SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 729 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 71 NR 4

ÖIVIND TOVERUD

CHEMICAL AND MINERALOGICAL ASPECTS OF SOME GEOCHEMICAL ANOMALIES IN GLACIAL DRIFT AND PEAT IN NORTHERN SWEDEN

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ABSTRACT

Geochemical anomalies in glacial drift were studied in three areas in northern Sweden. Chemical and mineralogical studies of the minus 2.00 mm fractions of the till indicate that most of their content of Zn and Pb and to some extent of Cu, is adsorbed and precipitated on the surface of mineral grains and furthermore occur as absorbed ions in a goethite phase. The mineralogical investigation of the heavy mineral fractions (minus 0.60 mm) of the anomalous till, showed that partly altered pyrites and chalcopyrites were the only sulphide minerals preserved, in spite of the presence of numerous Cu, Pb and Zn bearing ore boulders spread out on the surface of the glacial drift (Vargisträsk). Pb was present in the oxidation zones of altered pyrites and chalcopyrites and was contained in hydrous iron oxide on feldspars (mainly in the N. Fäbodliden area). Thus, it was found that the Cu-anomalies in the areas investigated were dominantly of a clastic type, while Pb and Zn were mainly hydromorphically displaced.

INTRODUCTION

Enhanced contents of base metals in till may be caused by primary or secondary ore minerals being present in the soil as clastic anomalies and/or by precipitation of the base metals which, without forming defined minerals, are fixed to some other components of the till, especially iron and manganese hydroxides, clay particles and humic substances (hydromorphic anomalies). It is of great importance in geochemical prospecting to know the tendency for different ore minerals to form clastic as well as hydromorphic anomalies. This tendency is a function of the weathering resistance of the minerals and the ability of the metals to migrate in solution. Thus, certain minerals, e.g. cassiterite, are strongly resistant to weathering and hence will mainly form clastic anomalies. Other minerals, e.g. sphalerite, are generally easily weathered, upon which the zinc passes into solution. In such cases the metal will mainly form hydromorphic anomalies.

The purpose of the present study has been to investigate the relationship between weak mineralizations, revealed by diamond drilling, and trace element distributions in the fine fractions of till. Chemical and mineralogical methods have been applied in order to determine to what extent the minerals of the three base metals Cu, Pb and Zn can form clastic as well as hydromorphic anomalies in the conditions prevailing in northern Sweden.

Earlier studies in Scandinavia of this type have been made by Kauranne (1959), Brundin (1966), Hyvärinen (1967), Brotzen et al. (1967) and Brotzen (1967). Kauranne (1959) identified by microscope examination the ore minerals, chromite, hematite, pyrrhotite, pyrite and chalcopyrite in a till from Outokumpu in Finland. From a Cu, Pb and Zn mineralized area in central Sweden, Brundin (1966) collected large (about 60 kg) till samples, where the heavy mineral fractions, after sieving at 10 mm, were enriched on a vibrating table. In the enriched fractions he found partly altered pyrite grains, e.g. pseudomorphs after pyrite. PbS-bearing carbonate boulders in till at Korsnäs, Finland were observed by Hyvärinen (1967). Brotzen et al. (1967) depicted oxide-rimmed clastic sulphide grains in a heavy-mineral concentrate from a clastic, stream sediment anomaly, representing reworked glacially transported soil, and emphasized the diagnostic value of microscopic study. Brotzen (1967), reporting on work completed prior to 1958, stressed the need to distinguish between hydromorphic and clastic anomalies based on the study of the actual state of the metals in the soil by extraction tests and microscope investigations.

SAMPLING MEDIA

TILL SAMPLES

Till sampling at a depth of 0.5 m below the surface has been carried out in two of the areas investigated. In the third area (Vargisträsk) the sampling depth was 0.8 m. The samples have generally been collected from the C-horizon (podsol) at 40—50 m intervals along lines 100 m apart as described by Brotzen (1967). For the deep sampling in the area west of Vargisträsk, a small rotating auger drill has been used. The pits in the areas were dug with a shovel. The samples were collected at vertical intervals of 0.2 m in the pits down to a depth of about 2 m. The trench (65 m in length), at N. Fäbodliden was dug by an excavator. A 2.0 kg sample was collected at every 0.5 m vertical level.

PEAT SAMPLES

In the area west of Vargisträsk organic samples were collected at seven sites along two traverses with a Hiller auger. In six of the sections, the sampling depth varies from 0.5 m down to 1.3 m. For the seventh sampling site, at local coordinate 640 N/75 E, the sampling depth is 3.5 m. The deepest sample consisted of mixed organic and inorganic material, and has been treated as a mineral soil sample.

LABORATORY METHODS

GENERAL

The preparation of samples and analytical methods have been described by Danielsson (1968). Peat samples were dried at 110° C, ignited in an oxidizing atmosphere at 450° C and reweighed to estimate the content of organic material. The ash is analysed by X-ray fluorescence and emission spectroscopy.

SIEVING

Prior to chemical extractions and mineral separations, the till was fractionated by sieving through nylon screens into the following size ranges: minus 0.06, 0.06—0.20, 0.20—0.60 and 0.60—2.00 mm. For emission spectroscopy analyses the grain-size fractions were further subdivided into the following sizes: 0.06—0.10 and 0.10—0.20 where the fraction 0.10—0.20 mm was used also for mineral separations.

SEPARATIONS

The primary and secondary ore minerals which might occur in the fractions obtained were concentrated by tetrabromoethane (density 2.96) and methylene iodide (density 3.31), an electromagnet and a Frantz isodynamic separator with current intensities 0.5, 1.0 and 1.5 A. The chute generally had a side slope and forward slope of 15°.

CHEMICAL ANALYSES

Generally chemical analysis was made by emission spectroscopy with the tape method (Danielsson 1968). This includes direct analysis of the minus 0.10 mm fraction of the normal soil samples. Separated size-fractions were ground and analysed after addition of a pulp and buffer containing an internal standard of Ge-Nb. Samples of ore boulders and solution extracts were analysed after sulphide isoformation. Small amounts of enriched heavy minerals were analysed in a photospectrograph (Hilger Large).

CHEMICAL EXTRACTIONS

Different cold chemical extractions have been used to examine the amount of trace elements associated with the different modes of occurrence in till. The following extraction media were chosen: 1, 4 and 8 M nitric acid (HNO_3), 0.05, 0.25 and 0.50 M citric acid ($C_6H_8O_7 \cdot H_2O$), 1 and 4 M ammonium acetate (CH_3COONH_4).

2 g of a till fraction were put into a 50 ml plastic test tube, which was filled with 20 ml of the cold extraction medium. The suspension was left to settle over night. 10 ml of the supernatant solution was used for Cu, Pb and Zn analysis upon sulphide isoformation, whereas 1 ml was diluted and analysed for Fe_{tot} by atomic absorption.

It has been assumed that sulphides of Cu, Pb and Zn are mostly soluble (extracted) in strong nitric acid. Ions occurring in secondary minerals, including limonitic matter, and exchange positions are assumed to be soluble in citric acid and ammonium acetate respectively. Zinc spinel is not soluble in any reagents used, whereas anglesite is partly soluble in ammonium acetate.

MINERALOGICAL WORK

The microscope investigations of transparent and opaque minerals have been

made with Leitz and Zeiss polarization microscopes with pertaining Polaroid photographic equipment.

An energy dispersive X-ray spectrometer combined with a Cambridge Scanning Electrone Microscope (SEM) was used for qualitative-semiquantitative analyses and identification of ore minerals and unknown phases. The voltage used was generally 30 kV, the measuring time varied in most cases between 20—30 seconds. The lowest detection limit is about 0.1 per cent when the above mentioned measuring time is used. A microprobe X-ray analyzer was used for quantitative analysis of minerals. A Debye-Scherrer 114.6 mm camera and a Hägg-Guinier camera with a diameter of 50.0 mm were used for mineral identification. Correction of d-values, correlated to a potassium chloride standard, was performed using a computer. Monochromatic Ni-filtered Cu-radiation was used for both cameras. Exposure time varied between 2—6 hours.

STATISTICAL APPROACH

According to Wennervirta (1968), the definition of geochemical anomalies is based on the fact that part of the concentration in an area under investigation is accepted as anomalous. In accordance with his suggestion, the threshold value has been chosen equal to the median plus *one* standard deviation. By using percentile values, the influence of extremely high and low values in the population is eliminated. The author has used four percentile limits (80th, 90th, 95th and 99th) in contouring Cu at W. Ballek.

Often the 80th percentile has been found to be below the threshold value as defined above.

TEST AREA N. FÄBODLIDEN

GENERAL DESCRIPTION

The location of the investigated area can be seen in Fig. 1. Norra Fäbodliden (N. Fäbodliden) is situated in a narrow valley near the Vindel river in the western part of the Skellefte district, Västerbotten county, northern Sweden. The mean annual temperature and mean annual precipitation (over a period of 9 years) in the area are 0.3 C° and 540 mm respectively. The altitude of the area varies between 320 and 400 metres above sea level. The vegetation is forest with spruce, pine and birch. Small areas of peat generally extending in an east—westerly direction occur in the eastern part of the investigated area. Till is the predominating soil type, showing a normal podsolic profile. The area is nearly free from boulders at the surface. A strong Pb-Zn-Cu-anomaly in inorganic stream sediments was detected here in 1965. Very weak mineralizations have been encountered in two drill holes.

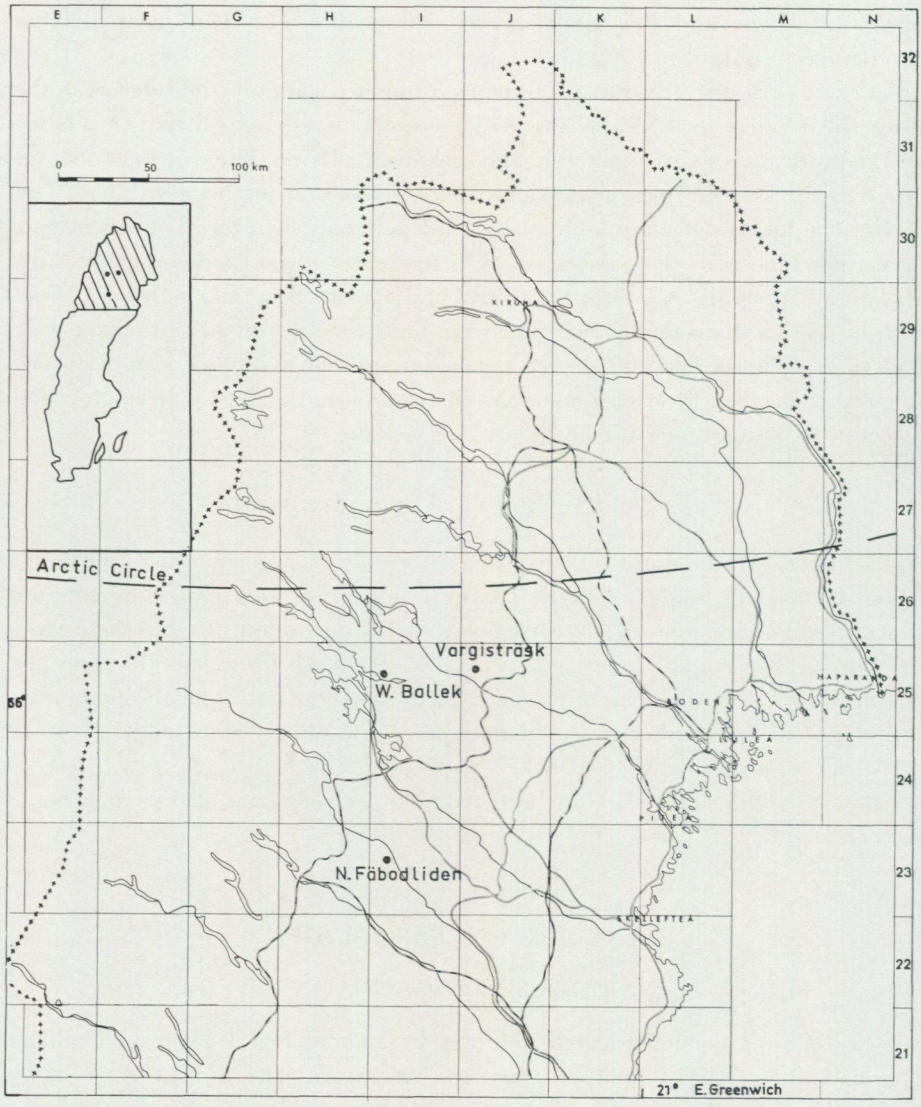


Fig. 1. Location of investigated areas in northern Sweden.

