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LICHEN BIOMONITORING AS A TOOL FOR ASSESSING AIR QUALITY IN GEOTHERMAL AREAS

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ABSTRACT

To answer the growing concern among inhabitants about possible health and environmental effects due to the industrial exploitation of geothermal resources, lichen biomonitoring programmes have been performed in the Italian geothermal fields of Travale-Radicondoli and Mt. Amiata. In both areas, the mapping of lichen diversity showed that the zone of worst air quality does not extend more than about 500 m from the power plants. Major injury to lichens are probably caused by hydrogen sulphide, a highly toxic gaseous pollutant. In both geothermal fields, the concentrations of trace elements found inside lichen thalli indicated some accumulation of arsenic, boron and sulphur. It is highly likely that hydrogen sulphide is both the main source of atmospheric sulphur and the main pollutant responsible for lichen decline around geothermal installations.

INTRODUCTION

It is now well known that the production of geothermal energy may affect the surrounding environment. Excluding geological and geophysical effects, the environmental impact is related to the emission to the atmosphere of significant amounts of uncondensable greenhouse gases, as well as elements and compounds of toxicological relevance which may be dangerous to public health (Axtman, 1975; Ármannsson & Kristmannsdóttir, 1992).

Lichens are one of the most valuable biomonitors of atmospheric pollution. They can be used as sensitive indicators to estimate the biological effects of pollutants by recording changes at the community or population level, and as accumulative monitors of persistent pollutants, which can be assessed by assaying their trace element content (Ferry *et al*., 1973).

The use of lichens as biomonitors of geothermal air pollution dates back to the beginning of the 20th century, when Bargagli-Petrucci (1915) reported the absolute absence of lichens in the geothermal area of Larderello (Italy), contrasting with their abundance in the surrounding regions.

In recent years, lichen biomonitoring programmes have been launched in the Italian geothermal fields of Travale-Radicondoli and Mt. Amiata, chiefly to answer the growing concern among inhabitants about possible health and environmental effects due to the industrial exploitation of the geothermal resource. The present paper reports the main findings of these studies.

STUDY SITES

The Travale-Radicondoli geothermal field (Fig. 1) is located in an area far removed from any local source of air pollution except the geothermal installations, consisting of four power plants (one 30 MW and three 20 MW). The elevation ranges from 300 to 560 m. The climate is humid sub-Mediterranean, over a range of 1000 mm for mean annual rainfall and 13°C for mean annual temperature (Barazzuoli *et al*., 1993).

The Mt. Amiata geothermal field (Fig. 1) was once well known for its cinnabar deposits, which, despite the cessation of mining and smelting activities in the late seventies, still cause high environmental mercury levels (Barghigiani & Ristori, 1994). In the area, four power plants are in operation (one 8 MW and three 20 MW). The elevation ranges from 350 to 1000 m. The climate is humid sub-Mediterranean, with mean annual rainfall in the range 1000-1555 mm and mean annual temperatures ranging from 9.7 to 11.3°C (Barazzuoli *et al*., 1993).

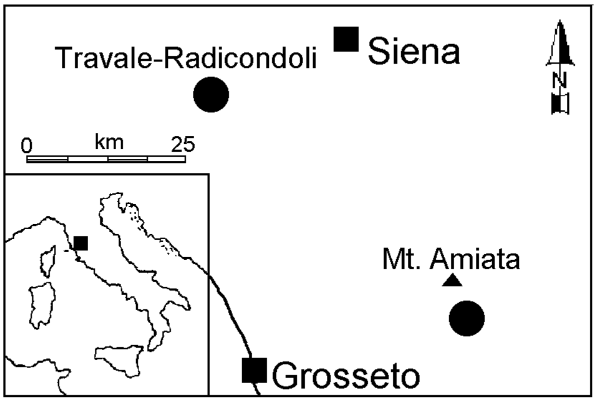

Figure 1. Map of the study area

MATERIALS AND METHODS

Lichen biomonitoring studies are based on the assumption that all environmental variables except air pollution are minimized by adopting a strictly standardized sampling protocol (Richardson, 1991). For this reason, in both geothermal areas lichens were sampled on the trunks of 1-5 isolated trees per station, at a height of 1.5-2 m above the ground.

The diversity of the epiphytic lichen flora was taken as an active indicator of air quality by calculating an "Index of Atmospheric Purity" (IAP). This method, which is currently in use in Italy (Loppi *et al.*, 1996), is based on the sum of lichen frequencies within a sampling grid of 50x30 cm, subdivided into 10 units of 10x15 cm, and allows expression of the richness of lichen vegetation with a single number, the IAP, according to which the higher the IAP the better the air quality (LeBlanc & De Sloover, 1970).

