# RESULTS OF GEOTHERMAL EXPLORATION IN CENTRAL ITALY (LATIUM-CAMPANIA)

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## ABSTRACT

The main areas of geothermal interest in Italy are, apart from Tuscany, almost all situated in Western Latium and in the Neapolitan area. The geothermal areas of Latium coincide with the volcanic centres of the Mt. Vulsini, Mt. Vico-Cimini and Mt. Sabatini. The presence of vast geothermal anomalies has been confirmed by numerous deep wells. The reservoir is generally at a depth of 500-2500 m in carbonate formations (Mesozoic Age) with a generally medium-low permeability. The positive wells produce a mixture of water and steam with temperatures of 140-220 °C and with high concentrations of gas, mainly C02 and $H_2S$. In the Latera area the installation of a 44 MW plant is in progress, while further projects are underway for exploitation in other areas. These are mostly multiple projects of binary group production of electrical energy (Marta) combined with plants for domestic heat production (Torre Alfina) and chemical substance production (Torre Alfina, Cesano).
In Campania, geothermal exploration has been carried out in the volcanic areas of the Phegrean Fields and Vesuvius. The Phegrean Fields reservoir consists of thick thermometamorphic volcanic formations with temperatures of 230-350°C at 500-3000 m; geothermal exploitation is problematic due to the low permeability of the reservoir and the high $H_2S$ and C02 content of the fluids. The only well drilled in the Vesuvius area showed the presence of a carbonate reservoir with low temperature.

## 1. INTRODUCTION

Research on geothermal resources of the **Latium** area began in the late 1950s. In the 1950s and 60s, about 15 shallow wells were drilled and reservoirs of low to medium temperature were found.
For about 25 years ENEL, which operates the Tuscan geothermal fields, carried out both research and exploration in joint venture with AGE'.
The area of greatest interest corresponds to the vast alkaline-potassium volcanic center of the Mt. Vulsini, Vico - Cimini and Sabatini, and the Albani Hills.
During the 1970s and early '80s, the many wells drilled in the area resulted in the identification of the Latera, Torre Alfina and Cesano geothermal fields. Further drilling during the early '90s was negative; as a matter of fact, only a very small productive structure was found in the Marta area (to the South of Bolsena Lake) and a few unexploitable positive wells were drilled in the Mt. Sabatini area.
Apart from those wells of the development projects of the single fields, in all about 50 geothermal wells were drilled, some of which were directional from the same site.
The first geothermal exploration was carried out in **Campania** on the island of Ischia from 1939 to 1953; numerous shallow wells were drilled. Fluids with temperatures up to 300°C were detected. Excluding balneotherapeutic activities, no project of industrial exploitation has ever been planned because of touristic and environmental constraints.
Subsequently, in 1975 a wild stratigraphic well was drilled north of the Phlegrean Fields up to 1800 m, recording temperatures below 100°C at the bottom, and thus was unproductive.
Afterwards, exploration was taken up systematically again throughout the whole area of interest (the Vesuvius and Phlegrean Fields). In Campania in the early '80s, 14 wells were drilled by the J.V. ENEL-AGE' and revealed the Mofete geothermal field as economically unexploitable.

## 2. GEOTHERMAL CHARACTERIZATION

### 2.1 Latium

The pre-Apennine zone of Latium is the ideal continuation of the Tuscany geothermal area, both for its structural characteristics and its tectonic evolution.
Volcanism of both the acidic type (Tuscan Magmatic Province: Cimini, Tolfa and Ceriti) and the alkaline-potassic type (Roman Comagmatic Province: Vulsini, Vico, Sabatini and Albani) covered the greater part of the tyrrhenian Latium; the latter generated the volcano-tectonic or explosive morphological depressions of the lakes of Bolsena, Vico, Bracciano, Albano and Nemi. Three sedimentary sequences outcrop inside the volcanic cover area and at its borders and characterize the substratum:
- Post-orogenic complex (Neogene - Quaternary), made of clays, sands and, secondarily, conglomerates at the base of the volcanites;
- Flyschioid complexes in the Ligurian facies, made of arenaceous, argillaceous or marly-calcareous formations (Cretaceous - Oligocene);
- Complexes of the Tuscan or Umbrian-Sabina Series, made of carbonate, with an anhydride-dolomitic formation and successive prevalent carbonate formations (Upper Trias - Eocene).