In the area of study, two different types of till deposits have been noted. In the northern part of the trench (shown in Fig. 3 and 4) a loosely packed till consisting of Revsund granite material predominates. Towards the south, especially at the bottom of the trench, in sections 1 and 2, a basal till of local origin appears. This till is very compact and rich in poorly rounded coarse-grained phyllite material. At 0.5 m depth in section 2, mixing of the different tills is noted.

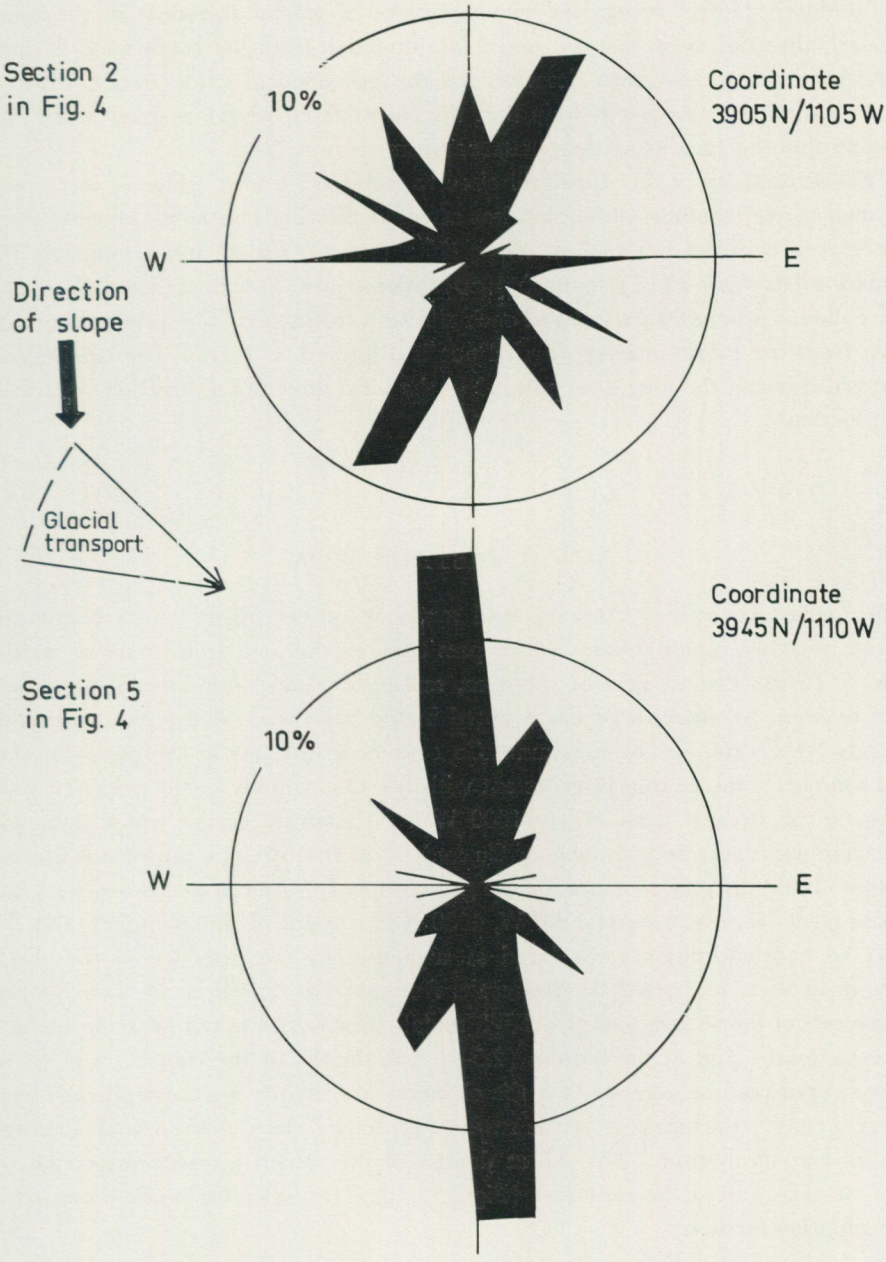


Fig. 2. Diagram showing particle orientation at two different sites in till at N. Fäbodliden.
I. Long-axis orientation, A=25—130 mm; for 90 particles with A:B $\geqslant$ 1.5, section 2.
II. Long-axis orientation, A=20—110 mm; for 90 particles with A:B $\geqslant$ 1.5, section 5, Fig. 4.

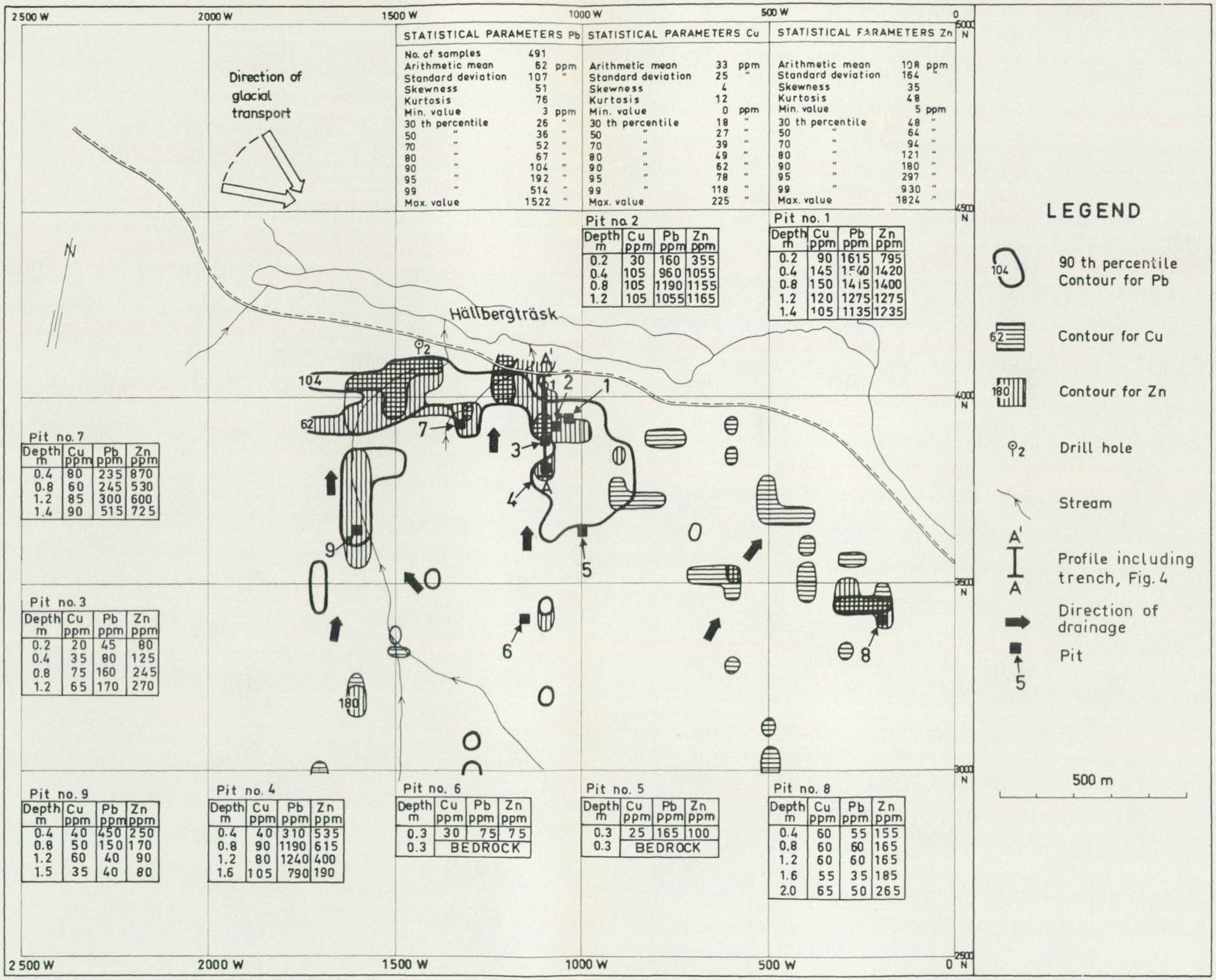
Lundqvist (1961) recognized two directions of glacial transport in the area, an early direction from the west and a late direction from the north-west. A similar situation has also been described in the geochemical study by Ek (1974). From Lundqvist's data it follows that the investigated area remained above the Highest Shore-Line during the Quaternary time period.

Fabric analyses of the upper till close to sections 2 and 5, (Fig. 4) were performed to see whether solifluction has affected the till. The measurements were made at a depth of 0.6—0.7 m on particles (stones) which had a long-axis inclination less than 30° (Johansson 1968). Investigation areas of 0.5 × 1.0 m size were chosen where 90 particles at each site were measured. The orientation pattern from the fabric analyses carried out is displayed in Fig. 2. The orientation pattern showing the long axes parallel to the local downslope direction, indicates solifluction.

METAL DISTRIBUTION

The highest Cu values from the grid sampling of the till at 0.5 m depth are found near two minor streams which pass through the area from south to north, Fig. 3. In the eastern part of the area, scattered points with anomalous values can be seen. An increase of Cu is noted in the basal part of the pits, especially in pits Nos. 1 and 2. The maximum Cu content in the pits is 150 ppm. Pb and Zn contents coincide to a large extent with the Cu anomaly in the northern part close to the streams. East of line 1000 W a Pb anomaly occurs which does not coincide with increased contents of Cu and Zn in the till. The impression gained is that clastic dispersion caused by the glacial flow from the west—north-west has taken place whereas around 1500 W, 4000 N and south of this point, Pb and Zn may be hydromorphically displaced as suggested by the presence of the small stream. This is supported by the results from pit No. 9, where Pb and Zn are enhanced in the surface samples. High metal contents are noted near the surface (0.5 m depth) and at the bottom (2.5—3.5 m depth) of the trench, Figs. 4—6. The overall picture suggests that the elements are mainly hydromorphically and biogenetically concentrated at the surface, especially close to the minor streams, whereas at the bottom (2.5—3.5 m depth) of the trench a clastic dispersion of ore minerals cannot be excluded (Figs. 3—6). The following work illuminates the situation further.

Fig. 3. Distribution of Pb, Cu and Zn at 0.5 m depth in the fine fraction, minus 0.10 mm, of till at N. Fäbodliden.


2 500 W
2000 W
1500 W
1000 W
500 W
0
5000 N
4500 N
4000 N
3500 N
3000 N
2500 N
STATISTICAL PARAMETERS Pb
No. of samples 491
Arithmetic mean 62 ppm
Standard deviation 107 "
Skewness 51
Kurtosis 76
Min. value 3 ppm
30 th percentile 26 "
50 " 36 "
70 " 52 "
80 " 67 "
90 " 104 "
95 " 192 "
99 " 514 "
Max. value 1522 "
STATISTICAL PARAMETERS Cu
Arithmetic mean 33 ppm
Standard deviation 25 "
Skewness 4
Kurtosis 12
Min. value 0 ppm
30 th percentile 18 "
50 " 27 "
70 " 39 "
80 " 49 "
90 " 62 "
95 " 78 "
99 " 118 "
Max. value 225 "
STATISTICAL PARAMETERS Zn
Arithmetic mean 108 ppm
Standard deviation 164 "
Skewness 35
Kurtosis 48
Min. value 5 ppm
30 th percentile 48 "
50 " 64 "
70 " 94 "
80 " 121 "
90 " 180 "
95 " 297 "
99 " 930 "
Max. value 1824 "
Direction of glacial transport
N
Hällbergträsk
Pit no. 2
Depth m | Cu ppm | Pb ppm | Zn ppm
0.2 | 30 | 160 | 355
0.4 | 105 | 960 | 1055
0.8 | 105 | 1190 | 1155
1.2 | 105 | 1055 | 1165
Pit no. 1
Depth m | Cu ppm | Pb ppm | Zn ppm
0.2 | 90 | 1615 | 795
0.4 | 145 | 1540 | 1420
0.8 | 150 | 1415 | 1400
1.2 | 120 | 1275 | 1275
1.4 | 105 | 1135 | 1235
Pit no. 7
Depth m | Cu ppm | Pb ppm | Zn ppm
0.4 | 80 | 235 | 870
0.8 | 60 | 245 | 530
1.2 | 85 | 300 | 600
1.4 | 90 | 515 | 725
Pit no. 3
Depth m | Cu ppm | Pb ppm | Zn ppm
0.2 | 20 | 45 | 80
0.4 | 35 | 80 | 125
0.8 | 75 | 160 | 245
1.2 | 65 | 170 | 270
Pit no. 9
Depth m | Cu ppm | Pb ppm | Zn ppm
0.4 | 40 | 450 | 250
0.8 | 50 | 150 | 170
1.2 | 60 | 40 | 90
1.5 | 35 | 40 | 80
Pit no. 4
Depth m | Cu ppm | Pb ppm | Zn ppm
0.4 | 40 | 310 | 535
0.8 | 90 | 1190 | 615
1.2 | 80 | 1240 | 400
1.6 | 105 | 790 | 190
Pit no. 6
Depth m | Cu ppm | Pb ppm | Zn ppm
0.3 | 30 | 75 | 75
0.3 | BEDROCK
Pit no. 5
Depth m | Cu ppm | Pb ppm | Zn ppm
0.3 | 25 | 165 | 100
0.3 | BEDROCK
Pit no. 8
Depth m | Cu ppm | Pb ppm | Zn ppm
0.4 | 60 | 55 | 155
0.8 | 60 | 60 | 165
1.2 | 60 | 60 | 165
1.6 | 55 | 35 | 185
2.0 | 65 | 50 | 265
LEGEND
90 th percentile Contour for Pb
Contour for Cu
Contour for Zn
Drill hole
Stream
Profile including trench, Fig. 4
Direction of drainage
Pit
500 m

