HELIUM PROSPECTING IN GEOTHERMAL AREAS

Preliminary Data on Larderello-Travale and Cesano Geothermal Fields

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Introduction

One of the objectives in geochemical prospecting for geothermal research is that of individuating, in the surface manifestations, indicators of buried geothermal reservoirs. Many chemical species present in gases, natural waters and soils have been proposed for this purpose (e.g., F. Tonani, 1970; A. Koga and T. Noda, 1975; H.R. Bowman et al., 1975; J.S. Matlick, III and P.R. Buseck, 1975).

Recently the helium present in the soil's gas was also proposed as an indicator in geothermal prospecting (A.A. Roberts et al., 1975; I. Friedman et al., 1976). This method has the advantages of being extremely simple and applicable even in areas with no natural manifestations. It has, however, never been experimented with on wide scale in known geothermal fields.

As part of a study which includes helium prospecting of a wide region of the pre-Appennine belt of Italy, this paper presents and discusses the data obtained in the geothermal fields of Larderello-Travale and Cesano.

Brief Geological Outline

- Larderello - Travale

Many papers describe in detail the geological and tectonic features of Tuscany's geothermal fields (e.g., R. Mazzanti, 1966; A. Lazzarotto, 1967;

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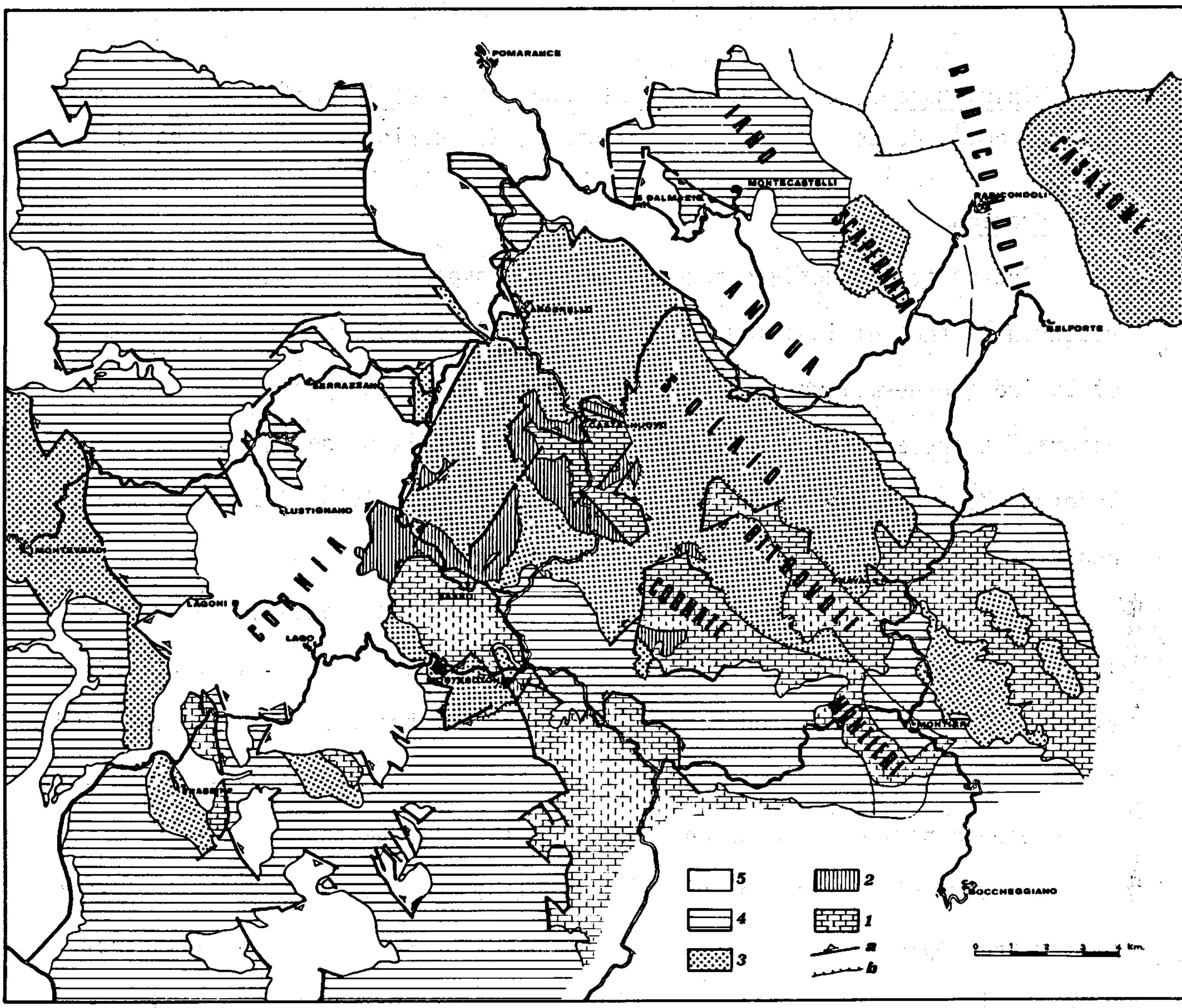

Fig. 1 - Geological-structural sketch of the Larderello-Travale region (from G.P. Brandi et al., 1968; A. Lazzarotto and R. Mazzanti 1976; redrawn).

1: Tuscanides: basal terrigenous complex, carbonate complex, upper terrigenous complex (Upper Triassic-Oligocene).

2: Ligurides: shale and limestone complex (Eocene).

3: Ligurides: marly limestone complex (Cretaceous-Upper Paleocene).

4: Ligurides: ophyolitiferous complex (Lower Cretaceous).

5: Lacustrine and marine sediments (Upper Miocene-Pliocene).

a: Faults, with triangle in the dipped side.

b: Overthrusts.

R. Cataldi et al., 1963; R. Celati, et al., 1978).

The geological history can be summarized as follows (Fig. 1):

- the oldest formations belong to a metamorphic Paleozoic basement, made up by phyllites and quartzites with intercalations of dolomites, marbles and anhydrites.

- A complex series of nappes lying on the basement were implaced during the last phases of alpine orogeny (Upper - Middle Miocene). From the bottom to the top it can be distinguished as: a) "Tuscanides" (Upper Triassic-Oligocene) constituted by a sequence of basal terrigenous complex, a carbonate complex and an upper terrigenous complex. The Tuscanides and the upper part of the basement represent the geothermal reservoir; b) "Ligurides" (Upper Jurassic - Eocene) which include three main flysch-facies units thrust one over the other, from bottom upwards: shale and limestone complex (Eocene), marly limestone complex (Cretaceous - Upper Paleocene), ophyolitiferous complex (Lower Cretaceous).

- Lacustrine and marine formations overlie the whole series with unconformity (Upper Miocene - Pliocene). These formations and the "Ligurides" are assumed to represent the impermeable cover of the geothermal reservoir.

-<u>Cesano</u>

The Cesano geothermal field, described by many papers (e.g., E. Locardi et al., 1975; P. Baldi et al., 1976a; P. Baldi et al., 1976b; R. Funiciello et al., 1976; R. Funiciello et al., 1979), is located about 20 km north of Rome, in the Sabatini Mts.

