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Exploration for disseminated lead in southern Norway

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Exploration for disseminated lead in southern Norway

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Synopsis

Lead exploration along the southeastern border of the Caledonian mountain chain in southern Norway is described.

Stream sediments were sampled at stream intersections with roads, and areas for more detailed exploration were selected on the basis of the lead anomalies obtained. At the follow-up level detailed stream-sediment sampling, geological investigations, boulder tracing and soil sampling along selected profiles were carried out. In more promising areas detailed investigations also included systematic soil sampling, induced polarization measurements (IP) and drilling.

Six lead deposits were revealed, one of which was drilled and abandoned; one drilled initially requires more drilling; one is considered promising and will be drilled; and three are not considered to be worth drilling. Several anomalies warrant further investigation.

The general experience is that (1) on a regional scale, stream-sediment analysis has proved to be a very useful method; (2) a combination of appropriate methods should be used during the follow-up, and a thorough understanding of the geology is vital for the interpretation of the results; and (3) selected geological, geochemical and geophysical methods, in particular the combination of IP and soil sampling, can be used with advantage in the more detailed exploration work.

Introduction

Along the southeastern border of the Caledonian mountain chain, which runs through central Sweden and southern and northern Norway, deposits of disseminated lead are known to occur (Fig.1). In Sweden two of these deposits, namely Laisvall and Vassbo, are being mined.[14]

The Laisvall deposit, which was found early in this century, was put into production in 1943. The yearly production is 1 200 000 tons with an average grade of 4% Pb. The Vassbo orebody was discovered in 1951 and production started in 1960. The yearly production is 200 000 tons, with an average of 6% Pb. Similar formations to those bearing lead in Sweden are also found in Norway, and, following the Swedish discoveries, there has been an increasing interest in this type of deposit in Norway. In the 1950s and early 1960s some lead occurrences were discovered in southern Norway – the deposits in Engerdal, Osen and Vardal – and during the period 1954-56 the Geological Survey had a regular lead exploration project under the leadership of state geologist S. Skjeseth. In Vardal, several additional lead occurrences were later found by a private company.[11]

After preliminary orientation surveys in 1967 around known deposits, the Geological Survey started a new project in 1968 for lead exploration along the Caledonian border in southern Norway (Fig.2). In this project various geological, geochemical and geophysical methods have been used in both regional and small-scale investigations. Several occurrences of lead have been found and claimed on behalf of the Department of Industry. One of these occurrences has been drilled and abandoned, but others warrant further investigation.

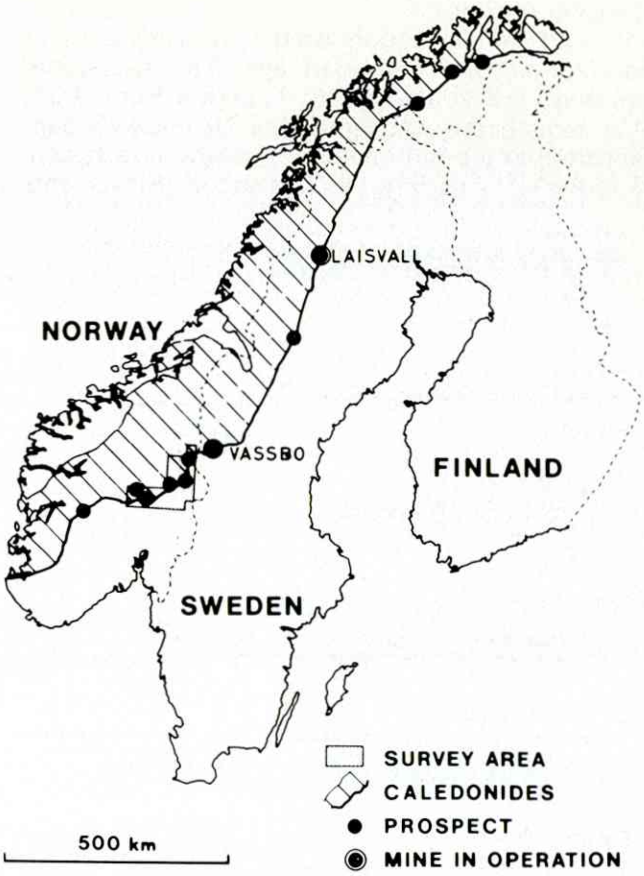


Fig.1 Lead mineralization along border of Caledonides

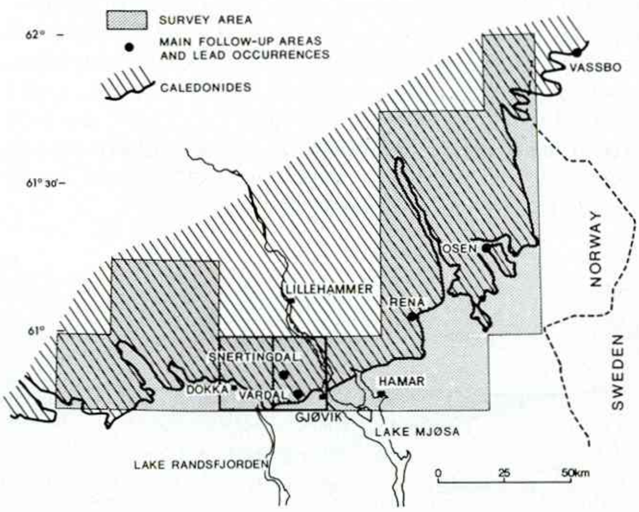


Fig.2 Survey area of NGU lead project, southern Norway

In this paper an account is presented of the methods used, together with some of the main results, some cost data and a discussion of the chosen strategy. As an introduction, a short description is given of the general geology, the type of mineralization and the character of the area surveyed.

REGIONAL GEOLOGY

The lead mineralization occurs in sandstones of Eocambrian and Cambrian age. The sandstones represent the youngest unit (Vangsås Formation) of a sedimentary sequence, the Hedmark Group, deposited in a basin delimited mainly by a system of faults[3,22] (see Figs. 1, 2, 3 and 4). Movements

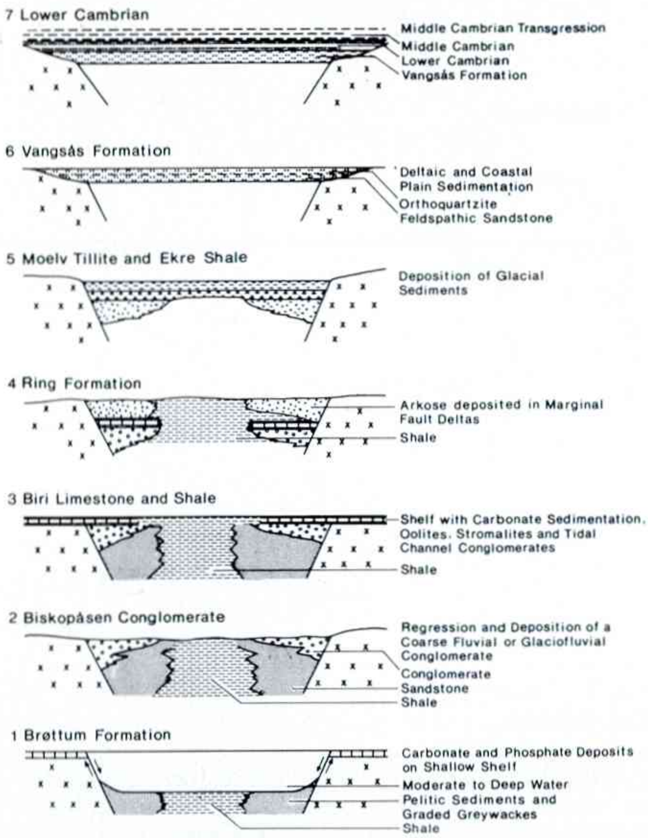


Fig.3 Schematic illustration of lithostratigraphical development of Hedmark Group, southern Norway. After Bjørlykke[3]

along these faults probably diminished during the period of deposition of the Vangsås Formation, which, in its lower parts, consists of feldspathic sandstone and in the upper part of orthoquartzite, developed during a deltaic and coastal plain sedimentation. The crystalline basement outside the basin gradually became a peneplain on to which the Lower Cambrian sediments were deposited in a transgressive sea.

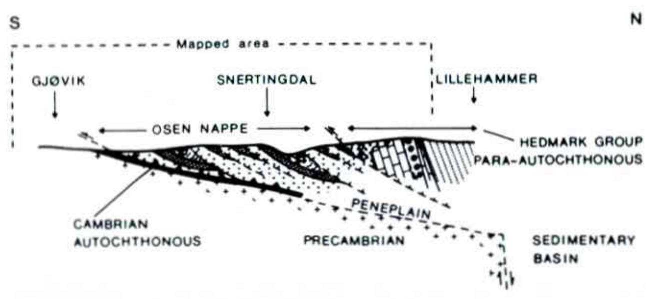


Fig.4 Schematic profile through survey area (for legend see Fig.6; for location see Fig.2)

The general stratigraphical succession of the Lower Cambrian consists of a basal sandstone, of varying thickness, followed by green shales and siltstones, with local developments of deltaic sandstones. The boundary to the overlying Middle and Upper Cambrian black shales is quite sharp.

During the Caledonian orogeny the sediments of the Hedmark Group were folded on east-west axes and to some extent moved out of the original basin, and differential movements in the shales between the more competent layers resulted in the development of nappes. Of particular interest in connexion with the lead mineralization is the movement of the Vangsås Formation. Together with the overlying Cambro-Silurian sediments, this formation was thrust 30-60 km towards the south above the Precambrian peneplain, cutting the autochthonous sequence in the Middle Cambrian shales (Fig.4). During this southward thrusting the competent layers in the nappe developed a marked imbricate structure.

LEAD MINERALIZATION

The lead mineralization in the sandstones is considered to belong to the 'red bed' type. Galena is the only lead mineral present; accessory sphalerite also occurs. The Zn/Pb ratio varies from 1:8 to 1:100. The silver content is low – approximately 100 g/ton of galena.

Some of the lead deposits are shown in Fig.1, Laisvall and Vassbo being the most important. At Laisvall there is a fossil weathered granitic basement above which lies a weakly mineralized basal arkose 5-9 m thick. Over this follows a mudstone 6-12 m thick and three different deltaic facies sandstone beds, here referred to as the lower, middle and upper sandstones. These have thicknesses of 25, 7 and 7 m, respectively. Above the sandstones are the Cambrian shales, with a basal conglomerate. The economic lead mineralization occurs in the lower sandstone and to some extent also in the upper sandstone; the middle impure sandstone is barren.[13]

At Vassbo a 5-m thick basal arkose overlies Precambrian sandstones, and is followed by 8 m of shales and 10 m of calcareous sandstone. The lead-mineralized quartz sandstone is a layer 10-12 m in thickness above the calcareous sandstone. A conglomerate occurs above this and is followed by Middle Cambrian black shales.[24] Both at Laisvall and at Vassbo the lead-mineralized sandstones are autochthonous. At the third main Swedish deposit, Dorothea, and at Vardal in Norway, however, the lead-bearing sandstones occur in an allochthonous position, and the intense imbrication in the nappe has created considerable problems for lead exploration, especially in the small-scale, detailed investigations.