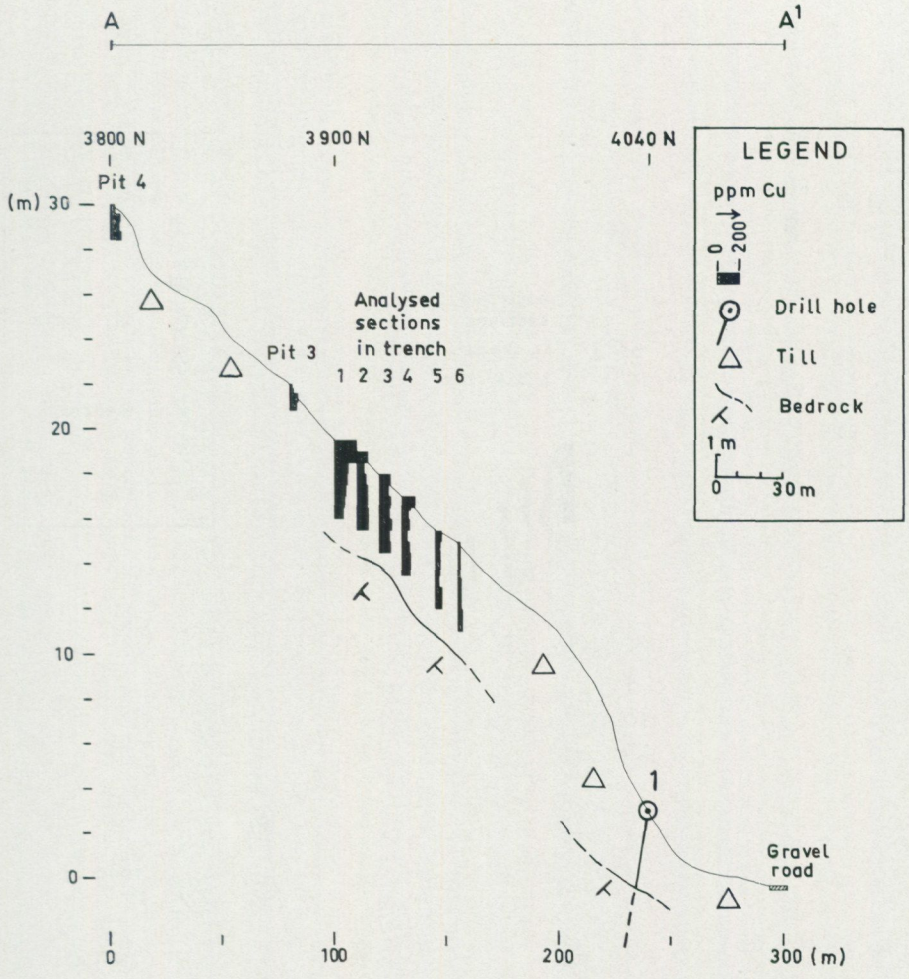


Fig. 4. Distribution of Cu in the fine fraction, minus 0.10 mm, of till at N. Fäbodliden.

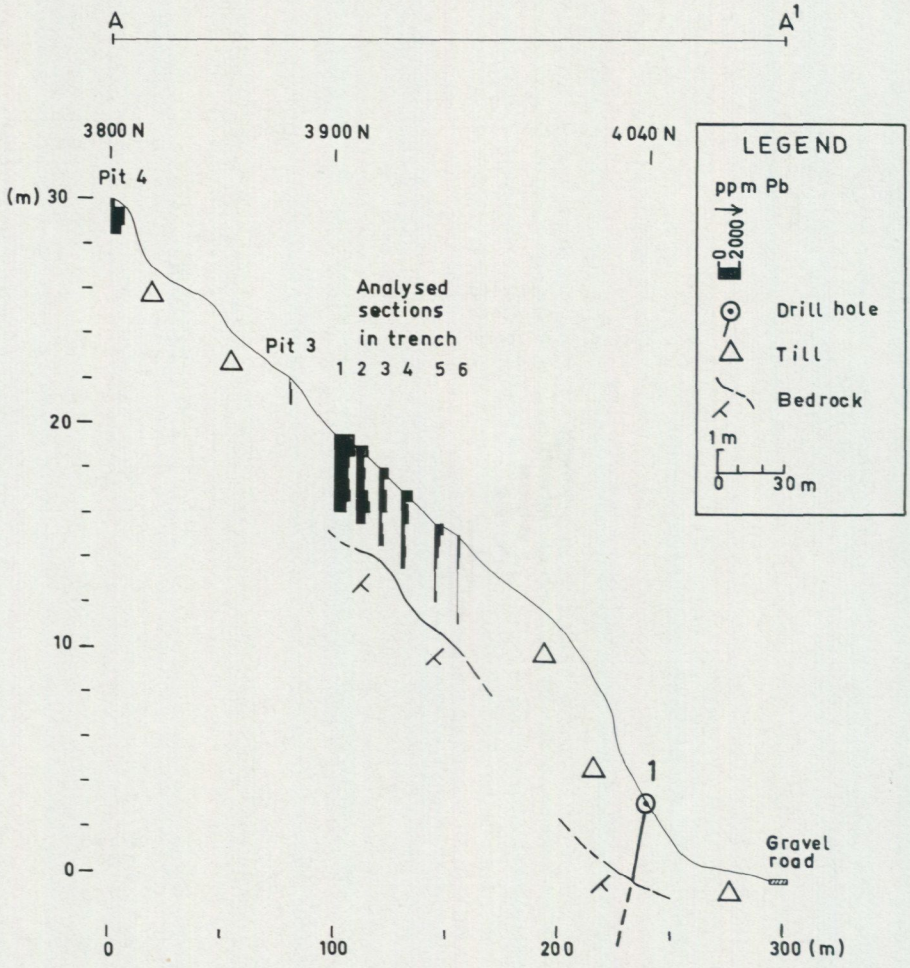


Fig. 5. Distribution of Pb in the fine fraction, minus 0.10 mm, of till at N. Fäbodliden.

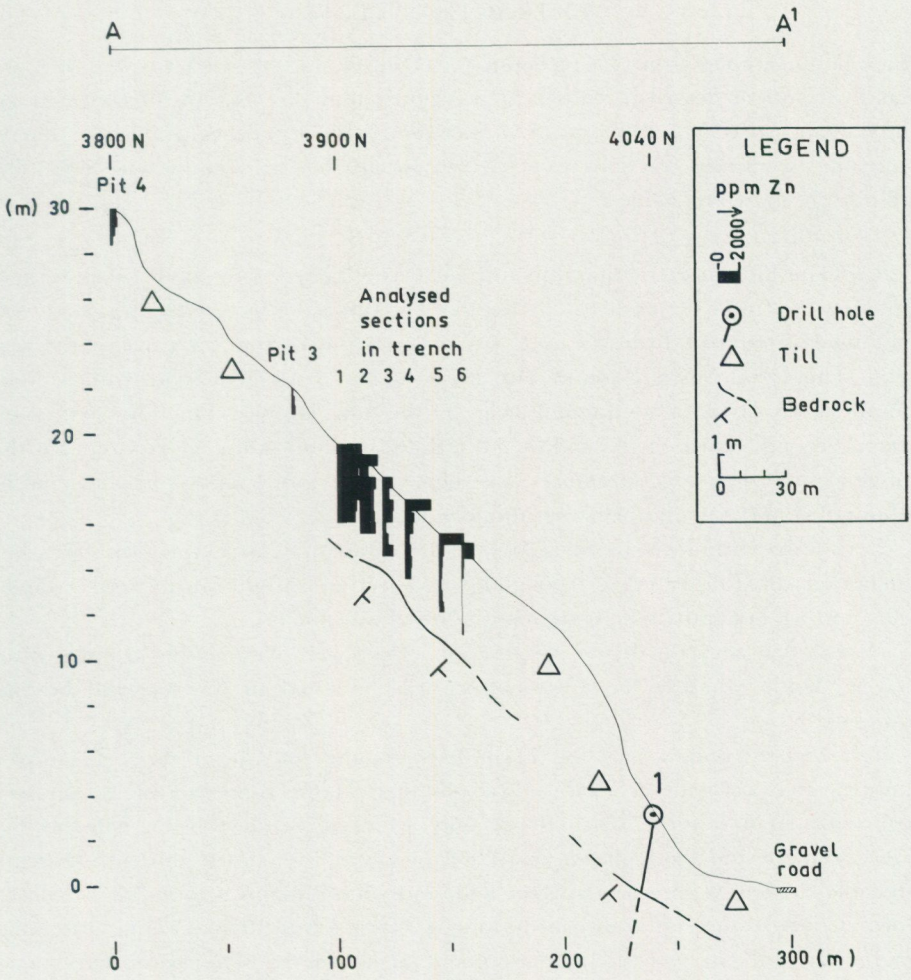


Fig. 6. Distribution of Zn in the fine fraction, minus 0.10 mm, of till at N. Fäbodliden.

EXTRACTION TESTS

Sieved till samples from 3.5 m depth in section 2, Fig. 6, were treated with the cold extractions described earlier. It was noted that the contents of cold-extractable copper (cxCu), cxPb and cxZn increased with decreasing grain size. Therefore the two finest fractions were chosen for further cold extraction tests. The results are shown in Table 1.

Cu. The highest extraction effect of Cu was obtained with the 8 M nitric acid in samples from 1.0 and 1.5 m depth. The lowest effect with this acid was obtained in samples from the top (0.5 m) and the bottom (3.5 m) of the section. This trend was also found with the 4 M and 1 M nitric acid, with a minimum value of 32 % extractable Cu in the top sample. The low extraction achieved with dilute nitric acid in the top and bottom samples may indicate the presence of reducing substances at these levels, presumably organic matter (humates) at 0.5 m and primary sulphides at 3.5 m.

If the two grain-sizes are compared it is obvious that the extraction effect was higher in the fine fraction throughout the section except for the top samples (0.5 and 1.0 m depth) where an opposite trend was noted.

With citric acid the highest extraction effect was obtained in samples from 3.0 m depth, whereas the lowest effect was obtained in the top and bottom samples.

The higher content and the lower extractability of Cu in the top samples indicate that Cu is here (in the lowermost part of the B-horizon of the podsol) concentrated in a form which is not fully attacked by the solvent, whereas the lower content and the high extractability for Cu at 1.0 and 1.5 m depth indicate that the element is here partially leached, and what remains is in an easily soluble form. Contents increase downwards, and at 3.0 m depth the maximum citric acid extraction indicates secondary enrichment at this level. The lower citric acid extraction at 3.5 m, at high total Cu-contents may indicate the presence of partially preserved chalcopyrite in this lowermost section.

Pb. The extraction effect for Pb was high throughout the section with the nitric acid except for the coarse fraction of the sample at 1.5 m depth, where the extraction effect was comparably low (67 %) with the 1 M acid. Compared to Cu and Zn, a high extraction effect was also obtained for Pb with the citric acid, showing the same trend as observed for the nitric acid extraction. The extraction with 4 M ammonium acetate is high especially in the top- and bottom samples.

Filipovic et al. (1970) found in a test that the stability constants of monoligand complexes of acetate showed increasing stability in the following order: Zn, Cu, Pb. They suggested that the strong tendency of the Pb ion towards polarization

TABLE 1. Cold extractable Cu, Pb and Zn in till fractions as percentages of total content from section 2 at N. Fäbodliden.

