# Some Naturally Heavy-Metal Poisoned Areas of Interest in Prospecting, Soil Chemistry, and Geomedicine

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Occurrences of naturally lead-poisoned soil and vegetation have been found in 5 different areas in Norway where deposits of galena occur in the bedrock, namely at Snertingdal, Galå near Rena, Nordre Osen, Nord-Aurdal, and Stabbursdalen. In the initial stages of lead poisoning at these locations *Vaccinium spp.* are replaced by *Deschampsia flexuosa*. Where lead poisoning is more advanced, the field characteristics are: abnormal, dying or deficient vegetation; apparently high stone content at the soil surface; a poorly developed or deficient bleached layer in podzol areas. Samples from lead-affected patches show average lead contents of up to 2.5% in soil and up to 400 ppm in vegetable dry matter, corresponding approximately to 400 and 70 times, respectively, the contents found at 'background stations'.

Elements other than lead can also be toxic to the vegetation. At a copper-bearing mineral deposit at Karasjok, average Cu contents of 7400 ppm and 330 ppm were found in soil and vegetation, respectively, from patches with abnormal or deficient vegetation. At the Tverrfjellet pyrite deposit at Hjerkinn poisoning symptoms of soil and vegetation are also pronounced but there the cause of poisoning is probably more complex.

Feeding experiments show that a natural high lead concentration in hay can result in an increased lead content in rabbit liver, kidneys, and bones already after 4 weeks.

The investigations indicate that (1) natural heavy metal poisoning of soil and vegetation in connection with sulphide mineralization in bedrock is more common than earlier expected; (2) searching for heavy metal poisoned areas may be an effective prospecting method, and the registration of special plant communities seems to be more effective in this connection than looking for rare indicator plants; (3) certain features of the natural geochemical environment may be noxious to animals.

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## Introduction

In an earlier publication (Låg et al. 1970) an occurrence of naturally lead-poisoned soil at Kastad, Vardal, was described. Analyses of soil samples showed high lead concentrations (up to ca. 10% Pb in dry matter). Vegetation samples also had high lead contents (nearly 0.4% Pb in dry matter). The lead poisoning at Kastad is due to natural processes, the lead deriving in solution from a nearby occurrence in bedrock and being deposited in the humus-rich parts of the soil where the lead-bearing groundwater emerges at

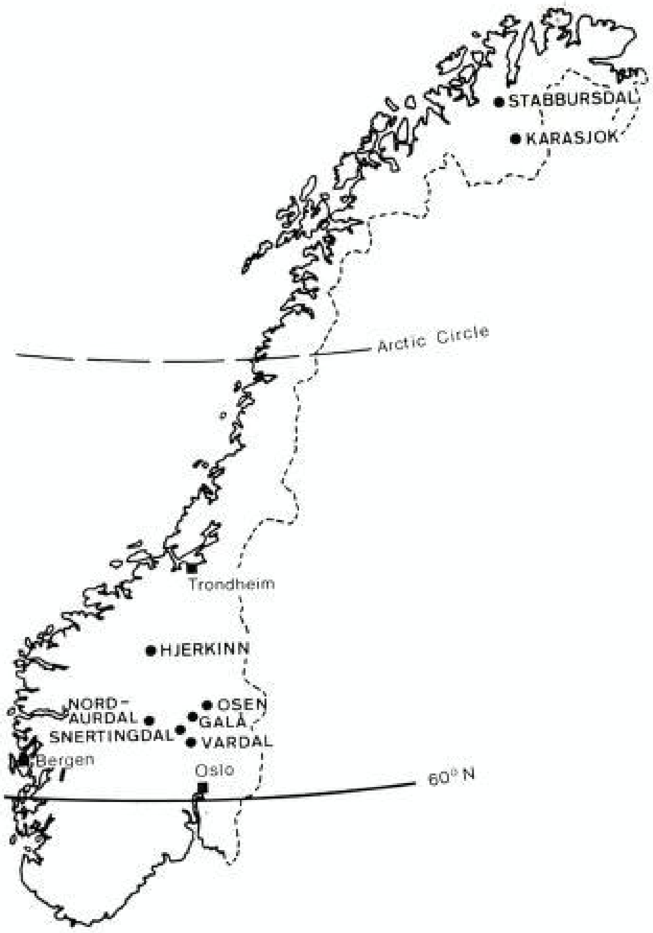

*Fig. 1.* Location of occurrences of naturally heavy metal poisoned areas.

the surface. Following up this example from Kastad, the present authors subsequently investigated other areas to see if similar poisoning phenomena could be demonstrated. Suitable bedrock lead occurrences are those found in recent years by Norges geologiske undersøkelse (NGU), since they have not as yet been disturbed by mining operations. The investigations have shown that lead poisoning can be demonstrated in connection with every one of the occurrences so far studied; these are at Nøssmarka in Snertingdal, Galå near Rena, Skavern in Nordre Osen, Kalvetjern in Nord-Aurdal, and Krokvann in Stabbursdalen (Fig. 1). The surveys have been directed towards indicating possible poisoning phenomena in the field, and thereafter sampling and analysing to determine the nature of the poisoning.

The observed field characteristics of lead poisoning are:

1. Abnormal, dying or deficient vegetation.
2. Apparently high stone content at the soil surface in morainic regions.
3. Poorly developed or deficient bleached layer in podzolic areas.

*Fig.* 2. Area of strong lead poisoning, Nøssmarka, Snertingdal. Scant vegetation of *Deschampsia flexuosa*. The light patch in the middle of the picture is barren soil with stones.

The normal ground-cover vegetation in the investigated areas includes plenty of *Vaccinium myrtillus* and *V. vitis-idaea.*In the initial stages of lead poisoning such species are replaced by *Deschampsia flexuosa.* This is one of Norway's most widespread plant species, and it grows especially at the expense of *Vaccinium* species in places where trees have been felled and the ground-cover vegetation in the forest thus receives more light. In lead-poisoned areas *D. flexuosa* dominates even in relatively dark, dense forests. The *Vaccinium* species which survive show symptoms such as stunted growth, discoloration of the leaves and lack of fruit. Other common plants species, such as *Trientalis europaea* and *Dryopteris linnaeana*, also show similar signs of retarded growth, though several of the larger species of fern appear to be fairly normal.

With comparatively weak lead contamination *Deschampsia flexuosa* grows profusely but rarely sets ears. With increasing contamination this species also becomes more and more stunted and discoloured before disappearing completely. Where lead poisoning is most advanced the ground is barren, the largest area so far observed being up to 100 m$^2$. These barren patches occur in the lowermost parts of the terrain, which are periodically influenced by percolating water. In regions with morainic soil material the patches apparently have an unusually high stone content at the surface, which in fact is a sign both of exposed ground due to lack of vegetation and of a real increase in coarse-grained mineral material because the finer particles are eroded faster than normal. When the poisoning is so strong that the ground cover vegeta-

*Fig. 3.* Area of moderate lead poisoning, Nøssmarka, Snertingdal. Vegetation of *Deschampsia flexuosa.* Light patches are stones and/or barren soil.

tion is killed off, the frequency of dead or stunted specimens of trees of Norway spruce in the adjacent area is also strikingly high.

As the poisoning hampers the plants' normal growth, the production of humus is correspondingly small. The normal podzolization processes with development of a bleached layer are therefore retarded.