DESCRIPTION OF SURVEY AREA

The topography of the survey area varies from rather gentle in the southern and eastern part to steep and hilly in the northern and western part. Altitude ranges between about 100 and 1200 m above sea level. Outcrops are frequent, especially in stream beds; otherwise, the area is covered mostly by superficial deposits of glacial origin, which have normally been deposited directly upon freshly eroded bedrock. Some chemical weathering of the bedrock is common in shale zones and in thinly covered high-level ($>$ 1000 m) areas prone to heavy frost action. A thin overburden of locally derived material (1-2 m) is more frequent in the western than in the eastern parts of the area. In areas where the overburden is thick, material becomes gradually more allochthonous towards the surface.[12] This type of layered superficial deposit is particularly common above the Cambro-Silurian shales in the southeastern part of the area. Glaciofluvial deposits occur mostly in the valleys and in the vicinity of now dried-up overflow channels. The glaciofluvial deposits may be long-transported and of considerable thickness. Fluvial deposits are mainly found along the largest river valleys. Bogs are frequent in the high-level areas; apart from these tracts, drainage is good. Soils are mostly of the podzol type, both humus and bleached horizon thicknesses normally being less than 6 cm.[16] Spruce and pine are common to 800 m, and birch above this altitude. The lowest part of the area is agricultural land. Climate varies with altitude: the mean temperature is 3-4°C and annual precipitation ranges from 300 to 700 mm.

Methods

Geological maps produced by the Geological Survey are generally published on the 1:50 000, 1:100 000 and 1:250 000 scales. Geophysical and geochemical maps are also reproduced. In the lead project the results of regional geological, geophysical and geochemical investigations have been compiled on the 1:50 000 map sheets. For follow-up areas the map scales used were mostly those of the air photos (approximately 1:15 000 and 1:30 000). Where detail was required, a grid was constructed and maps of 1:5000 were used. The grids were usually marked out with pegs every 25 m along profiles at right angles to the strike, the distance between profiles normally being 100 m, but in some cases 200 m. Geophysical measurements were usually made at every peg, and in anomalous zones also at one or more intermediate points. Soils were generally sampled at the grid-peg stations.

Before the project began, all geological information about the region surveyed was compiled on 1:250 000 maps. From this was decided which particular area would be covered by regional stream-sediment sampling. To date, eight 1:50 000 sheets have been mapped geologically as part of the project, and an additional five sheets have been mapped as part of NGU's ordinary geological mapping programme.

Besides the actual field work, air-photo interpretation and aerogeophysical maps (magnetic, electromagnetic and radiometric) have constituted the basis for the regional geological mapping programme.

In detailed investigations at the follow-up level, the lithostratigraphical formations have been divided up into suitable members with a view to distinguishing possible ore-bearing layers. Registration of the phyllosilicates, galena and pyrite in the sandstone, together with their textures, has also been undertaken. As it has been of prime importance to locate the sources of the anomalies as quickly as possible, an intensive block-searching has been carried out in areas of poorly exposed bedrock.

In the closing stages of the investigations diamond drilling has been carried out to obtain reference data for the geophysical, geochemical and geological interpretations. The above-mentioned geological parameters have been registered from the drill cores and chemical analysis has been carried out on selected lithologies taken from these cores.

GEOCHEMISTRY

Stream sediments

At the regional level, stream sediments were collected at stream intersections with roads: sample density therefore varies with the density of the road network. At each sample site two separate samples were taken 10 m apart and at least 30 m upstream from the road (Fig.5). The two samples were analysed independently. At the follow-up level, stream sediments were collected systematically along all streams, the distance between sampling stations being from 100 to 250 m along the stream or at varying intervals dependent on the geology. All stream-sediment samples were wet-sieved in the field to −0.18 mm (*ca* 80 mesh) by use of a specially made aluminium sieve with nylon cloth.

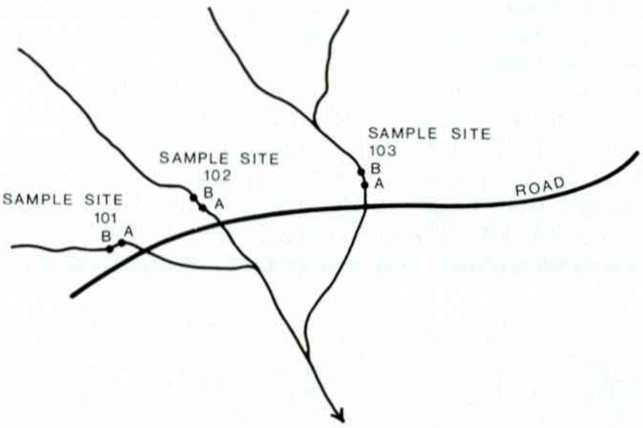


Fig.5 Stream-sediment sampling model: sample *A* taken at least 30 m above road, with 10-m distance between samples *A* and *B*

Only active sediments, preferably inorganic, from the middle of the stream, were sampled.

Soil samples

At the follow-up level, soil samples were collected along selected profiles. In detailed work soil samples were taken systematically along profiles in the grid. Three types of soil sample were collected: (1) humus samples, (2) *B* horizon soil samples and (3) parent material. The humus was sampled with a gardener's trowel at a depth of 2-5 cm, and one full paper bag (12 cm x 20 cm) was collected. Soil *B* was sampled from the middle of the horizon, the normal depth being 20-30 cm, depending on the profile. Parent material was sampled with a spade at a depth of 60-80 cm.

Treatment of samples

The various types of samples were packed in paper bags and dried in warm air (50-80°C). The soil samples were dry-sieved to −0.18 mm; 1 g of the fine fraction of all sample types was then digested in 5 ml of hot HNO_3, 1:1, for 3 h. Humus samples tended to froth during this treatment and had to be heated carefully. After digestion, the solution was diluted to 20 ml, filtered through a 20-μm nylon cloth and analysed by atomic absorption spectrometry.

Treatment of geochemical data

The geochemical data were presented in the form of frequency distributions and geochemical maps. Frequency distributions were calculated for various groups of data, and frequency-distribution diagrams were drawn on probability paper, cumulation starting with low concentrations. For map presentation the concentration ranges were grouped, the limits of the intervals following a geometric progression.[7] Each interval is symbolized on the maps either by dots of varying diameter or by iso-concentration contours.

GEOPHYSICS

Induced polarization (IP), apparent conductivity (σ_a) and self-potential (SP)

Combined IP, σ_a and SP gradients were surveyed in all promising areas selected for detailed prospecting. For IP and σ_a the current electrodes were located such that a current direction at approximately right angles to the strike of the bedding was obtained. The IP measurements were carried out in the time domain with current on-time and current off-time both 2 sec. The IP effect was measured as the mean potential between 0.1 and 0.58 sec after current cutoff, and is expressed as a percentage of the potential in the current on-time.

Analogous measurements were also carried out in drill-holes with both asymmetrical and symmetrical Wenner configuration, the distance between electrodes being 10 and 2 m, respectively. The borehole-IP measurements were carried out with a measuring time between 0.40 and 0.88 sec after current cutoff in order to avoid pick-up of electromagnetic transients due to the long parallel cables involved in the measuring system.

Conductive electromagnetic measurements (EM)

EM measurements were tried at one locality in the Snertingdal area. Alternating current (frequency, 500 p/sec; current, *ca* 1 A; energy, *ca* 200 W) was supplied through a 6-km long rectilinear cable parallel to the strike of the bedding and earthed at both ends. The strength of the in-phase and out-of-phase vertical component of the electromagnetic field, calculated as a percentage of the

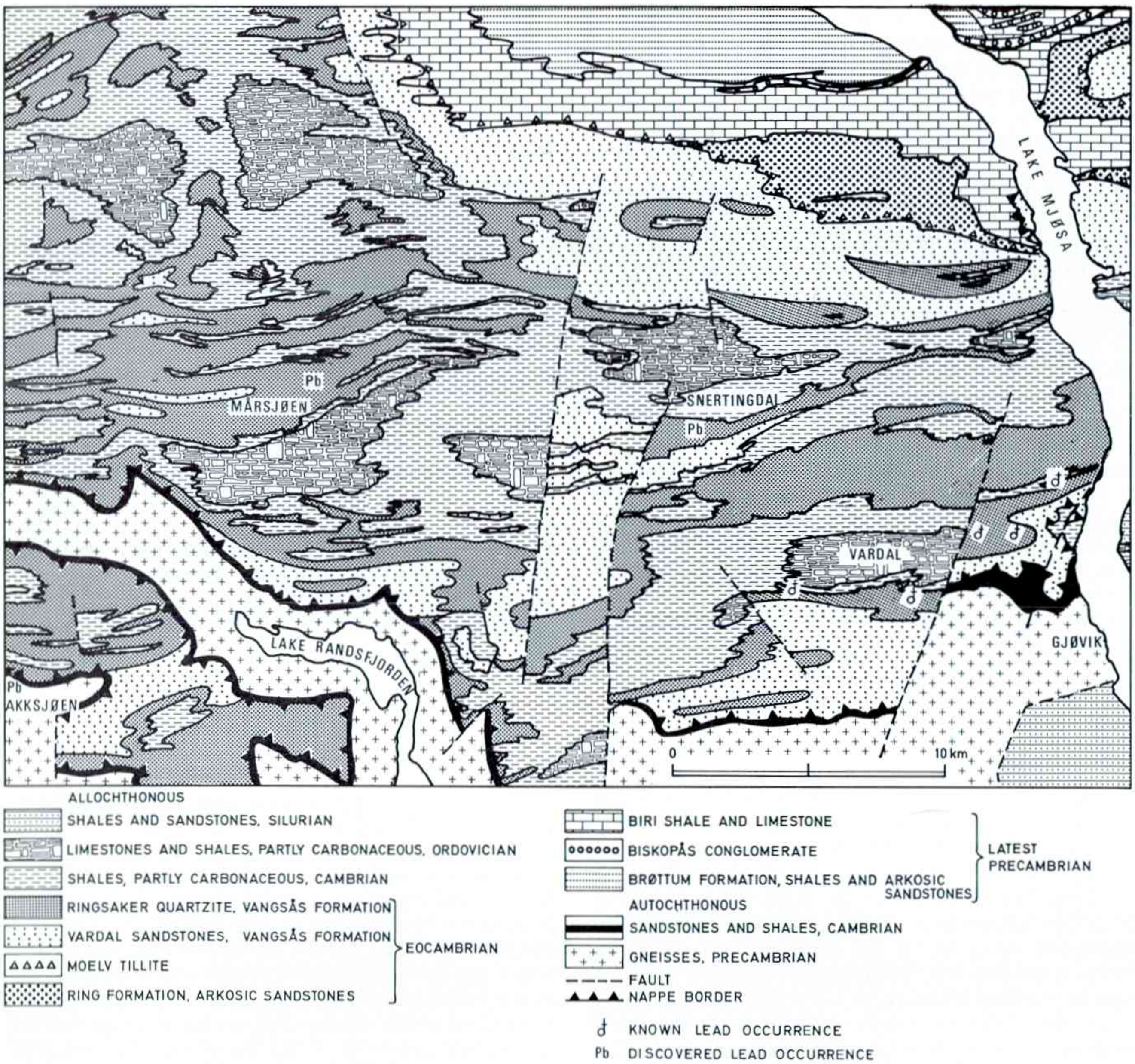


Fig.6 Simplified version of 1:50 000 geological map sheets Dokka and Gjøvik (for location see Fig.2: complete maps are in press[2])

normal field around the cable, was surveyed in profiles at right angles to the cable. The absolute value of the strength of the field was measured at one point per profile; results were otherwise recorded as field strength quotients.