The underlying regional metamorphic basement of the Paleozoic age (phyllites and quartzites) outcrops only to the west of the Mt. Vulsini.
Extensional tectonics began in the middle-upper Miocene and generated a series of structural highs and lows. The subsequent marine invasion, during the Pliocene and Quaternary, filled the depressions with terrigenous sediments. Magmatism and surface volcanic activity occurred along the same regional tectonic trends (NW-SE direction).
From a hydro-geologic point of view, the volcanic cover is the shallowest fresh aquifer of no geothermal interest. The post-orogenic and Ligurian flyschioid complexes show generally low permeability and constitute the impervious cover, while the underlying, mainly carbonate, Mesozoic rocks, usually permeable due to fracturing, may contain water under pressure at very high temperatures and act as a regional geothermal reservoir
The surface waters are generally of low total dissolved salinity (TDS) content and of earthy alkaline bicarbonate type. The deep geothermal fluids are mainly alkaline-chloride with TDS content ranging 7-10 g/l and variable amount of $CO_2$ and $H_2S$; concentrated brines may be locally present.
The integrated analysis of the results coming from different interdisciplinary surveys led to the determination of the potentially favorable areas, generally located near the volcanic centers around which a widespread thermal anomaly is present.
Thermal anomalies were reconstructed on the basis of more than 180 test holes drilled to depths of between 100 and 300 m, as well as from the results of the deep wells. The distribution of the heat flow anomalies is shown in Figure 1. The iso-flow line at 100 $mW/m^2$ (about twice the average earth heat flow) delimits the area including all the Latium volcanoes. Limited but more intense anomalies involve the alkaline-potassic volcanic centers and are associated with magmatic bodies located in the upper crust, at depths of 2-6 km.
Heat flow maxima with low wavelengths correspond to the structural highs of the carbonate reservoir where thermal fluids are present at

