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HEAVY METALS AS LITHOGEOCHEMICAL INDICATORS FOR ORE DEPOSITS IN THE IILINJÄRVI AND AIJALA FIELDS, SW-FINLAND

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WITH 8 FIGURES AND 4 TABLES IN THE TEXT

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A lithogeochemical method was tested both in regional and local prospecting in a well-known Precambrian area, the Orijärvi leptite zone, in SW Finland. The known mineralizations in the area consist in addition of oxide iron ores pyritic and arsenic mineralizations as well as polymetallic Cu-Pb-Zn-Ag deposits. The samples were analyzed for As, Co, Cu, Hg, Mo, Ni, Pb, Zn and S. The arithmetic means, the geometric means and the medians are given for each rock type as well as for the total of the samples. Factor analysis was applied to the data and the factor matrix includes a factor which is interpreted as the ore factor. The distributions of the elements are presented on maps. The variations in the Hg contents is regional and correlates with the structure and rock types of the bedrock, Hg also indicated the ore deposits. The variations in the contents of As, Cu, Pb, Zn and S indicate the ore deposits or zones favourable for their occurrence.

The authors' addresses:
Dr. Heikki Wennervirta
Outokumpu Oy
P.O.B. 280
SF-00101 Helsinki 10, Finland

Prof. Heikki Papunen
Institute of Geology and Mineralogy
University of Turku
SF-20500 Turku 50, Finland

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INTRODUCTION

The investigated area belongs to the east-west trending schist zone in the Precambrian of Southwest Finland. Since the eighteenth century, several iron ore showings as well as sulfide copper-zinc-lead deposits have been exploited in this zone known as the Orijärvi leptite zone (Eskola, 1963). Nowadays, only the Metsämonttu lead-zinc mine of the Outokumpu Oy is in operation. Owing to its numerous small ore showings, the area has long been an object of geological interest. It has been described by Eskola (1914, 1915, 1950 and 1963), Tuominen and Mikkola (1950), Mikkola (1955) and Tuominen (1951, 1957 and 1961). The geology of the Orijärvi leptite zone was carefully remapped during exploration carried out by Suomen Malmi Oy (Finnish Ore Co) in 1945—1952. A thorough geophysical survey was completed at the same time.

The aim of the lithogeochemical study carried out by the exploration department of Outokumpu Oy under the guidance of the present authors was to clarify: 1) the base metal dispersion patterns around the known sulfide deposits of the zone; 2) the distribution of metals in different rock types; as well as 3) to apply the lithogeochemical method in the exploration of this particular area.

METHODS

The field work was carried out mainly in the summer months of 1969 and was concluded in June, 1970. The total investigated area is shown in Fig. 1. The original geological maps made by Suomen Malmi Oy on a scale of 1 : 2 000 were used in the planning of the sampling.

The samples were collected along traverses across the strike of the leptite schist zone. The traverses which were planned on the best exposed areas, were from about 700 m to 1 km apart with a spacing between sampling sites of 30—50 m. The poorly exposed western part of the zone was studied by only three traverses.

More dense sampling was done in the periphery of all the known ore showings. Around the Orijärvi and Iilinjärvi deposits (Iilinjärvi field) the regular sampling grid measured 50 × 200 m, whereas around the Aijala and Metsämonttu deposits (Aijala field) a random sample was taken from almost every outcrop.