Results

Within the investigated area (Fig.2) the map sheets Gjøvik and Dokka have been selected for a demonstration of the type of results obtained. Examples of other results have been published earlier.[6,8,10] The following brief account of the exploration within these map sheets is divided into three parts: (1) regional survey, (2) examples of the follow-up of selected anomalies and (3) examples of results of detailed prospecting in one of the follow-up areas.

REGIONAL

A simplified version of the geology on the map sheets Gjøvik and Dokka is shown in Fig.6, and a geological profile is given in Fig.4. The complete maps are in course of preparation.[2] The general lithostratigraphy and the tectonic setting have been outlined earlier. A few comments on the geology relevant to the lead mineralization are given below.

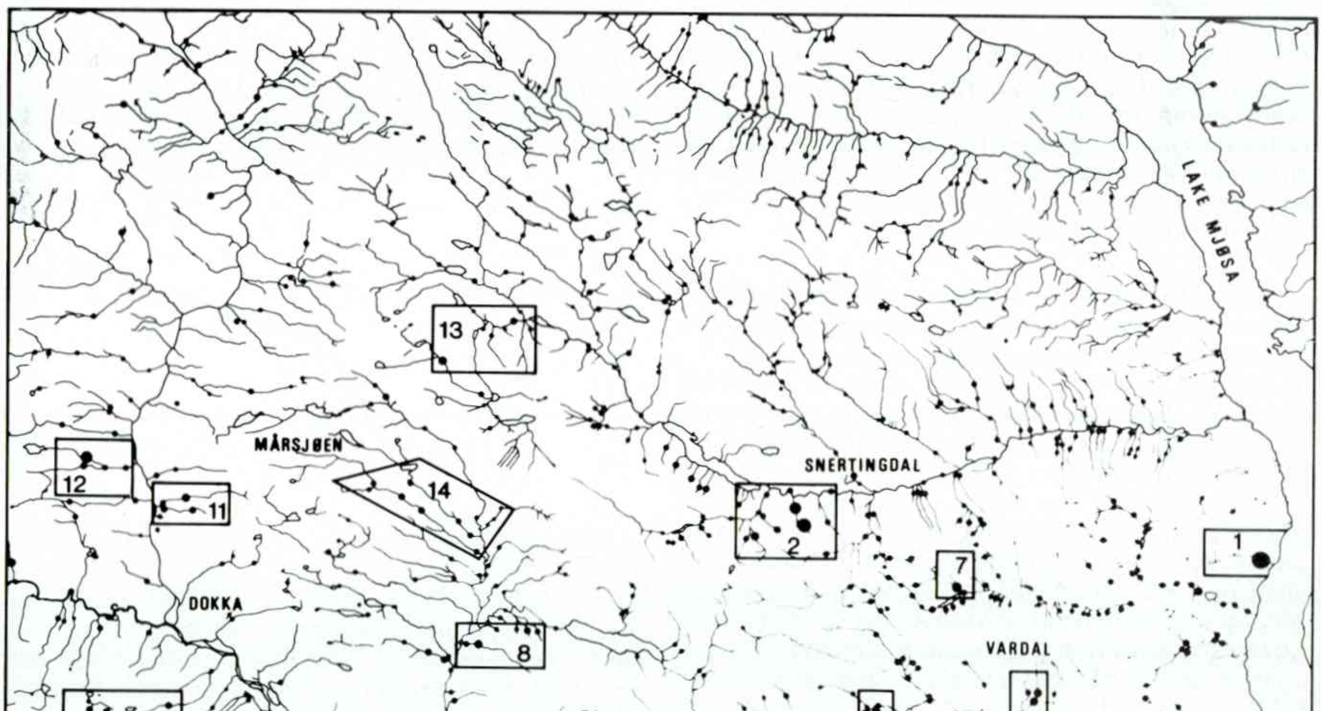
The area is dominated by the Osen nappe, the border of which is in contact with the autochthonous Cambrian shales in the south of the mapped area. Two large synclinoria are present in Snertingdal and at Mustad (7 km south of Snertingdal). Competent beds (e.g. Vangsås Formation) have developed an imbricate structure, and the Cambro-Ordovician strata are disharmonically folded.

The Vangsås Formation is divided into the Vardal Sandstone (lower member) and the Ringsaker Quartzite (upper member). The Vardal Sandstone consists of varying coarse- and fine-grained arkoses in its lower part. These gradually give way to a feldspathic sandstone in the upper units, with conglomeratic beds of deltaic origin in the southern part of the mapped area. The thickness of the member is approximately 150 m.

The Ringsaker Quartzite can be divided into a lower part, which has a phyllosilicate-rich matrix, and an upper part, which is a rather pure orthoquartzite. The total thickness is about 100 m.

The autochthonous Cambrian beds were deposited on the Precambrian peneplain, which now has a NNE dip of 3°. A thin basal conglomerate lies directly upon either unweathered gneiss or a breccia formed by *in situ* weathering. This is followed by green silty shales of lower Cambrian age. At the top of this sequence, which is from 10 to 20 m in thickness, there is a thin layer of black shales of Middle Cambrian age. In the autochthonous succession within the Gjøvik and Dokka map areas lead mineralization similar to the deposits at Osen and Vassbo has not been found. This is probably because the sandstone facies is missing.

All the known lead deposits in this area occur in the upper part of the Ringsaker Quartzite. This detailed lithostratigraphical control is not always



Pb in ppm · <10 · 11 – 15 · 16 – 25 · 26 – 40 · 41 – 65 ● 66 – 100 ● 101 – 150 ● 151 – 250 ● 251 – 400

Fig.7 Lead in stream sediments on Dokka and Gjøvik map sheets. Location of map sheets shown in Fig.2. Frames indicate anomalies selected for follow-up work. Frequency distribution of data given in Fig.18

valid, however, outside this map area: for example, the Rena deposit (Fig.2) is a lead mineralization occurrence in the Vardal Sandstone, but even in this the mineralization is petrographically controlled by the total content of phyllosilicates – always less than 5-6%, a rule which seems to be valid throughout the area surveyed in southern Norway.

Stream-sediment survey

The geographical distribution of lead in stream sediments on the map sheets Dokka and Gjøvik is shown in Fig.7. Two features are apparent: lead concentrations seem to form regional trends and several groups of sample sites with high lead contents can be defined.

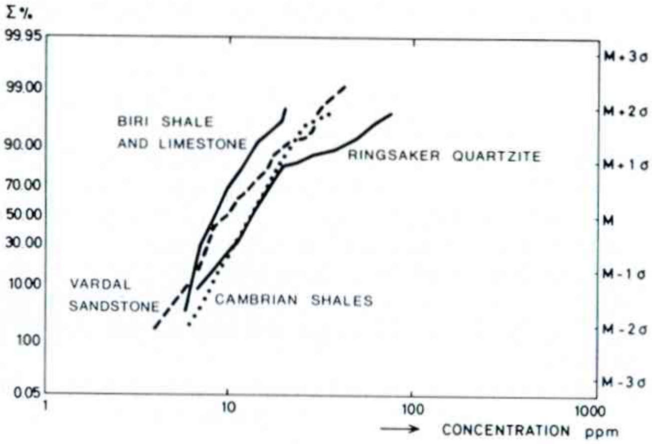


Fig.8 Cumulative frequency distributions of lead contents in stream sediments from different geological formations on Gjøvik map sheet (see Figs. 2, 6 and 7). Only samples from streams which drain minimum 200 m through same geological formation above sample sites are included. Abscissa gives metal content, left-hand ordinate cumulative per cent and right-hand ordinate scale for estimation of standard deviation

The regional lead trends in the stream sediments appear to reflect the regional geology. This feature, which has been demonstrated earlier for Cu,[10] is illustrated in Fig.8, where the frequency distributions of lead in stream sediments from some selected geological formations are compared. Only samples from streams which drain a minimum of 200 m through the same geological formation above samples sites are included in this selection. Some parameters estimated from the frequency distributions[7] are listed in Table 1. The various geological formations obviously produce different lead distributions in the stream sediments.

It is seen that the medians of the distributions are different for the various geological formations, Biri Shale and Limestone having the lowest (8 ppm) and Ringsaker Quartzite and Cambrian shales having the highest (13 ppm). Ringsaker Quartzite yields the highest dispersion of lead concentrations, its geometric deviation being 2.0, whereas those of the other formations are of the order of 1.5-1.6.

Table 1 Median (*M*) and geometric deviation (*S′*) estimated from cumulative frequency distributions of lead contents in stream sediments from different geological formations at the Gjøvik map sheet (see Fig.8 and reference 7)

	M, ppm	*S′*
Cambrian shales	13	1.5
Ringsaker Quartzite	13	1.9
Vardal Sandstone	10	1.7
Biri Shale and Limestone	8	1.5

Sample sites with high lead concentrations were selected, and the defined anomalies were numbered consecutively, as shown in Fig.7. The following criteria were considered when setting the priorities: (1) lead content, (2) knowledge of the geology and (3) content of base metals other than lead.

Any lead anomaly occurring in the same area as Ringsaker Quartzite is given high priority. From the frequency distributions presented in Fig.8 it can be seen that the Ringsaker Quartzite is the only formation which produces a clear bimodal distribution of lead in the stream sediments – indicating that an anomalous distribution is present in addition to the background distribution. Lead values may also occasionally be high within other formations, especially within the Cambrian shales (Fig.8). High lead due to Cambrian shales is, however, often associated with high values for other base metals. Altogether, 14 anomalies were selected, anomaly 1, Vardal (Fig.18), representing the area of lead deposits known before the survey was begun.[1] The remaining anomalies were followed up by further investigations.

Follow-up in Dokka – Gjøvik area

Anomalies 2-14 (Fig.7) were investigated with various combinations of two or more of the following methods: (1) geological investigations, including photo interpretation; (2) detailed stream-sediment sampling; (3) boulder searching; and (4) soil sampling.