Sample No.	Depth m	Grain size mm	Total content, ppm Cu	Pb	Zn	Percentage extracted in cold: 8 M HNO_3 Cu	Pb	Zn	4 M HNO_3 Cu	Pb	Zn	1 M HNO_3 Cu	Pb	Zn	0.50 M Citr. acid Cu	Pb	Zn	0.25 M Citr. acid Cu	Pb	Zn	0.05 M Citr. acid Cu	Pb	Zn	4 M Am. acetate Cu	Pb	Zn	1 M Am. acetate Cu	Pb	Zn
103	0.5	0.06–0.20	120	830	1555	76	100	100	64	100	77	*32*	92	*22*	*17*	60	*4*	na	na	na	—	31	*4*	—	**51**	3	—	29	2
		<0.06	140	825	1830	*56*	100	*71*	*51*	100	*60*	na	na	na	21	70	*4*	25	67	*5*	*15*	39	*4*	—	**52**	3	na	na	na
102	1.0	0.06–0.20	45	340	530	**100**	100	100	**84**	92	79	53	97	*32*	—	71	*7*	—	65	*9*	—	44	*7*	—	**44**	**5**	—	19	**4**
		<0.06	70	560	655	**97**	100	*93*	70	100	*73*	50	100	*32*	33	71	*10*	32	68	*10*	—	45	*9*	—	**41**	**5**	—	27	**4**
101	1.5	0.06–0.20	75	300	930	**100**	97	100	**84**	93	100	**61**	*67*	63	—	53	15	—	47	11	—	37	7	na	na	na	—	20	4
		<0.06	100	650	1150	**100**	100	100	**95**	100	100	**67**	100	79	—	60	17	—	55	17	—	40	11	—	26	4	—	17	2
100	2.0	0.06–0.20	40	250	545	na	na	na	na	na	na	na	na	na	—	64	33	—	56	28	—	44	18	—	29	4	na	na	na
		<0.06	125	740	1400	80	100	100	71	100	100	59	93	86	26	57	26	23	57	24	18	38	17	—	27	2	—	16	3
099	2.5	0.06–0.20	85	525	770	61	95	87	56	100	87	56	95	48	—	59	14	—	55	12	—	34	9	—	23	—	—	18	—
		<0.06	130	1315	1085	77	100	100	77	100	100	60	100	79	21	57	24	22	52	23	—	30	16	—	20	3	—	14	—
098	3.0	0.06–0.20	115	805	1065	65	100	94	65	100	94	67	89	**83**	**40**	67	**45**	**31**	60	**40**	20	39	**29**	—	**39**	4	—	29	3
		<0.06	195	1315	1550	67	100	97	67	100	97	59	100	**84**	**39**	65	**43**	26	62	**40**	**24**	39	**29**	—	**37**	3	—	25	1
097	3.5	0.06–0.20	195	615	1505	*62*	98	100	*56*	98	93	*49*	89	54	*23*	60	21	*21*	57	19	*22*	44	15	—	**39**	2	—	31	—
		<0.06	205	880	1655	*68*	100	100	*63*	100	100	*49*	95	57	*21*	50	18	*20*	52	18	*18*	41	15	—	**31**	2	—	23	2

Notes: na = not analysed
— below the detection limit (20 ppm)
100 high values in the column
56 low values in the column

probably causes the relatively high stability of its monoligand complexes. The test performed by the author shows that Pb in the till is easily extracted in ammonium acetate compared to the elements Cu and Zn especially. This probably depends upon the ability of Pb to form complexes with acetate, and indicates that Pb might occur in fine-grained anglesite (Hornbrook 1975), or that Pb is easily available (adsorbed) in exchange positions. The strong extraction by cold nitric and citric acid indicates Pb-adsorption, rather than the presence of anglesite.

Zn. High extractions of Zn were observed throughout the whole section with 8 and 4 M nitric acid except for the fine fraction of the top samples. With the 1 M acid, the lowest extraction effect was in the top samples. This trend was also observed with the citric acid. The highest extraction effect with ammonium acetate (very low however compared to the extraction effect of Pb) was obtained in the sample at 1.0 m depth.

The extraction trend for Zn is similar to that of Cu but the proportion of extractable Zn with citric acid in the top samples is lower than that of Cu. This means that Zn is more strongly bound in the top samples, which probably can be correlated to a biogenic enrichment process, cf. Ek (1974). In the lower part of the section Zn is mainly hydromorphic, especially at 3.0 m depth, where the highest citrate-extraction indicates fixation in limonitic matter.

The extractability of Fe (not shown in Table 1) shows a trend similar to that of Zn, which means medium extraction effects in citric acid and a rather high extractability in the strong nitric acid. This could indicate that Fe and Zn occur in a goethite phase.

Eight carbonate analyses were made of till from N. Fäbodliden to find out whether carbonate-bearing minerals (calcite) existed in the material. Five samples (097—101) from section 2, and three samples from sections 4 (129, 0.5 m depth; 123, 3.5 m depth) and 5 (136, 0.5 m depth) were analysed.

No carbonate could be detected in any of the samples. A test with warm hydrochloric acid gave similar results. The analyses performed show that the possibility of finding secondary, carbonate bearing ore minerals in the till is limited or absent.

SIEVING AND MINERAL SEPARATION TESTS

The result of sieving and heavy mineral separations is shown in Table 2. It is seen that the heavy minerals form only a small fraction of the original samples. Ore minerals, if preserved, would be concentrated in the heavy fractions, and give rise to strongly increased contents of the base metals here. This is not observed, and it is therefore concluded that the original sulphide minerals, if at all present, occur in insignificant amounts.

TABLE 2. Cu, Pb and Zn in till fractions, section 2, at N. Fäbodliden

Sample No.	Depth m	Grain size mm	Weight of sample g	Weight of fraction density <2.96 g/cm³ g	Weight of fraction density >2.96 g/cm³ g	*Metal content light fraction density <2.96 g/cm³ ppm			**Metal content heavy fraction density >2.96 g/cm³ ppm		
103	0.5	0.20–0.60	22.00	21.05	0.95	**120**	**875**	**1370**	100	**1800**	**1600**
		0.10–0.20	16.72	14.85	1.87	**85**	**520**	**1140**	100	**1500**	**1300**
		0.06–0.10	10.70	9.76	0.94	**185**	**755**	**2030**	70	1000	800
		<0.06	18.75	18.23	0.52	**190**	**770**	**2025**	80	1400	300
102	1.0	0.20–0.60	28.26	26.98	1.28	50	330	455	50	850	300
		0.10–0.20	13.68	11.93	1.75	30	200	285	40	1000	300
		0.06–0.10	5.78	4.90	0.88	25	170	215	40	800	300
		<0.06	2.54	2.22	0.32	30	205	275	50	850	300
101	1.5	0.20–0.60	26.94	25.93	1.01	35	225	400	**120**	1200	**1200**
		0.10–0.20	25.95	23.78	2.17	40	195	480	40	1100	300
		0.06–0.10	12.79	10.97	1.87	55	215	630	40	1100	300
		<0.06	11.84	11.31	0.53	110	385	1155	50	1400	300
100	2.0	0.20–0.60	33.45	32.00	1.45	25	205	315	60	900	**790**
		0.10–0.20	22.11	19.59	2.52	30	170	305	50	1100	300
		0.06–0.10	3.40	2.65	0.75	35	170	390	40	650	300
		<0.06	2.41	2.08	0.33	45	245	475	60	1100	300
099	2.5	0.20–0.60	28.74	27.68	1.06	40	**425**	430	**250**	**1900**	300
		0.10–0.20	28.43	25.88	2.55	40	240	370	60	**1300**	300
		0.06–0.10	17.19	15.85	1.34	65	**625**	550	50	**2000**	300
		<0.06	8.33	8.02	0.31	55	**660**	465	60	**2000**	300
098	3.0	0.20–0.60	25.17	23.79	1.38	**95**	**735**	**1040**	50	1000	**490**
		0.10–0.20	7.42	6.38	1.04	**70**	**570**	**755**	50	900	**450**
		0.06–0.10	2.47	1.76	0.71	**65**	**515**	**650**	50	1000	**480**
		<0.06	5.86	5.73	0.13	**90**	**600**	**740**	50	1300	300
097	3.5	0.20–0.60	15.06	12.27	2.79	**160**	**535**	**1510**	50	400	**460**
		0.10–0.20	4.76	3.72	1.04	**120**	**405**	**1205**	70	500	**570**
		0.06–0.10	2.25	1.76	0.49	**105**	**425**	**920**	70	700	**520**
		<0.06	0.67	0.60	0.07	**140**	**950**	**1200**	not analysed		

Notes: * analysed by optical emission spectroscopy (tape) with Ge-Nb buffer and pulp
** analysed by photographic spectroscopy
120 high values in the column

Cu. Relatively high contents of Cu were noted in the light fraction of the top (0.5 m) and the bottom (3.0 and 3.5 m) samples. Notable contents in the top sample were mainly found in the fine fractions, whereas the enhancement in the bottom samples was mainly in the coarse fraction. Furthermore, an increased Cu-content in the heavy coarse fraction (0.20—0.60 mm) at 1.5 and 2.5 m depth was observed.

The results indicate that Cu is concentrated in the top sample (lowermost B-horizon), partially leached down to 3.0 m depth, and partially reprecipitated in the light fraction at 3.5 m (hydromorphic displacement). However the higher values observed in the coarse heavy fraction at 1.5 and 2.5 m depth indicate the possible presence of chalcopyrite.

Pb. The amount of Pb in the light fraction is rather evenly distributed within the different grain sizes throughout the section, with the highest content at the top (0.5 m) and at 2.5—3.5 m depth, whereas the content between 1.0—2.0 m depth is moderate but still anomalous. Also within the heavy fraction, Pb is evenly distributed throughout the section with some higher values at the top and at 2.5 m depth. The element level in the heavy fraction is 2—6 times higher than that of the light fraction, except in the bottom sample, where the content of Pb is nearly the same in heavy as well as in the light fraction.

The distribution of Pb in the light fraction is similar to that of Cu, which indicates concentration in the top sample, a leaching down to 2.5—3.0 m depth, where some reprecipitation of the Pb may have taken place. The rather even Pb-distribution regardless of grain-size in the heavy fraction throughout the section (the bottom sample not considered) indicates no particular concentration of clastic fragments.

Zn. The distribution pattern of Zn in the light fraction is similar to that of Cu and Pb, which means a high content at the top (0.5 m) and at the bottom (3.0 and 3.5 m) of the section. In the top sample the highest values are in the fine fractions, whereas in the bottom samples an opposite trend is observed (cf. Cu). A notable content in the heavy coarse fraction for samples at 0.5, 1.5 and 2.0 m depth was observed as well as moderate amounts of Zn in the heavy fraction in the bottom samples.

These data indicate that the distribution of Zn is similar to that of Cu and Pb, implying a concentration in the top sample, a leaching down to 3.0 m depth, where a reprecipitation (hydromorphic displacement) of the Zn may have taken place. In the heavy coarse fraction at 0.5, 1.5 and 2.0 m depth it is possible that Zn-bearing magnetite is present. Analysis of magnetically separated heavy mineral fractions of samples from 0.5 m depth in section 4 and 5 indicated 2500 and 2200 ppm Zn in the ferromagnetic fraction, where magnetite and ilmenite dominated. (These contents may be somewhat too high due to interference from Fe.)

STABILITY RELATIONS

Eh-pH measurements were performed in samples from section 2 stored at the laboratory, which means that the oxidation-reduction potential (Eh) may be a little higher than in a moist sample in situ. The results have been plotted in diagrams, based on calculations by the author, using data ($\triangle F^\circ$) from Garrels (1960). Total ionic activity has been taken as 10^{-6}, total dissolved sulphur 10^{-1} M and P_{CO_2} 10^{-4} atm. which is approximately that of the atmosphere.

The stability relationships among Pb compounds in water at 25°C and 1 atmosphere total pressure can be seen in Fig. 7, where it is found that in the chemical environment in the section at N. Fäbodliden the sole stable Pb phase ought to be anglesite.

The stability relationships among Zn compounds under the conditions mentioned above can be seen in Fig. 8. Compared to Pb compounds the major difference is the absence of an insoluble sulphate in this system. (The solubility of zincosite in water at room temperature is 531.2 g/l.) Thus, it is obvious that in the N. Fäbodliden area, the Zn minerals sphalerite and smithsonite are not stable in the till. This means that sphalerite in the till easily disintegrates and that the metal ions move away from their source and subsequently may be reprecipitated on the surface of other minerals and particles present (hydromorphic displacement) cf. Wolfe (1975).

MINERALOGY

Four polished sections from dh. 69002 at N. Fäbodliden have been studied. The sulphide minerals observed in the bedrock sections were pyrite, pyrrhotite, galena, sphalerite and chalcopyrite. The minerals frequently occur as fine disseminations. The sphalerite identified was mostly of an iron-poor type.

Some of the till samples from N. Fäbodliden (minus 0.06 mm fraction) were difficult to separate in the heavy liquid (methylene iodide), as in the heavy fraction approximately 50 per cent of the mineral grains present were quartz and feldspars. These grains were often surrounded by Fe-rich coatings. Limonitic spots on the surface of the grains also occur. This was also observed for zircons, garnets and some apatite grains.

