DEEP DRILLING RESULTS AND UPDATING OF GEOTHERMAL KNOWLEDGE ON THE MONTE AMIATA AREA

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ABSTRACT

Deep geothermal exploration begun in Bagnore and Piancastagnaio geothermal fields in the late 1970s, has led to the discovery of a deep water-dominated reservoir with a temperature of 300°-350°C and a pressure of 20-25 MPa.

In the Piancastagnaio field 24 wells have been drilled, with a success ratio of about 90% and an average specific productivity of about 4 MW per well. Three 20 MW power plants are in operation, one is presently under construction and will be on line in 1995, and another three are to be installed.

In the Bagnore field seven wells have been drilled to assess the resource. In this area too the results were positive: it is planned to drill 13 wells and build three 20 MW power plants.

The geological and geophysical data have been reconsidered and the structural features of the geothermal reservoir have been reconstructed.

A recent granitic intrusion (the probable source of the Monte Amiata thermal anomaly) has been hypothesized at a depth of 7 km over a much wider area than previously believed.

An additional seven deep exploratory wells have therefore been planned at the borders of the geothermal fields and in other areas of Monte Amiata.

1. INTRODUCTION

The geothermal area of Monte Amiata, located in southern Tuscany about 70 km SE of Larderello geothermal field, is characterized by the presence of a Quaternary volcanic structure (0.3 - 0.2 M.y.) with a chemical composition ranging from rhyodacitic to latitic-femic (Bigazzi *et al.*, 1981). This volcano is located on a wide geological structure, roughly oriented in N-S direction, composed of sedimentary formations of the allochthonous flysch facies complex (Liguridi) and of the Tuscan Nappe, mostly carbonate. This structure is bordered to the east by the Radicofani Neogene basin and to the west by the Cinigiano basin (Damiani *et al.*, 1980), as shows in Figure 1.

Geothermal research in this area started in the 1950s and led to the discovery of Bagnore, Rancastagnaio and Poggio Nibbio geothermal fields. These fields are located on the southern edge of the volcanic apparatus. The reservoir top is located at a depth ranging from 400 m to 1000 m in correspondence to positive structures of the carbonate-anhydrite formation of the Tuscan Nappe. The areal extent of these fields is limited to a few square kilometers.

The maximum temperature recorded in the reservoir is 160°C at Bagnore and Poggio Nibbio and 220°C at Piancastagnaio.

At the end of the 1960s the drilling activity was halted since the field borders had already been reached.

Two 3.5 MW units were installed at Bagnore and one 15 MW unit at Piancastagnaio, whereas the Poggio Nibbio geothermal field was not developed because its exploitation was not economically feasible. The three units were of the back-pressure type due to the high noncondensable gas content in the fluids produced.

Based on experience gained from deep drilling in the Larderello field, the research in the Monte Amiata area was resumed in 1978: two deep exploratory wells were drilled in the Bagnore and Piancastagnaio fields to find additional fluid below the layers already under exploitation. Both wells turned out to be productive and led to the implementation of a deep drilling program.