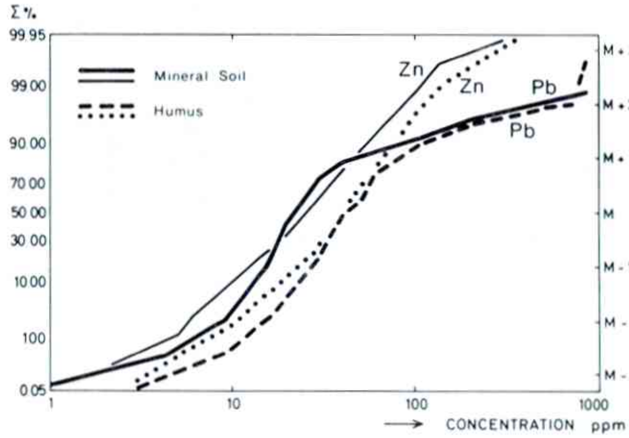


Fig.9 Cumulative frequency distributions of lead and zinc contents in humus and mineral soil (B_2 horizon) from Snertingdal anomaly area. Abscissa gives metal content, left-hand ordinate cumulative per cent and right-hand ordinate scale for estimation of standard deviation

Anomaly 2, Snertingdal (Fig.7), was given the highest priority of those detected on the map sheets Dokka and Gjøvik. During the first day of reconnaissance the geologist discovered lead-mineralized bedrock in the stream bed upstream from the sites producing anomalous samples. The lead was found to occur as galena disseminated in quartzite. Knowledge of the geology of the region enabled the area of interest to be restricted both to the north and to the south. A detailed stream-sediment survey confirmed the anomalies from the regional survey and outlined an area for further investigations of approximately 6 km^2 (Fig.11). The anomaly was selected for detailed exploration.

Anomaly 3, Akksjøen (Fig.7), was given high priority after interpretation of the regional geochemical map, but was later abandoned. During geological investigations in the anomalous stream lead mineralization was found in boulders in the stream bed. The mineralization consists of coarse-grained galena and sphalerite in calcite-filled fractures in a Precambrian gneiss just south of the autochthonous Cambrian sediments. The same type of mineralization was also found at several places in the bedrock of the area drained by the anomalous stream. No further prospecting has been carried out in this area because the type of mineralization was considered to be of no economic interest.

After some follow-up work on the second-priority anomalies (4-14) they were all abandoned for one or more of the following reasons: (1) the anomaly source was found to be of the desired type of mineralization, but was considered too small to be of economic interest; (2) the anomaly source was found, but was considered to be of an economically uninteresting type of mineralization; (3) the anomaly was considered to be caused by particular geochemical conditions rather than bedrock mineralization; (4) the anomaly source could not be found, but the anomaly was not considered sufficiently promising to justify the amount of work necessary to locate it; and (5) the regional anomaly could not be verified by repeated sampling during follow-up.

DETAILED EXPLORATION WITHIN SNERTINGDAL ANOMALY AREA

General description of area

Topographical maps of the area are available at a scale of 1:5000 (Fig.10). The anomalous area is situated on a gently inclined north-facing slope leading to the Stokkelva River. The thickness of the superficial deposits reaches an estimated maximum of about 10 m, but a general average thickness is around 1 m. Outcrops, generally rare, are frequent in stream beds. The cover consists mainly of moraine, and its soil profile shows a normal podzol development with a bleached layer thickness of between 2 and 15 cm. Spruce is the most common tree, and *Vaccinium* sp. dominates in the ground-cover vegetation.

Geology

A geological map of the Snertingdal anomaly is shown in Fig.12. The Ringsaker Quartzite (upper member of the Vangsås Formation) is divided into a lower and an upper part: the lower part is 40 m thick and consists of quartz sandstone with thin layers of green shales (2-5 cm thick); the ore-bearing upper part starts with a light presolved orthoquartzite with some stylolites. The primary texture is poorly visible, but the mean grain size is estimated to be 0.5 mm. Most of the galena occurs as poikiloblasts, but some must have been mobilized during the nappe movement and is now deposited along joints. The thickness of this unit is 20 m in the eastern part of the area, decreasing to 7 m in the western part. This is followed by a 15-m thick horizon of alternating light orthoquartzite and darker quartz sandstones. This unit is almost barren. At the top there is a 10-m thick layer of bluish, coarse-grained orthoquartzite. The mean grain size is about 1 mm and pressure solution is not common. Galena, together with silica, occurs as a cement between the primary quartz grains. Replacement of the grains by galena is seldom apparent.

A profile across the area is given in Fig.14. The imbrication and folding of the strata are normally more intensive than is shown in the profile. The result of this deformation is an increased thickness of the layers, which makes it difficult to estimate the thickness of the ore both along strike and in the vertical plane. Graphite has developed along the imbrication surfaces in the black shales.

Geochemistry

Maps illustrating the distribution of lead in humus and in mineral soil (B_2 horizon) from the Snertingdal anomaly area are shown in Figs. 10 and 11, together with results from the follow-up sampling of stream sediments. Corresponding frequency distributions are illustrated in Fig.9, together with frequency distributions for zinc, this element being randomly distributed and therefore not depicted on the maps. In all, 1605 samples of both humus and mineral soil were collected. On both maps contours are drawn at 100 and 1000 ppm lead, and the corresponding number of standard deviations above the mean are estimated from Fig.9 and indicated in Table 2.

Table 2 Number of standard deviations (SD) above median (estimated from Fig.9) corresponding to contours 100 and 1000 ppm on map of lead distribution in soil, Snertingdal anomaly area, (Figs. 10 and 11)

Contour	100	1000
Humus	1.2	3.0
Soil *B* horizon	1.4	2.3

A distinct lead anomaly, fairly similar in intensity in both the humus and the mineral soil, occurs between coordinates 5500-6000 N and 4500-6400 W. The lead anomalies in the stream sediments are found downstream from the soil lead anomalies.

Geophysics

A map of the results of the surface IP and σ_a measurements in the Snertingdal anomaly area is shown in Fig.13. SP measurements were carried out simultaneously with the IP and σ_a measurements. EM was measured in a separate survey. Examples of results of the SP and EM measurements are presented from typical profiles, together with geological, geochemical and other geophysical data, in Fig.14.

In addition to surface measurements, IP, σ_a and SP were measured in one diamond drill hole (no.3); IP and σ_a measurements were also carried out in the laboratory on core specimens. The core specimens were later investigated petrographically and, finally, were analysed for lead.

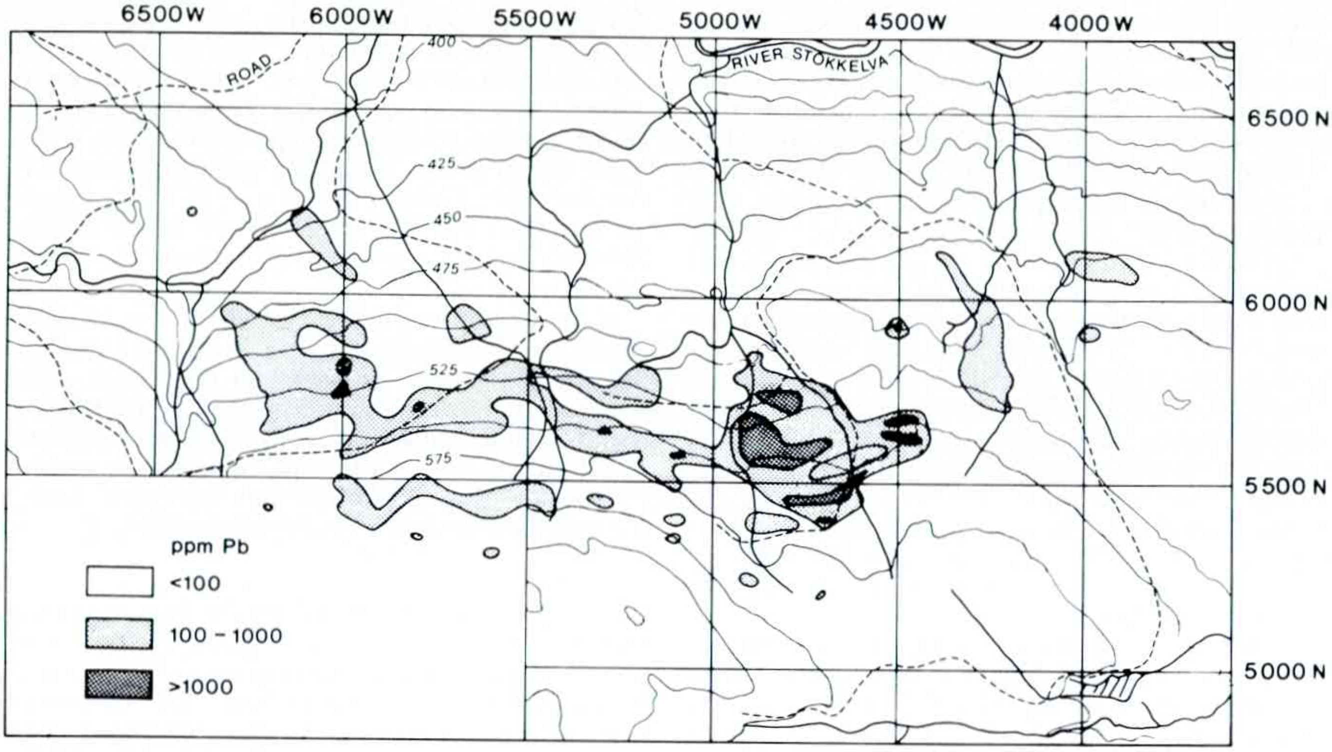


Fig.10 Lead in humus from Snertingdal anomaly area. Humus samples are collected every 25 m between 5000 N and 6500 N along all 100-m profiles between 3700 W and 6700 W. Location of area is indicated in Fig.7. Frequency distribution of data given in Fig.9

The drill-hole measurements indicated a close positive correlation between IP effect and lead content (Fig.15). The laboratory investigations disclosed a strong correlation between IP effect and lead content of drill-core specimens. Results from 38 samples gave the regression equation

$$\% \text{ IP} = 5 \times \% \text{ Pb} + 1.5\%$$

with a correlation coefficient of 0.96. Neither graphite nor sulphides other than galena were found to vary simultaneously with the lead.

Only samples with high lead contents showed better conductivity than unmineralized sandstone, but even the strongest lead-mineralized samples (Pb about 6%) had lower conductivities than samples with a high phyllosilicate content.