Polished sections of the nonmagnetic heavy fractions (density plus 3.31) showed no ore minerals of the elements Cu, Pb and Zn. However, it was possible, by handpicking limonite-coated mineral grains from the coarse fractions

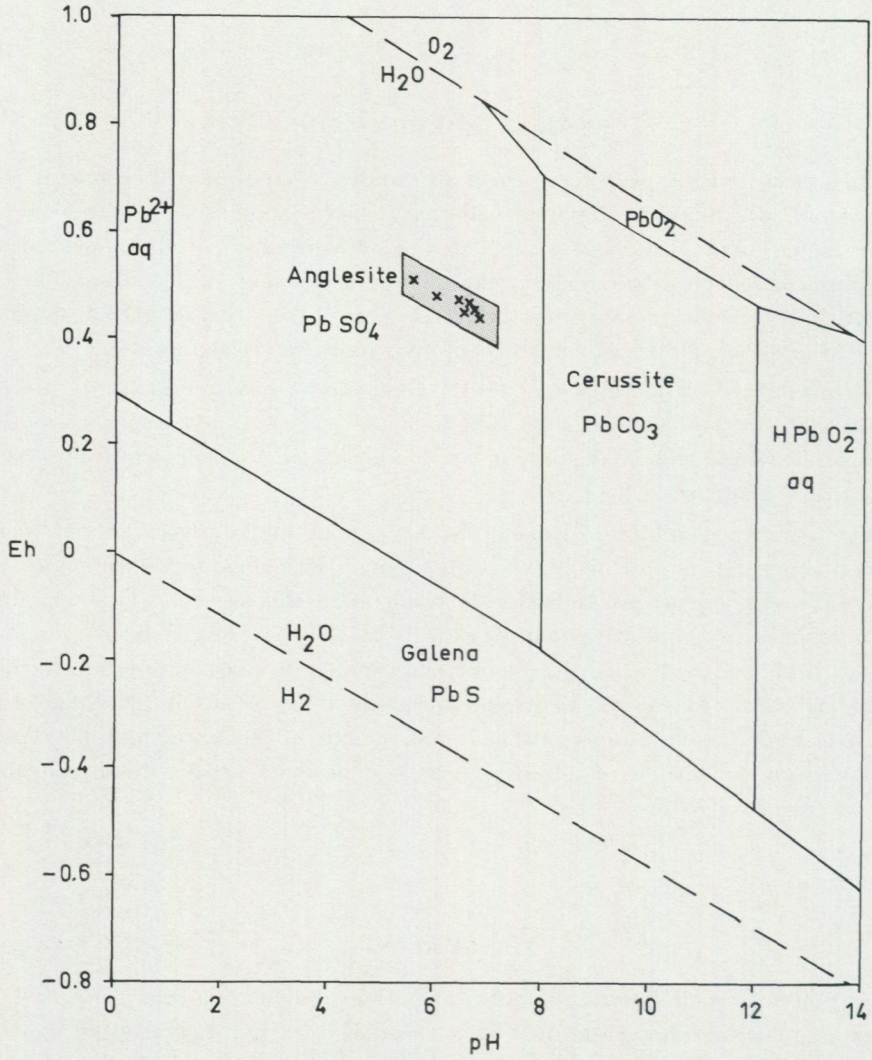


Fig. 7. Stability relationships among lead compounds in water at 25° C and 1 atmosphere total pressure. Boundaries of solids at total ionic activity of 10^{-6}. Modified after Garrels (1960). × = observed values.

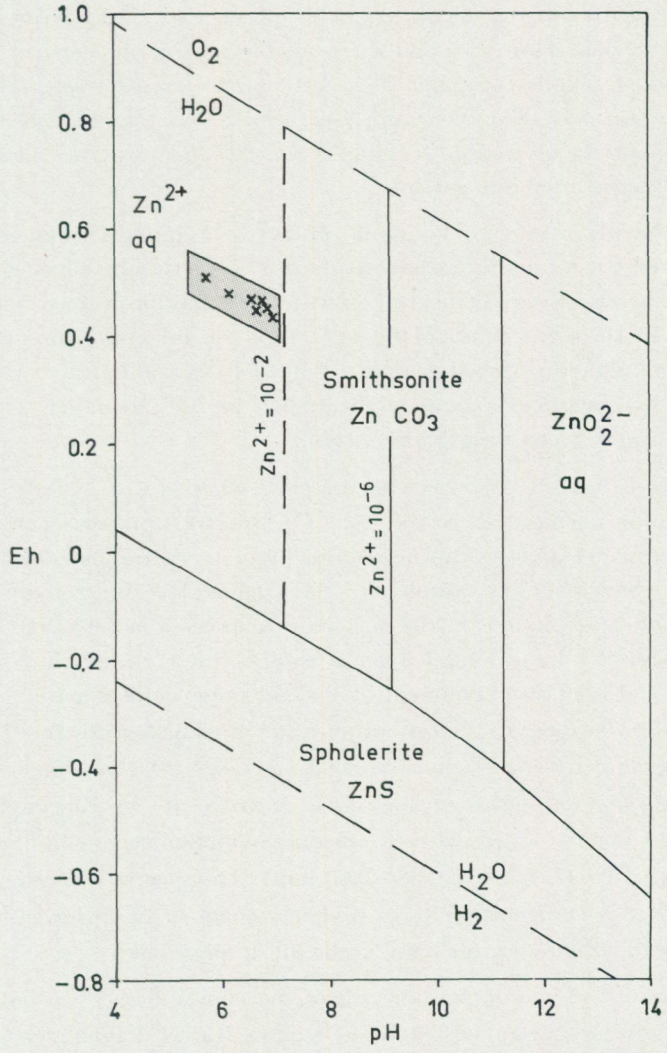


Fig. 8. Stability relationships among zinc compounds in water at 25° C and 1 atmosphere total pressure. Boundaries of solids at total ionic activity of 10^{-6}. Dashed line is contour at activity of dissolved zinc species of 10^{-2}. × = observed values.

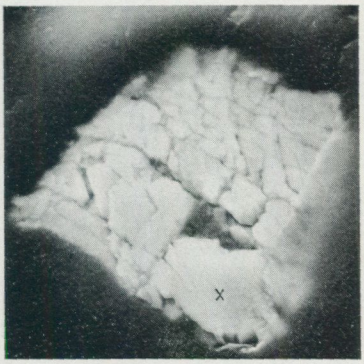
under the microscope, to obtain grains of pyrite and chalcopyrite, identifiable in polished section. Thus, two and three small grains of chalcopyrite were found in the coarse fractions of sample Nos. 101 and 099 respectively (cf. Table 2), and a large zoned chalcopyrite grain (see below) was found in the coarse fraction at the bottom of section 2 (sample No. 097). The pyrites identified were almost completely altered to goethite.

The frequently occurring Fe spots observed on different minerals and the highly altered pyrites, indicate that weathering has partly dissolved the sulphides and probably also some Fe-bearing silicates. Fe has been then reprecipitated together with trace elements on the surface of the mineral grains present. The occurrence of altered pyrites throughout the whole section indicates partial oxidation down to a depth of 3.5 m in the trench at N. Fäbodliden. (The ground water level was not observed in the section.)

In Fig. 9 a, a minute grain (45 micron size), dark brown — red brown under the polarisation microscope, can be seen. The spectra from the energy dispersive X-ray spectrometer analysis can be seen in Fig. 9 b. Pb occurs together with the dominating element Fe. In sample No. 099 (minus 0.06 mm fraction) a spot of Fe was found precipitated on the surface of a potassium feldspar. In this spot an enrichment of Pb and some Cu could also be noted. In sample No. 099, fraction 0.20—0.60 mm, an enrichment of Pb and presence of Cu were observed in the outer oxidized zones of almost entirely altered chalcopyrites (cf. Table 2). In a completely altered pyrite, sample No. 098, fraction 0.20—0.60, an enrichment of Pb was found in a light cross cutting phase. A partly altered chalcopyrite grain of about 250 × 250 microns size with two distinct oxidation zones can be seen in Fig. 10 a (sample No. 097, fraction 0.20—0.60 mm). The spectra from the three zones analysed are presented in Fig. 10 b—d. The content of Cu is lower, and that of Pb higher in the thin outer zone than in the thick inner zone.

The result of the microprobe analysis of the core and the two outer zones of the chalcopyrite, found at the bottom of section 2 at N. Fäbodliden is presented in Table 3. It is seen from this table and the corresponding spectra (Fig. 10 b—d), that the amount of Fe has increased, whereas nearly all S and Cu have disappeared in the inner zone. Fe in the outer zone corresponds to the value in the unaltered core. A further decrease in S, Cu and Si is noted, whereas the amount of Pb has increased in the outer zone.

It is obvious that in micro-environments of single sulphide grains in till, weathering and hydrogen ion activity cooperate in a successive disintegration of the mineral grains present. Thus, minerals containing ferrous iron and sulphur will be oxidized to ferric iron and sulphate in contact with the atmosphere and water-dissolved oxygen. During oxidation, a release of the sulphide and later



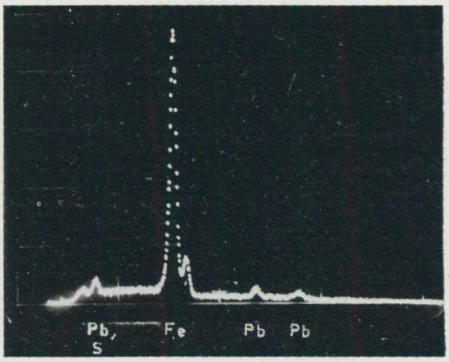


Fig. 9 a. Fragment of the oxidized zone (goethite) of a pyrite grain? Nonmagnetic, heavy mineral fraction of till from section 2 at 1.5 m depth, grain size minus 0.06 mm, N. Fäbodliden. × = analysed point. SEM 1500 X.

Fig. 9 b. Spectrum of the fragment.

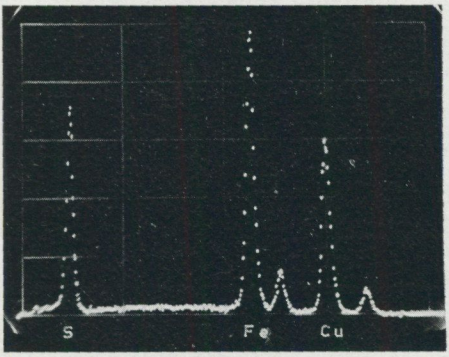
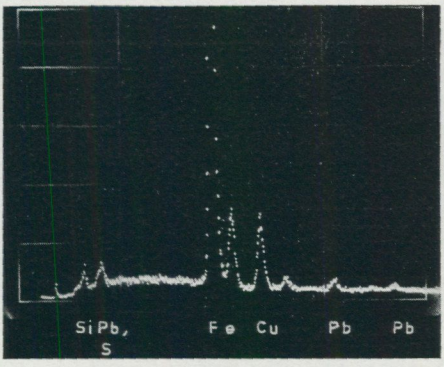


Fig. 10 a. Partly altered chalcopyrite in a heavy-liquid separated fraction of till from section 2 at 3.5 m depth, grain size 0.20—0.60 mm, N. Fäbodliden. × = analysed points. Refl. light. 160 X.

Fig. 10 b. Spectrum of the chalcopyrite core.



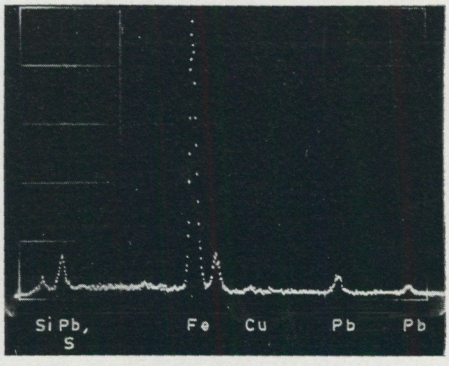


Fig. 10 c. Spectrum of the light inner oxidized zone.

Fig. 10 d. Spectrum of the dark outer oxidized zone.

on a release of the metal ions takes place (cf. Fig. 10 d and Table 3). Pb appears to be picked up (adsorption-absorption) by the goethite phase thus formed. The content of Pb decreases towards the core of unaltered chalcopyrite.

The mineralogical analyses of the fractionated till show that the single preserved ore mineral of Cu, Pb and Zn in the chemical environment at N. Fäbodliden is chalcopyrite. This indicates that the Cu anomaly is partly of a clastic type. Several transparent minerals (zircon, apatite, garnets and feldspars) were covered by spots of secondary Fe-rich crusts, where Pb was identified on some feldspars. Pb was also found in the alteration zones of pyrite and chalcopyrite grains. This indicates that Pb minerals (galena) have disintegrated and that Pb-ions become reprecipitated on/in other minerals and particles present in the till. The increased Pb-contents in the goethite may also explain the higher Pb-values in the heavy mineral concentrates noted in Table 2. Thus, Pb may to some extent be redistributed by hydromorphic processes. Zn has not been identified in any of the samples analysed by mineralogical methods. This could indicate that Zn occurs as a very finely dispersed and hydromorphically displaced element, which cannot be detected in/on individual mineral grains with the analytical equipment used (energy dispersive X-ray spectrometer).