It corresponds to a minor structural high, bordered by normal faults, inside a large graben that developed beginning in the Upper Miocene on the pre-Appenine belt.

Phreatomagmatic activity occurred between approximately 200,000 and 100,000 years ago, corresponding to the youngest volcanic activity of the Sabatini Mts. The Sabatini activity (mainly fissured-type) started around 500,000 years ago. The first products were acidic trachytic pyroclastic flows followed by markedly alkaline lavas and pyroclastics. The thickness of pyroclastic products may reach 1000 meters.

The sedimentary deposits beneath the volcanic cover are described below (see Fig. 2):

- a) discontinuous post-orogenic sedimentary activity, including lithotypes ranging in age from Lower Pleistocene to Upper Miocene, mainly clay, occasionally silty, with conglomeratic horizons.

- b) Flysch-facies complex, 200-900 meter thick: numerous lithotypes are represented (shaly argillites, marls, sandstones and limestones), the age of which range from Middle Cretaceous to Lower Miocene.

- c) Carbonate basal sequence including marls, marly limestones, and limestones, ranging in age between Oligocene and Upper Trias. The Upper Trias is present both as dolomitic limestone and as calcareous-anhydritic formations.

Experimental Work

The survey consisted of a grid sampling in the Larderello-Travale and Cesano fields, with a density of one sample per square kilometer. The work took place in July, August and September 1980, when climatic conditions were quite uniform with little precipitation.

A total of more than 1000 samples were collected, out of which 800 in Larderello-Travale and 280 in Cesano. In the latter area, some profiles were made with a sampling density roughly of 3 points per square kilometer.

Three samples were taken at each sampling point by inserting a metallic

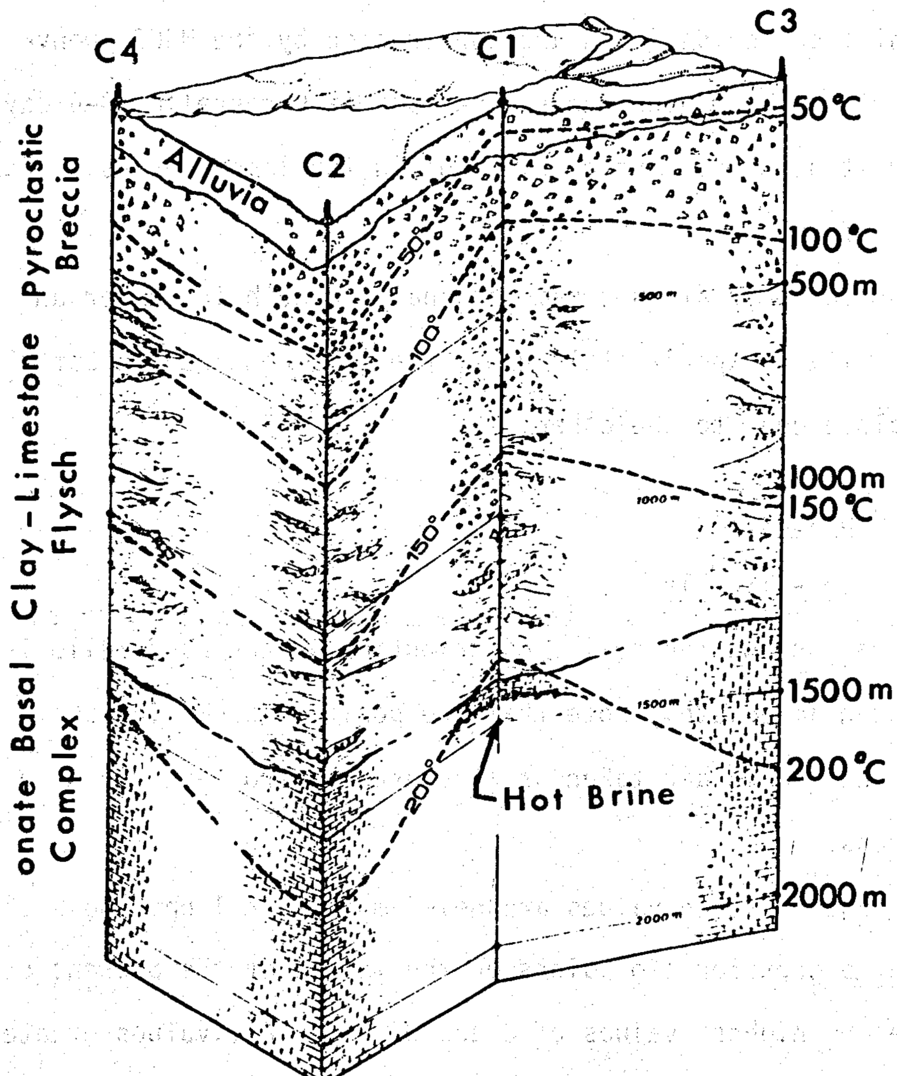

Fig. 2 - Block diagram showing the relationship between volcanic cover and sedimentary cycle on Cesano geothermal field (from P. Baldi et al., 1976b).

probe in the ground, according to the technique used by the USGS laboratories at Denver (G.M. Reimer and G.C. Bowle, 1975). The samples were collected in evacuated glass containers (VACUTAINER®, VENOJECT®), fitted with rubber caps.

The measurements were made using a Dupont 120 SSA-leak detector, fitted with an inlet device designed and constructed by the USGS, Denver, (G.M. Reimer, 1976). Part of the measurements were made at Larderello, 3-4 days after sampling, although most of these were carried out in the laboratories at Denver about 15-20 days after.

The results of aliquot samples analysed both in Denver and Larderello show that, within experimental error, the data obtained in both laboratories are very close one to the other.

Results and Discussion

Larderello - Travale

Figure 3 shows the helium distribution in the Larderello-Travale area.

One can immediately note that the positive anomalies above the concentration of helium in air taken as a reference zero, are found in rather well-defined areas.

The concentration values are never more than 1 ppm above that in the atmosphere, except for two points on the margin of the present study area which have the highest values of 8 and 33 ppm. All values greater than 50 parts per billion (ppb) above the 5240 ppb found in air are considered anomalous.

The main characteristics of this distribution are:

1. Practically no anomalous helium concentrations were found in a wide zone in the north (Micciano-Pomarance).
2. Some anomalous concentrations were recorded near the productive