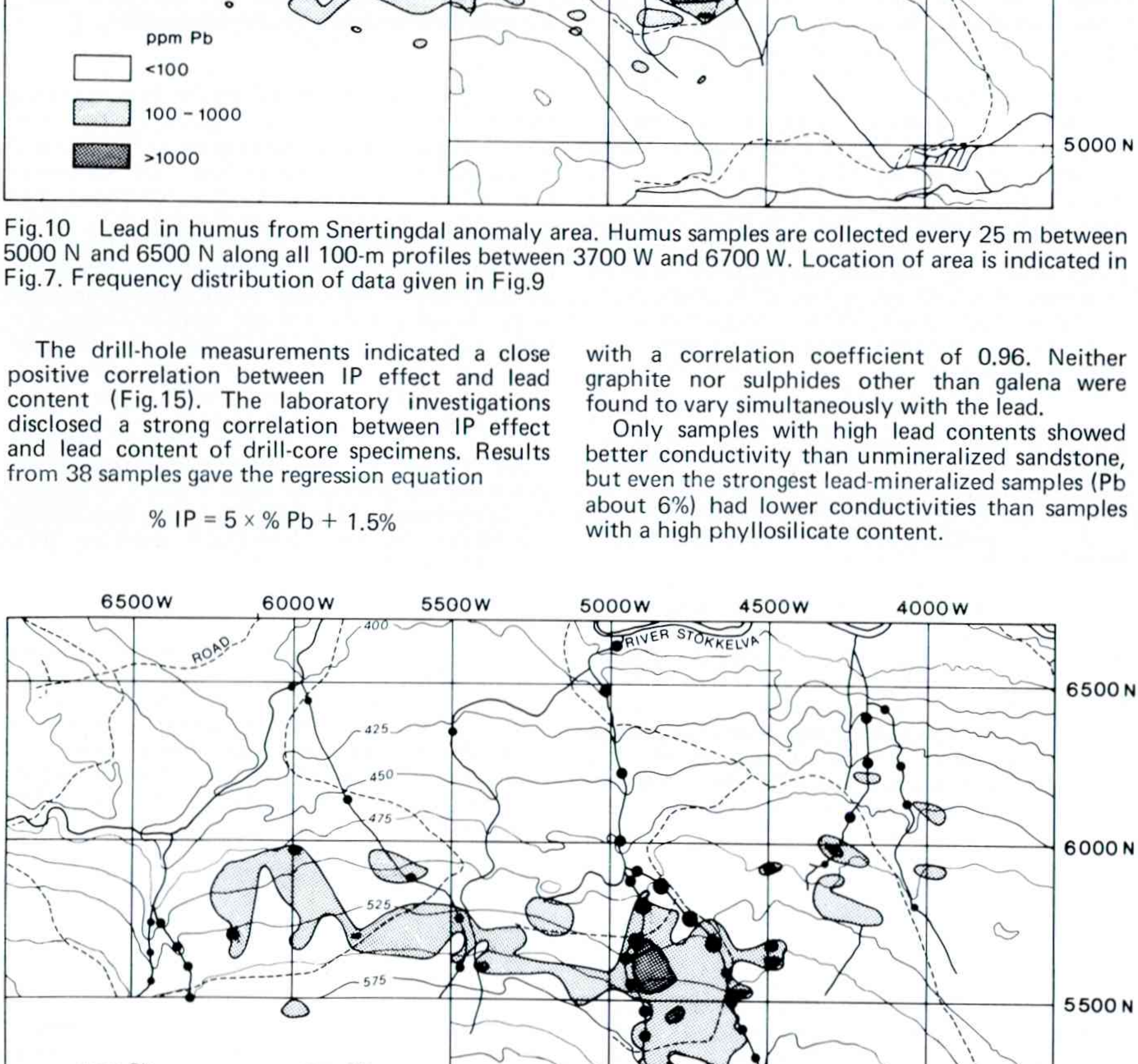


Fig.11 Lead in stream sediments and mineral soil (B_2 horizon) from Snertingdal anomaly area. Soil samples are collected every 25 m between 5000 N and 6500 N along all 100-m profiles between 3700 W and 6700 W. Location of area is indicated in Fig.7. Frequency distribution of data given in Figs. 9 and 18

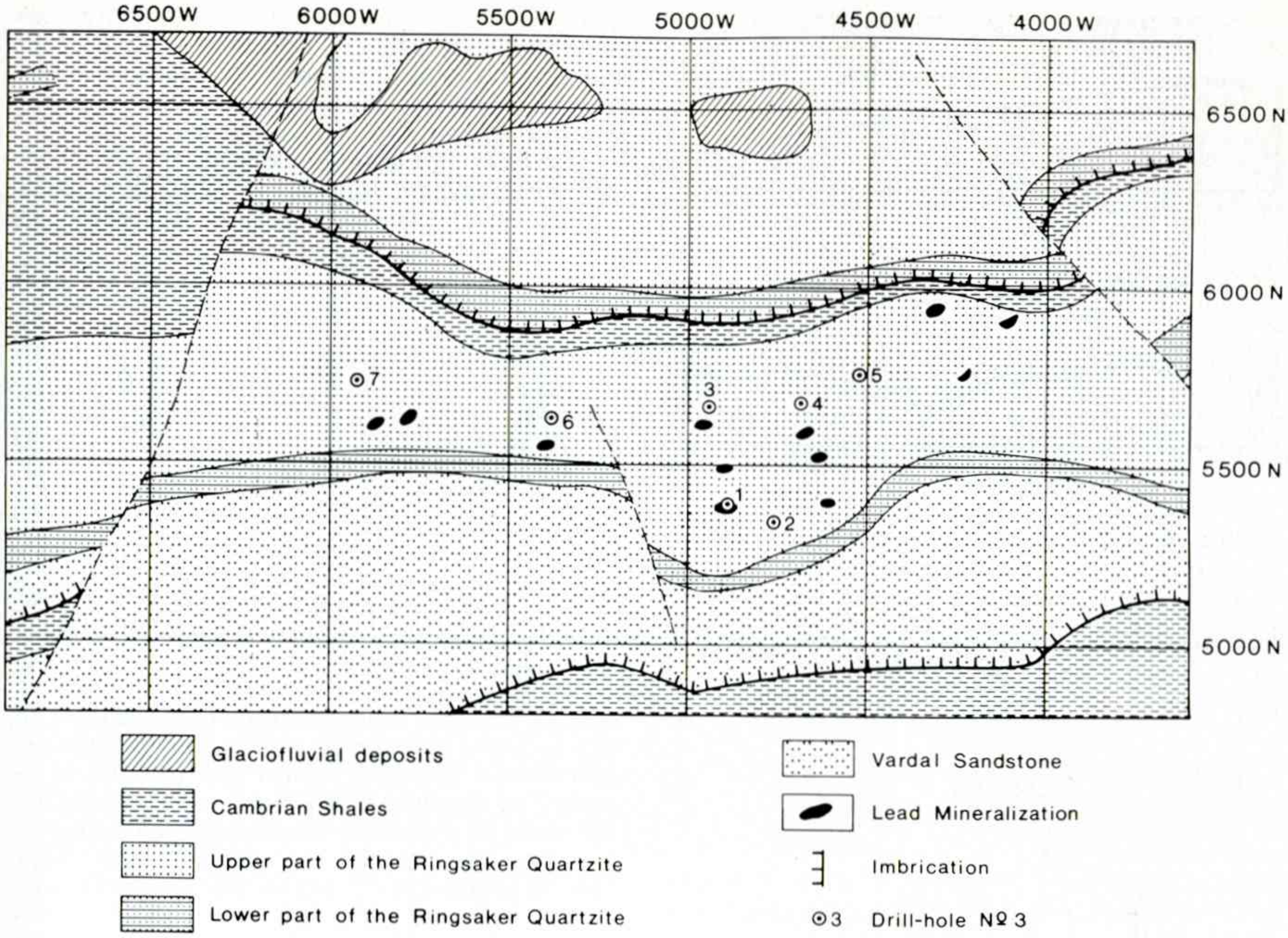


Fig.12 Geological map of Snertingdal anomaly area (for location see Fig.7)

Interpretation of results

There are three lead-mineralized zones: one at about 5400N, 4700-5000W, another at 5500N, 4500-5500W, and a third at 5600N, 4100-6100W.

The zones are indicated by (1) outcrops of lead-mineralized quartzite, (2) lead anomalies in humus and mineral soil and (3) IP anomalies.

The geochemical anomalies are displaced

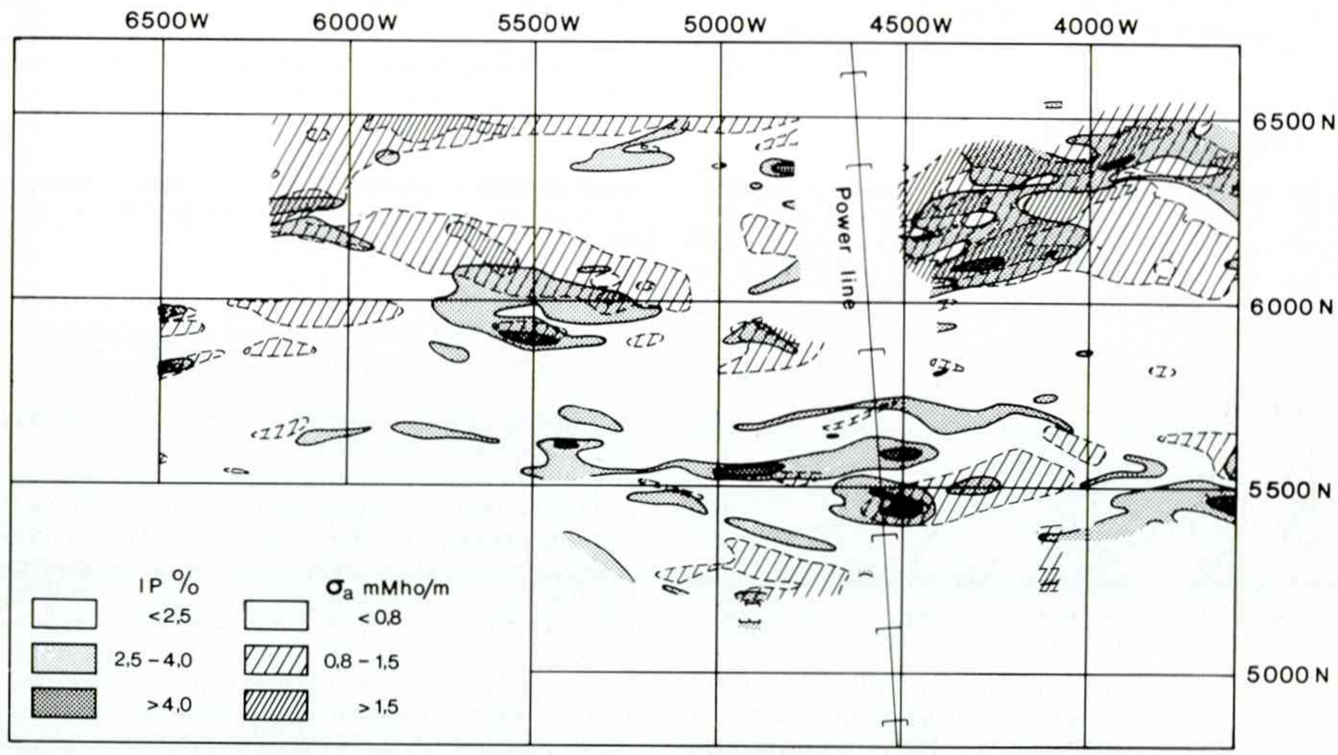


Fig.13 Induced polarization (IP) and apparent conductivity (σ_a) of Snertingdal anomaly area. Sample stations at 25-m intervals along north-south running profiles, the intervals between which are 100 m (for location of area see Fig.7)