TABLE 3. Chemical composition of altered chalcopyrite from N. Fäbodliden (microprobe analysis)

Element	Chalcopyrite core	Inner oxidized zone	Outer oxidized zone
Fe	30.1	39.8	29.1
S	35.6	0.3	0.1
Mn		0.0	0.0
Cu	33.9	2.7	0.9
Pb		6.7	11.7
Si		4.3	2.3
*	99.6	53.8	44.1

* Element sum (weight per cent)

TEST AREA W. BALLEK

GENERAL DESCRIPTION

The location of the area investigated can be seen in Fig. 1. The mean annual temperature and precipitation in the area are —1.3 C° and 520 mm respectively. The vegetation is similar to that in the N. Fäbodliden area. The altitude of the

area varies from 530 to 560 m a.s.l. Thus, the area has not been covered by the sea during Quaternary times (Lundqvist 1961).

The area is covered by a normal boulder-bearing sandy, silty till. In some places glaciofluvial sediments occur. Bogs in the middle of the area show a SSE trending elongation, which coincides with the direction of glacial transport. This means that the dispersion of ore debris coincides with the direction of drainage. A strong Cu anomaly in the till can be partly correlated with the ore-bearing boulders in the moraine-ridges, and a weak mineralization outlined by four drill holes. The direction of glacial transport is verified by glacial striae observed on an outcrop of basaltic andesite close to the gravel road east of the W. Ballek area. Many moraine ridges are elongated in the same direction.

METAL DISTRIBUTION

The area of W. Ballek, which was investigated in detail, is part of a large regional soil grid system from which the samples were collected in 1966, and it extends from the Lulepotten orebody in the south, to the N. Ballek mineralization in the north (Toverud 1974, p. 28). Fig. 11 shows the distribution of Cu in the till in the W. Ballek test area. The anomaly occurs in a rather flat area where the variation in elevation is only ten metres. The pattern of the anomaly indicates a clastic dispersion of ore minerals caused by glacial erosion and transport from the mineralized zone.

In Fig. 12 (upper part), vertical sections from two of the drill holes and five of the pits in the area are presented. The bedrock formation probably dips steeply to the east. It appears that the mineralized zones in the drill holes have contributed ore mineral fragments which were dispersed in the till by the advancing ice. Additional mineralized zones may occur in the extension of profile I towards the WNW.

Fig. 12 (lower part) shows the distribution of Cu in profile II at W. Ballek. The glacial drift is thicker than in profile I. The weakly mineralized chalcopyrite zone around the 50 m level in drill hole 68601 probably sub-outcrops beneath pit No. 6. The high content of Cu in the till in the bottom of pit No. 2 is believed to be related to this mineralized zone. Drill hole 67601 indicates another mineralized zone below and between pits Nos. 2 and 9. The Cu content in pits Nos. 3 and 10 might be caused by further mineralizations east of drill hole 67601.

MINERALOGY

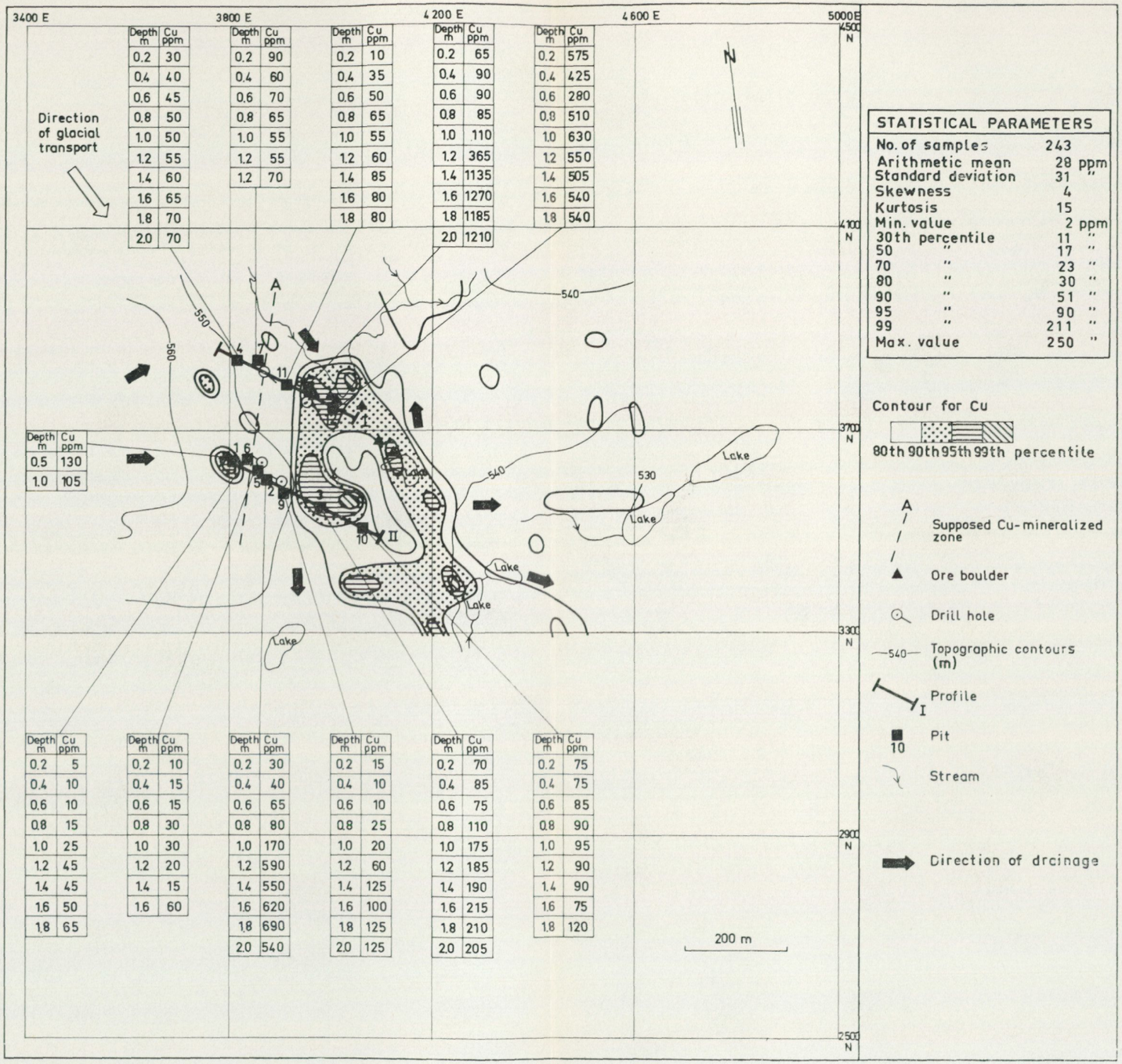
The opaque minerals identified in the nonmagnetic fraction were chalcopyrite and pyrite grains, nearly always surrounded by a goethite shell of varying thickness. Some of the chalcopyrite grains are not surrounded by this zone, but it is possible that the brittle shell has been lost during the preparation of the samples. Much interest has been devoted to the pyrites because of their use as sulphide weathering indicators.

In the samples from pits Nos. 1, 2 and 8, several pyrite and chalcopyrite grains were found, where the oxidized zones around the primary sulphide cores were mostly missing. In a sample from 0.4 m depth in pit No. 10, eleven pyrite grains with thick oxidized zones were identified. Furthermore, 18 framboid-like pyrite grains were identified, grown together with silicates (minor grains in Fig. 13 a). A highly altered pyrite grain was observed in the same section (Fig. 13 b). From Fig. 13 a it can be seen that two oxidized zones occur, one light inner, and one dark outer zone. In pit No. 11 at 1.8 m depth, 16 pyrite grains with oxidized zones, 10 micron thick, were observed. One of these can be seen in Fig. 14. In samples from 0.4 and 1.8 m depth in pit No. 12, several chalcopyrite grains were observed. Those from the upper part of the pit had thick oxidized zones (Fig. 15 a) and grains at depth had thinner oxidized zones (Fig. 15 b).

The frequency of pyrite grains in the fractions increases with depth in the pits. Furthermore, most of the pyrite and chalcopyrite grains were found in the coarse fraction (0.20—0.60 mm). The thickness of the oxidized zones around the unaltered cores decreases with depth. In the nonmagnetic fraction (0.06—0.20 mm, at 0.8 m depth) from pit No. 8, *one* small flake of a chalcopyrite was found, whereas in the nonmagnetic fraction (0.10—0.20 mm) from pit No. 12 *no* chalcopyrite grains were observed. However, several chalcopyrite grains were found in the coarse heavy fraction (0.20—0.60 mm) at both 0.4 m and 1.8 m depth in pit No. 12.

The content of Cu (ppm) in the minus 0.10 mm light fraction in the basal parts of pit No. 8 is about 1200 ppm, whereas the content of Cu in pit No. 12 is about 500 ppm in the corresponding fraction (cf. Fig. 12). Pit No. 8 is situated on a high ridge (elongated in the direction of glacial flow),where rather strong oxidation conditions prevail also at depth. In pit No. 12, which is situated near a peat bog, the till is rather moist with the groundwater level occurring at 1.5 m depth. Because of the stronger oxidation conditions in pit No. 8, the chalcopyrites have been altered and the Cu ions have been reprecipitated in the deeper section (1.4—2.0 m).

Fig. 11. Distribution of Cu at 0.5 m depth in the fine fraction, minus 0.10 mm, of till at W. Ballek.



Depth m	Cu ppm
0.2	30
0.4	40
0.6	45
0.8	50
1.0	50
1.2	55
1.4	60
1.6	65
1.8	70
2.0	70

Depth m	Cu ppm
0.2	90
0.4	60
0.6	70
0.8	65
1.0	55
1.2	55
1.2	70

Depth m	Cu ppm
0.2	10
0.4	35
0.6	50
0.8	65
1.0	55
1.2	60
1.4	85
1.6	80
1.8	80

Depth m	Cu ppm
0.2	65
0.4	90
0.6	90
0.8	85
1.0	110
1.2	365
1.4	1135
1.6	1270
1.8	1185
2.0	1210

Depth m	Cu ppm
0.2	575
0.4	425
0.6	280
0.8	510
1.0	630
1.2	550
1.4	505
1.6	540
1.8	540

Depth m	Cu ppm
0.5	130
1.0	105

Depth m	Cu ppm
0.2	5
0.4	10
0.6	10
0.8	15
1.0	25
1.2	45
1.4	45
1.6	50
1.8	65

Depth m	Cu ppm
0.2	10
0.4	15
0.6	15
0.8	30
1.0	30
1.2	20
1.4	15
1.6	60

Depth m	Cu ppm
0.2	30
0.4	40
0.6	65
0.8	80
1.0	170
1.2	590
1.4	550
1.6	620
1.8	690
2.0	540

Depth m	Cu ppm
0.2	15
0.4	10
0.6	10
0.8	25
1.0	20
1.2	60
1.4	125
1.6	100
1.8	125
2.0	125

Depth m	Cu ppm
0.2	70
0.4	85
0.6	75
0.8	110
1.0	175
1.2	185
1.4	190
1.6	215
1.8	210
2.0	205

Depth m	Cu ppm
0.2	75
0.4	75
0.6	85
0.8	90
1.0	95
1.2	90
1.4	90
1.6	75
1.8	120

STATISTICAL PARAMETERS

No. of samples	243
Arithmetic mean	28 ppm
Standard deviation	31 "
Skewness	4
Kurtosis	15
Min. value	2 ppm
30th percentile	11 "
50 "	17 "
70 "	23 "
80 "	30 "
90 "	51 "
95 "	90 "
99 "	211 "
Max. value	250 "