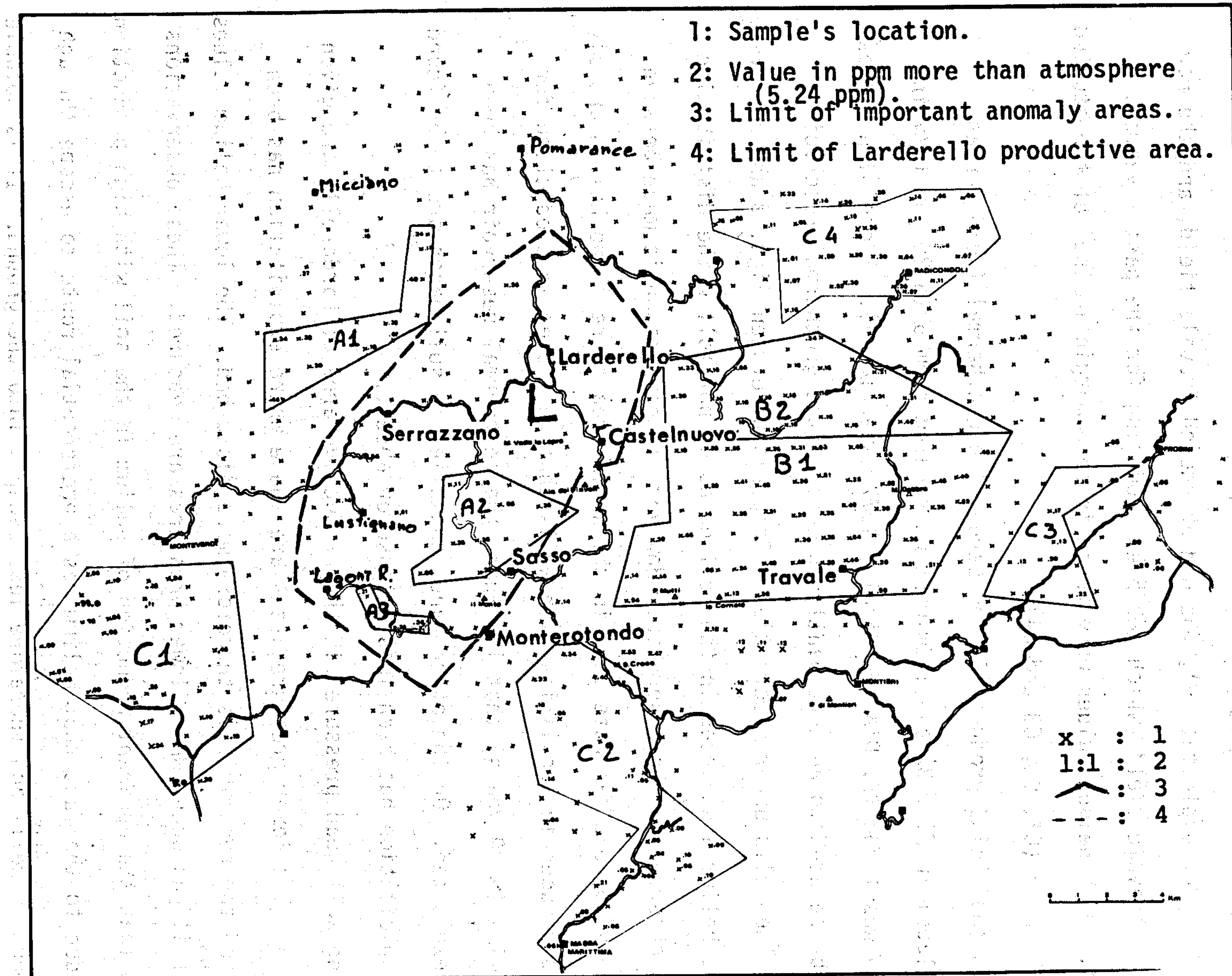

Fig. 3 - Distribution of the helium in the soil gases in the Larderello-Travale geothermal field.

fields in the Larderello zone (A1, A2 and A3 in Fig. 3).

3. An anomaly zone extends between Larderello and Travale (B1 and B2), including: the area of gas wells at Sesta (which are not under exploitation), the old abandoned Travale field, and the new Travale field (which has been producing for the past 7 years).

4. High helium values were found in some marginal zones of the studied area (C1, C2, C3 and C4).

In the fluids produced in the Larderello geothermal field (areas with L label in Fig. 3) a helium content ranging from 5 to 20 ppm (v/v in the gas) was found (F. D'Amore et al., 1977; see Fig. 4). These high values should be related to an accumulation process in the geothermal reservoir feeding the wells under observation. Comparison between Figs. 3 and 4 shows that the helium abundances in the soil gases do not follow the distribution pattern observed in the reservoir. However, if comparison is made between Figs. 3 and 5, one can note that in the whole area there is no helium anomaly or it is reduced in localities with wells that have been in production for a long time ($>$ 30 years) that is, where the geothermal reservoir has been highly exploited. On the other hand, anomalies in soil gases are to be found where exploitation has been less intense or absent.

The well head pressures in the productive area of Larderello are given in Fig. 6. The lower pressure areas are those where exploitation has been higher and the reservoir is therefore more disturbed. The lower helium values in the soil gas occur where lower pressures are measured. These observations suggest that the apparent reduction of helium in the soil with high production may be due to the fact that helium has a preferential route to escape through the producing wells and therefore less escapes into the ground. It is notable that many of the surface manifestations have disappeared in the Larderello area with the onset of exploitation.