On the basis of these observations, during our field work (in all cases in podzol regions) we have divided the lead poisoning into three classes:

Class 1. Strong poisoning. (Fig. 2).

The ground-cover vegetation of higher plants is totally absent over areas from 0.1 $m^2$ to several tens of square metres. The soil lacks a bleached layer.

Class 2. Moderate poisoning. (Fig. 3).

The normal vegetation, which in the investigated areas often consists of *Vaccinium spp.* and ferns, is replaced by *Deschampsia flexuosa* which shows stunted growth and discoloration. Some barren patches measuring ca. 0.1 $m^2$ or less may be present. The soil lacks the bleached layer.

Class 3. Weak poisoning. (Fig. 4).

The ground-cover vegetation is dominated by *Deschampsia flexuosa,* without *Sphagnum spp.,* where one should expect to find *Vaccinium spp.* and ferns. Sporadic specimens of such plants within the *D. flexuosa* areas show discoloration and stunted growth. The bleached layer is either weakly developed or absent.

Soil and plant samples were collected for laboratory analysis from the poisoned areas and from neighbouring normal ground. The results of the analyses have in all cases provided clear factual evidence of lead poisoning.

*Fig. 4.* Area of weak lead poisoning, Nøssmarka, Snertingdal. Profuse vegetation of *Deschampsia flexuosa.* Light patches are stones and/or barren soil.

Elements other than lead can also cause the poisoning of soil and vegetation. Poisoning phenomena have been observed at a copper occurrence at Karasjok and the Tverrfjellet pyrite deposit at Hjerkinn.

With high lead concentrations in vegetation there exists a possibility that animals which obtain their nourishment partly or wholly from such vegetation can be affected by harmful quantities of lead. To illustrate aspects of this geomedical problem we have carried out simple preliminary experiments whereby rabbits have been fed on *Deschampsia flexuosa* hay from lead-poisoned areas.

A brief account is given below of investigations of natural heavy metal poisoning of soil and vegetation which we have made subsequent to the publication of our studies on the Kastad area (Låg et al. 1970). Nøssmarka in Snertingdal has been studied in most detail, and the experiences from this area form the basis for the investigations in the other areas described in this account.

## The poisoned areas

### LEAD POISONING

### *Nøssmarka in Snertingdal, Gjøvik*

A lead mineralization was discovered by NGU in Nøssmarka belonging to the farm Øvre Nøss in Snertingdal, Gjøvik (Bjørlykke et al. 1973); see Fig. 1. The mineralized area is situated on a gently inclined north-facing slope lead-

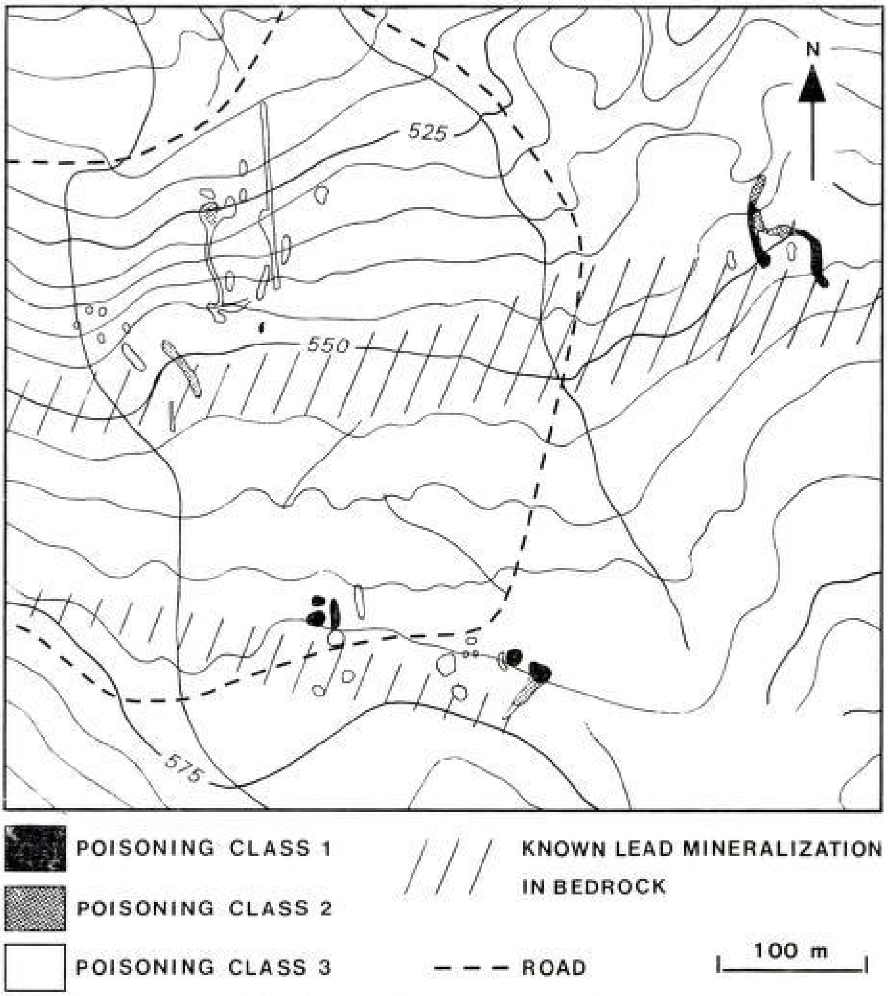

*Fig. 5.* Patterns of naturally lead-poisoned areas, Nøssmarka, Snertingdal.

ing down to the river Stokkelva at an altitude of ca. 500 m a.s.l., the annual precipitation and mean temperature being approximately 700 mm and 2°C, respectively. The thickness of the superficial deposits is variable, up to an estimated maximum of 10–15 m; a general average thickness is considered to be 1–2 m. These deposits consist mainly of morainic material, and the soil profile shows a normal podzol development with a bleached layer between 2 cm and 15 cm. Norway spruce is the prevalent tree while the ground-cover vegetation is generally of blueberry *(Vaccinium myrtillus)* type with or without ferns *(Dryopteris)*.

The area has been investigated by different exploration methods, but none of these is thought to have contaminated the surroundings to any mentionable degree. The lead mineralization consists of galena disseminated in a quartzite which strikes approximately E–W and dips ca. 60° towards the north (Fig. 5). The mineralized zone is exposed in only a few places but was found to be about 2 km long with an optimum grade of 1% Pb over 15–20 m; hand specimens may show up to 6% Pb.

The poisoned areas which have been found so far (Fig. 5) occur as patches in the low parts of the terrain (where groundwater or percolating water periodically reaches the surface) forming irregular patterns which follow the natural drainage system down-slope from the lead-mineralized bedrock. Often the patches have developed into a fan-shaped form, with the most pronounced poisoning at the apex of the fan where the groundwater issues at the surface.