Thalli of *Parmelia* sp. were collected for elemental analysis. Lichen samples were powdered and homogenized, and about 150 mg of material was mineralized in a pressurized digestion system with concentrated HNO_3 for 8 h at 120°C. Total concentrations of trace elements, expressed on a dry weight basis, were determined by: 1) atomic absorption spectrophotometry, using a graphite furnace for Cd, Co, Mo and Pb, a hydride generator for As and Sb and the cold vapour technique for Hg; 2) inductively coupled plasma emission spectrometry for Al, B, Cr, Cu, Fe, Mn, S and Zn. Analytical quality was checked by analyzing the Standard Reference Materials No. 1572 'Citrus Leaves' and No. 1573 'Tomato Leaves'.

RESULTS AND DISCUSSION

In both geothermal fields the lowest IAP values were found around geothermal power plants, and the mapping of lichen diversity showed that the zone of worst air quality does not extend more than about 500 m from the power plants. The ranking of IAP values in 10%-class intervals (Fig. 2) showed that the air quality recorded in the Mt. Amiata area is generally better than for the nearby area of Travale-Radicondoli, where the frequency of low IAP values was higher. To a certain extent, this could be due to the higher generating power at Travale-Radicondoli with respect to Mt. Amiata, (90 vs. 68 MW of total nominal power).

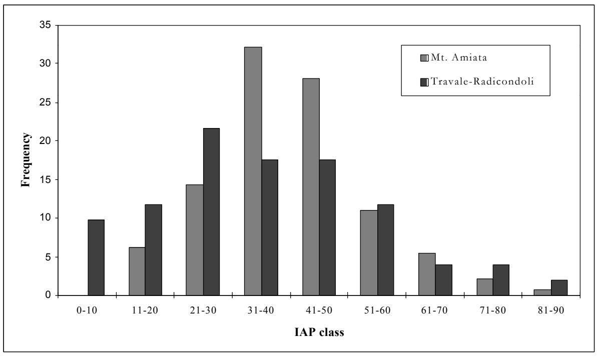

Figure 2. Rank comparison between the IAP values measured in the geothermal areas of Mt. Amiata and Travale-Radicondoli

The overall pattern of the increase in IAP values with increasing distance from geothermal power plants suggests that air pollution arising from geothermal installations is the main cause of the observed zonation of lichen communities. It is not known whether the decrease in lichen frequency in the study areas is due to a single pollutant or a mixture of pollutants; however, it seems reasonable to suppose that major injury to lichens is caused by hydrogen sulphide, a highly toxic gaseous pollutant (Beauchamp *et al.*, 1984), which is present in relatively high concentrations as a local air contaminant around geothermal installations (Rolfe, 1980). Furthermore, in the atmosphere hydrogen sulphide is oxidized to sulphur dioxide (Perry *et al.*, 1976), an air pollutant typically responsible for lichen decline (Seaward, 1993). An alternative explanation is that H_2S undergoes aerobic oxidation to sulphate within the lichen thalli, with the concomitant production of free radicals, that are effective agents of metabolic damage (Tretiach & Ganis, 1999).
The few analytical measurements of H_2S available for the study sites indicate a wide range of variation, mostly depending on wind characteristics and ambient temperature; however, mean H_2S concentrations around geothermal power plants were twice those of more distant areas (about 14 and 7 ppb respectively). This strengthens the hypothesis that hydrogen sulphide is the main contaminant responsible for lichen decline around geothermal power plants.
Table 1 summarizes the concentrations of trace elements found inside lichen thalli in both geothermal areas. In general, compared to data reported for lichens from unpolluted areas of Tuscany (Bargagli, 1995; Loppi *et al.*, 1998), the concentrations of arsenic, boron and sulphur indicate some accumulation phoenomena.

Table 1. Mean trace element concentration ± standard deviation (range in parentheses, µg/g dw) of lichens from the geothermal areas of Travale-Radicondoli and Mt. Amiata

	Travale	Mt. Amiata
Al	969 ± 528 (150 – 2750)	2364 ± 1285 (376 – 6343)
As	1.19 ± 0.79 (0.19 – 3.55)	2.68 ± 0.70 (0.81 – 4.21)
B	12.3 ± 5.9 (5.1 – 25.4)	12.3 ± 4.0 (5.4 – 21.4)
Cd	0.33 ± 0.16 (0.11 – 0.69)	0.19 ± 0.07 (0.04 – 0.34)
Co	1.15 ± 0.33 (0.61 – 1.99)	0.28 ± 0.22 (0.07 – 1.02)
Cr	4.5 ± 2.0 (1.3 – 8.4)	3.6 ± 1.8 (0.7 – 8.6)
Cu	10.8 ± 4.6 (4.5 – 25.4)	9.1 ± 5.7 (2.4 – 35.4)
Fe	1019 ± 450 (275 – 2370)	1822 ± 1053 (409 – 5727)
Hg	0.20 ± 0.11 (0.05 – 0.56)	0.50 ± 0.82 (0.13 – 5.66)
Mn	85.8 ± 70.6 (10.9 – 280.0)	38.3 ± 23.8 (13.0 – 131.8)
Mo	1.25 ± 0.68 (0.22 – 3.07)	0.23 ± 0.16 (0.03 – 0.89)
Pb	6.3 ± 3.8 (2.1 – 19.7)	16.0 ± 11.1 (3.6 – 52.6)
S	1541 ± 507 (990 – 2860)	1743 ± 859 (381 – 3806)
Sb	0.43 ± 0.19 (0.15 – 0.83)	0.30 ± 0.21 (0.05 – 0.97)
Zn	43.0 ± 11.5 (22.2 – 66.1)	66.1 ± 32.5 (22.7 – 239.5)