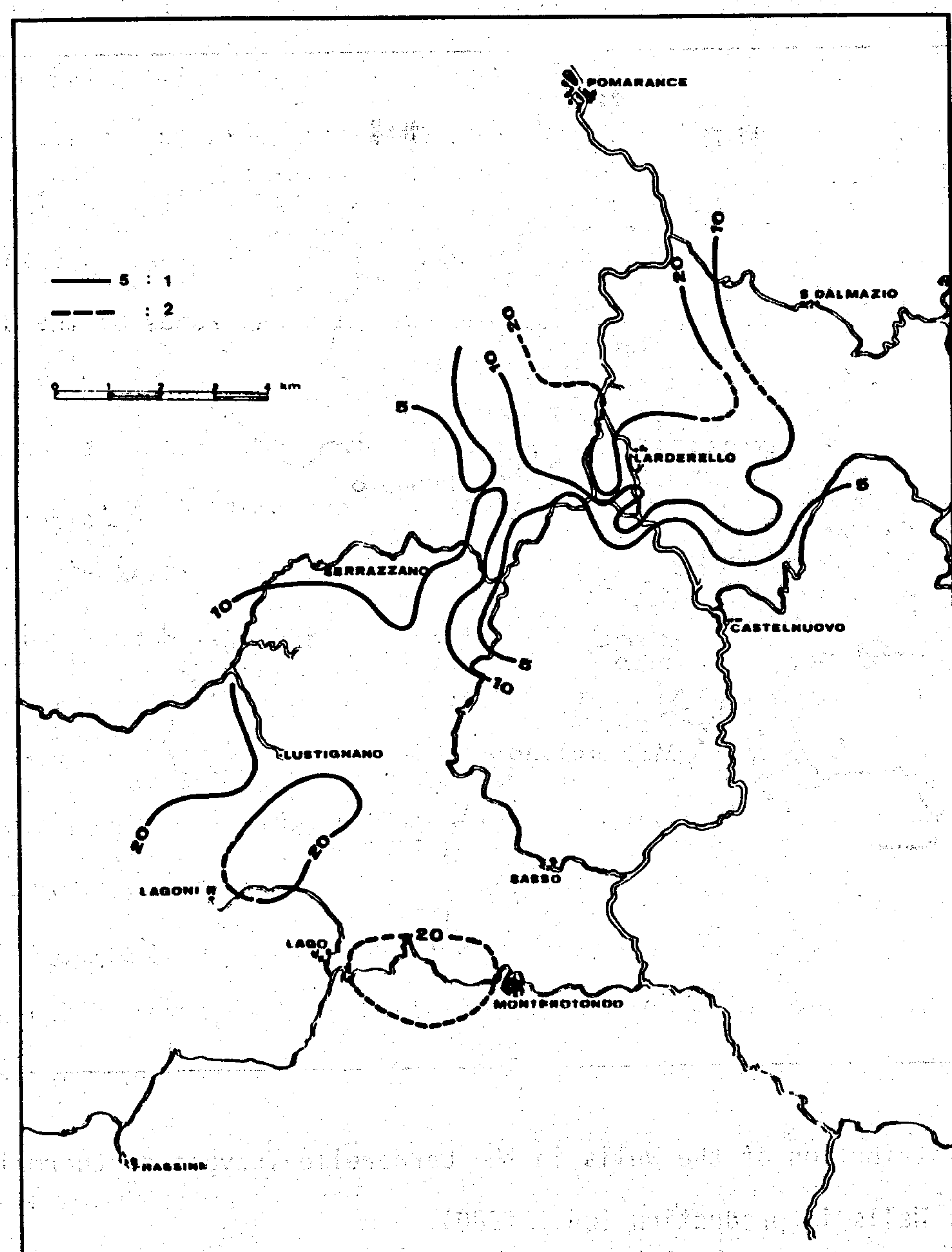

Fig. 4 - Helium concentrations in the wells in the Larderello geothermal field (from D'Amore et al., 1977).
1: Interpolated isoconcentration lines with values in ppm.
2: Isoconcentration lines for areas with few wells surveyed.

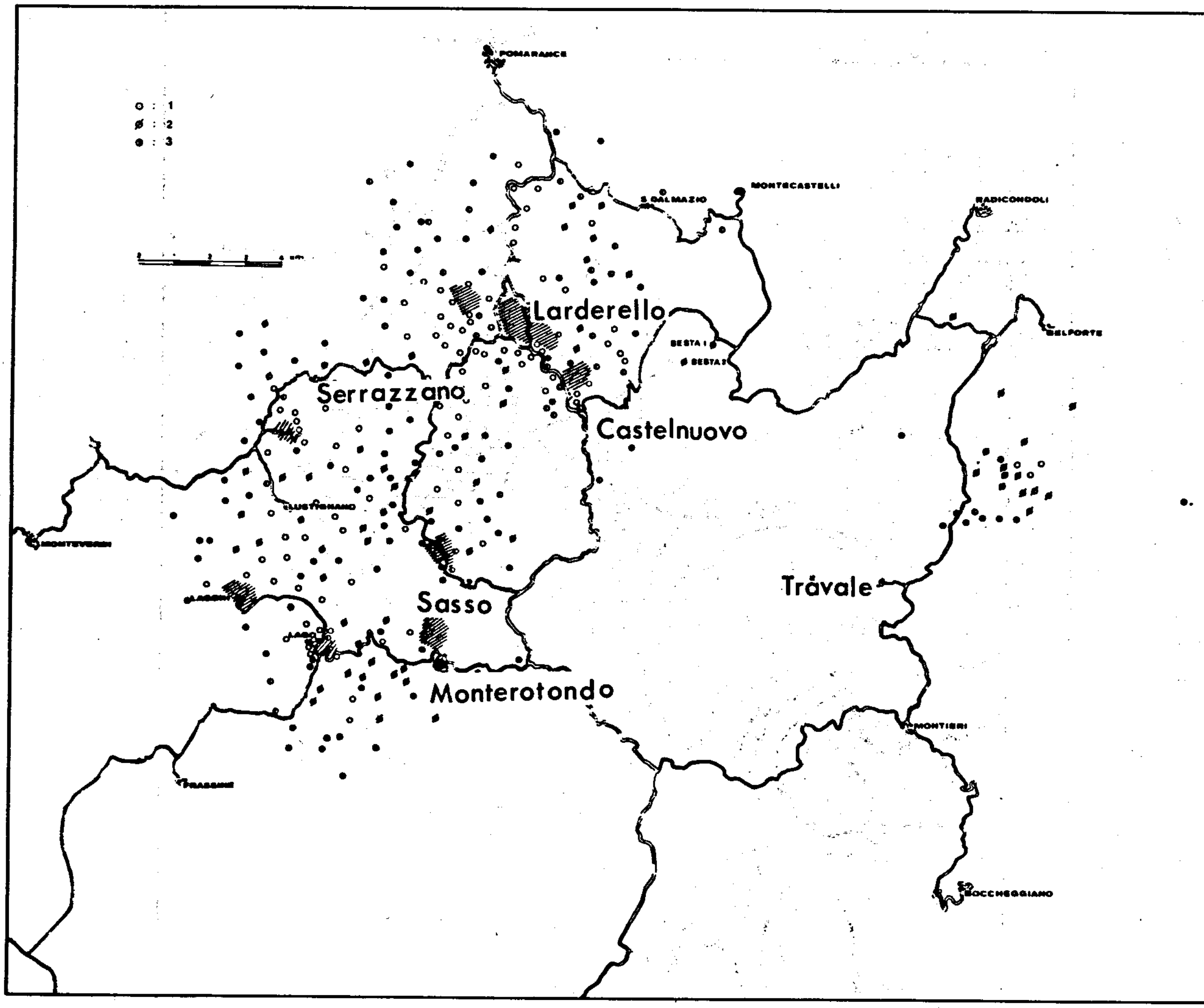

Fig. 5 - Distribution of the wells in the Larderello-Travale geothermal field.

1: Wells in production (July 1980).

2: Productive wells not in production (July 1980).

3: Not productive wells.

Dashed areas: intensively drilled areas with most of the wells in production.