Vegetation samples were collected of species which either grew upon or had parts of their root systems in the poisoned areas. *Deschampsia flexuosa* was collected from all the patches, and *Dryopteris linnaeana, Trientalis europaea, Vaccinium myrtillus, V. vitis-idaea, Sorbus aucuparia,* and *Betula pubescens,* wherever this was possible. Only the exposed parts of the plants were sampled and care was taken not to contaminate the specimens with soil material during the sampling process. Before the vegetation samples were put into paper bags, they were sprayed thoroughly with distilled water on a nylon sieve in order to remove dust. As a rule two soil samples were taken for every sample of vegetation, one at a depth of 2–5 cm and another at a depth of 20–25 cm. Each soil sample was made up of at least 10 subsamples taken over the whole area from which the vegetation sample had been collected. For comparison, vegetation and soil were also sampled at 4 background stations in the surrounding area. The analytical results of this sampling correspond fairly well with those found in the literature (see for example Brooks 1972, Hawkes & Webb 1962, Lounamaa 1956). The collected samples were dried at 105°C and the metal content of the dry material was determined by atomic absorption in the diluted solution after ashing at 430°C and digestion of the ash with hot nitric acid.

Tables 1 and 2 give a summary of the analytical results, briefly commented upon in the following paragraphs:

The lead poisoning is confirmed since the soil samples show a lead content 100–400 times higher than normal (Table 1), an increasing content from poisoning class 3 (100–200 times the normal) to poisoning class 1 (about 400 times the normal) (Table 1), and no clearly abnormal contents of elements other than lead (Table 2).

The lead content in the soil-poisoned areas is higher at a depth of 2–5 cm than at 20–25 cm (Table 1), the average values being 1.9% and 0.69% and the maxima 4.2% and 3.6%, respectively.

The ash content of the soil samples from the poisoned areas is high, this being pronounced at a depth of 2–5 cm beneath the barren patches, where it is approximately twice that of the normal (Table 1, Fig. 6). This high ash content confirms that the poisoning prevents normal growth, since the production of humus must have been low. Our earlier investigations (Låg et al. 1970) and work by Szalay (1969) and Szalay & Szilagi (1968) has sug-

*Table 1.* Ash, lead content and pH in dry matter of soil; ash and lead content in dry matter of vegetation from Nossmarka, Snertingdal

| | Class | N | Ash % | Pb ppm | pH |
|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm, barren areas | 1 | 9 | 66.1 | 24,500 | 4.5 |
| Soil samples, depth 20–25 cm, barren areas | 1 | 8 | 93.5 | 9,900 | 4.8 |
| Soil samples, depth 2–5 cm, background stations | BG | 15* | 33.3 | 57 | 4.0 |
| Soil samples, depth 20–25 cm, background stations | BG | 16* | 92.5 | 26 | 4.6 |
| Deschampsia flexuosa, leaves | 2–3 | 23 | 4.8 | 99 | |
| Deschampsia flexuosa, leaves | BG | 6 | 5.4 | 3 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 23** | 47.3 | 17,200 | 4.4 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 22** | 94.0 | 4,700 | 4.7 |
| Trientalis europaea, above surface | 2–3 | 3 | 8.0 | 184 | |
| Trientalis europaea, above surface | BG | 3 | 7.7 | 10 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 3 | 49.8 | 19.000 | 4.3 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 3 | 88.8 | 10,800 | 4.7 |
| Dryopteris linnaeana, above surface | 2–3 | 3 | 8.9 | 253 | |
| Dryopteris linnaeana, above surface | BG | 4 | 8.7 | 4 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 3 | 25.2 | 17,500 | 4.3 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 3 | 92.3 | 8,200 | 4.7 |
| Dryopteris spp., (mainly filix-mas.) | 2–3 | 3 | 10.0 | 410 | |
| Dryopteris spp., (mainly filix-mas.) | BG | 4 | 6.9 | 6 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 3 | 47.5 | 23,300 | 4.5 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 3 | 94.7 | 4,000 | 4.9 |
| Vaccinium vitis-idaea, stem | 2–3 | 2 | 3.4 | | |
| Vaccinium vitis-idaea, stem | BG | 2 | 2.8 | 6 | |
| Vaccinium vitis-idaea, leaves | 2–3 | 3 | 2.9 | 64 | |
| Vaccinium vitis-idaea, leaves | BG | 2 | 3.6 | 2 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 3 | 68.0 | 23,200 | 4.5 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 3 | 89.7 | 12,800 | 4.8 |
| Vaccinium uliginosum, above surface | 2–3 | 1 | 1.3 | 78 | |
| Vaccinium uliginosum, above surface | BG | 1 | 2.0 | 9 | |
| Vaccinium myrtillus, stem | 2–3 | 6 | 2.9 | 159 | |
| Vaccinium myrtillus, leaves | 2–3 | 6 | 4.9 | 40 | |
| Vaccinium myrtillus, whole plant | BG | 3 | 3.7 | 4 | |
| Corresponding soil samples, depth 2–5 cm | 2–3 | 6 | 50.8 | 20,200 | 4.5 |
| Corresponding soil samples, depth 20–25 cm | 2–3 | 6 | 91.8 | 6,400 | 4.6 |
| Betula, second year twig | 3 | 2 | 1.6 | 78 | |
| Betula, second year twig | BG | 4 | 2.0 | 14 | |
| Betula, first year twig | 3 | 2 | 2.4 | 65 | |
| Betula, first year twig | BG | 4 | 3.2 | 9 | |
| Betula, leaves | 3 | 2 | 4.7 | 14 | |
| Betula, leaves | BG | 3 | 5.6 | 5 | |
| Corresponding soil sample, depth 2–5 cm | 3 | 2 | 54.5 | 14,800 | 4.4 |
| Corresponding soil sample, depth 20–25 cm | 3 | 2 | 95.5 | 2,800 | 4.8 |
| Sorbus aucuparia, second year, twig | 3 | 2 | 2.3 | 22 | |
| Sorbus aucuparia, second year, twig | BG | 4 | 2.3 | 4 | |
| Sorbus aucuparia, first year, twig | 3 | 2 | 3.2 | 19 | |
| Sorbus aucuparia, first year, twig | BG | 4 | 2.8 | 4 | |
| Sorbus aucuparia, leaves | 3 | 2 | 7.0 | 6 | |
| Sorbus aucuparia, leaves | 3 | 4 | 6.0 | 4 | |
| Corresponding soil samples, depth 2–5 cm | 3 | 2 | 44.3 | 7,800 | 3,9 |
| Corresponding soil samples, depth 20–25 cm | 3 | 2 | 93.1 | 2,300 | 4.7 |

Figures indicate arithmetic means.

Each soil sample for analysis (composite samples) consists of 10 subsamples. Classes 1–3: Very strong to weak lead poisoning (see text). BG: background. N: Number of composite samples.

* pH: Average of 3 samples

** pH: Average of 8 samples

*Table 2.* Ash and metal contents in dry matter (105°C) of soil samples from Nøssmarka, Snertingdal

| | N | Ash % | Ag ppm | Cd ppm | Co ppm | Cr ppm | Cu ppm | Fe % | Mn ppm | Ni ppm | V ppm | Zn ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barren patches, depth 2–5 cm | 9 | 66.1 | <1 | 0.9 | 10 | 14 | 15 | 1.1 | 1300 | 12 | 17 | 44 |
| Background samples, depth 2–5 cm | 15 | 33.3 | <1 | 0.8 | 3 | 5 | 7 | 0.3 | 400 | 5 | 7 | 57 |
| Barren patches, depth 20–25 cm | 8 | 93.5 | <1 | 0.9 | 18 | 25 | 18 | 2.0 | 120 | 27 | 22 | 64 |
| Background samples, depth 20–25 cm | 16 | 92.5 | <1 | 0.8 | 11 | 24 | 10 | 2.3 | 240 | 20 | 30 | 31 |

Figures indicate arithmetic means.
Each soil sample for analysis (composite samples) consists of 10 sub-samples.
N: Number of composite samples.