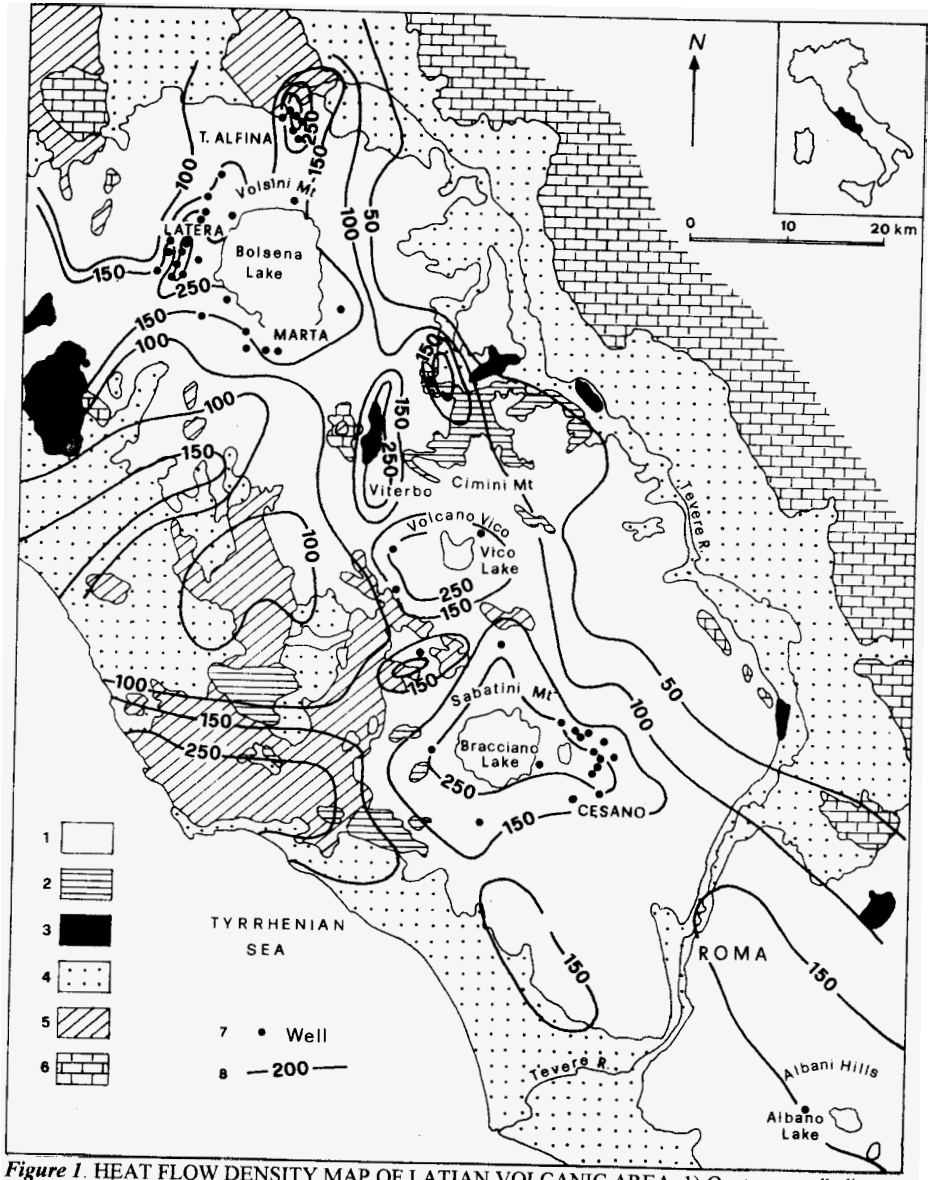


*Figure 1*. HEAT FLOW DENSITY MAP OF LATIAN VOLCANIC AREA. 1) Quaternary alkaline-potassic volcanics; 2) Pliocene - Quaternary acidic volcanics; 3) Travertine (Quaternary); 4) Messimam - Pleistocene marine and continental deposits; 5) Ligurids (Cretaceous - Oligocene); 6) Carbonate formations of Tuscan and Umrian Sabina Series (Trias sup. - Eocene); 7) Well sites; 8) Heat flow contour lines.