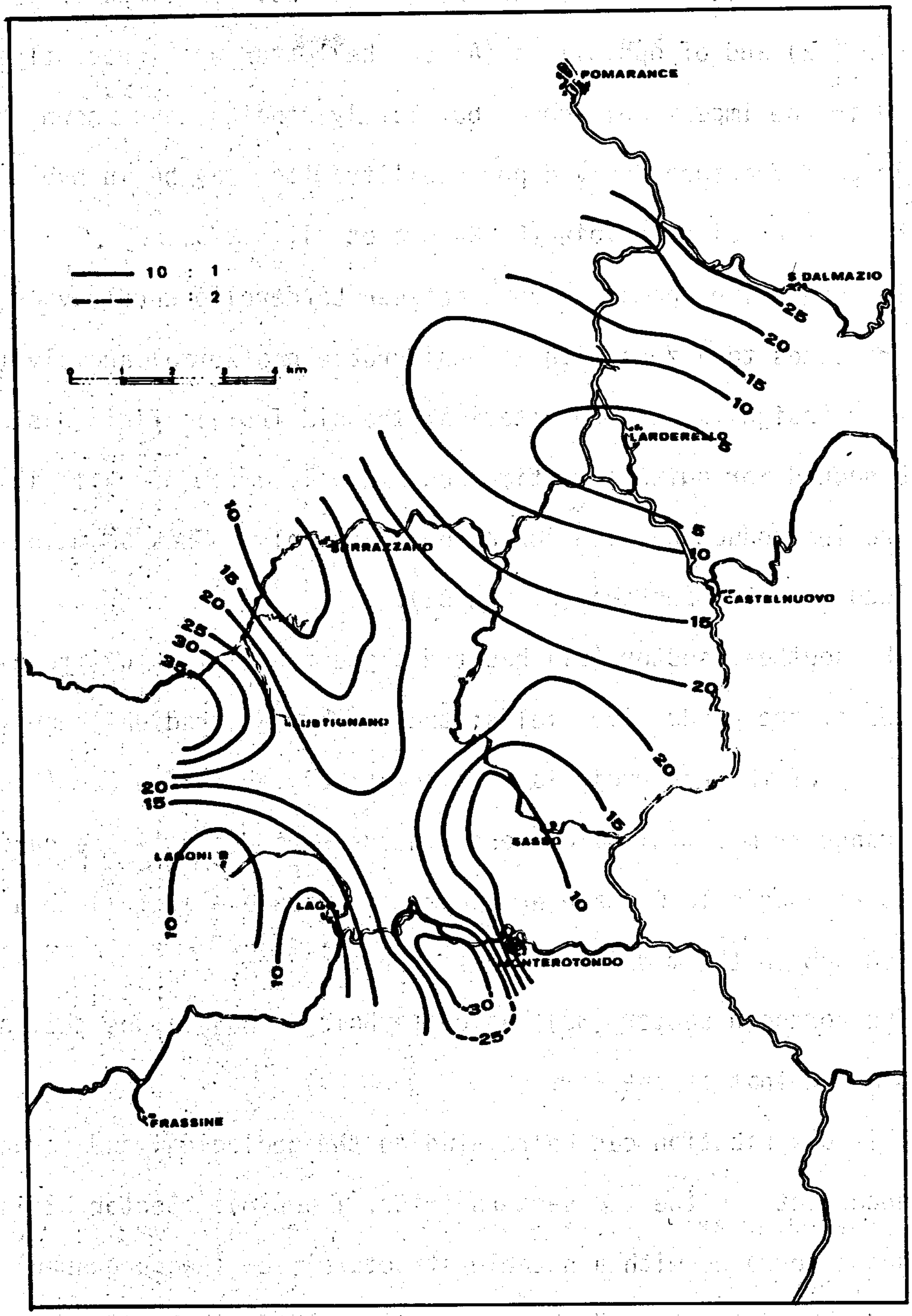

Fig. 6 - Well shut-in pressures in the Larderello geothermal field.

1: Interpolated isopressure lines with values in Kg/cm^2.

2: Extrapolated isopressure lines.

However, the anomalies of areas A1, A2 and A3 (Fig. 3) may be controlled by a higher rock permeability, as these zones have small outcrops of the reservoir (A2) and of ophyolites (A1). The latter until recently were included in the impermeable cover but lately studies have shown that, due to their good fracture-derived permeability, they may be in hydraulic contact with the geothermal reservoir (C. Calore et al., 1979).

The extensive anomalous zone between Larderello and Travale (B1 and B2) corresponds to a zone with a considerable geothermal anomaly (Fig. 7) and relatively insignificant exploitation; the old Travale field has, in fact, been abandoned for quite some time now and only a few of wells in the new field are in production, and for a few years only. This anomalous zone can be divided into two sectors (B1 and B2).

The southern sector (B1) has the highest helium values found on the perimeter of the productive fields; the geothermal gradient here reaches 0.1°C/m and the top of the reservoir is at a relatively shallow depth (Fig. 8). The values range from a minimum of zero (in correspondence to the carbonatic outcrops at Poggio le Cornate and south of Travale - Fig. 1) to a maximum of about 600 ppb in the middle of the sector.

The northern sector (B2) has quite homogeneous values that are about 160 ppb above that of the air.

This distribution can be related to the geological and structural differences between the two sectors (Figs. 1 and 8). Sector B2 is an area of Neogenic terrains with a notable structural low (Anqua graben) where the maximum depth of the top of the reservoir is 1200 m below sea level (R. Cataldi et al., 1977).

It would appear from this that certain major tectonic factors, such as the faults and uplifted structures of the Anqua-Salaio zone (Fig. 1), have

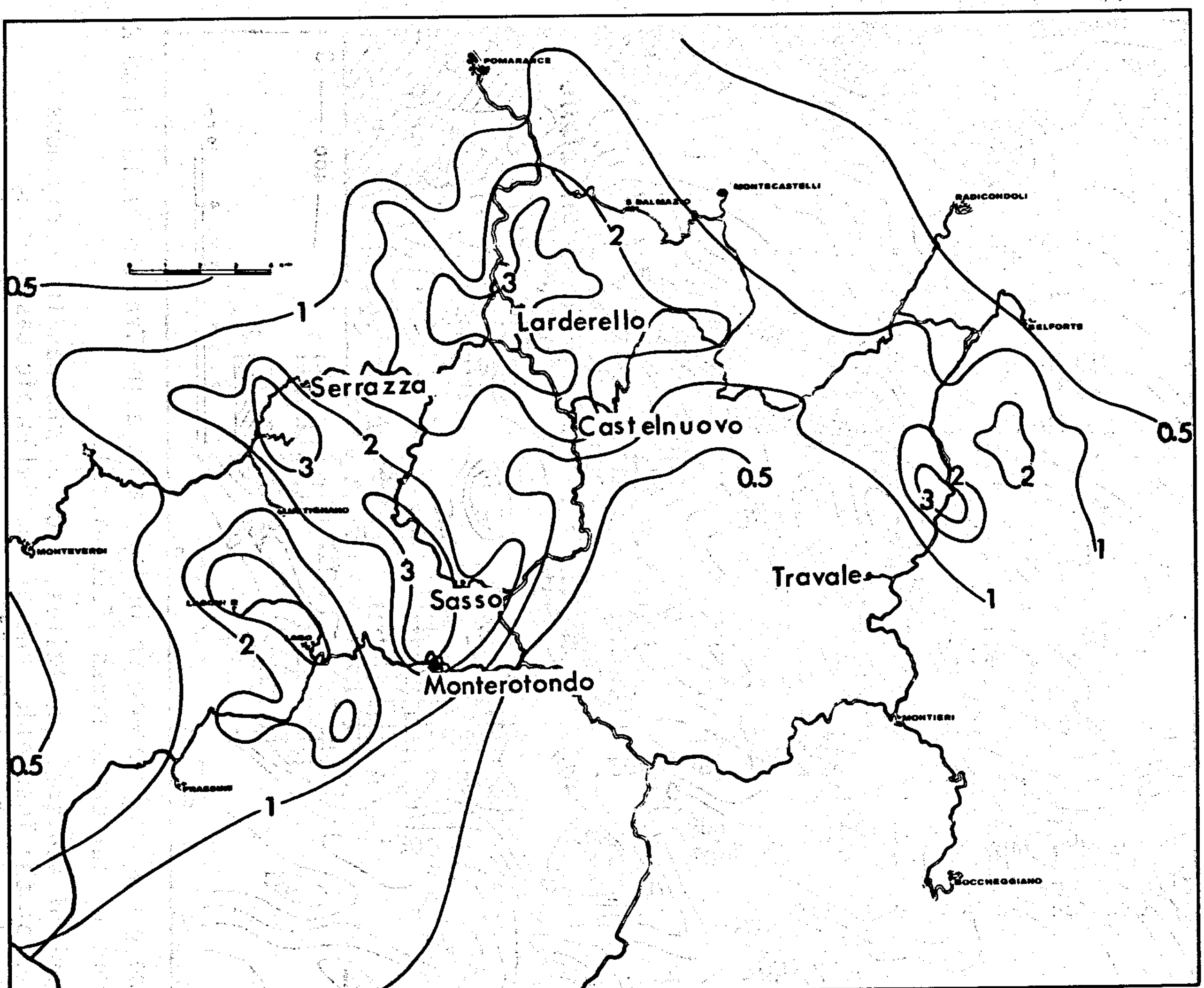

Fig. 7 - Trend of the geothermal graident on the inside of the Larderello-Travale field.
Values are in °C per 10 m depth.