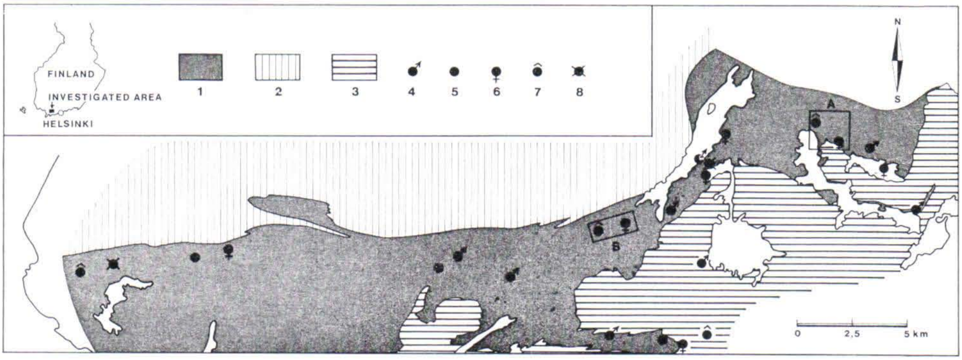

FIG. 1. Map and location of the investigated area. 1. Leptite zone, 2. Perniö granite, 3. granodiorites and basic intrusives, 4. iron ore deposits (sulfide and oxide), 5. arsenic mineralization, 6. copper ore deposits, 7. zinc ore deposits, 8. lead ore deposits, A, Iilinjärvi field, B, Aijala field.

The total amount of analyzed samples was 3 700. Each collected chip sample weighed on an average 4 kg. At each sampling site the rock type was determined carefully. In heterogenous rocks not more than one rock type was included in one sample. Weathered surfaces were avoided. In order to compare sampling methods, cuttings were taken along some traverses by a motor drill, but their analytical results did not notably deviate from those of the chip samples.

The samples were crushed in a jaw crusher, and the divided portions were milled in a »schwingmill». Heavy metals were extracted by means of brominated nitric acid treatment. Ag, Co, Cu, Fe, Ni, Pb and Zn were determined by atomic absorption spectrometry; As by X-ray fluorescence; and Hg by »Resonik» Hg-analyzer. Sulfur was determined titrimetrically.

The analytical data are presented on maps. In order to evaluate the deviations from the background values, the statistical parameters of the analytical data were estimated by computer. The frequency distributions and their geometric means, arithmetic means and medians were calculated for all samples as well as for each rock type. Factor analysis was also performed.

GEOLOGY

The schist zone sampled consists mainly of the fine-grained quartz-feldspar-rich metamorphic rocks known as leptites and their varieties. Amphibolites and calcareous schists are also present in this zone. The schist zone is surrounded by the Perniö granite in the west and north, and by granodiorites and more basic intrusive rocks in the south and southeast. Eskolas conceptions of mineral facies (Eskola 1922) were mainly based on his investigation in the Orijärvi region. His study of the contact aureole around the Orijärvi granodiorite gave the impetus to his ideas on magnesium metasomatism (Eskola 1914). Tuominen (1957) emphasized the role of faulting and fracturing on the structure of the Orijärvi region.

The geology of the Orijärvi region is dealt with in an abundant literature and there is no need for a detailed geological description in this study. For practical reasons, however, the terminology of the rock types used during the sampling deviates in some respects from those of the former studies. The terms employed and their definitions are presented in the following section.

Rock types:

Leptites:

- even grained
- with additional index minerals: cordierite, almandite, andalusite, muscovite or anthophyllite
- with calcareous intercalations
- blastoporphyritic, with insets of quartz and feldspar
- intermediate leptite denotes biotite and/or hornblende-rich darker variety of leptite

Leptite gneiss: medium- to coarse-grained gneissose leptite
Calcite marble (limestone)

Skarns:

- diopside skarns
- amphibole skarns
- garnet skarns

Diopside amphibolite: amphibolite with skarn or garnet-bearing intercalations, evidently calcareous sediment in origin

Amphibolites:

- biotite amphibolite: no primary textures indicating the origin
- homogeneous amphibolite: metagabbros or metadolerites
- volcanic banded amphibolites, agglomerates, inhomogeneous fine-grained hornblendeschists
- uralite- and plagioclaseporphyrites

Cordierite-anthophyllite rocks, also strongly tectonized biotite-anthophyllite-cordierite rocks

Mica gneisses, veined gneisses and phyllites

Intrusive rocks:

- peridotites, hornblendites, cortlandites
- gabbros: pyroxene and/or hornblendegabbros

— diorites, quartzdiorites, granodiorites and their contact varieties (esp. Orijärvi granodiorite)
— granites (esp. Perniö granite), pegmatite, quartz veins

Ore types:

1) The oxide iron ores:

a) low-grade titanomagnetite mineralizations encountered in the intrusive gabbros,
b) massive or disseminated magnetite ores in hornblende-garnet skarns,
c) quartz-banded iron ores associated with volcanic amphibolites where they are interbedded as long narrow stripes.