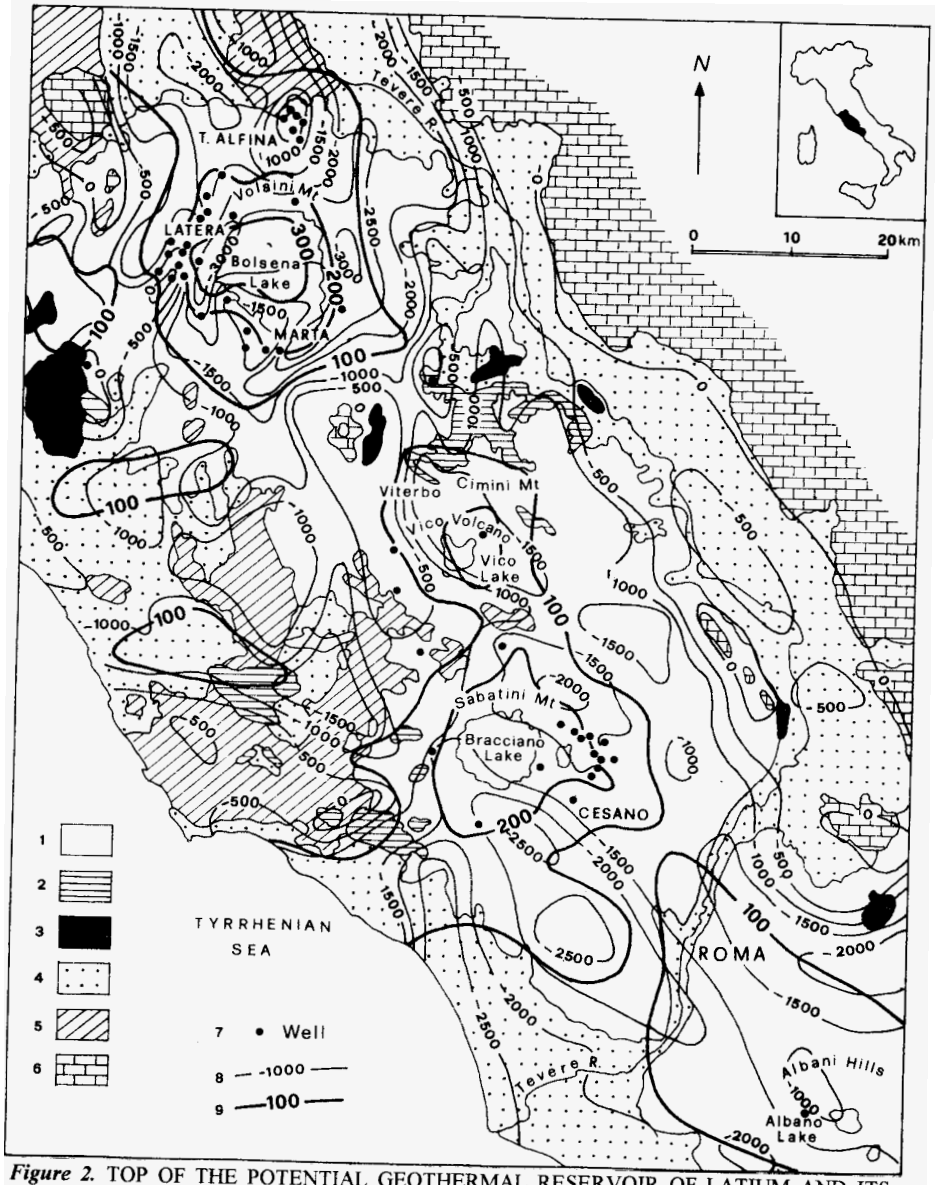


*Figure 2.* TOP OF THE POTENTIAL GEOTHERMAL RESERVOIR OF LATIUM AND ITS TEMPERATURES. 1) 7) see Fig. 1; 8) Isobathes, depth in meters b.s.l.; 9) isothermes, in °C.

shallow depth. The main objective of deep exploration was the mesozoic carbonate rocks which, due to their structural and hydrological properties, represent the reservoir most promising from an industrial point of view.

Many geophysical prospectings have been carried out for geo-structural reconstruction.

Seismic reflection tests have made evident how the volcanic cover, quite dishomogenous from a lithologic point of view, scatter strongly the seismic energy, thus masking deep reflections.

Extensive geoelectric and gravity surveys were carried out. About 2500 VES Schlumberger, with AB ranging between 4 and 10 km, were carried out with an average density greater than 1 sounding/km$^2$. These allowed a reliable reconstruction of the top of the potential reservoir which is correlated with the carbonate formations and is characterized by a resistivity > 100 ohm.m.

More than 3000 gravity stations are distributed evenly over the whole area of geothermal interest, with an average density of 1.5 stations/km$^2$. The Bouguer anomaly made evident that areas of positive gravity anomaly can be related to the structural highs of the carbonate formations and/or those in flysch facies with high marly and arenaceous components. The main contrast between densities often occurs among the light volcanites of the cover (2.2 g/cm$^3$) and the underlying dense flysch formations (2.5-2.6 g/cm$^3$).

Reliable 2-D modeling was possible only by means of a comparison with geoelectrical data and numerous calibration wells. Gravity data, on the contrary, were decisive in locating and modeling deep light bodies of intrusive origin.

A detailed aeromagnetic survey was carried out on all geothermal areas of Central Italy. Pole reduction of the total magnetic field revealed the strict dependence of magnetic anomaly intensity versus the thickness of the volcanic cover.

The geothermal reservoir is characterized by a series of structural highs and lows, often delimited by faults.

The downlifted zones correspond to a graben trending **NW-SE** and, partly, to volcano-tectonic collapsed zones. The uplifted zones are found to correspond to the top of folds or overthrusts of the Mesozoic units. The underlying metamorphic basement has never been encountered in wells at least **up** to a depth of 4800 m.

The top of the potential reservoir, shown in Figure 2, corresponds to the uppermost geologic horizon of the Mesozoic carbonate formations or Triassic evaporites.

The highest temperature values (higher than 200°C) were recorded in the areas of most recent volcanic activity. The middle temperature values were detected in correspondence with structural highs, peripheral to the volcanic areas, or where many interactions with cold surface hydro-geological circulation developed.

### *2.2* Campania

As far as the Campania region is concerned, the existing regional aquifer, made of mesozoic carbonate platform, presents only medium low temperatures (Figure **3).** Favorable conditions from the geothermal point of view (i.e. high enthalpy) occur in the volcanic areas, where very high temperatures at shallow depth are present (the Phlegrean Fields, west of Naples, and the Island of Ischia)

The recent volcanism developed during the Upper Pliocene in the Campania tectonic depression formed at the borders of the Apennine mountain chain. Significant subsidence occurred in this depression, and the carbonate basement downlifted by more than 3500 m bsl.

The volcanism is characterized by numerous vents which have erupted lava and mainly pyroclastic products. Chemically, the products belong to the potassic series of the Roman Magmatic Province, ranging from trachybasalts to peralkaline trachyphonolite.

The main structure is the wide subcircular caldera with a diameter of about **13 km,** originating from the collapse following the eruption of the Campanian ignimbrite –35,000 years ago.

The presence of a shallow magmatic chamber of large dimensions provides the heat source for the geothermal system, and its existence is proved by numerous geological and geophysical features, such as, the natural manifestations near Pozzuoli **gulf,** gravity anomalies, bradysism, etc

## 3. RESULTS OF EXPLORATION

Figure 4 shows some geologic cross-sections sketching the deep structural features and the temperature distribution in the Latium geothermal areas.