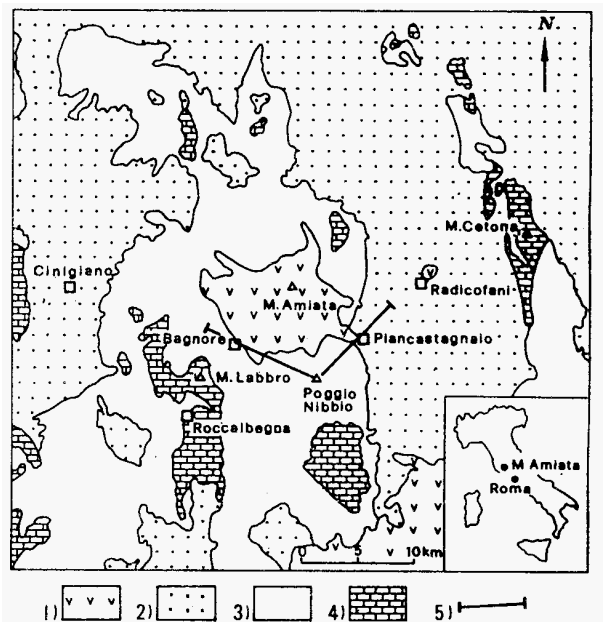

Figure 1. Geological sketch map of Monte Amiata geothermal area: 1) Volcanites of Monte Amiata, Radicofani and Monti Vulsini (1.3 - 0.2 M.y.); *2)* Neogene formations (U. Miocene - L. Pliocene); 3) Flysch complex "Liguridi" (L. Cretaceous - Eocene); 4) Mainly carbonate formations 'Tuscan Nappe" (U. Trias - L. Miocene); 5) Trace of the section.

2. DEEP DRILLING RESULTS

2.1 Piancastagnaio field

The deep wells (2200 - 4180 m) drilled in the Piancastagnaio field crossed, beneath the shallow calcareous-anhydrite productive horizon, a sequence of metamorphic rocks of late Devonian-Upper Permian age composed of graphite phyllites, metasandstones including carbonate layers and chlorite phyllites with dolomitic intercalations.

At depths ranging from 1300 m to 3000 m b.s.l., water-dominated productive horizons have been discovered, with temperatures of *300* to 360°C and pressures that are in hydrostatic equilibrium with the shallow reservoir, although they are separated by impermeable rocks at least 800-1000 in thick. The maximum reservoir pressure is 25 MPa .

The deep reservoir fluid is basically alkaline-chloride with a high content of ammonium and boric acid.

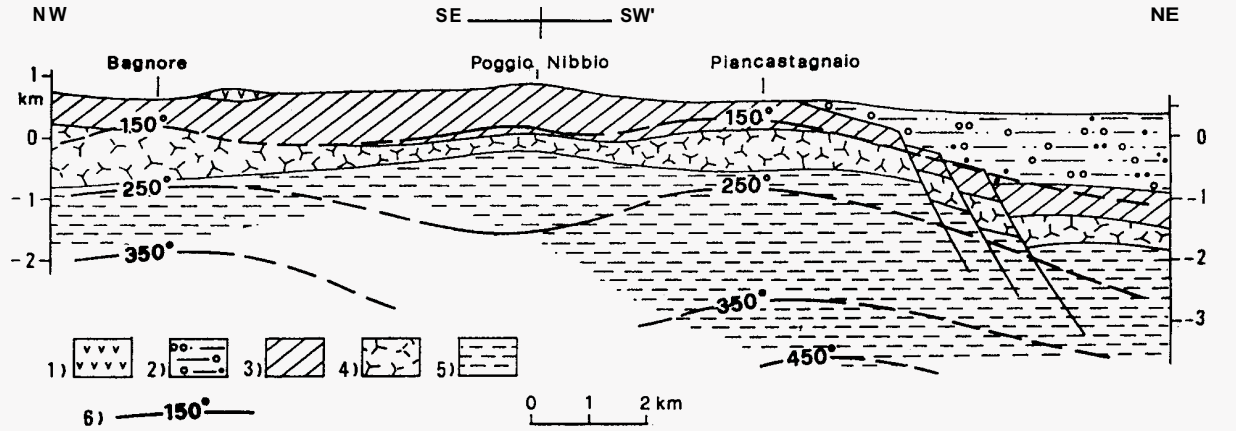

Figure 2. Geological sections through the Monte Amiata geothermal fields: 1) Volcanites (0.4 - 0.2 M.y.); 2) Neogene formations (U. Miocene - L. Pliocene); 3) Flysch Complex "Liguridi" (L. Cretaceous - Eocene): 4) Mainly calcareous-anhydrite formations 'Tuscan Nappe" (U. Trias); 5) Graphite-chlorite phyllites and dolomitic laycrs of h e metamorphic formations (Devonian - U. Permian); 6) Isotherm (°C).

Below these productive horizons the metamorphic formation has ken found to be impermeable, with a conductive gradient of about 100 °C/km. At 4000 m depth a temperature of 450°C has been measured (Figure 2).