*Table 3.* Ratio of ash, Fe, Mn and Pb of lead poisoned versus background soils, Nøssmarka, Snertingdal

| | | | | Poisoned/background | | | |
|---|---|---|---|---|---|---|---|
| | | Depth cm | $N_p/N_b$ | Ash | Fe | Mn | Pb |
| Soil, poisoning class | 2–3 | 2–5 | 23/15 | 1.4 | 3.5 | 2.4 | 300 |
| » » » | 2–3 | 20–25 | 22/16 | 1.0 | 0.9 | 3.6 | 180 |
| » » » | 1 | 2–5 | 9/15 | 2.0 | 4.2 | 3.2 | 430 |
| » » » | 1 | 20–25 | 8/16 | 1.0 | 0.9 | 4.9 | 380 |

$N_p$ : Number of samples from poisoned areas.
$N_b$ : Number of samples from background areas.

gested that lead is associated with the organic part of the soil. Lead is probably so strongly bound to humus (Chowdury & Bose 1971) that humus-rich soil may not be toxic to plants until the lead content becomes fairly high. With a steady supply of more lead than is carried away, however, sooner or later lead concentrations in the soil-water will become restrictive for natural plant growth. The rate of humus production is then reduced and the breakdown of humus may occur faster than the supply of new organic matter. This situation will probably facilitate a comparatively rapid and accelerating poisoning of the soil, since the amount of humus required to fix the lead diminishes simultaneously as lead is being brought in. Because of this process, lead poisoning may probably occur within a relatively short space of geological time.

The lead poisoning also influences the distribution of Fe and Mn during the podzolization processes, even though the two elements respond differently. As can be seen from Table 3, contents of both Fe and Mn are high in

*Table 4.* Lead content in vegetation in relation to lead content of corresponding soil. Nøssmarka, Snertingdal

| | | N | %Pb in veg/Pb in soil | |
|---|---|---|---|---|
| Soil depth, cm | | | 2–5 | 20–25 |
| Betula pubescens, leaves | P | 2 | 0.36 | 14 |
| | B | 4 | 21 | 39 |
| Betula pubescens, first year twig | P | 2 | 0.39 | 2.9 |
| | B | 4 | 38 | 39 |
| Betula pubescens, second year twig | P | 2 | 0.64 | 6.8 |
| | B | 4 | 61 | 61 |
| Sorbus aucuparia, leaves | P | 2 | 0.10 | 0.28 |
| | B | 4 | 7.5 | 18 |
| Sorbus aucuparia, first year twig | P | 2 | 0.35 | 0.86 |
| | B | 4 | 8.1 | 20 |
| Sorbus aucuparia, second year twig | P | 2 | 0.34 | 1.0 |
| | B | 4 | 7.9 | 14 |
| Vaccinium myrtillus, leaves | P | 6 | 0.26 | 1.3 |
| Vaccinium myrtillus, stem | P | 6 | 0.95 | 5.3 |
| Vaccinium myrtillus, whole plant | B | 3 | 6.0 | 12 |
| Deschampsia flexuosa, leaves | P | 21 | 0.68 | 3.1 |
| | B | 6 | 5.4 | 10 |
| Dryopteris linnaeana | P | 3 | 2.1 | 4.6 |
| | B | 4 | 9.2 | 31 |
| Dryopteris spp. (mainly filix-mas) | P | 3 | 3.5 | 22 |
| | B | 4 | 9.9 | 27 |
| Trientalis europaea | P | 3 | 1.0 | 6.3 |
| | B | 4 | 22 | 49 |

N: Number of vegetation samples, number of soil samples.
P: Poisoned area.
B: Background area.

the topsoil (upper 2–5 cm) of the poisoned areas, whereas Fe is fairly normal but Mn still high at a depth of 20–25 cm.

The high lead content in the soil of the poisoned areas is also reflected in several plant species. *Dryopteris spp.* show the highest average lead content (70–80 times normal) and deciduous trees the lowest (1–7 times normal). Leaves of *Deschampsia flexuosa* have an average lead content of about 30 times the normal, while the lead content of the exposed part of *Trientalis europaea* is approximately 20 times the normal value. In the *Vaccinium* species the lead content is generally higher in the stems than in the leaves; plants from the poisoned ground contain from 10 to 40 times more lead than normal.

The lead content of the vegetation in relation to that of the soil is shown in Table 4. It is clear that the different species take up the available lead in different amounts. There is no simple relationship between the lead content of a species and lead content in the soil, or the ability of the species to

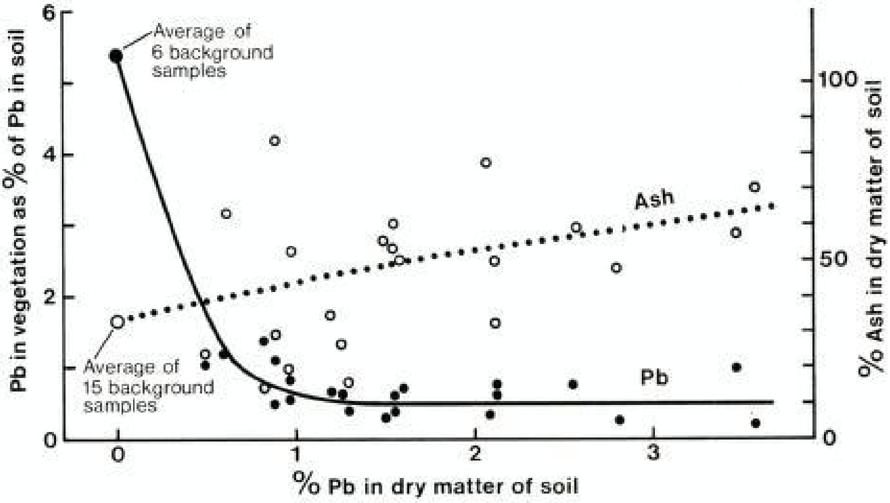

*Fig. 6.* Lead content in soil (depth 2–5 cm) versus (1) ash in soil (right hand ordinate, open circles, dotted line) and (2) lead content in *Deschampsia flexuosa* as percentage of lead content in the corresponding soil (left hand ordinate, closed circles, continuous line). Data from Nøssmarka, Snertingdal. See also Table 4.

tolerate high lead concentrations in the soil. Consequently, the lead content of a species may not be reliable as a direct indication of its lead tolerance.

The response of the species *Deschampsia flexuosa* to various lead contents in the soil is illustrated in Fig. 6, where the ratio 'Pb in plant/Pb in soil' is plotted against 'Pb in soil'. It can be seen that when the lead content of the topsoil increases from 60 ppm (normal) to 1% (high), the ratio 'Pb in plant/Pb in soil' decreases from a normal range of 5–6% down to 0.6%. From then on the ratio is more or less constant with an increasing lead content in the soil. The increasing ash content towards the right in Fig. 6 seems to indicate that the content of organic matter in the soil decreases with an increasing lead content in the soil.