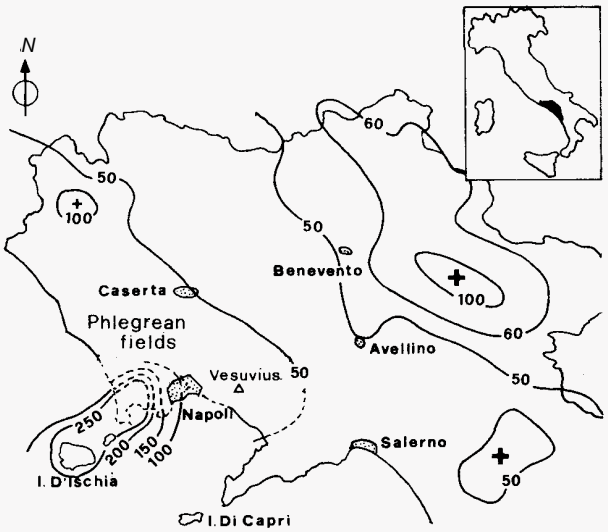


*Figure 3.* Temperature distribution at the top of the regional geothermal reservoir of northern Campania.

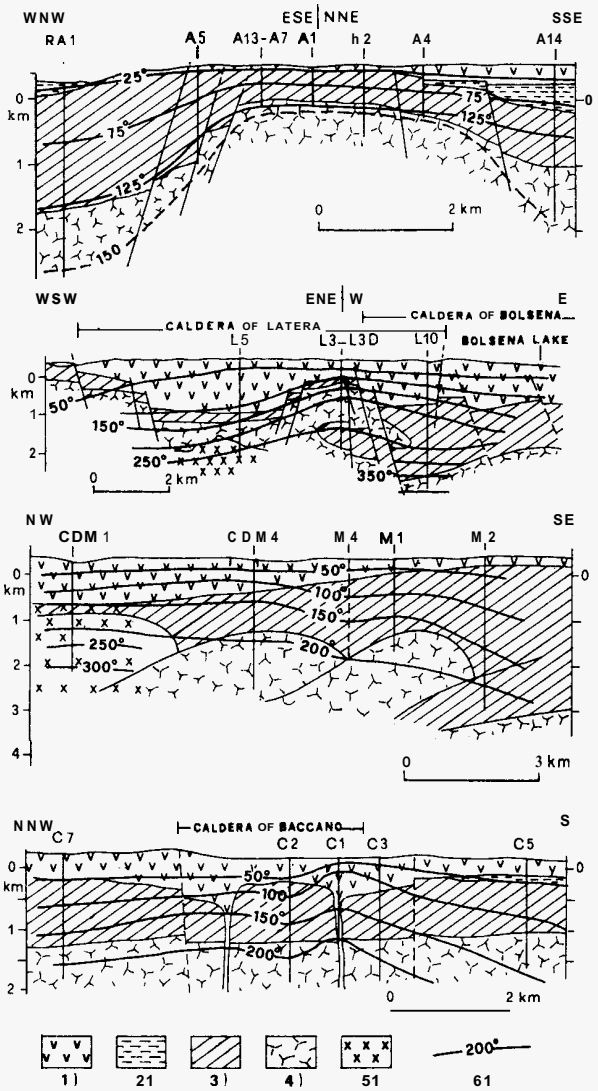


*Figure 4.* Schematic geological cross sections, showing the thermal and structural conditions of the Torre Alfina, Latera, Marta and Cesano geothermal fields. 1)Quaternary volcanics; 2)Pliocenic marine clastic deposits; 3)Ligurids (Cretaceous-Oligocene); 4)Formations of Tuscan and Umbrian Series (Trias sup.-Eocene); 5)Syenitic intrusions and thermometamorphic complexes; 6)isotherms (“C).

### 3.1 Vulsini Mt. Area

In the Vulsini Mt. region two geothermal fields with different characteristics were discovered.

The **Torre Alfina** geothermal field is located in the northern sector where 10 wells were drilled and the highly permeable reservoir made up of carbonate formations of the Tuscan series is situated at a depth of 550 to 2000 m.
The fluid is water with a salinity of about 6 g/l, gas saturated (1-2% by weight, mostly C02 and traces of $H_2S$), temperatures of 130-140°C, and water level at 200 m below ground level.
At the top of the reservoir a gas cap with about 50 bar pressure is present. The single well flow-rate is generally of about 400 t/h. The deepest well in this area reached a depth of 4826 m; it did not reveal any deeper reservoirs at higher temperature and pressure.
In this field two projects are under development: one, already in operation, concerns the $CO_2$ production, and the other, in the course of realization, forecasts electrical production by a binary cycle unit of 1MW and heat supply for greenhouses, with initial thermal power of 2MW that will possibly be increased to 12 *MW*.