The areal extent of the deep potentially productive layers has been estimated at about 30 km^2. In this area, 24 deep wells have been dnlled from nine pads. The success ratio was as high as 90%, with a total steam flowrate of about 170 kg/s, equivalent to 85 MWe.

Despite the low permeability-thicknessproduct (about 10^{-12} m^3), the wells are commercial because of the high reservoir temperature and pressure.

Steam quality is generally as high as 90% because the low kh product causes the flash to move into the formation; the noncondensable gas content ranges from 4 to 15% by weight.

Three 20 MW units are currently operating and a fourth is under construction and will be on line in 1995.

To complete the development project, another 26 wells are to be drilled and the construction of three additional 20 MW power plants is planned for a total installed capacity of 140 MW.

2.2 Bagnore field

The deep exploration project has been completed with seven wells (2300-3600m deep), five of them productive. The wells crossed a thick sequence of graphite phyllites. Productive fractures were found between 1700m and 2400 m b.s.l.

The reservoir temperature ranges from 300°C to 330°C (Figure 2) and the maximum reservoir pressure is 19MPa. The available steam flowrate is sufficient to feed a first 20 MW unit at full load.

Also in this field a development program has been planned including the drilling of 14 deep wells and the construction of three 20 MW units.

2.3 Poggio Nibbio field

In this field a 3263 m deep exploratory well has been drilled.

A thick sequence of metamorphic rocks, mainly graphite phyllites similar to the Bagnore field ones, was found.

A sequence of fractures was crossed inside the metamorphic rocks without any impermeable stratum below the shallow reservoir.

This deep reservoir is in hydraulic equilibrium with those of Bagnore and Piancastagnaio, but the temperature is lower (260°C). Due to both the low permeability and temperature, the well was not commercial and a deep exploration program was not drawn up for this area.

3. GEOTHERMAL OUTLINE AND PROSPECTS FOR DEEP EXPLORATION

The data from the deep drilling in the Piancastagnaio, Bagnore and Poggio Nibbio geothermal fields make it possible reconstruct the temperature distribution at depths of 2000 m and 3000 m (b.s.l.) over the whole area as shown in Figure 3.

The thermal anomaly is still open beyond the area investigated with the wells, both north of Piancastagnaio (Abbadia San Salvatore) and to SW of Bagnore (Roccalbegna).

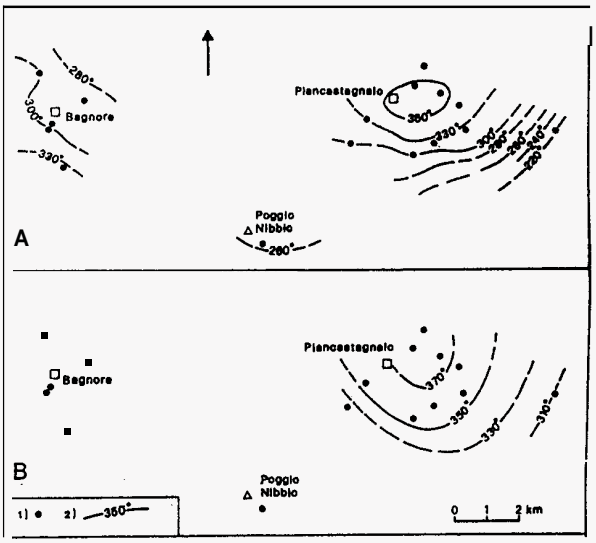

Figure 3. Temperature distribution at 2000 m (A) and at 3000 m (B) b.s.l.: 1) Deep wells; 2) Isotherms (°C).

In order to better define the extent of this anomaly, the existing geophysical and geological data have been reconsidered and integrated with new data and hypotheses.

- In the Piancastagnaio field a temperature of 450°C at 3800 m b.s.l. and a gradient of 90°C/km has been measured; a melting granitic body is therefore expected at a depth of about 7 km.
- Thermometamorphic rocks with Biotite and hydrothermal mineralizing zones with Calcite + Quartz, Chlorite + Quartz and Epidotes with ± Albite and ± K-Feldspar have been found in the deep wells of the Piancastagnaio field.