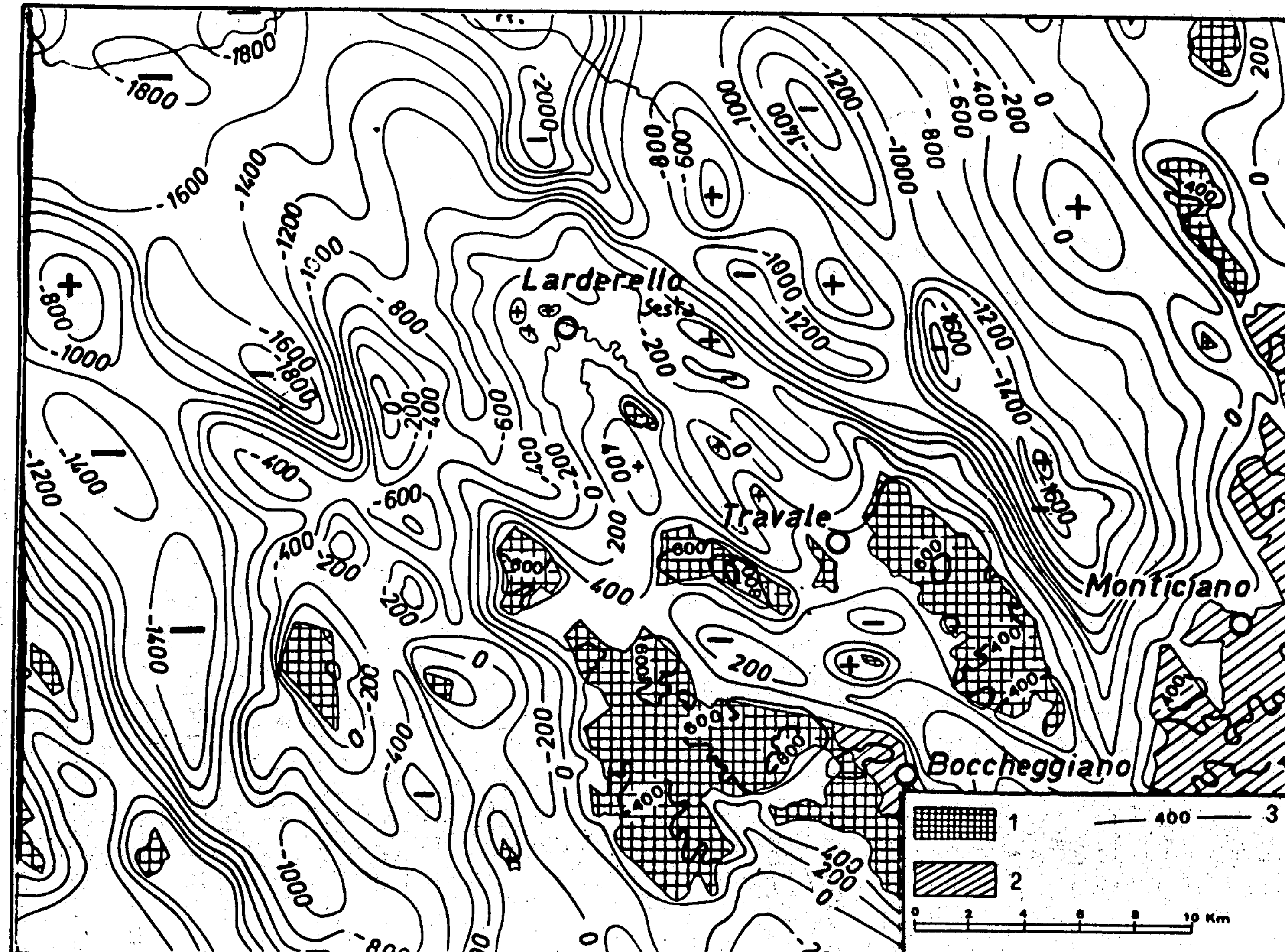

Fig. 8 - Isobaths of the top of the geothermal reservoir in the Larderello- Travale field (from R. Cataldi et al., 1977). 1: Outcrops of carbonate rocks (Tuscanides).

2: Outcrops of schists, quartzites, etc. of the basalt terrigenous complex of the Tuscanides and of the Paleozoic basement.

3: Contours on top of the main reservoir in meters relative to sea level datum.

an influence on the presence of helium anomalies on the surface.

It should, however, be noted that the great thickness of sedimentary cover (mostly in excess of 1000 meters thick in sector B2) is unable to block the escape of helium in this area.

The tectonic structures of Anqua-Salaio extend towards Pomerance, which is a zone with no recorded helium anomalies. The top of the reservoir in this zone plunges downward and is more than 2000 meters below the ground surface.

The anomalies recorded on the margins of the study (C1, C2, C3 and C4) are generally near important fault systems and where the top of the reservoir is within a few hundred meters from the surface (C1, C3, C4) or even outcrops (C2). The large quantities of helium present in the geothermal reservoir presumably find an easy escape route through these areas which are characterized by carbonate and evaporitic Mesozoic formation and Triassic-Paleozoic quartzitic-phyllitic formations. In addition, tectonics plays an important role in facilitating the helium leakage as all four areas are near the borders between horst and graben structures.

The presence of granitic bodies at shallow depth near the area C2 (Niccioleta) and west of C1 (Campiglia) could have a bearing on the helium anomalies in these zones.

- <u>Cesano</u>

Fig. 9 shows the location of sampling sites and the helium anomalies in the Cesano area.

The positive anomalies are located mainly in two belts, east and south of Bracciano lake. The helium enrichment found in soil gases compared with air composition is fairly high. The positive values range from 50 to 150 ppb and a few are even higher, reaching a maximum of 400 ppb. The anomalous values are represented in Figs. 10 and 11.