The **Latera** geothermal field was found in the western Volsini Mts. where 21 wells were drilled; half of these were productive .
The carbonate reservoir is made up of mainly carbonate formations of the Tuscan Series featuring a recumbent fold with a **NE-SW axis** and SE vergence.
Permeability is high along the structural **axis** and decreases away from it. The fluid is pressurized water, with salinity of 8-12 g/l, gas of 3.5% by weight with 1% $H_2S$ gas by volume, and temperature from 190 to 230°C. The pressure at the top of the reservoir is about 100 bar. **A** gas cap is present over the structure's top.
A project is currently under development: a 40 MW power plant, with two condensation turbines, and four binary groups (4 *MW)* are being installed for an effective power of 30 *MW*. Water for thermal uses will be available downstream from the power plant.
It is planned to exploit the field by means of five production wells in the central **part** and three reinjection wells located at the northeastern margins.

One slim hole was drilled in the marginal zone southwest of the Mts. Volsini, and crossed a reservoir starting from about 300 m, with calcium-sulfate water at 50-60°C.

Ten wells were drilled surrounding Bolsena Lake. At the lake's northern border two wells, drilled to the depth of 3000 m, failed to reveal any reservoir; the maximum recorded temperature was 270°-300" C. **This** area is subject to phenomena of thermal metamorphism, which make the presence of deeper reservoirs improbable.
In the eastern and southwestern area the deep drilling verified that there are not structural and thermal conditions for *any* reservoir at economically exploitable depths.

In the southern area **(Marta)** only two wells are productive at a depth of about 2000 m. The productive area is too small and not currently suitable for any development. In fact, some further wells were unproductive, not having crossed the potential reservoir. In the two productive wells the fluid presents temperatures of 180-190°C, salinity 20-40 g/l, gas 2% by weight and $H_2S$ 0.5%, with pressure 200 bar.
**A** loop between the two productive wells can be carried out, with a total flow rate of 200 t/h; the exploitation project foresees the installation of some binary groups for an effective power of 2 *MW*.

### 3.2 Vico-Cimini Area

In the early 70s, two wells were drilled in the western area of the Vico-Cimini region. They crossed a carbonate reservoir at a depth of 500 m with calcium-sulfate water at 60-70°C. Subsequently, a 2900 m deep well was drilled in an unsuccessful attempt to find a second higher temperature reservoir, but because of the continuity among the permeable strata only a very modest temperature increase was obtained.
In the central Vico area, an unproductive well revealed a low permeability carbonate reservoir at 2600 m, characterized by low hydrostatic pressure and temperatures of 230°C at 2950 m.
Northernward, another well entered a low temperature reservoir, with a very high gas content and which is unsuitable for geothermal purposes.

### 3.3 Sabatini Mt. Area

In the Sabatini Mt. area, geothermal fluids with extremely variable characteristics were found.

In the eastern sector the **Cesano** geothermal field is located. *As* elsewhere in the Sabatini Mts. the geothermal reservoir is composed of the mesozoic formations (mainly carbonate) of the Umbrian Series.
Twelve wells were drilled up to 960 - 3200 m, only four of which were productive. In correspondence with volcanic chimneys, local residual high permeability reservoirs are present; self sealing phenomena, subsequent to the hydromagmatic activity, and hot hydrothermal circulations, occurred for a long time in the area, closing in all the directions these residual permeable zones and increasing the salinity of the fluids.
Two wells, situated in the Baccano Caldera, produce a brine with salinity over 350 g/l, rich in sodium and potassium chlorides and sulfates slightly overpressurized (150 bar); the temperatures are 210°C and 150°C respectively.
Another two wells, external to the caldera, crossed fluids with different conditions, respectively, temperature of 145 and 220 °C, and salinity of 60-70 g/l. All evidence points to a discontinuity of the productive zones, with a sporadic peimeability related to faults, fractures and volcanic chimneys. Moreover, the liquid phase is extremely saline and the gas phase high in $H_2S$. Therefore, the wells are not economically exploitable for the generation of electric power as demonstrated in the early '80s by experimentation with a Helical Screw Expander pilot plant. It is possible instead to exploit the dissolved salts in the fluids.