This may indicate that a defence mechanism of *D. flexuosa* combined with a restricted availability of Pb in the soil, effectively counteracts poisoning of the plant due to large quantities of lead in the surroundings, up to ca. 1% Pb in the soil's upper layer corresponding to a tolerable content of ca. 60 ppm in dry matter of the plants. Above this concentration the lead content of the plants increases more or less proportionally with the lead content of the soil until poisoning takes effect and kills off the plants.

## *The Galå area, Åmot in Hedmark*

In 1970 NGU discovered a lead deposit outcropping in small tributary streams on the south side of the Galå river, ca. 20 km north of Leiret, Elverum (Fig. 1). The type of lead mineralization is similar to that found at Nøss-

*Table 5.* Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation from lead poisoned patches in the Galå area, Åmot in Hedmark

| | N | Ash % | Cd ppm | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 2 | 54.0 | 0.7 | 6 | 9 | 6,400 | 40 | 4.1 |
| Soil samples, depth 20–25 cm | 2 | 94.8 | 0.8 | 9 | 21 | 8,300 | 65 | 4.6 |
| Betula, composite/leaves and twigs | 1 | 1.8 | 0.2 | 5 | 3 | 62 | 157 | |
| Sorbus aucuparia, leaves | 1 | 7.2 | 0.1 | 4 | 5 | 18 | 22 | |
| Vaccinium myrtillus, leaves | 2 | 4.9 | trace | 7 | 3 | 73 | 29 | |
| Vaccinium myrtillus, stem | 2 | 2.6 | 0.1 | 6 | 2 | 32 | 50 | |
| Deschampsia flexuosa | 2 | 4.5 | 0.1 | 4 | 4 | 51 | 32 | |

Figures indicate arithmetic means.
N: Number of samples.

marka, Snertingdal, but at present its extent and grade is unknown (Bjørlykke et al. 1973).

The climate and other general surroundings are similar to those at Snertingdal. Superficial deposits of glacial material are somewhat irregular with great thicknesses in some of the depressions. Symptoms of poisoning of the soil and vegetation were observed at localities near to lead-mineralized outcrops, where the superficial cover is moderate. The occurrences of poisoning in the Galå area are analogous to those in Snertingdal, the affected patches being found in relatively low terrain, where water may appear at the surface in wet periods. The normal vegetation of blueberry, ferns and other herbaceous plants of these patches is stunted or absent; instead *Deschampsia flexuosa* prevails (poisoning class 3). In a few places *D. flexuosa* is also lacking, so that small barren spots are present (poisoning classes 1–2). Soil and vegetation were sampled as described earlier (p. 79), except that in this case the plants were not washed after picking. The analytical results (Table 5) confirm that lead poisoning has occurred as the lead content is relatively high, while contents of the other analysed elements are moderate.

### *Skavern, Nordre Osen, Åmot in Hedmark*

Several hundred blocks of a local galena-bearing quartzite occur at Skavern, ca. 4 km east of the northern end of Osensjøen, Åmot in Hedmark (Fig. 1). The lead mineralization, which has also been proved in outcrops and in drill holes, is similar to that already described.

The climatic conditions are much the same as in the Snertingdal and Galå areas. A fairly thick and coarse-grained superficial cover (of glacial origin) occasions a relatively deep groundwater level, which has promoted the formation of well-developed podzolic soils, and a forest where pine often prevails over spruce. The ground-cover vegetation is dominated by *Vaccinium myrtillus, V. vitis-idaea* and *Calluna vulgaris*. The poisoning symptoms are similar to

*Table 6.* Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation from lead poisoned patches at Skavern, Nordre Osen, Åmot in Hedmark

| | Class | N | Ash % | Cd ppm | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 1 | 2 | 44.1 | 0.9 | 126 | 37 | 97,000 | 416 | 5.5 |
| Soil samples, depth 20–25 cm | 1 | 2 | 86.6 | 1.2 | 130 | 40 | 40,000 | 496 | 5.4 |
| Soil samples, depth 2–5 cm | 2–3 | 7 | 48.7 | 1.9 | 55 | 42 | 48,000 | 360 | 4.9 |
| Soil samples, depth 20–25 cm | 2–3 | 7 | 91.2 | 1.5 | 69 | 50 | 19,000 | 588 | 5.4 |
| Betula pubescens, leaves | 2–3 | 2 | 3.8 | 0.4 | 3 | 4 | 32 | 363 | |
| Betula pubescens, first year twig | 2–3 | 1 | 1.8 | 0.1 | 3 | 3 | 71 | 337 | |
| Betula pubescens, second year twig | 2–3 | 1 | 1.7 | 0.1 | 3 | 2 | 89 | 345 | |
| Vaccinium myrtillus, leaves | 2–3 | 4 | 4.6 | trace | 5 | 4 | 19 | 45 | |
| Vaccinium myrtillus, stem | 2–3 | 4 | 2.7 | trace | 6 | 4 | 61 | 994 | |
| Deschampsia flexuosa | 2–3 | 7 | 4.2 | 0.2 | 3 | 5 | 99 | 41 | |
| Ptilium crista-castrensis | 3 | 1 | 4.5 | 0.3 | 6 | 12 | 3,600 | 93 | |

Figures indicate arithmetic mean.
N: Number of samples.
Classes 1–3: Strong to weak lead poisoning (see text).
Range 5–208 ppm.

those found at Nøssmarka and Galå. The presence of *Deschampsia flexuosa* indicates poisoning of classes 2 and 3, and barren patches also signify a more complete poisoning. The symptoms of poisoning appear down-slope from the lead mineralization, just above swampy areas, i.e. at places where the groundwater is present close to or at the surface as distinct from the predominating terrain of deep groundwater level.

Some comments on the analytical results from soil and vegetation samples of the Skavern area (see p. 79 for methods; also Table 6), are as follows:

1. Of the elements Cd, Cu, Ni, Pb and Zn only lead occurs in possible toxic concentrations, being 5–10% at a depth of 2–5 cm and 2–4% at a depth of 20–25 cm in the soil of the areas of poisoning. Soil patches designated poisoning class 1 have a higher lead content than those from classes 2 and 3.
2. The high lead content of the soil is reflected in the vegetation; *Deschampsia flexuosa,* for example, shows 99 ppm lead in dry matter. In a sample of the moss species *Ptilium crista-castrensis* 3600 ppm of lead was detected, the corresponding lead content of the soil being 3.5% at a depth of 2–5 cm and 1.3% at 20–25 cm. Occasional samples of moss species from lead-poisoned patches in other areas also show high lead contents. These examples and the fact that *Sphagnum spp.* are as a rule absent from lead-poisoned soil – even though the topography and water regime might be favourable for their growth – suggest that a poor ability to reject lead is a feature common to mosses.

3. The zinc content of both soil and plants is relatively high at Osen compared with that in the Nøssmarka and Galå areas, probably because the lead mineralization at Osen is more zinc-rich than that in the other areas.

*Table 7.* Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in vegetation from poisoned areas at Kalvtjern, Nord-Aurdal

| | Class | N | Ash % | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 1–3 | 7 | 49.7 | 26 | 11 | 973 | 33 | 4.6 |
| Deschampsia flexuosa | 2 | 1 | 5.6 | 3 | 4 | 37 | 22 | |
| Colloidal precipitations in stagnant water downslope from poisoned patches | | 4 | 48.6 | 7 | 14 | 2,246 | 69 | |

Classes 1–3: Strong to weak poisoning (see text).
Figures indicate arithmetic means of N samples.