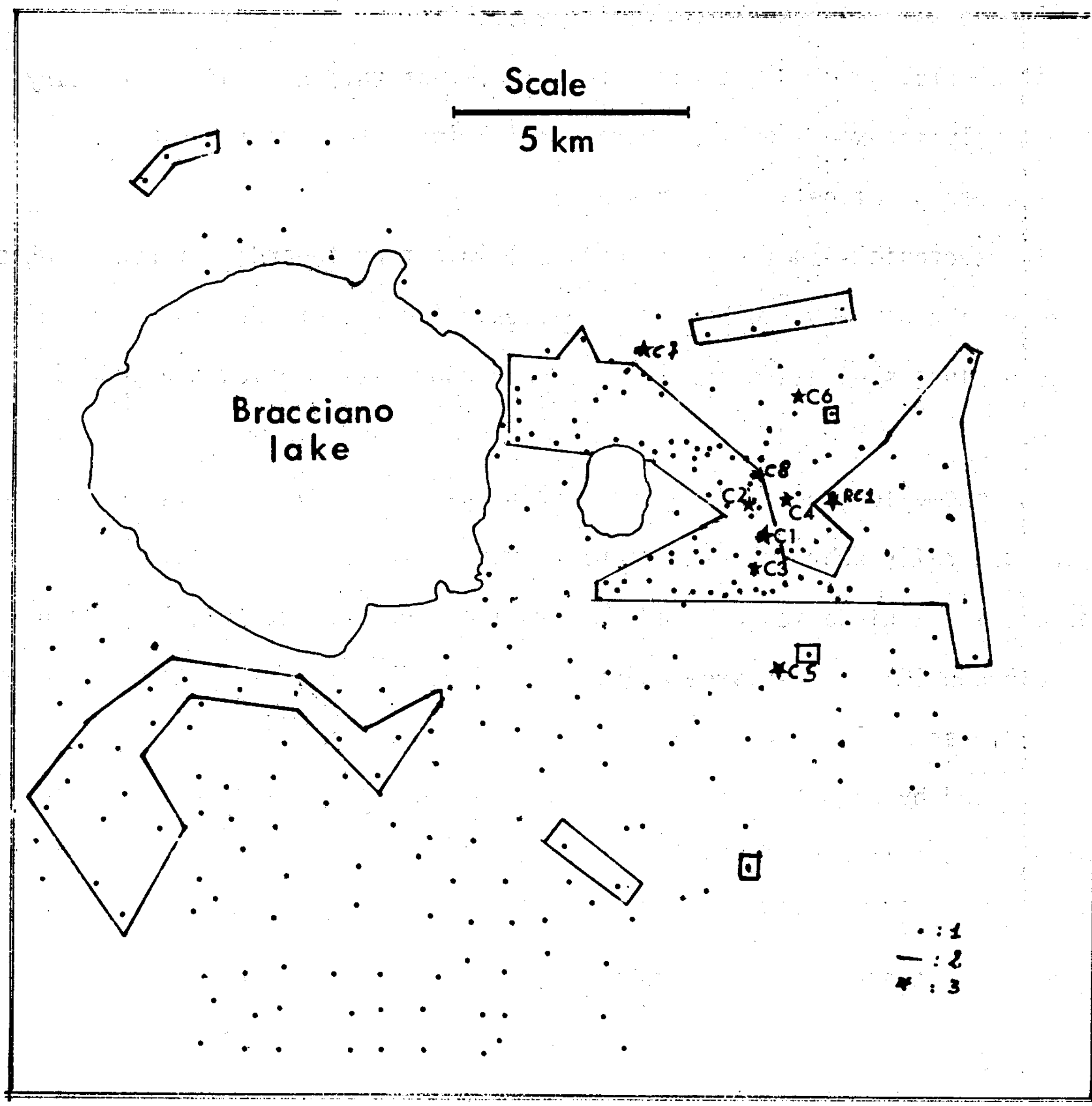

Fig. 9 - Distribution of the helium anomalies in the soil gases in the Cesano geothermal field.

1: Sample's location.

2: Limit of important anomaly areas.

3: Geothermal wells.

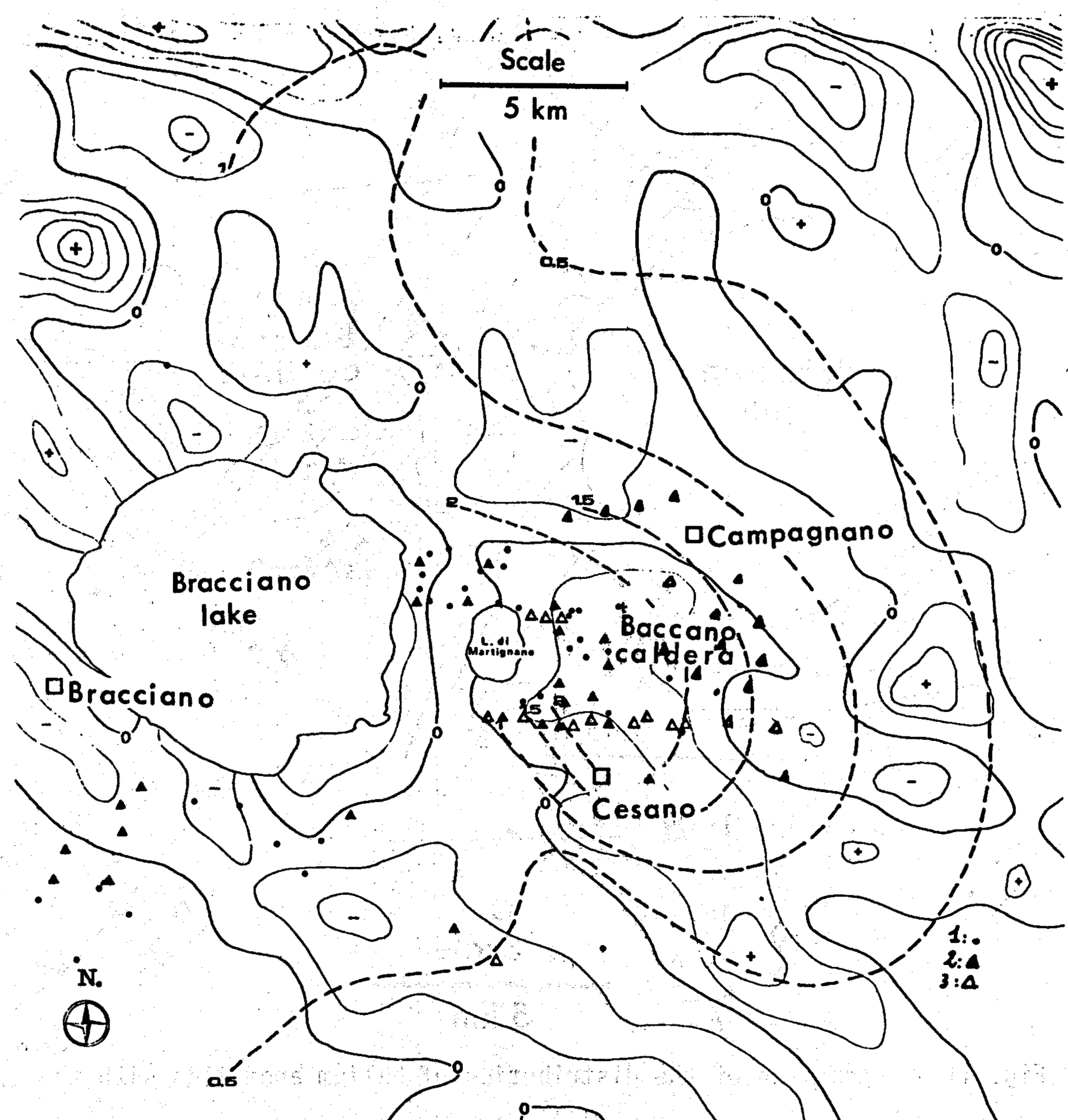

Fig. 10 - Comparison of the distribution of helium anomalies with the gravimetric profiles (from G. Buonasorte and A. Fiordelisi, 1979). The geothermal gradient east of Bracciano lake is also shown.

1: Anomalies between 50 and 100 ppb;

2: Anomalies between 100 and 150 ppb;

3: Anomalies exceeding 150 ppb.