After the first drilling in the Cesano area, the available knowledge indicated the remaning Sabatini zone was propitious for the existence of hot geothermal fluids.
Two wells were drilled in the southern zone of Bracciano Lake. The former was productive, with fluids at 210°C and 200 bar, gas 7% by weight, high $H_2S$ content, corresponding to 9% gas volume. On the other hand, the second directional well is to be considered unproductive because of its lack of permeability; therefore, the reservoir previously found is likely to be of small dimensions.

North and east of Bracciano Lake, some unproductive wells were drilled; they crossed isolated pockets of pressurized fluid (water rich in dissolved C02 and $H_2S$). In these zones high temperature and strong phenomena of thermomethasomatismare present; in one well a temperature of 368 "C at depth of only 2175 m was recorded. The sole productive well found fluid at 210°C and 176 bar, but it was impossible to cany out experimentation because of the lack of a nearby available reinjection well.

In the western zone two other wells were drilled: the first was unproductive because of lack of permeability; on the other hand, the second entered a low temperature reservoir, about 60°C, in continuity with the structure detected previously during the Vico-Cimini Mt. exploration.

The Sabatini Mt. area therefore presents considerable structural complexity: high thermo-metamorphic and hydrothermal phenomena reduce the permeability of the potential reservoir, which thus is substantially linked to local and sporadic factors. The dissolved $CO_2$ would give rise to problems of scaling, and mainly the highly saline fluids with high $H_2S$ content would lead to very strong environmental complications. Considering the problems connected with possible exploitation (high costs and high mining risk) the resource was excluded from plans for further development.

### 3.4 Albani Hills Area

The wide and strongly urbanized Albani Hills volcanic area, southwest of Rome, was investigated with one well; it did not reach any potential reservoir by 790 m, and revealed a very low geothermal gradient (41°C at 610 m).

The very strict environmental constraints and the disappointing results obtained by drilling discouraged further exploration.

### 3.5 Campanian Geothermal Areas

Within the large caldera of the Phlegrean Fields 13 wells were drilled. The four wells located in the vicinity of S. Vito revealed high temperatures, up to 420°C, and modest permeability; another two wells, located just north of Mofete, showed no permeability.

In the Mofete zone, 7 wells were drilled; the present geothermal system is water dominant, made up of three aquifers.

Figure 5 shows a schematic geological cross section of the Mofete geothermal field.

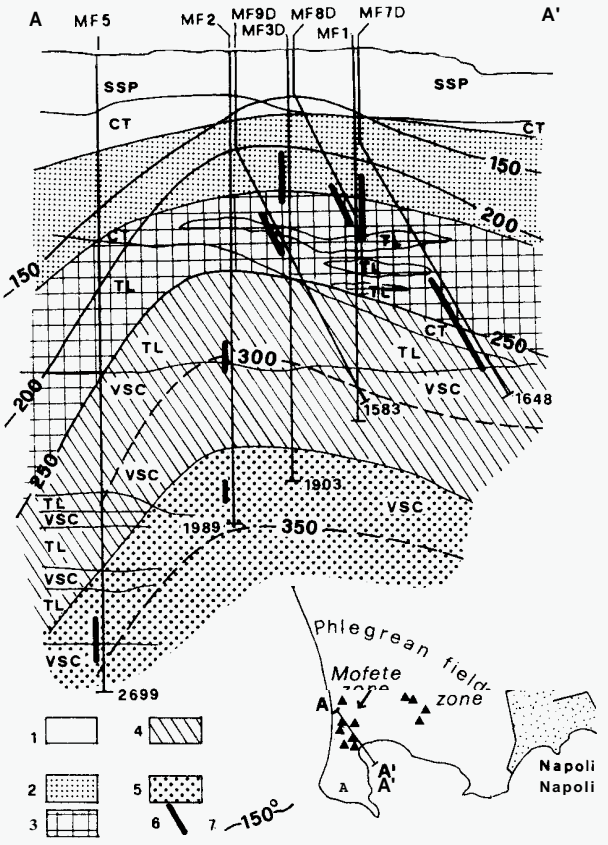


*Figure 5.* Schematic geological cross section of the Mofete geothermal field. Geological description: SSP) Subaereal and submarine Pyroclastics; CT) Chaotic tuffs; TL) Mainly trachitic lavas; VSC) Volcano-sedimentary Complex. Alteration Mineral Zonation: 1)Argillic zone; 2) Transition zone; 3) Chlorite - Illite zone; 4) Calcium - Aluminium Silicatic zone; 5) Thermometamorphic zone; 6) Productive levels; 7) Isotherms ("C).