### *Kalvetjern, Nord-Aurdal*

During a regional survey in 1971 NGU discovered a strong geochemical anomaly at Kalvetjern, Nord-Aurdal (Fig. 1), with a lead content in the stream sediments up to nearly 1%. The drainage basin of the anomalous streams lies at ca. 1000 m above sea level, which in that part of Norway is just above the timber line. Precipitation is estimated at around 600 mm per year and the mean temperature close to 0°C. The overburden, which is mostly of glacial origin, is generally very thin and contains an unusually high frequency of surface boulders. Most of these boulders are of local origin, having been transported only short distances by the ice, while others are very likely more or less *in situ,* being products of frost action on the quartzitic bedrock. A thorough geological surface investigation (which considering the local conditions could be regarded as fairly complete) and some soil sampling along selected lines have been conducted in the area, but no lead mineralization was found apart from accessory galena. The bedrock is estimated to have an overall content of less than 100 ppm lead; nevertheless, poisoning of soil and vegetation is apparent. Some patches, several tens of square metres in extent, consist of barren soil. These patches seem to be connected with the occurrence of some rather large and irregular porphyroblasts of pyrite in the bedrock. Other features are similar to those described from the Snertingdal, Galå, and Nordre Osen areas. These were judged in the field to be patches of lead poisoning, a suggestion which we consider to be confirmed by the analytical results of the soil and vegetation samples (see Table 7).

In areas with frequent temperature variations around 0°C where the overburden is thin, frost action could result in the development of innumerable joints and fissures in the bedrock. The possibilities for the extraction of

*Fig. 7.* Naturally lead-poisoned area near Krokvann, Stabbursdalen, Alta. Light patches in the front are stones in barren soil.

heavy metals from this mechanically weathered rock are greater than normal because of the increased surface area of minerals exposed to water and air. With a low humus production there is only a restricted amount of loose material to tie up any lead brought into solution. A more than hundred-fold increase in lead concentration could occur within a few hundred metres due to solution, transportation in water and subsequent redeposition. The results from Kalvetjern show that under these conditions lead poisoning may occur even at relatively low lead concentrations in the bedrock. This might indicate that lead poisoning could be more common in certain districts than earlier expected.

### *Krokvann, Stabbursdalen, Alta*

In 1971, during the follow-up of a stream sediment anomaly, an occurrence of lead mineralization was found in Stabbursdalen near Alta (Fig. 1). The area is situated at an altitude of 400 m a.s.l. some 40 km from the nearest fjord, which at this latitude (70°N) means a climate of a sub-arctic continental type. The mean temperature in the area is supposed to be well below 0°C, and the annual precipitation approximately 300 mm. The lead, which is present as irregular aggregates of galena in a quartzite, is thought to be closely related to the type of lead mineralization described earlier in this paper (p. 78). The superficial cover in the trea consists chiefly of morainic and glaciofluvial material of variable thickness. The soil belongs to a high-

*Table 8.* Ash, heavy metals and pH in dry matter (105° C) of soil; ash and heavy metals in dry matter of poisoned area at a lead occurrence near Krokvann, Stabbursdalen, Alta

| | Class | N | Ash % | Cd ppm | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 2–3 | 4 | 83.0 | 1.8 | 260 | 48 | 10,400 | 860 | 5.8 |
| Betula pubescens, leaves | 3 | 1 | 3.5 | 0.2 | 3 | 3 | 16 | 180 | |
| Betula pubescens, first year twig | 3 | 1 | 2.1 | trace | 6 | 2 | 9 | 110 | |
| Betula pubescens, second year twig | 3 | 1 | 1.3 | trace | 4 | 1 | 20 | 150 | |
| Deschampsia flexuosa | 3 | 1 | 4.9 | trace | 5 | 2 | 320 | 100 | |
| Festuca ovina | 3 | 1 | 4.7 | trace | 8 | 4 | 270 | 60 | |
| Scirpus caespitosus | 3 | 2 | 4.5 | trace | 8 | 6 | 385 | 90 | |
| Scorpidium scorpidodes and other moss species | 2–3 | 1 | 59.5 | 1.8 | 65 | 65 | 11,200 | 710 | |

Classes 1–3: Strong to weak poisoning (see text).
Figures indicate arithmetic mean of N samples.

mountain podzol type with a very thin bleached layer, often marked only by isolated white quartz grains beneath the humus cover, which is generally from 1 to a few cm thick. The vegetation is sparse, generally stunted birch with occasional taller birch on some south-facing slopes and a more ordinary mountainous ground-cover vegetation. (Fig. 7).

Because of the rather special vegetation the symptoms of poisoning in this area are less obvious than those demonstrable in the other areas further south. In small patches where the mineralized rock is exposed the vegetation is absent, but these patches can easily be confused with ground made barren by wind erosion, a common feature under these conditions. The vegetation pattern is nevertheless supposed to be lead affected, since in the vicinity of the mineralization the grass species *Deschampsia flexuosa* and *Festuca ovina* dominate totally at the expense of the normal plant cover with a more diverse variety of species. This suggestion was confirmed by high Pb and somewhat increased Cu and Zn contents of the soil samples (Table 8). The high percentages of ash show a low humus content, which promotes the occurrence of lead- and other metal-poisoning, perhaps even at only relatively moderate concentrations in the soil (see also p. 87). The lead content of *Deschampsia flexuosa* from the Stabbursdal areas (Table 8) is considerably higher than in corresponding samples taken further south in the country. It is, however, uncertain if this is a general trend since only one sample from Stabbursdalen was analysed. Another grass species, *Festuca ovina,* appears to have a similarly higher lead content, as also do *Scirpus caespitosus* and small patches of mosses collected at the edge of a stream just below the visible lead mineralization.

*Fig. 8.* Naturally copper-poisoned area in birch forest, Karasjok. Dark area in the middle right hand side of the picture is barren soil. Ground-cover vegetation in the left hand side consists mainly of *Juncus trifidus, Festuca ovina, Deschampsia flexuosa* and *Viscaria alpina.*

## OTHER POISONED AREAS

### *Karasjok*

South of the village of Karasjok (mean temperature – 2.6°C and annual precipitation ca. 300 mm, Fig 1) about 300 m a.s.l. in a dry and rather cool area, chalcopyrite and pyrite occur disseminated in a nearly flat-lying muscovite- and amphibole-bearing gneiss. Above the gneiss there is a concordant black schist rich in carbon and pyrrhotite. Both the gneiss and the schist are weathered down to approximately 0.5 m (B. Røsholt, geologist, A/S Sydvaranger, personal communication) The superficial deposits generally consist of a few metres thickness of morainic material, mostly of a fine-sand character; in the mineralized area, however, a thickness of 0.5–1 m is common. Among tree species birch *(Betula pubescens)* predominates with some pine *(Pinus silvestris),* and in the ground-cover vegetation *Vaccinium myrtillus* and *V. vitis-idaea* are abundant. Patterns of natural poisoning were observed in the field and these could be verified by chemical analyses of soil and vegetation samples (Figs. 8 and 9, Table 9). The poisoned areas may be recognized: (1) as open areas in the otherwise dense birch forest; these vary in size and form from small patches to areas several thousands of square metres in extent, often with long axes normal to the map contours; (2) through the ground-cover vegetation, where *Juncus trifidus, Festuca ovina, Deschampsia flexuosa* and *Viscaria alpina* predominate instead of the normal vegetation rich in various herb species, and *Vaccinium myrtillus* and *V. vitis-*