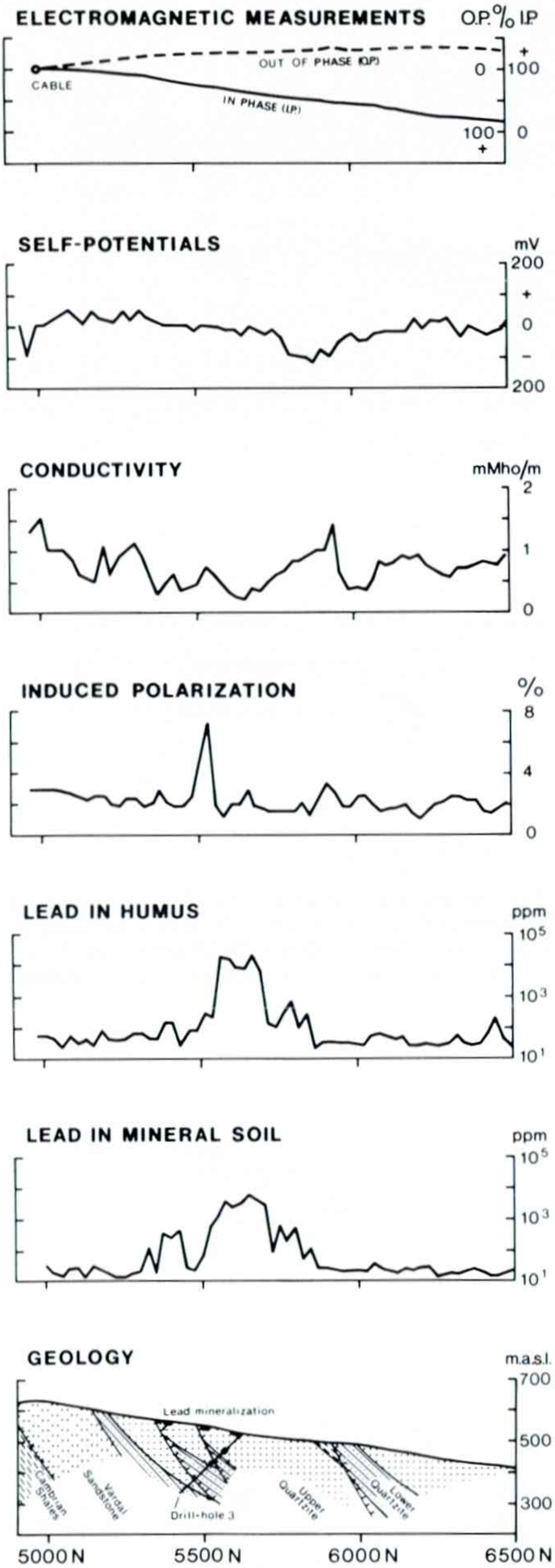


Fig.14 Geology, lead in mineral soil (B_2 horizon), lead in humus, induced polarization, apparent conductivity, self-potentials and electromagnetic measurements at profile 4900 W, Snertingdal anomaly area (for location of profile see Figs. 10-13)

downslope in relation to the geophysical anomalies, probably due to hydromorphous movement of metals. The drilling targets are the localities where strong IP anomalies coincide with the upper parts of soil lead anomalies.

Based on geological knowledge, the anomalies can be classified into (1) IP anomalies, with corresponding lead anomalies in soil, which are

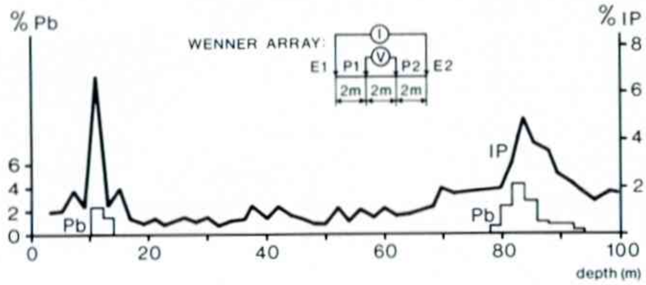


Fig.15 Lead content and induced polarization in drill-hole no.3, Snertingdal anomaly area (for location of hole see Fig.12; I, current; V, measured voltages; E1 and E2, current electrodes; P1 and P2, potential electrodes)

considered to be caused by lead; (2) coincident IP, SP, σ_a and EM anomalies, with no corresponding geochemical anomaly, which are thought to be caused by graphite along imbrication planes; and (3) other IP anomalies, which might be caused by lead. In this case the lead mineralization might have no actual outcrop even if the overburden were to be removed. It might also be that lead mineralization cannot be detected by geochemical methods due to the thickness and the character of the overburden.

Conclusions

Based on the joint interpretation of the geological, geochemical and geophysical data, diamond drilling was carried out in seven holes over a total length of 785 m (Fig.12). The drilling disclosed a lead-mineralized zone about 2 km in length between coordinates 4200-6200W and 4400-5000W. In the eastern part of the zone a mean lead content of 1% over 15-20 m has been demonstrated. Towards the west the thickness and grade of the mineralized zone decrease. Because of the low grade, further investigations were not recommended within the area.

Costs

The professional staff of the lead project consisted of one project manager (S.S.), one geologist (A.B.), one geochemist (B.B.) and one geophysicist (P.E.), and, in addition, two technicians. Each member has also performed other duties, so an average full-time attachment would be two professionals and one technician per year. Some costs are given in Table 3 for prospecting on the map sheets Dokka and Gjøvik. It should be remembered that the project has involved routine prospecting, experimentation with various methods and systematic mapping. It is difficult to determine that part of the costs which is due solely to routine prospecting, especially the various items of office work. Map-drawing and report-preparation costs are, therefore, not given. Even the field work includes costs in addition to those for prospecting alone. For example, during regional stream-sediment sampling the number of

Table 3 Examples of exploration costs* – map sheets Dokka and Gjøvik

Area	Level	Method	Working days in field	Total cost	Cost per unit	Cost of chemical analyses
Gjøvik–Dokka	Regional	Geology	300	60 000	500/km²	
Gjøvik–Dokka	Regional	Stream sediment	100	20 000	30/*A+B* sample	3/sample and element
Gjøvik–Dokka	Follow-up	Different combinations	250	50 000	3000/anomaly	
Snertingdal	Detail	Setting up the grid	215	43 000	15/station	
Snertingdal	Detail	EM	215	43 000	15/station	
Snertingdal	Detail	IP	62	12 400	9/station	
Snertingdal	Detail	Soil samples, both humus and mineral soil	60	12 000	7/sample site	3/sample and element
Snertingdal	Detail	Geological work	75	15 000		
Snertingdal	Detail	Diamond drilling (880 m)		176 000	200/m	

* All costs are given in Norwegian Kroner (1972) : N.kr. 15 = £1.00 = $2.50 (approximate values). Cost per man-day, all areas, N.kr. 200.

samples could probably have been reduced by a factor of about 4 if only the geologically favourable areas for lead mineralization had been sampled with just one sample per site instead of whole map sheets and duplicate samples at each site. Both total costs and cost per sample site could, therefore, have been reduced considerably if prospecting alone had been the aim of the investigations.

At the follow-up level all methods have been used in close cooperation, so unit prices per method cannot be given. The costs given in Table 3 cover the expenses for following up 13 anomalies, of which three were promising.

The detailed investigations in Snertingdal could be considered as an orientation survey for trying out methods for later use in lead prospecting in Norway. For example, both mineral soil and humus were sampled during the detailed geochemical survey. If routine prospecting alone had been carried out, expenditure for the geochemical investigations could probably have been reduced by almost half.

Evaluation of methods

During the NGU lead project investigations several exploration methods in various combinations have been tried, and valuable experience has been accumulated concerning their feasibility and usefulness under Norwegian conditions. A discussion now follows of some aspects of the various techniques, methods or combinations which have been tried: it is divided into three parts according to the prospecting levels: (1) regional, (2) follow-up and (3) detail.

REGIONAL METHODS

The aim of the prospecting at the regional level is to locate the first indications of lead mineralization, in other words, to find areas in which follow-up work may be profitable. In addition to the traditional geological mapping, stream-sediment surveys have constituted the main methods of regional investigation. In stream-sediment surveys one will normally have to choose between the following three sampling systems. (1) Sampling all streams at certain intervals (e.g. 200-500 m) along the stream courses: this is a widely accepted system and has been used for a long time in routine work in Scandinavian countries (see, for example, references 9 and 15). (2) Sampling at a certain density per unit area, for example, 1 sample per square mile: this is a well established procedure and has been reported by, for example, Nichol *et al.*[20] (3) Sampling only at easily accessible sites: this is the regional system used in NGU's lead project; although it was proposed many years ago,[25] it does not seem to have been widely employed.

Within any large area there might exist a great number of ore deposits within a certain depth. An attempt to locate all these deposits during a regional prospecting programme would have very little chance of success, and it is therefore wiser to try to find just one of the bodies since any exploration programme is obviously successful if one economically profitable deposit comes to light.

Sampling systems (1) and (2) aim at a complete survey of metal distribution at a certain degree of density. Stream-sediment sampling along roads (3), however, aims at skimming off the cream and falls in line with the philosophy of being successful in finding just one deposit. This sampling system has the advantage of rapid and cheap screening of anomalies, which, since they are all positioned at the roadside, should be attractive in any prospecting programme as they are easily accessible and, therefore, less expensive to follow up than remote anomalies.

Norway is sparsely populated and the density of roads is irregular and varies with habitation, which, in turn, is dependent on topography and soil fertility. Thanks to many forest roads in certain districts, however, remote areas may be accessible by vehicle. The sample density for sampling stream sediments along roads may, therefore, be fairly regular in agricultural and forestry areas, but outside these areas sampling will generally be confined to the main valleys. The sample density on the various map sheets varies between 0.3 and 0.5 samples per km^2. Examples of patterns of sample-site distribution can be seen in Fig.7; other examples have been given elsewhere.[6,8,10]

The extent to which a sediment represents the drainage above the sampling site is not well known and no attempt is made to quantify the sampling error on that basis. Under Norwegian conditions anomalous lead has in one or two cases been found 2-3 km downstream from the source, whereas in other instances high lead contents can be traced only for 100 m or so. In the interpretation of results from stream sediments sampled along roads it may, therefore, be wise to place emphasis on positive indications, i.e. to take high lead concentrations as indications of the presence of ore rather than exclude areas because of a few scattered samples with low lead contents.

On account of the method of duplicate sampling the total error of the results is well known and indicates that the sampling and analytical precision for lead can be considered adequate.[10]

NGU's lead project has shown that by means of analyses of stream sediments sampled at stream intersections with roads one can (1) disclose geochemical provinces and (2) locate mineral deposits. Examples of point (1) are given under the treatment of the results from the Dokka and Gjøvik map sheets and by the distribution of lead on the Nordre Osen and Rena map sheets, where it can be seen from the frequency distributions (Fig.17) that Rena generally has much higher lead contents than the neighbouring Nordre Osen map sheet.

Point (2) is also illustrated by the results from the Dokka and Gjøvik map sheets, which can be summarized as follows: (*a*) if its occurrence had not been known before the survey commenced, the mineralized area at Vardal would most probably have been found from one highly anomalous sample close to the main road; (*b*) the Snertingdal lead deposit was found from two anomalous samples along private forestry roads; and (*c*) the mineralization at Akksjøen was located from three anomalous samples along a private forestry road.