It is worth noting that in this area the mineralizations are still in equilibrium with the present reservoir temperatures. The presence of a young hydrothermal circulation is in accordance with the hypothesis of a recent granitic intrusion.

- A wide negative gravimetric anomaly exists in the area (minimum values about 20 mGal) with a N-S trend on the east side and an ENE-WSW trend on the west side (Figure 4). This anomaly is due to the presence of thick Neogene formations on the east side and it is probably due to the intrusion of a granitic body into the metamorphic basement on the west side (Gianelli et al., 1988).
- The presence of this granitic body, modelled by inversion of the gravity data, is in accordance with the shape and magnitude of the uplift of the Neogene formations, which on the SW side of the Monte Amiata area reaches the value of 1000 m (Figure 5). It is also in accordance with the deep K seismic horizon shape (Batini et al., 1983)as shown in Figure 6.
- An additional thermal survey by gradient holes revealed the presence of a thermally anomalous area close to Roccalbegna (SW of Monte Amiata), with temperature gradients above 100°C/km. A zone cooled by meteoric water circulation separates this area from the Bagnore field.

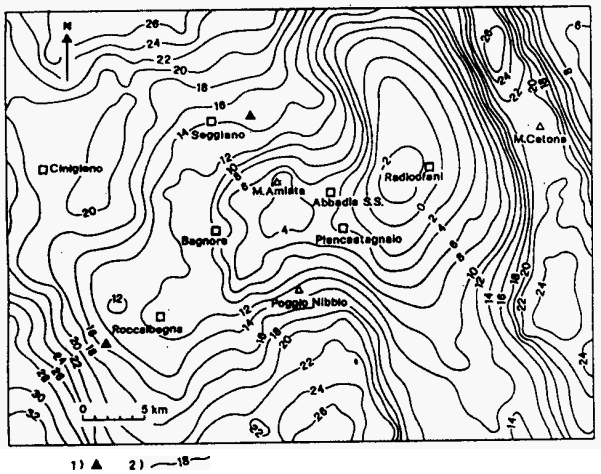

Figure 4. Bouguer anomaly map of the Monte Amiata area (d=2400 kg/m3): 1) Deep exploratory well; 2) Bouguer anomaly contour line (mGal).

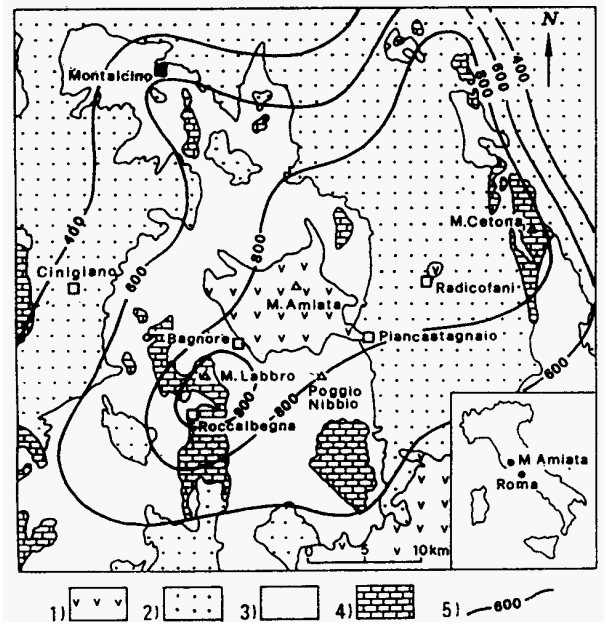

Figure 5. Uplift of the Neogene formations of the Monte Amiata area: 1)Volcanites of the Monte Amiata. Radicofani and Monti Vulsini (1.3 - 0.2M.y.); 2) Neogene formations (U. Miocene - L. Pliocene); 3) Flysch complex "Liguridi" (L. Cretaceous - Eocene); 4) Mainly carbonate formations "Tuscan Nappe"(U. Trias - L. Miocene); 5) Contour lines (meters above sea level) of the uplift of the Neogenic formations.