Contour for Cu

80th 90th 95th 99th percentile

A / A' Supposed Cu-mineralized zone

Ore boulder

Drill hole

540 Topographic contours (m)

I Profile

10 Pit

Stream

Direction of drcinage

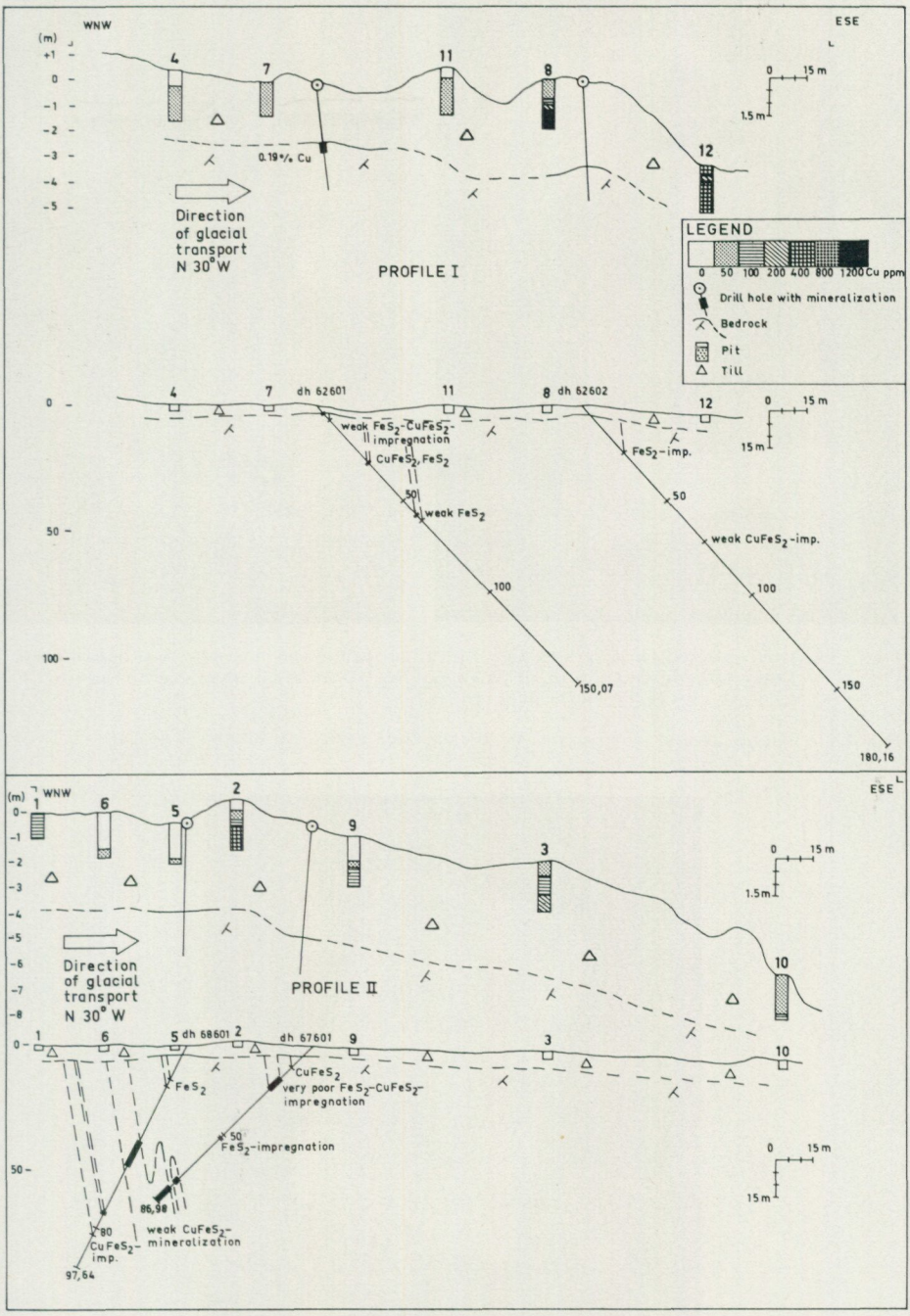


Fig. 12. Vertical sections showing the distribution of Cu (profile I and II) in the fine fraction, minus 0.10 mm, of till at W. Ballek.

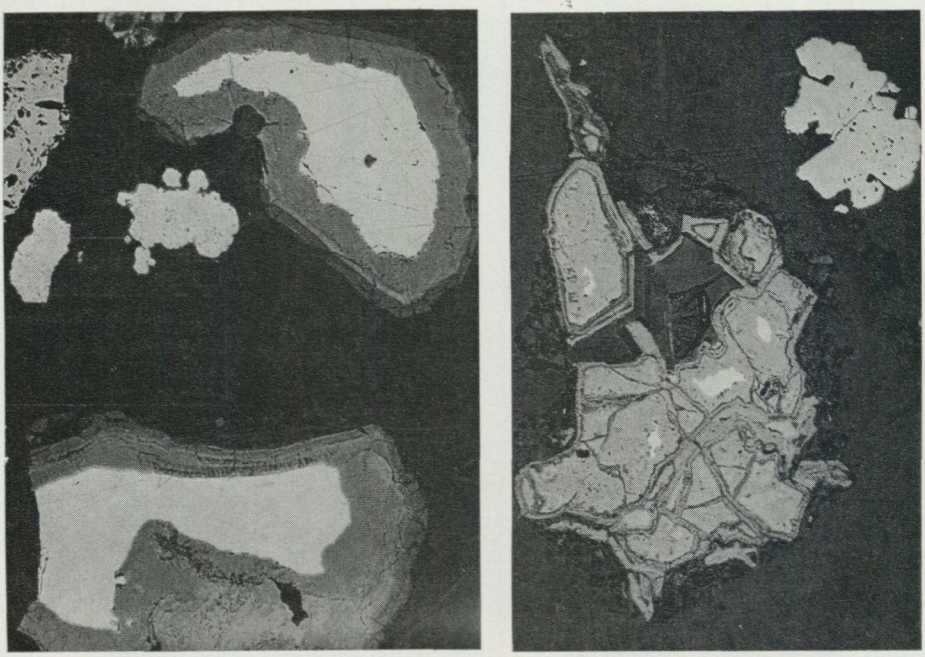


Fig. 13 a. Partly altered pyrite grains and framboidal aggregates of pyrite in a nonmagnetic, heavy mineral fraction of till from pit No. 10 at 0.4 m depth, grain size 0.20—0.60 mm, W. Ballek. Refl. light. 160 X.

Fig. 13 b. Highly altered pyrite grain, W. Ballek. Refl. light. 160 X.

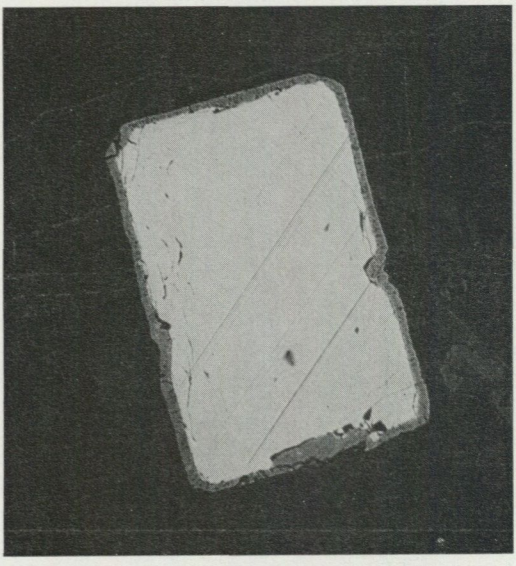


Fig. 14. Partly altered pyrite grain with thin, 10 μ size, oxidized zone from pit No. 11 at 1.8 m depth, grain size 0.20—0.60 mm, W. Ballek. Refl. light. 160 X.

Fig. 15a. Highly altered chalcopyrite grain in a nonmagnetic, heavy mineral fraction of till from pit No. 12 at 0.4 m depth, grain size 0.20—0.60 mm, W. Ballek. Refl. light. 160 X.

Fig. 15b. Chalcopyrite grain with small remnants of a thin oxidized zone from pit No. 12 at 1.8 m depth, grain size 0.20—0.60 mm, W. Ballek. Refl. light. 160 X.

The chemical-mineralogical analyses of the fractionated till samples from the area, show that the Cu anomaly at W. Ballek is mainly of a clastic type with several chalcopyrite grains preserved in the till, mostly in the coarse fraction, 0.20—0.60 mm. However, depending on the topographical position and oxidation conditions in some of the pits, the chalcopyrites have disintegrated (sulphide weathering) and subsequently the Cu ions have become reprecipitated on other minerals and particles present in the till. This evidently means that the anomaly is also partly influenced by hydromorphic processes.

As most of the preserved pyrites and chalcopyrites were found in the coarse fraction (0.20—0.60 mm), it is logical to consider this and coarser fractions for investigations regarding the presence of primary sulphide grains.

TEST AREA VARGISTRÄSK

GENERAL DESCRIPTION

The area investigated, 6 km west of the village of Vargisträsk, is situated about 50 km east of W. Ballek (Fig. 1). Mean annual temperature and precipitation in the area are —1.2 C° and 480 mm respectively. The area is situated above the Highest Shore-Line. Single pines and birches occur. The peat areas occurring to the north in the sampling area have a SW trending elongation. A strong Pb, Cu,

Zn anomaly in the till is partly related to a minor Pb, Cu, Zn mineralization, outlined by six drill holes (Padget et al. 1969).

The area is generally covered by a relatively coarse-grained till. A boulder rich till of ablation type occurs between the line 400 S, Fig 16, and the Vargisån river. The topography is typical for ablation till areas, with kettle holes and undulating steep hillocks. South of this line, basal till domanites. NNE of line 900 N, and east of line 200 W, the surface of the ground is free from boulders and rather even. Silt is the dominating size fraction, representing post-glacial sediments of the Vargisån river. The direction of glacial transport is from the north-west, verified by glacial striae observed within the area. In total, 50 ore-bearing boulders have been found in the region, irregularly distributed over a distance of 2 kilometres in a south-easterly direction from the area investigated.

METAL DISTRIBUTION IN TILL

The distribution of Pb, Cu and Zn at 0.8 m depth in the till is displayed in Fig. 16. An extensive Cu, Pb and Zn anomaly, south of line 200 N and west of line 200 W, is noted near the source of the drainage system in the area. This anomaly is a new one compared to an earlier soil sampling program (Padget et al. 1969). A clastic glacial dispersion of ore minerals is possible, and a source would be expected north-west of line 600 W. The anomalies close to the pits Nos. 5—8 probably are related to a mineralization found immediately to the west. The trace element distribution in the pits, Fig. 17, shows a marked concentration of Cu in the deeper parts of pits 5 and 6, i.e. those pits closest to the known mineralization. The dislocation of the anomaly to the east from the sub-outcrop of the mineralization has probably been caused by solufluction.

MINERALOGY

Mineralogical investigations were made on the heavy (plus 3.31) concentrates. Several pyrite grains were found in polished sections from pits 8 and 9, and in paramagnetic (0.5 A) and four nonmagnetic concentrates from pit No. 7. The impression is, that the pyrites will be preserved to a greater extent in the deeper parts of the pits. However, the degree of alteration varies from totally altered grains, to grains with at least half of the primary sulphide left. No visible difference in the degree of alteration can be found in grain sizes 0.10—0.20 and 0.20—0.60 mm. Also no general enrichment of the pyrites in a particular magnetic fraction was observed. The alteration of the pyrites indicates that moderately oxidizing conditions exist to a depth of 2 m in the glacial till of this area. The groundwater level was observed only in pit No. 8 at 0.5 m depth.

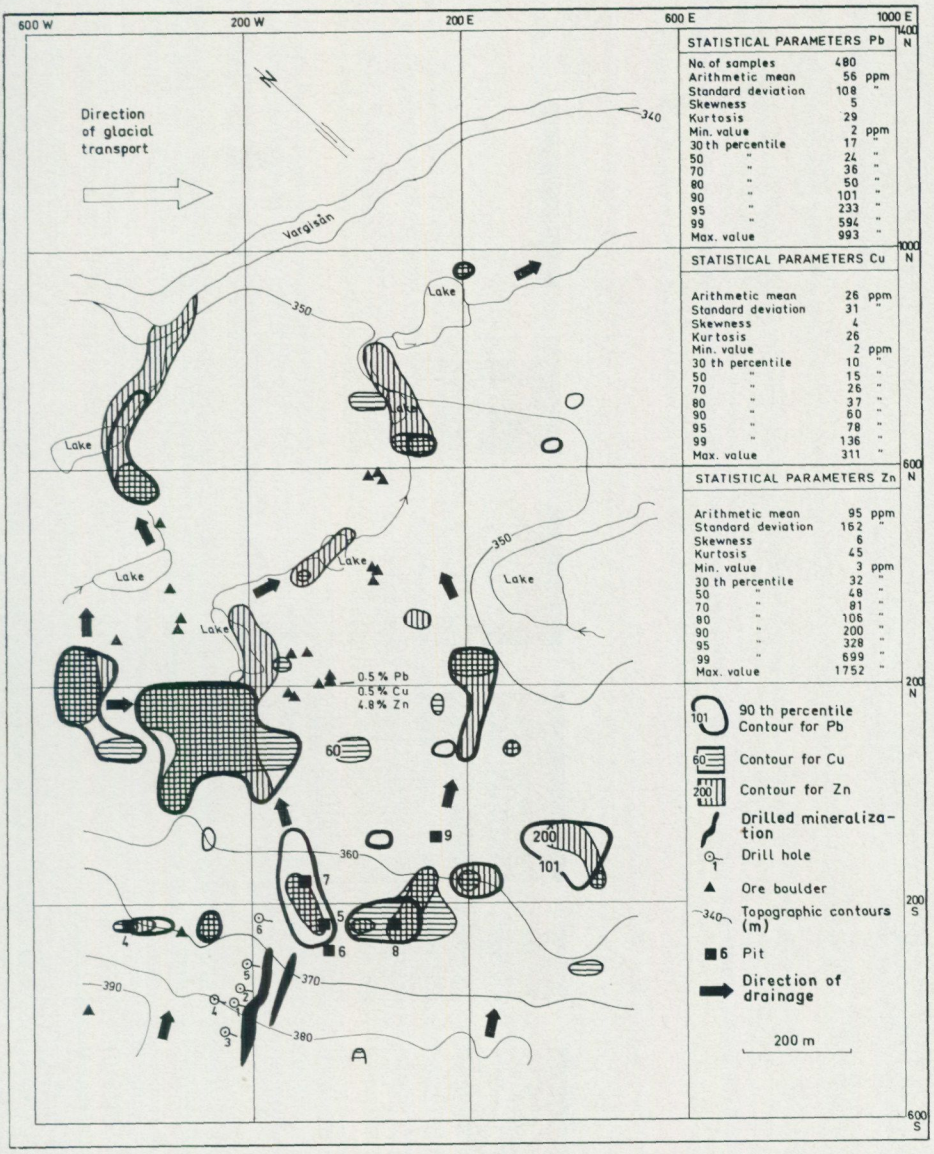


Fig. 16. Distribution of Pb, Cu and Zn at 0.8 m depth in the fine fraction, minus 0.10 mm, of till west of Vargisträsk.