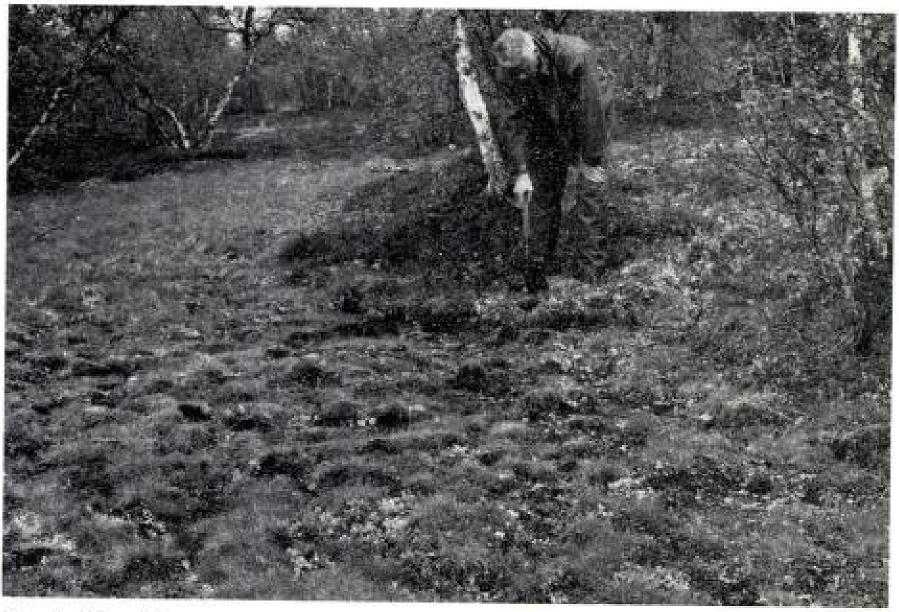

*Fig. 9.* Naturally copper-poisoned area in birch forest, Karasjok. Normal ground cover vegetation of *Vaccinium spp.* Vegetation of *Juncus trifidus, Festuca ovina* and *Deschampsia flexuosa* in copper affected area (open space)

*idaea;* (3) as barren areas up to several tens of square metres in extent at places where the water issues at the surface.

According to the results shown in Table 9 the contents of Cd, Ni, Pb and Zn lie within a more or less normal range for soils. The copper contents, however, are abnormal, being about 7000 ppm and 3000 ppm at depths of 2–5 cm and 20–25 cm, respectively. The corresponding ash percentages are 85% and 97%, indicating a comparatively low humus content, and consequently a limited ability to bind copper since the metal to a large degree is presumably

*Table 9.* Ash, heavy metals and pH in dry matter (105° C) of soil; ash and heavy metals in dry matter vegetation from poisoned areas at a copper occurrence in Karasjok

| | N | Ash % | Cd ppm | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 9 | 85.1 | 0.6 | 7,400 | 32 | 18 | 36 | 5.0 |
| Soil samples, depth 20–25 cm | 5 | 96.6 | 0.9 | 3,000 | 38 | 20 | 58 | 5.1 |
| Betula pubescens, leaves | 4 | 1.9 | trace | 7 | 6 | 4 | 102 | |
| Betula, first year twig | 4 | 1.2 | trace | 5 | 1 | 2 | 116 | |
| Betula, second year twig | 4 | 1.5 | trace | 12 | 4 | 3 | 178 | |
| Deschampsia flexuosa | 2 | 5.8 | 0.2 | 271 | 7 | 3 | 42 | |
| Festuca ovina | 3 | 3.9 | trace | 334 | 5 | 4 | 97 | |
| Juncus trifidus | 1 | 3.5 | 0.5 | 69 | 9 | 3 | 112 | |
| Viscaria alpina | 1 | 5.7 | 0.3 | 895 | 10 | 3 | 63 | |

Figures indicate arithmetic means of N samples.

*Fig. 10.* Naturally poisoned area at Tverrfjellet, Hjerkinn. Light patches in the front are stones and boulders in barren soil. In the background *Betula nana, Eriophorum vaginatum, Juncus trifidus,* and *Viscaria alpina* are frequent species of the vegetation.

bound in the organic part of the soil. Copper might therefore become accessible and toxic to plants even at moderate concentrations.

In the vegetation *Deschampsia flexuosa, Festuca ovina* and particularly *Viscaria alpina* have high copper contents. *Viscaria alpina,* often called the 'copper flower' in Scandinavia, has for a long time been known for its copper tolerance (Vogt 1939, 1942a, 1942b).

### *Tverrfjellet, Hjerkinn*

The Tverrfjellet pyrite deposit is situated ca. 3 km west of Hjerkinn station (Fig. 1). The deposit was discovered towards the end of the 1950's and is now being mined, but the mining operations and technical installations have not disturbed the suboutcrop of the ore and the adjacent areas to any appreciable degree. The mineralization consists of massive pyrite with chalcopyrite and sphalerite in Lower Palaeozoic greenstones (Waltham 1968). The deposit is located at 1000 m a.s.l. in an area with about 300 mm annual precipitation and a mean temperature of 0°C.

The vegetation is sparse, consisting mainly of dwarf birch and juniper, *Vaccinium spp.* and mosses with a modest mixture of herbaceous plants. Morainic deposits and glaciofluvial material, often a few metres thick, constitute the overburden. In spite of the low mean temperature the ore, which is

*Table 10.* Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation samples from poisoned area at Tverrfjellet pyrite deposit Hjerkin

| | N | Ash % | Cd ppm | Cu ppm | Ni ppm | Pb ppm | Zn ppm | pH |
|---|---|---|---|---|---|---|---|---|
| Soil samples, depth 2–5 cm | 9 | 50.5 | 1.3 | 785 | 18 | 57 | 232 | 3.8 |
| Betula nana, leaves | 1 | 2.8 | 0.3 | 51 | 2 | 9 | 336 | |
| Betula nana, stem | 1 | 1.5 | trace | 46 | 1 | 9 | 456 | |
| Deschampsia flexuosa | 3 | 4.2 | 0.2 | 9 | 3 | 3 | 50 | |
| Empetrum hermaphroditum | 1 | 8.5 | 2.4 | 76 | 3 | 23 | 36 | |
| Eriophorum vaginatum, dead plants | 1 | 49.2 | 7.8 | 4,600 | 30 | 107 | 1,500 | |
| Juncus trifidus | 2 | 3.4 | trace | 25 | 2 | 8 | 187 | |
| Paludella squarrosa with salt precipitations | 1 | 17.4 | 3.5 | 2,700 | 10 | 30 | 520 | |

Figures indicate arithmetic means of N samples.

completely covered, has suffered an intense chemical weathering represented on the surface by clear subsidence phenomena and extensive precipitation of secondary iron oxides downstream from the suboutcrop of the ore. Where the rust-coloured deposits are particularly prominent vegetation is often completely absent, the surface then appearing as extensive red-brown barren areas. At the edges of such areas, the borders of which are often sharp (Fig. 10), *Eriophorum vaginatum, Juncus trifidus* and *Viscaria alpina* are frequent. These plant species have earlier been observed by Vogt and coworkers at mine dumps in the similarly mineralized Røros area, (Vogt 1939, 1942a, 1942b; Vogt & Braadlie 1942). Vogt and coworkers have also analysed samples of vegetation from this area (Vogt & Bugge 1943, Vogt, Braadlie & Bergh 1943). As a whole, Tverrfjellet appears to be a clear example of natural poisoning caused by the weathering products of the pyrite mineralization. High contents of copper, zinc and lead and sometimes also low pH have been demonstrated from stream sediments, soil and water in this area (Bølviken 1967, Mehrtens & Tooms 1973, Mehrtens et al. 1973).