On the basis of the above data, it is possible to consider the presence of a recent granitic body in the Monte Amiata area as the source of the deep thermal anomaly. At the surface, outside the geothermal fields, a cold circulation of meteoric water masks the deep thermal anomaly.

In the Monte Amiata area, considering the above mentioned data, a deep exploration program has been drawn up at the margins of the geothermal areas already investigated and in other more outlying areas.

The selected areas are Abbadia San Salvatore (north of the Piancastagnaio field), Seggiano (north of Monte Amiata) and Roccalbegna (SW of Monte Amiata), as shown in Figure 7.[1]

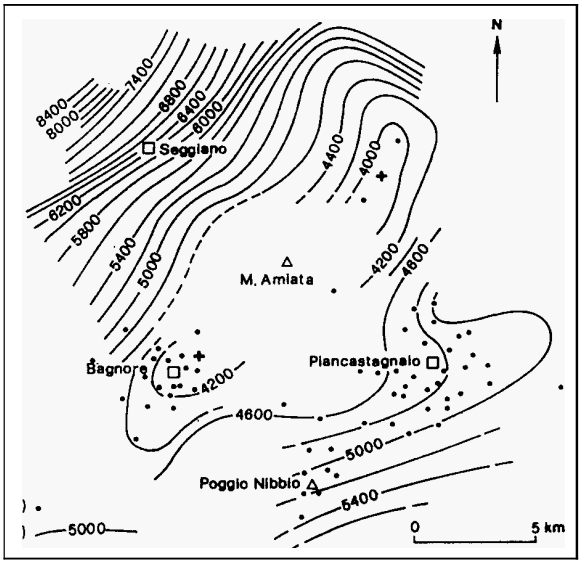

Figure 6. Map of the K seismic horizon: 1) Geothermal well; 2) K horizon contour line (m b.s.l.).

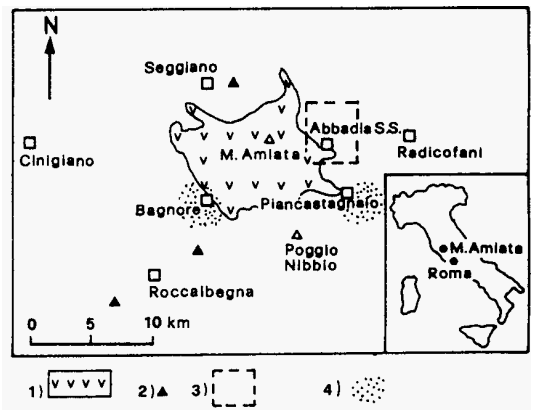

Figure 7. Monte Amiata geothermal area: 1) Volcanites; 2) Deep exploratory wells; 3) Area selected for a deep exploration project; 4) Deep development project area.

4. CONCLUSIONS

The success of the deep drilling in the Bagnore and Piancastagnaio geothermal fields will make it possible to complete the development projects currently under way. These projects envisage drilling a total of 70 wells and constructing 10 power plants for a total installed capacity of 200 MW.

[1] The first positive result of the exploratory program in the Abbadia San Salvatore area was achieved in August 1994. A deep geothermal reservoir was found at a depth of 3500 m with characteristics similar to those of the Piancastagnaio geothermal field.

Moreover, the possibility of extending the deep geothermal exploration to other areas of Monte Amiata has been considered.
A conceptual model of the Monte Amiata area has been drawn up through reinterpretation of the gravimetric data, the new seismic reflection profiles and the surface and subsurface geological data.
The presence of a granitic intrusion with estimated temperatures of 750-800°C at a depth of about 7000 m has been predicted over an area much wider than the area presently investigated.
Based on this model, a deep exploration program was recently started in the areas of Abbadia San Salvatore, Seggiano and Roccalbegna for a total of seven exploratory wells.

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