Solid lines: gravimetric contours (m gal.)

Dashed lines: geothermal gradient contours (^{o}C per 10 m. depth).

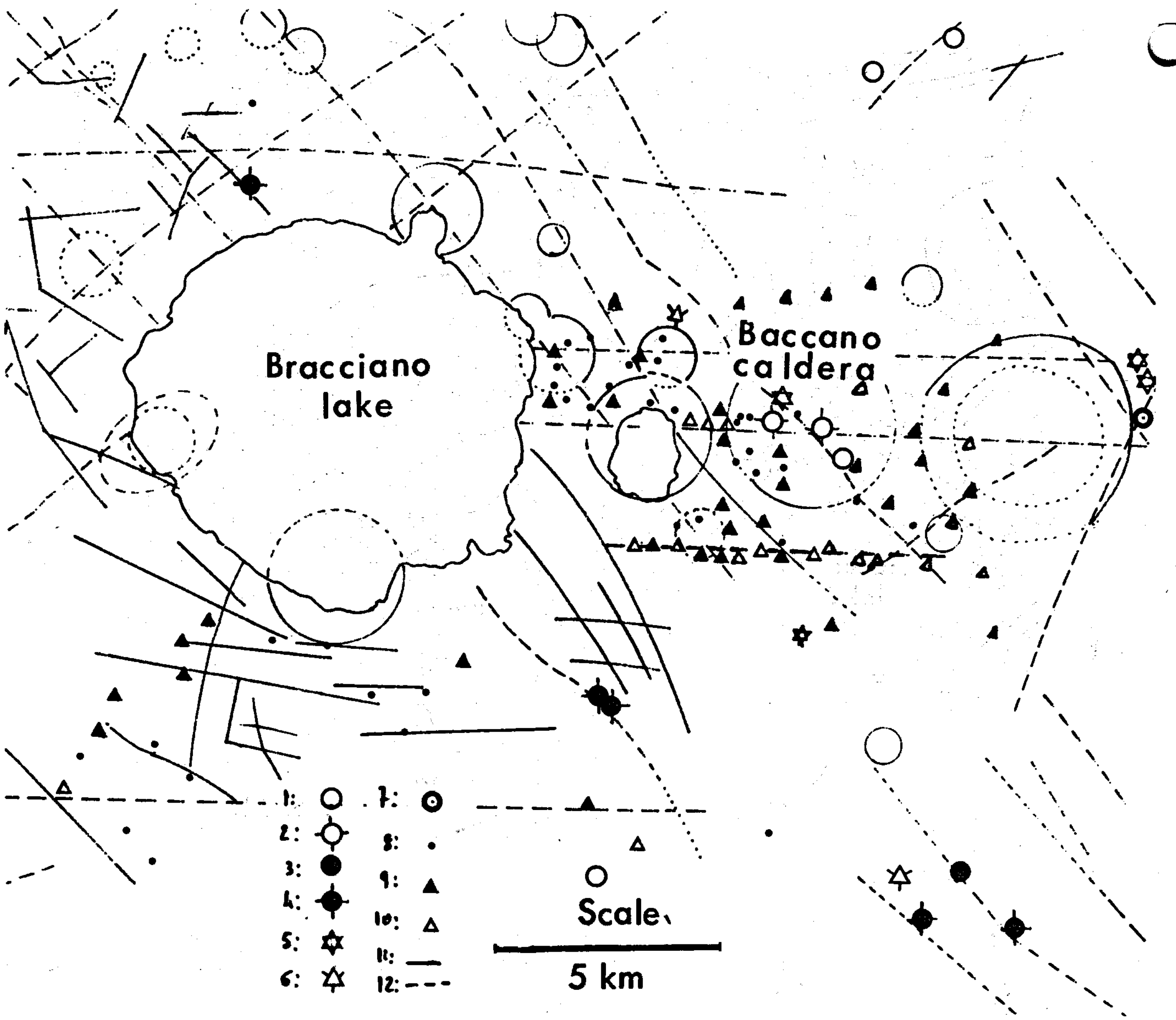

Fig. 11 - Comparison of the distribution of helium anomalies with the tectonic features of Sabatini Mts. area (from R. Funiciello, personal communication).

1: Helium in soil gas from 50 to 100 ppb.
2: Helium in soil gas from 100 to 150 ppb.
3: Helium in soil gas over 150 ppb.
4: Mineral springs.
5: Mineral springs with gas.
6: Hot mineral springs.
7: Hot mineral springs with gas.
8: Mineral wells
9: Mineral wells with gas.
10: Gas manifestation.
11: Faults.
12: Inferred faults.

In the former they are superposed on a gravimetric map, which also shows geothermal gradient in the east zone of Bracciano lake. It can be noted that the most striking helium values do correspond to a gravimetric high where the geothermal gradient reaches its maximum value (0.2°C/m).

In Fig. 11 a comparison is made with the alignment of the main fault systems (mostly normal faults) and the location of the craters produced by recent phreatomagmatic activity of the Sabatini Mts. Both faults and craters are in line with the main tectonic trends of the pre-Apennine belt. It can be seen that the distribution of the helium anomalies is related to these main trends and, in particular, to the distensive tectonics which have been active in the area during successive phases from Early Neogene to present.

The anomalies, at least in part, are located in the zone of the younger phreatomagmatic calderas (≈100,000 years), which moreover are related to the recent distensive tectonics.

Finally, it is worth stressing that in the area where we find the higher anomalous helium values in soil gases, drilling has proved the existence of a peculiar geothermal field.

First Conclusions

The results of this study show that a large helium anomaly exists in the Larderello-Travale geothermal field. However, since the productive wells provide a preferential escape route from the reservoir, the helium can be detected in the soil gases where the reservoir is relatively undisturbed and the rock permeability is favorable.

The depth of the top of the reservoir is probably a controlling factor for the existence of positive helium anomalies on the surface: where the cover is of the type found in the study areas, the helium probably can no longer escape if the roof of the reservoir lies below 2000 m from ground level.

The tectonic framework has also an important role in controlling helium leakage, and fracture systems are clearly delineated by this gas.

Furthermore helium tends to escape from the water recharge zones. The only exception to this rule is Poggio le Cornate (with outcrops of the reservoir and no helium anomalies) which is located near the Castelnuovo productive area, where the exploitation has brought about a strong decrease in the reservoir pressure and in helium abundance.

In the Cesano area, the helium anomalies correlate well with the high geothermal gradient and with the structure.

In this area the highest helium anomaly is located east of Bracciano lake, where a peculiar geothermal field has been discovered in recent years.

It is worth noting that, contrary to Larderello, the Cesano field has not yet been affected by intensive exploitation.

Future Development

Considering the results obtained so far, the study will proceed along the following lines:

- completing the case histories by prospecting of the whole region between Larderello and Rome and in particular other known fields where exploitation has been less intense than at Larderello (Alfina, Latera) or the reservoir still undisturbed (Colli Albani);
- more detailed surveys in correspondence to particular tectonic features;
- isotopic analyses of the helium found near the geothermal fields, both on the surface and in the reservoir, to obtain a better definition of its origin and leakage mechanism;
- further study of possible relationships between helium anomalies and seismic activity.

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