The shallowest reservoir is made by fractured volcanic rock and coincides to the chloride-illite alteration zone. It was reached by 5 wells and is a+a depth of 550 to 1500 m. The fluid is characterized by salinity from 28000 and 52000 ppm and temperatures from 230 to 308°C. This reservoir is within tuff and trachytic lavas; self-sealing processes in the upper part of these terrains created the impervious cover, while fracturing in the deeper part produced the present reservoir.

The other two reservoirs correspond to thermometamorphosed sedimentary volcanic rocks.

In paricular, an intermediate reservoir was revealed by another well that crossed a deep productive zone at 1900 m; it presents a temperature of 340°C and low salinity, 18000 ppm. The deepest reservoir, with a hypersaline fluid (200000 ppm), and temperature of 350°C, was crossed by another well at 2700 m.

The fluids produced during the experimentation phase caused problems of scaling. Although the estimated potential of the area is about 7-8 MW, the problems of low productivity and fluid management (scaling and corrosion) together with environmental constraints, linked to the large urban settlement, led to the end of the exploration activity.

A stratigraphic research well was drilled in the Vesuvius region, East of Naples, where a temperature of about 50°C was recorded at a depth of 2000 m. In this area the reservoir below the volcano is represented by dolomitic formations, characterized by fracture-derived permeability. Because of the low temperature, geothermal exploration was abandoned.

## 4. FINAL REMARKS

In about 25 years of geothermal research in Latium and Campania, all volcanic zones (15,000 $Km^2$) of the entire Tyrrhenic belt, potentially suitable to find high temperature fluids, have been investigated.

Exploration activities have been systematically carried out in areas where, at first, deep geology was unknown. They consisted of geological, geochemical and geophysical surveys and many deep wells.

The first geological and hydrogeological models were developed from the regional surface knowledge, locating the potential reservoir in carbonate formations, on the basis of the outcrops at the edges of volcanic areas. Volcanic cover generally has thousand-meter thicknesses and masks deep structures from the geological, hydrogeological and geophysical points of view.

In spite of this, the good contrast of electric resistivity between the carbonate reservoir and the overlaying flyschoid formations allowed a reliable regional reconstruction of the buried structures. The drilling of sufficiently deep thermal test holes also allowed the reconstruction of deep temperatures.

High reservoir structures were already located in the first exploration phase, even though the Latera, Torre Alfina and Cesano geothermal fields turned out to be very small and very complex structurally. At Phlegrean Fields, the situation is different. Here both the cover and the geothermal reservoir are hosted inside of the volcanic sequence. Under these conditions, the Mofete and S. Vito geothermal structures were located mainly through gravimetric and magnetometric surveys.

All the geothermal systems found are water dominated, with high pressures.

The results of the geothermal research in Latium and Campania, however, have fallen short of our expectations: the production of electric power is foreseen only for the Latera geothermal field, where a plant is now under construction. Other utilization, projected or already underway, consists of diversified and collateral activities. In total, 47 MW will be installed (44 Latera, 2 Marta and 1 Torre Alfina). Projects for C02 commerce and heat production (Torre Alfina) and for the extraction and commerce of potassium salts, with the possibility of autonomous production of electricity (Cesano), are already underway or under completion.

The negative results derive from the high mining risk of these areas and give little space for exploitable resources as yet undiscovered. These unfavourable factors are mainly due to the low and discontinuous permeability of the potential reservoir. Generally, high temperatures, connected with hydrothermal and thermometasomatic phenomena have been measured in wells; these phenomena often caused a drastic reduction of permeability that remained low if natural fracturing was not continually renewed.

High temperature (300" C) and low permeability areas were located at a depth of 2000 - 3000 m and correspond to wide volumes of dry, hot rocks.

Another negative factor concerns the nature of geothermal fluids. They are scaling, highly reactive, and have high concentrations of polluting gases ($H_2S$), which, together with various environment constraints, increase the cost of an eventual exploitation.

In the course of the exploration, especially in wide areas of Latium, medium-low temperature resources have also been located. Exploitation of these resources does not involve technical mining problems, but political and promotional actions are necessary in order to stimulate enterprising projects for the direct utilization of heat in the same places where resources are found. These have been integrally listed in the Inventory of National Geothermal Resources, compiled in the last few years on behalf of the Department of Industry, Trade and Craftwork, based on the necessary support of data acquired during exploration.

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