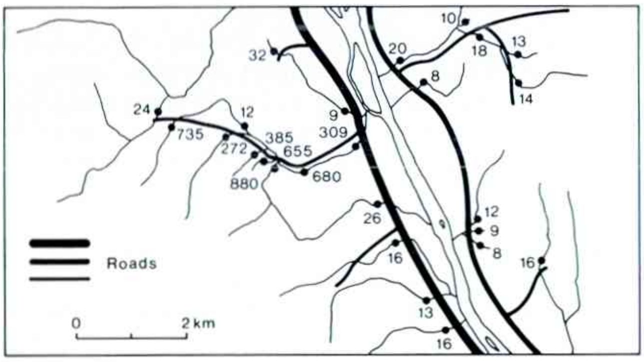


Fig.16 Lead in stream sediments from Rena regional anomaly. Numbers indicate lead content in ppm. Samples are collected along motorable roads (for location see Fig.2). Frequency distribution of all regional samples on Rena map sheet given in Fig.17

The most outstanding discovery outside the Gjøvik-Dokka area is the Rena anomaly (Figs. 2 and 16). Here, one anomalous sample was found at the main road (309 ppm Pb) and a further six along a private forestry track (272-880 ppm Pb) leading to a lead deposit now under detailed investigation. The anomaly lies within a high background area (Fig.17).

It is our experience that this particular stream-sediment survey is an excellent regional exploration method under the conditions present in this part of Norway. The main limitation of the method may possibly be its poor sensitivity in areas of thick overburden. Although we have no definite

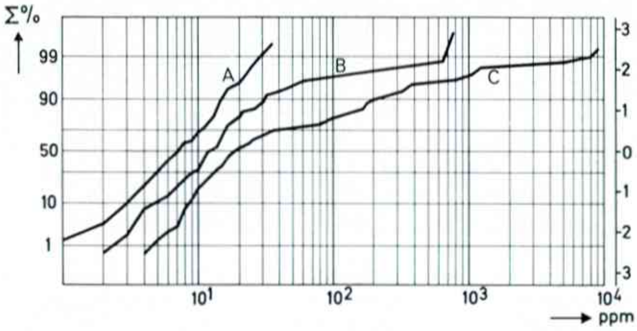


Fig.17 Cumulative frequency distributions of lead in stream sediments on neighbouring map sheets. *A*, regional sampling along roads on map sheets Nordre Osen (260 sample sites); *B*, regional sampling along roads on map sheet Rena (156 sample sites); *C*, follow-up sampling at 250-m intervals along streams within Rena anomaly area (183 samples). Abscissa gives metal content, left-hand ordinate cumulative per cent and right-hand ordinate scale for estimation of standard deviation

data, we believe that superficial glacial or glaciofluvial deposits thicker than 4-5 m may occasionally hinder the dispersion of lead from a bedrock source into the stream bed to the extent that lead would be undetected in the sediments. No doubt, the critical thickness of the overburden varies within wide limits, depending on local conditions, in particular the relief, and also on the character and porosity of the deposits. An advantage implicit in the stream-sediment method is that the material sampled originates from places where local erosion is relatively deep.

The cost per unit area of the regional stream-sediment survey is low compared with most other prospecting methods (Table 3). As was noted earlier, entire map-sheet areas are sampled in NGU's lead project on account of the combined aim of prospecting and general geochemical mapping. If sampling had been restricted to areas chosen only for prospecting purposes, the area sampled could probably have been reduced by approximately 50%.

FOLLOW-UP METHODS

We consider the aims at the follow-up level to be (1) to discover the source of the anomaly and (2) to delimit the extent of the area of principal interest.

Some of the anomalies found at the regional level were dubious, primarily due to large deviations between sub-samples. Such results would have to be verified by complementary resampling before any extensive follow-up work could be started. In areas of thin overburden the simplest follow-up method used is the geological inspection of the stream bed above the site of the anomalous sample from the regional survey. In two cases (Snertingdal and Rena) discoveries of interesting lead mineralization were made on the very first days of such inspections.

In several instances investigation of the geology of anomalous streams disclosed uninteresting types of mineralization — for example, in black shales with high heavy metal content or in weathered granites; in these cases further examination of the anomalies was discontinued.

Poorly exposed areas created greater problems at the follow-up level. Boulder searching was normally the first method used in such areas. If this method proved negative, detailed stream-sediment sampling, in some cases supplemented by the collection of soil samples, was carried out with the intention of locating the source of the anomaly.

Some anomalies seemed to be rather promising, but later proved to be uninteresting from an ore prospecting point of view. Such anomalies can be classified as (1) those derived partly from strong iron-manganese precipitation and (2) those derived partly from weathering due to heavy frost action.

In the sampled area many streams originate in bogs. Downstream from the marshy area, where the water is more aerated, a strong iron-manganese precipitation may sometimes occur. Stream sediments from areas of such precipitation may be rich in Pb, Zn and Cu, even though the area drained by the stream is not enriched in these elements. Other aspects of base-metal enrichment in the area due to Fe-Mn precipitation have been

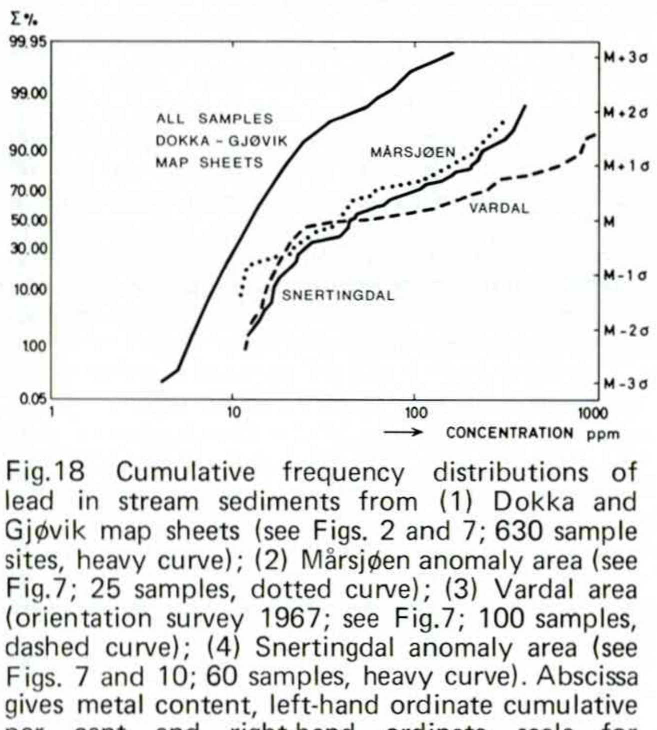


Fig.18 Cumulative frequency distributions of lead in stream sediments from (1) Dokka and Gjøvik map sheets (see Figs. 2 and 7; 630 sample sites, heavy curve); (2) Mårsjøen anomaly area (see Fig.7; 25 samples, dotted curve); (3) Vardal area (orientation survey 1967; see Fig.7; 100 samples, dashed curve); (4) Snertingdal anomaly area (see Figs. 7 and 10; 60 samples, heavy curve). Abscissa gives metal content, left-hand ordinate cumulative per cent and right-hand ordinate scale for estimation of standard deviation

discussed elsewhere,[10] this type of enrichment being well known.[19] Fig.18 shows data from an anomaly at Mårsjøen (Fig.7). Even though the lead content of the stream sediment is as high as 800 ppm, only insignificant lead mineralization could be found in the area after fairly intensive investigation, including thorough geological mapping, boulder searching and soil sampling.

Ideally, this type of anomaly should be identified as soon as possible through Fe and Mn analyses of the stream sediment and inspection in the field, especially by looking for signs of extensive Fe-Mn precipitation in the stream and/or for the presence of bogs near the stream source.

In some cases, two examples of which are outstanding, strong geochemical anomalies have been obtained over large areas where no interesting lead mineralization has been found, and where Fe-Mn precipitation is not considered to be the main cause of the anomaly. We think that these anomalies are caused by frost action, since they occur in high-level areas (more than 1000 m above sea level) with fairly thin overburden. In northern Norway this type of anomaly has earlier been suggested for Cu.[5] It is believed that with a thin moraine cover and mean temperature close to zero innumerable joints are formed in the bedrock. Because of the larger surface exposed to weathering, any lead present may be more easily leached out from the bedrock than is normal. Norwegian investigations have shown that lead is strongly bound by humus.[18] Under conditions in which frost action is strong, humus production is low and, consequently, there might be only small amounts of humus present to tie up the lead. The lead will thus accumulate in the stream sediment even though the actual lead content in the bedrock is relatively low.

In a few cases, the sources of anomalies were never found and it was not considered justifiable to carry out more work in the areas as long as more simple anomalies were available. In the future these anomalies may be investigated by geophysical methods, such as IP and VLF.

In an early phase of the project detailed stream-sediment sampling was combined with geochemical field tests to guide the sampling. This procedure was later changed for two reasons: (1) the field test used (cold-extractable heavy metals method[4]) was not suitable since it concentrates mainly on the Zn content of the sediments;[23] results from this field test have, therefore, often been inconclusive in the case of monomineralic lead mineralization; and it was found more effective to guide the stream-sediment sampling by geological investigations: such combined sampling-geological investigation can be carried out as a routine by trained technicians and it is now the main technique for delimiting the extension of areas of interest.

In prospecting for strata-bound ores the delimitation of the area of prime interest can be carried out exclusively by geological mapping. In the future VLF may well provide useful data for the geological interpretation of covered areas. Within the ore-bearing formation, or in covered areas where stream density is low, it is sometimes necessary to use soil sampling to determine the extent of the area of interest.

DETAILED METHODS

The aims at this level of the investigation are (1) to determine the extent of the lead-mineralized area and (2) to make a rough estimate of the size and quality of the mineralization in order to judge whether or not an intensive drilling programme should be recommended.

The last glaciation period in the survey area ended about 10 000 years ago and very little weathering of the bedrock has taken place. The overburden causes only minor problems for the interpretation of the IP results, as it appears as a rather uniform blanket of moderate electrical conductivity above the freshly eroded rocks. Geochemical anomalies in the soil, however, could in some cases be a complex combination of glacial, hydromorphous and biogenic patterns.

Of the two most successful methods on the detailed level, IP and soil sampling, we think that IP should usually be carried out first because (1) IP gradient measurements are little influenced by the composition and thickness of the overburden, which is normally between 0 and 20 m thick; (2) IP can be expected to give anomalies for any galena mineralization which could possibly be discovered by the follow-up methods used in this project, the flat-lying autochthonous deposits probably being an exception; and (3) the IP results are available very soon after the actual measurements have been carried out, which makes it possible to follow interesting zones or to discontinue useless investigations at an early stage.

One of the main problems in the interpretation of the IP results is to distinguish between anomalies caused by lead mineralization and those from other sources, such as graphite or pyrite. Three types of anomaly can be distinguished: (1) with high IP only; (2) with high IP and high σ_a; and (3) with high IP, high σ_a and negative SP.