In addition to the sulphides, isotropic, colourless, transparent grains were found in the nonmagnetic, coarse and fine fractions of samples collected at 1.6 m depth in pit No. 7, and in the coarse fraction from 0.8 m depth in pit No. 8. Energy dispersive X-ray spectrometer analysis showed that the mineral identified was a Zn spinel, gahnite, $ZnA1_2O_4$ (Toverud 1974, p. 82).

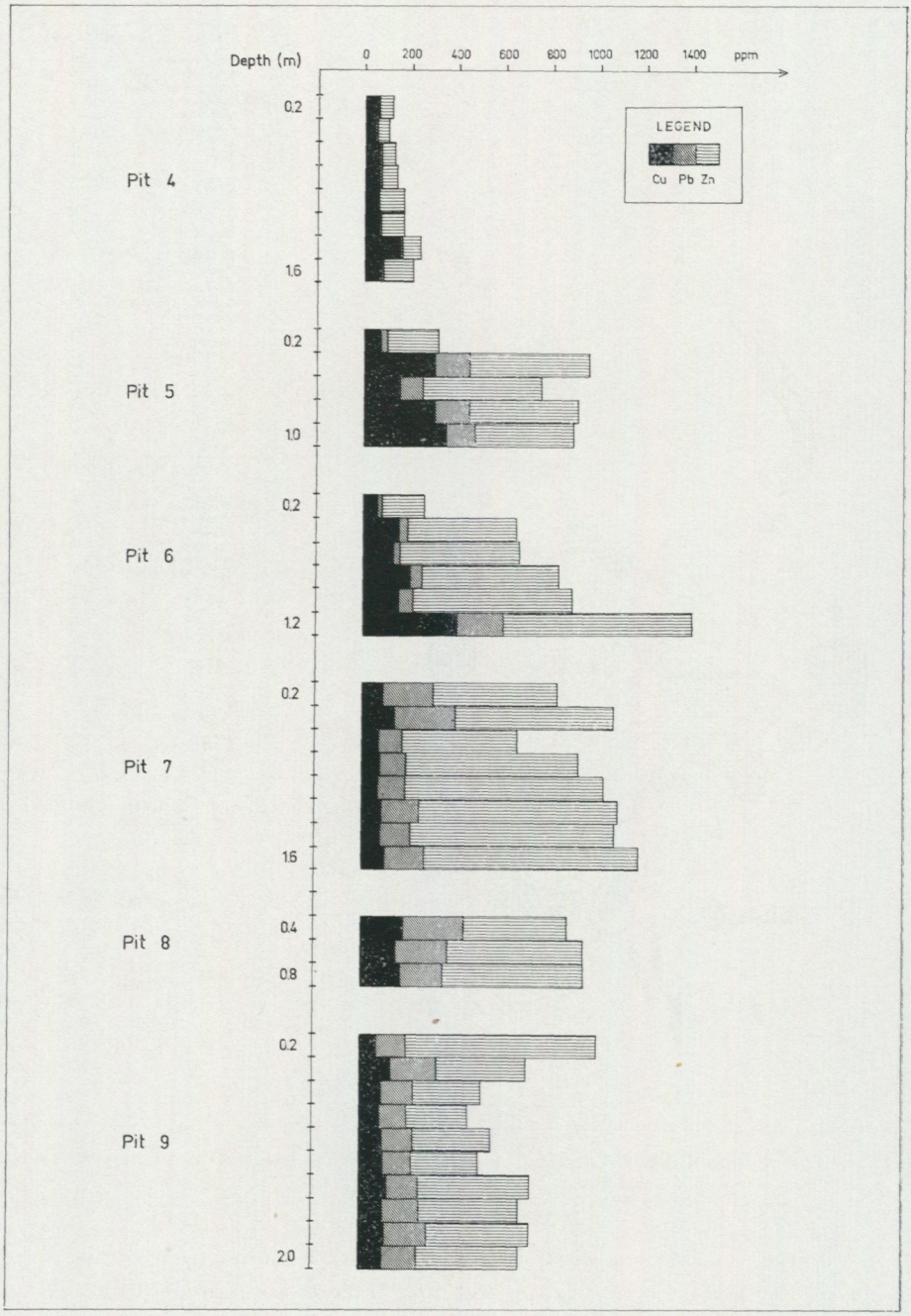


Fig. 17. Distribution of Cu, Pb and Zn in the fine fraction, minus 0.10 mm, of till taken at 0.2—0.3 m intervals from pits dug within the anomalous area west of Vargisträsk.

The mineralogical investigation shows that the sulphide minerals preserved (apart from pyrite) in the till were altered chalcopyrites, where only small amounts of the nonweathered core of the grains were left. Thus, sphalerite and galena were not preserved in the investigated till fractions (minus 0.60 mm). The single mineralogical indication of a Zn mineralization in the area is the presence of a well preserved Zn spinel in the nonmagnetic heavy mineral fraction of the samples investigated.

PEAT ANOMALIES

The two elongated anomalies in the northern part of Fig. 16 represent metal concentrations in soil below the peat. The ash content, Fe_2O_3 and Zn content in the ash of the peat samples from the bog zones are displayed in Fig. 18. The ash content and humification of the dominating *Sphagnum* peat increases with increasing depth. The Zn content in the samples increases with depth, except for two of the sections. This probably depends on the sample location close to a stream, which has caused intermixing of inorganic material (sample No. 18508), as indicated by the high ash content. The highest Zn value found in the ash (at 0.8 m depth at coordinate 320 N/280 W) attains to 15.9 % Zn, as well as 0.84 % Cu and 0.72 % Pb. The highest Pb value, 1.53 % Pb (A.A. analysis), was found at the same coordinate at 0.5 m depth.

High metal contents are often noted in organic rich swamps or peat deposits (Salmi 1950, 1954, 1967; Cannon 1955; Armands 1967). Some of the trace elements have been found to be more enriched in certain horizons. Thus Pb, Zn and Mo tend to display high concentrations in the upper layers of peat bogs (Hvatum 1964 and Larsson 1970). In our peat samples, increasing contents of Zn were noted with increasing depth, which is opposite to that found by the authors above.

The inorganic soil below the peat may represent till, or inorganic stream sediments. In a sample collected here at 3.5 m depth and below the peat, partly altered pyrite, chalcopyrite and framboids of pyrite (Fig. 19) were found.

CONCLUSIONS

Trace element anomalies in glacial overburden from northern Sweden have been chemically and mineralogically investigated in order to explain the geochemical distribution patterns observed. The following conclusions emerge:

1. The geochemical pattern of the trace elements indicate that the Cu anomalies at N. Fäbodliden, W. Ballek and Vargisträsk are mainly of a clastic type. This is confirmed by the mineralogical study where several chalcopyrite grains

Sample no.	Coord.	Depth m	Ash %	Fe_2O_3* %	0 1 2 3 4 5 % Zn**	
18500	240N/160W	0.5	7.5	12.1		
501		1.0	35.7	3.6		
502	280N/240W	0.5	4.3	30.7		
503		1.0	52.5	2.1		A.A.***
504	320 N/280W	0.5	5.0	4.6		
505		0.8	9.5	2.8	15.9%	A.A.
506	400N/280W	0.5	1.6	11.1		
507		1.0	15.8	1.5		
508	560N/90E	0.5	28.2	2.8		A.A.
509		1.0	43.7	3.5		A.A.
510	640N/75E	0.5	3.4	12.3		
511		1.0	4.1	16.5		
512		1.5	44.1	2.2		
513		2.0	50.7	2.5		
514		2.5	56.3	3.7		
515		3.0	56.1	3.4		
24521		3.5	–	1.2	till sample	
18516	720N/60E	0.5	3.2	3.9		
517		1.0	7.5	2.8		

* Fe analysed by direct reading emission spectrograph.
** Zn analysed by X-ray fluorescence.
*** Values checked by Atomic Absorption.

Fig. 18. Ash content, Fe_2O_3 and Zn contents in the ash of peat samples from the area west of Vargisträsk.

in the fractionated till were identified. The Pb and Zn anomalies at N. Fäbodliden and the area west of Vargisträsk are considerably influenced by hydromorphic processes (best demonstrated in the northern parts of each area). This is confirmed by the mineralogical study where no primary or secondary minerals of Pb and Zn were identified (gahnite in the Vargisträsk area not considered).

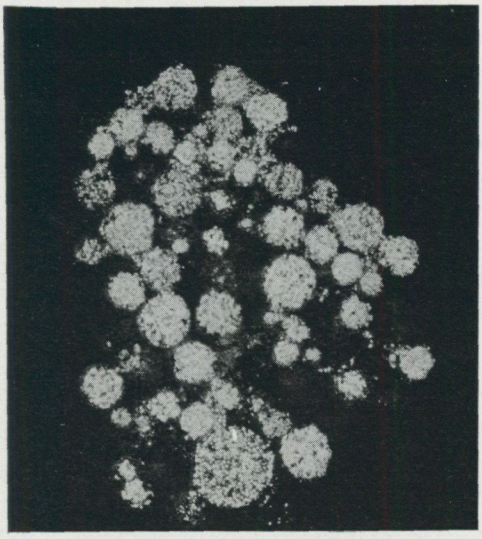


Fig. 19. Framboidal pyrite in a nonmagnetic, heavy mineral fraction of soil, grain size 0.20—0.60 mm, collected at 3.5 m depth below a peat bog west of Vargisträsk. Refl. light. 400 X.

2. Preserved grains of pyrite and chalcopyrite occur with the greatest frequency in the coarsest fraction investigated, 0.20—0.60 mm. Systematic study of primary sulphides in till should therefore preferably be directed at the plus 0.60 mm fraction.

3. The chemical cold-extraction tests indicate that Pb, Zn, and to some extent Cu, occur as adsorbed/absorbed ions on/in other minerals. Cu and Zn also occur in partly acid soluble phases (humic Fe-Mn substances) in the top sample.

4. Pb was detected in the alteration zones (mostly goethite) of pyrite and chalcopyrite by energy dispersive X-ray analysis. Pb was also found, enriched together with hydrous Fe oxides, on grains of feldspar. This evidently indicates a precipitation of Pb ions from weathered galena, showing that the element is hydromorphically displaced in the till.

5. Calculations performed on the stability relationships among Pb and Zn compounds in the till in the N. Fäbodliden area, indicate that the single ore mineral which might be stable in the chemical environment is anglesite, which however, was neither observed in the drill cores from the bedrock nor in the till samples. Likewise its presence is not indicated by the extraction tests.

6. The weathering processes operating in the disintegration of the sulphide minerals probably are of a postglacial nature. This is indicated by the fact that brittle oxidized zones around the pyrites and chalcopyrites are well preserved.

If an advancing ice had been operating on the gossan of an orebody, the preglacial goethite shells would have been crushed, eroded and removed.

7. In the N. Fäbodliden area it is possible that further mineralizations may be found by diamond drilling west of the trench and south-west of drill hole No. 2. In the area west of Vargisträsk it is most probable that the element distribution in the till north-west of line 200 W cannot be correlated to the mineralization found by diamond drilling. An unknown mineralization in a north-westerly direction from the coordinate 100 N/200 W close to line 600 W in the local grid system may have caused the high trace element values observed in this part of the area.

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