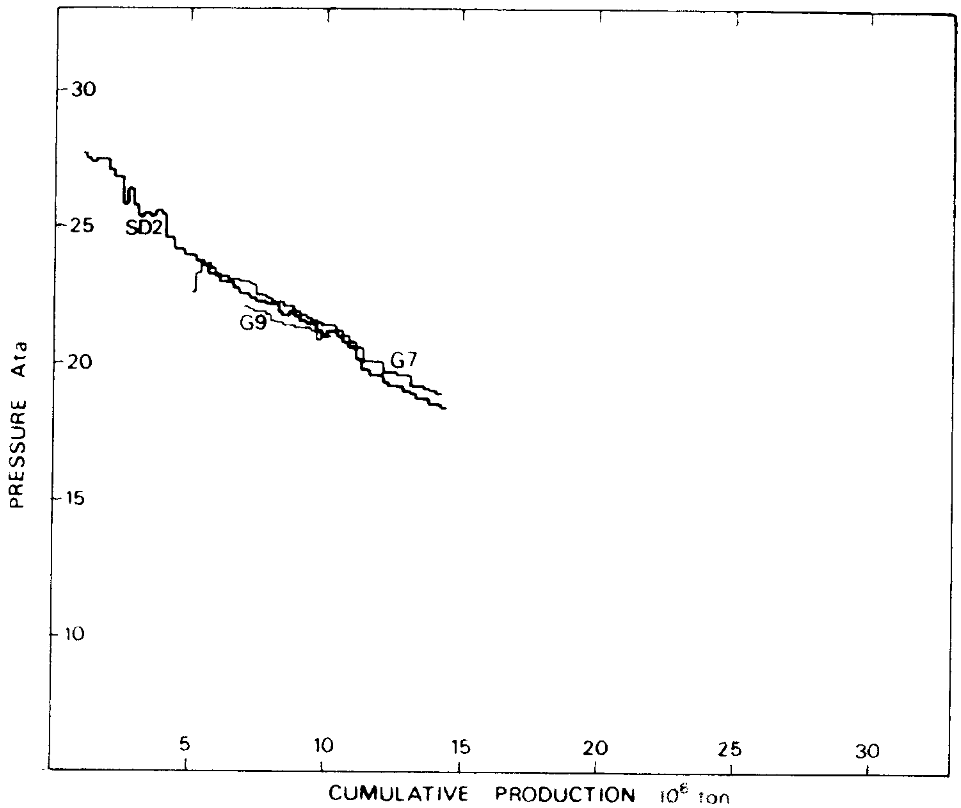

Fig. 6 - G9 - G7-SD2 well-head shut-in pressures versus cumulative production.

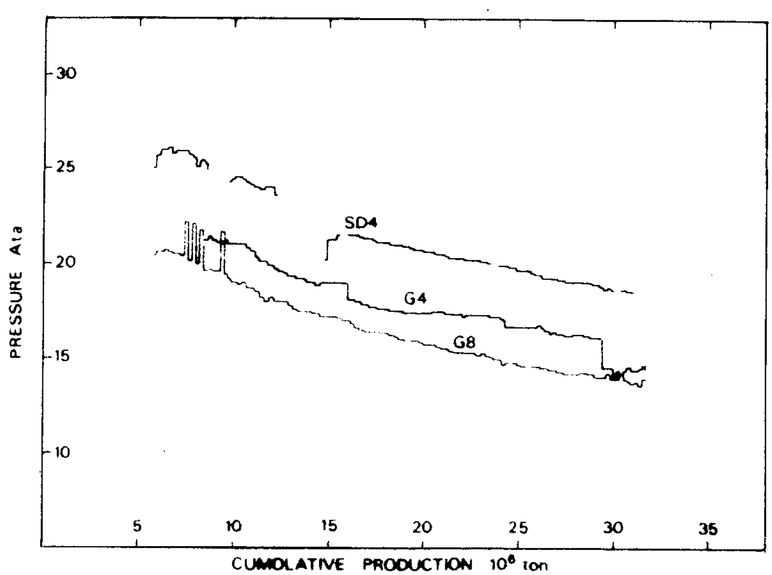

Fig. 7 - G4 - G8-SD4 well-head shut-in pressures versus cumulative production.

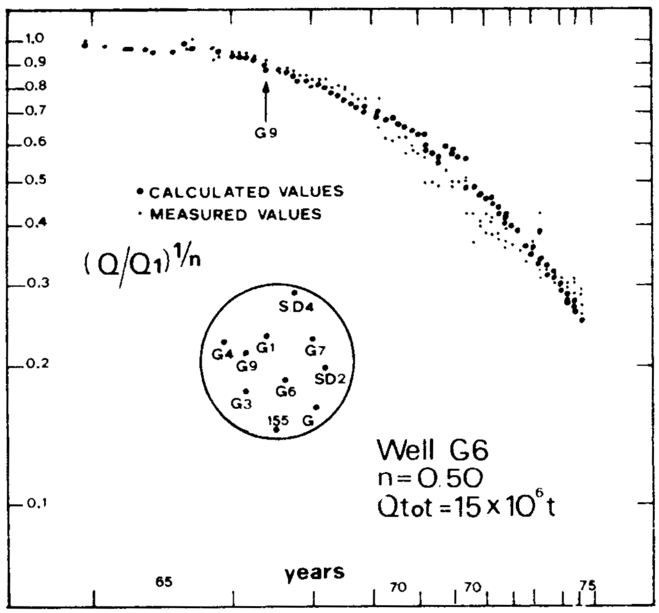

Fig. 8 - $(Q/Q_1)^{1/n}$ ratio versus time on logarithmic paper.