These results are perfectly in line with the data reported by Loppi *et al.* (1997), which found that in the surroundings of geothermal power plants, concentrations of arsenic and boron in *Quercus cerris* leaves and *Parmelia caperata* thalli were higher than in background areas. High concentrations of arsenic are common in hydrothermal deposits and solfataras (Adriano, 1986). The results of the present survey indicate that geothermal power plants are a source of arsenic and release significant amounts of this element into the atmosphere. Boron is one of the most typical elements associated with geothermal activity (Nicholson, 1993), and elevated concentrations of this element in geothermal areas are thus not surprising.

The rather high sulphur concentrations found can be due to H_2S emissions. Although the predictive power of total S in lichens for atmospheric SO_2 is doubtful (Brown, 1995), exposure of plants to elevated concentrations of hydrogen sulphide is known to be associated with accumulation of sulphur (Adriano, 1986).

At Travale-Radicondoli, some elements – namely Co, Mn, Mo, and Sb – turned out to be accumulated in higher concentrations than in more remote areas. The presence in this area of ophiolitic soils rich in these elements (Proctor & Woodell, 1975) may well explain their higher concentrations with respect to lichens of unpolluted areas. Furthermore, Co, Mo and Sb are used in alloys for geothermal pipes and Mo is also used as a corrosion inhibitor (Adriano, 1986). Also Brondi *et al*. (1986) found that concentrations of some trace elements in geothermal steam are mainly due to their release from pipes and not to natural processes.

As far as Hg is concerned, only lichens from the Mt. Amiata area showed high concentrations of this metal with respect to lichens from unpolluted areas. Mt. Amiata is part of the geologic anomaly of the Mediterranean basin which contains about 65% of the world's cinnabar (HgS) deposits. Since 1850, total production of mercury output from mines in the Mt. Amiata area exceeded 3 million flasks (Bacci, 1995). Mining and smelting activities ceased in 1976 and the works were abandoned without any effort of cleanup, so that mercury-rich processing residues and adandoned mine structures still constitute an environmental pollution problem (Bacci, 1995). However, it must also be considered that according to recent estimates (Ferrara *et al*., 1998) in the Mt. Amiata area, the release of mercury into the atmosphere from geothermal power plants is about 1000 kg/y. Comparison with some unpublished data showed that lichen Hg levels in geothermal areas and in areas with natural Hg sources, such as thermal springs and solfataras, were about twice those in background areas, while Hg concentrations in lichens from abandoned mining and smelting areas were much higher, being 3-5 times those in remote areas. To explain this point, the height of the emission source must be taken into account. In fact, while in the case of geothermal exploitation gaseous mercury is released into the atmosphere from the stack of power plants at an height of about 15 m, in the mining areas, especially above the large waste deposits of roasted cinnabar, degassing of mercury obviously takes place at soil level. As a consequence, geothermal mercury has large opportunities for dispersal over wide areas, while mercury originating from soil degassing is highly concentrated at ground level.

CONCLUSIONS

From the above biomonitoring studies, it can be concluded that geothermal emissions resulting from industrial exploitation are generally responsible for air pollution in limited belts up to a distance of about 500 m from the power plants.

Lichens indicated that trace element pollution is generally low in the investigated geothermal areas. Arsenic, boron and sulphur were the main elements of geothermal origin, and it is highly likely that hydrogen sulphide is both the main source of atmospheric sulphur and the main pollutant responsible for lichen decline around geothermal installations. In addition, although there are no primary data to prove synergism among pollutants, it might be possible that the joint effect of some noxious pollutants (e.g. As and B) could cause a detrimental effect on lichens.

The use of lichens for monitoring air quality is becoming routine in several countries (Sigal, 1988) since these organisms provide an estimate of the biological impact of air pollution and give an integrated picture of air quality by supplying information on the effects of all pollutants present in the atmosphere and of their reaction products. It is quick and inexpensive and provides results on which predictions for human health can be based: a recent study showed a very high correlation between the diversity of lichen communities and the incidence of lung cancer in Northern Italy (Cislaghi & Nimis, 1997).

Lastly, due to the fact that lichens are slow-growing organisms, they can be used as long-term biomonitors of air pollution, i.e. summarizers of environmental conditions, constituting a well suited tool for monitoring air quality in geothermal areas over long periods of time.

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