In Snertingdal the lead mineralization gave anomalies of types (1) and (2) and graphite anomalies of types (3) and (2). Such a distinction may, therefore, be of some help in deciding whether the IP anomalies are caused either by lead mineralization or by graphite. As the ore in Snertingdal has a relatively low lead content, however, it might well be thought that lead mineralization in other areas with higher lead contents could give anomalies of type (3). In addition, pyrite impregnations or other economically uninteresting mineralization may give anomalies of types (2) and (1).

The geophysical methods alone seem, therefore, in many cases not to be able to distinguish between interesting and uninteresting anomalies. In some areas the geological investigations at a detailed level will overcome this problem, but, generally, the IP measurements should be followed by an investigation of lead in soil samples from the IP anomaly areas.

We consider lead anomalies coincident with, or occurring downslope from, the IP anomalies to be a strong indication of lead mineralization. The results from Snertingdal indicate that humus and mineral soil may produce a rather similar anomaly pattern (Figs. 10, 11 and 14). The question as to which of the two soil materials ought to be sampled in future surveys would depend largely on which of the minerals is the easier to deal with in the field and laboratory. Mineral soil has been found to be the more favourable for the following reasons: (1) collected at a depth of no more than 40-50 cm it is easier to sample than humus; (2) extreme variations in the lead content of humus with minor variations in drainage conditions[18] indicate that very large sampling errors may sometimes apply in the case of humus; (3) samples of mineral soil require less space and are easier to sieve than humus samples; and (4) mineral soil causes less problems during analysis than humus, which tends to froth when digested in HNO_3.

Results from Snertingdal and other experience[18] strongly indicate that the lead anomalies are hydromorphous, i.e. lead must have been leached out of the bedrock or the overburden, transported by groundwater and deposited in the topsoil where the groundwater emerges at the surface. The dispersion pattern of lead in humus and mineral soil would, therefore, depend both on the thickness and composition of the overburden. If the overburden is thick, formation of topsoil lead anomalies may be hindered because groundwater may lose its lead content when passing through large masses of superficial material. If the overburden is coarse-grained, the groundwater level may be at great depth, with little tendency for the water to issue at the surface. Consequently, lack of soil anomalies does not necessarily indicate lack of lead mineralization in the bedrock. These features strongly indicate that mapping of the Quaternary geology and groundwater movement constitute an important part of the interpretation of soil analyses.

Another aspect of lead geochemistry of interest in this connexion is lead poisoning of vegetation. Such poisoning was demonstrated by Låg and co-workers[18] near one of the lead occurrences at Vardal (Fig.7). Later, natural lead poisoning has also been observed at Snertingdal, Rena and Osen (Figs. 2 and 7), as well as at other localities in Norway.[17] Striking field characteristics of lead poisoning are small patches with high stone contents at the soil surface and deficient or dying vegetation. Adjacent areas may often have patterns of abnormal vegetation where *Vaccinium* sp. is replaced by *Deschampsia flexuosa.*[17] Observations of barren patches and patterns of particular vegetation, which can easily be made by trained personnel, constitute an interesting supplement to the prospecting methods for lead both at the follow-up and detailed levels.

The combined IP and soil surveys, together with the available geological information, enable a good judgment to be made of the distribution of the near-surface parts of the lead mineralization. Normally, diamond drilling has to be used to obtain reliable results from the deeper parts. The often complicated geometry of the lead mineralization and conducting bodies involved in lead prospecting makes it difficult to interpret, for example, IP pole/dipole measurements, which, otherwise, can usually give information about the deeper parts of mineralized zones.

The above considerations account for deposits of the Snertingdal type — allochthonous, with steep dips, more or less imbricate and with the main thrust plane at a considerable depth.

At another allochthonous deposit (Rena; Fig.2) the depth to the main thrust plane is considerably less (20-150 m), and this made the usual IP gradient measurement difficult because energizing current follows the thrust plane. To achieve sufficient energizing of the lead mineralization one of the current electrodes had to be moved along the measuring profile together with the potential electrodes. This slowed down the investigation considerably.

In an autochthonous deposit with horizontal bedding (Osen; Fig.2) the lead mineralization is situated in the sandstones, which lie beneath a layer of black shales 30-50 m thick. Within the black shales graphite has developed along the main thrust plane. This geometrical configuration creates even greater problems for IP measurement because of difficulties in energizing the lead mineralization in order to distinguish between anomalies caused by the lead mineralization and those caused by the graphite. We have carried out some experimental IP measurements in this area, but the results obtained are inconclusive. For the present, the detailed investigations in such cases have to be based on diamond drilling.

As is shown in the example from Snertingdal, the EM measurements gave no response from the lead mineralization, but the results could be used as an aid in the interpretation of geological structures. These measurements, however, which need a fairly accurate grid, are too costly to be recommended for this use (Table 3). We believe that the very cheap VLF measurements may, to some extent, replace the EM measurements.

We think that the IP measurements can be used as a tool for crude estimates of the size and the lead content of the deposit at an early stage of the investigations. Laboratory measurements on core specimens show that the IP effect is strongly correlated with the lead content of the specimen. In the field the IP effects are also influenced by geometrical factors, such as thickness of the overburden, dip of the mineralization, position of conducting zones (imbrication and thrust planes) and the position of the current electrodes. The IP effect caused by lead mineralization is, in most cases, assumed to be roughly proportional to both the content and the thickness of the upper parts of the mineralization. For the deeper parts the quantitative behaviour of the IP method fails in practical terms. Provided that the lead mineralization is monomineralic and we have sufficient geological information to determine its geometric configuration, the IP measurement may help in deciding whether the investigations should be continued or not. A few drill-holes as an aid to the establishment of reference levels greatly improve the opportunity to make a crude estimate of the size and grade of the ore.

At later stages of the investigations, when the main task is to obtain more reliable data for estimation of ore reserves, extensive diamond drilling is necessary, but we believe that by intelligent use of the IP results and geological information the drilling programme can be significantly reduced.

Conclusions

(1) Several new occurrences of lead mineralization have so far been found; one of these has been drilled and abandoned, two will be drilled in the near future, and the others are considered to be of no economic interest.

(2) Stream-sediment survey by sampling along road-stream intersections appears to be an efficient regional method for lead prospecting in southern Norway.

(3) Geological inspection of the drainage areas of anomalous streams, followed by detailed stream-sediment sampling, boulder searching and reconnaissance soil sampling, have proved to be the most suitable follow-up methods.

(4) On a detailed level, IP anomalies, with corresponding lead anomalies in soil, give a good indication of the lead distribution and form the basis for the location of drill-holes.

(5) Knowledge of the geology is essential for an intelligent use of the geochemical and geophysical methods at any stage of the exploration.

Acknowledgment

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References

1. Bjørlykke A. En undersøkelse av blymineraliseringen i kvartssandstensdekket i Vardal nord for Gjøvik. *Det store eksamensarbeid i faget Malmgeologi ved Norges tekniske høgskole.* Maskinskrevet, 1967. (Unpublished thesis, Technical University of Norway, 1967), 80 p.

2. Bjørlykke A. Geologisk beskrivelse av 1:50 000 kartbladene Gjøvik og Dokka. *Norg. geol. Unders.,* 1973. (In preparation). (Norwegian text with English summary)

3. Bjørlykke K. En sedimentologisk faciesanalyse av sedimentene i sparagmitt-bassenget i Syd-Norge. Paper presented at Norwegian Geological Societies winter meeting, 8-10 January, 1973.

4. Bloom H. A field method for the determination of ammonium citrate-soluble heavy metals in soils and sediments as a guide to ore. *Econ. Geol.,* **50**, 1955, 533-41.

5. Bølviken B. Recent geochemical prospecting in Norway. Reference 15, 225-53.

6. Bølviken B. Geokjemisk kartlegging av metallinnhold i bekkesedimenter. In *Symposium om tungmetaller* Underdal B. ed. (Norges landbruksvitenskapelige forskningsråd, 1972), 71-84.

7. Bølviken B. Statistisk beskrivelse av geokjemiske data. *Norg. geol. Unders.* 285, 1973, 10 p. (Norwegian text with English summary)

8. Bølviken B. and Follestad B. A. Bekkesedimentenes og morenematerialets geokjemi. In *Løten. Beskrivelse til kvartærgeologisk kart 1916 I—1:50 000* Follestad B. A. *Norg. geol. Unders.* (In press).

9. Bølviken B. Nilsson C. A. and Wennervirta H. Summary of research and development in geochemical exploration in Scandinavian countries. In *Geochemical exploration* (Montreal: CIM, 1971), 11-4. *(CIM Spec. vol. 11)*

10. Bølviken B. and Sinding-Larsen R. Total error and other criteria in the interpretation of stream-sediment data. In *Geochemical exploration 1972* (London: IMM, 1973), 285-95.

11. Eriksen E. A. Noen trekk fra prospekteringen i våre dager. *Tidsskr. Kjemi Bergv. Metall.,* **22**, 1962, 134-42.

12. Follestad B. A. Personal communication.

13. Grip E. The lead deposits of the eastern border of the Caledonides in Sweden. *Rep. 21st Int. geol. Congr.* (Copenhagen: Berlingske Bogtrykker, 1960), **16**, 1960, 149-59.

14. Grip E. On the genesis of the lead ores of the eastern border of the Caledonides in Scandinavia. In *Genesis of stratiform lead — zinc — barite — fluorite deposits* Brown J. S. ed. (Lancaster, Penna.:

Economic Geology Publishing Co., 1967), 208-18.
15. Kvalheim A. ed. *Geochemical prospecting in Fennoscandia.* (New York: Interscience, 1967), 350 p.
16. Låg J. Registrering av hovedtyper av jordsmonn i skogene i Norge. In *Taksering av Norges skoger, Landsskogtakseringen 50 år,* 1919-1969, (Oslo: Landsskogtakseringen, 1970), 143-9.
17. Låg J. and Bølviken B. Some Norwegian occurrences of natural heavy metal poisoning of soil and vegetation. *Norg. geol. Unders.* (In preparation).
18. Låg J. Hvatum O. Ø. and Bølviken B. An occurence of naturally lead-poisoned soil at Kastad near Gjøvik, Norway. *Norg. geol. Unders.* 266, 1969, 141-59.
19. Nichol I. Horsnail R. F. and Webb J. S. Geochemical patterns in stream sediment related to precipitation of manganese oxides. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **76**, 1967, B113-5.
20. Nichol I. *et al.* Regional geochemical reconnaissance of the Derbyshire area. *Rep. Inst. geol. Sci.,* 70/2, 1969, 37 p.
21. Sakshaug G. F. Elektromagnetiske undersøkelser, Ringsjøområdet/Snertingdal. *Unpubl. Rep. Norg. geol. Unders.* 965/Del I, 1970, 11 p.
22. Skjeseth S. Contributions to the geology of the Mjøsa districts and the classical Sparagmite area in southern Norway. *Norg. geol. Unders.* 220, 1963, 126 p.
23. Stanton R. E. *Rapid methods of trace analysis* (London: Edward Arnold, 1966), 96 p.
24. Tegengren F. R. Vassbo blymalmfyndighet i Idre och dess geologiska inramming. *Sver. geol. Unders.* 586, 1962, 61 p.
25. Webb J. S. Personal communication.

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