Some of our analytical results from soil and vegetation are presented in Table 10. It is uncertain which of the elements are most effective in producing the poisoning. Under these rather difficult climatic conditions a combination of high contents of heavy metals and low pH values is probably the main cause. The low pH may also facilitate the solution of elements such as Al to toxic concentrations in the soil.

At high altitudes and in the far north in Norway the climate is decidedly unfavourable for plant growth. The vegetation in the investigated areas Nord-Aurdal, Stabbursdalen, Karasjok and Hjerkinn, would therefore be generally more vulnerable to metal poisoning than vegetation growing under more favourable climatic conditions.

*Table 11.* Lead content in organs of 4 rabbits (1–4), fed 4 weeks with hay of *Deschampsia flexuosa* with naturally high lead content (70 ppm Pb). Control group from same litter (5–8) received normal feeds (1–2 ppm Pb). Age at slaughter: 12 weeks

| | Diet high in lead | | | | Diet low in lead | | | |
|---|---|---|---|---|---|---|---|---|
| Rabbit No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Thigh-muscle | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| Thigh-bone | 72 | 81 | 43 | 73 | 24 | 32 | 27 | 27 |
| Liver | 7 | 14 | 5 | 9 | 1 | 2 | 2 | 1 |
| Kidney | 12 | 10 | 9 | 16 | 2 | 2 | 2 | 1 |
| Faeces | 70 | 99 | 34 | 101 | 2 | 2 | 2 | 48 |
| Urine | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |

Figures indicate ppm lead in dry material (105° C) of organs.

## Feeding experiments

Some of Norway's most common pasture grass species, *Agrostis, Deschampsia* and *Festuca,* are especially resistant to strong heavy-metal influence. It is not unlikely that lead which occurs naturally in lead-bearing grass may be fairly soluble and detrimental to herbivores, even to a greater extent than some of the artificially supplied lead which may occur principally as relatively stable compounds. In order to obtain some idea as to whether or not naturally high lead contents in vegetation can be taken up by animals, we have carried out tentative feeding experiments. Four rabbits were fed on a diet consisting of hay of *Deschampsia flexuosa* from naturally lead-rich patches in Nøssmarka, Snertingdal, and a control group of four rabbits from the same litter were simultaneously fed on a normal, lead-deficient diet. The rabbits' age at the start of the experiment was 8 weeks, and the duration of the experiment 4 weeks. After slaughter, the rabbits were dissected and a few different organs were analysed; Table 11 shows some of the results.

The lead-rich diet has produced higher lead contents in thigh bones, liver and kidneys, with lead-affected/normal ratios of 2.4, 5.8 and 6.7 respectively. For the thigh muscles the results are less conclusive, although a tendency in the same direction is indicated. The lead content of the faeces was, in most cases, about the same as that in the fodder; in urine the content of lead was below the detection limit of the analytical method. The results show that rabbits have the ability to allow some of the naturally supplied lead to pass undigested; with a continual supply of lead-rich fodder, however, ingested lead may be taken up by the organism at an increased rate producing concentrations higher than normal already after 4 weeks.

The experiments provide no definite data as to what will happen over the long-term with less drastic lead concentrations, but indicate nevertheless that the lead-metabolism of herbivores can be directly influenced by the habitat. It may, therefore, also be assumed that the lead-metabolism of human beings may to some degree be influenced by the local, natural, geochemical environment, and that this could have consequences for the state of health of population groups. Although our understanding of relationships between geochemical environment and health and disease is incomplete there does, however, appear to be a rapidly increasing interest in these important geomedical problems (see for example Bersin 1963, Cannon & Hopps 1971, 1972, Hemphill 1968, 1969, 1970, 1971, 1972, Hepple 1972, Låg 1972, Schormüller 1965–1970, Underwood 1971, Usik 1969, and Zaijk 1969).

## Conclusions

Research on different aspects of natural heavy metal poisoning and other related phenomena may contribute to a better understanding of basic geochemical processes in the environment to the eventual benefit of subjects such as prospecting, geomedicine, and pollution. The investigations reported here will therefore be continued. The conclusions of the present work are somewhat preliminary and tentative but the main aspects may be summarized as follows:

1. Through the effect of natural processes lead and other heavy metals can be extracted from crystalline mineralizations in bedrock and overburden and thereafter transported over considerable distances.
2. When natural heavy-metal solutions during their transportation meet variations in the geochemical environment, e.g. pass through material with a relatively high content of humus, the heavy metals can be precipitated and thereby enriched to concentrations far greater than those at the place where they originated.
3. By these processes heavy metals derived from bedrock occurrences may be enriched in the soil downslope from the source to concentrations toxic to vegetation within relatively short geological periods, the degree of poisoning depending on many factors such as: the rate of neutralization of sulphuric acid produced during the oxidation of sulphides at the source; the amount and composition of humus in the soil; the thickness and composition of other parts of the overburden; the topography; the depth of the groundwater table; distance from the bedrock source; and climate and climatic variations during the time of transport.
4. Small areas with heavy-metal poisoning of soil and vegetation appear to be a rather common feature in Norway in connection with sulphide mineralizations in the bedrock. As the symptoms – atypical plant communities, stunted growth and barren areas – are often easily recognizable and the affected areas often of considerable size, searching for signs of natural poisoning may prove to be an effective prospecting method.
5. The typical vegetation indication of heavy-metal poisoning of the soil is not necessarily the occurrence of rare species. On the contrary, the most common grasses such as *Agrostis, Deschampsia* and *Festuca spp.* as well

as other widespread plants, e.g. *Dryopteris spp. Eriophorum vaginatum* and *Juncus trifidus* seem to be important indicators. Consequently, rather than looking for rare indicator species, the registration of special and unusual vegetation types should be an effective geobotanical tool for discovering anomalous metal contents in the soil. Stands of *Deschampsia flexuosa* without *Sphagnum spp.* growing in moist depressions in forest are a typical example of such a vegetation type characteristic of lead-rich soils.

6. A high metal content in the soil produces a high metal content in the vegetation growing upon it. Furthermore, a high metal content in feeds may result in high metal contents in the organs of herbivores. Since some of the most common grass species of normal pasture are amongst those showing pronounced heavy-metal tolerance, it seems quite possible that natural high contents of these elements in the habitat can cause high heavy-metal concentrations in the local herbivores, and perhaps also in the local carnivores and human beings. Some heavy metals are thought to be harmful to human beings even in very small amounts. It is consequently reasonable to consider the possibility that the heavy-metal status of the geochemical environment may in some cases affect the health and physical condition of human population groups.

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