2) Iron sulfide deposits:

Pyrite-pyrrhotite mineralizations, with low Cu, Pb or Zn contents, and associated with banded iron ores.

3) Arsenic mineralization:

A weak, heterogeneous arsenopyrite mineralization among the volcanic amphibolites of the leptite belt. An arsenopyrite mineralization north of Iilinjärvi is gold-bearing, but in general this type does not contain any other ore minerals.

4) Complex Cu-Pb-Zn-Ag mineralization:

Economically the most important ore type of the region, and all of the mined deposits, Aijala, Orijärvi, Iilinjärvi and Metsämonttu belong to it. The textures vary from disseminated ores to massive veins and brecciated ores. This type can be further divided into several subgroups on the basis of their main sulfide minerals:

a) pyrite-pyrrhotite assemblage (e.g. Nygruva in Orijärvi),
b) chalcopyrite-rich ores (e.g. the main masses of Orijärvi and Aijala),
c) ores characterized by sphalerite (Iilinjärvi, some shoots of Metsämonttu),
d) galena ores which usually also contain precious metals, especially Ag (Metsämonttu).

The wall rocks are either silicious leptites, which in some places are bleached into sericite schists in the immediate vicinity of the deposits, or cordierite-anthophyllite rock or very often skarn or marble. Also a quartz or pegmatite vein can act as the host of the lead mineralization.

Geology of the Iilinjärvi field

The Iilinjärvi field (Fig. 2) is geologically characterized by a leptite belt surrounding the northern edge of the Orijärvi granodiorite. In the vicinity of the grano-

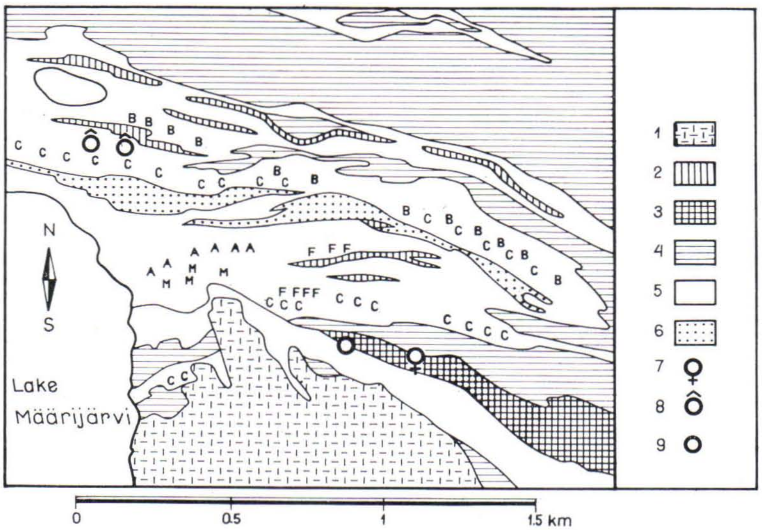

FIG. 2. Geology and ore deposits of the Iilinjärvi field. 1. Orijärvi granodiorite, 2. skarn, 3. cordierite-anthophyllite rock, 4. amphibolite, 5. leptite, 6. porphyritic leptite (A = andalusite, B = biotite, C = cordierite, F = anthophyllite and M = muscovite as porphyroblasts and as the characteristic mineral of leptite), 7. Orijärvi copper-zinc deposit, 8. Iilinjärvi zinc-lead deposit, 9. Nygruva pyritic ore.

diorite, the leptites contain abundantly cordierite, anthophyllite, andalusite and almandine as porphyroblasts. Farther north, the even-grained or porphyroblastic leptites are interbedded by silicic porphyritic leptites. Also several skarn and marble beds have been encountered. The banded amphibolite zone on the northern border of this sampling area has thick beds with an agglomeratic texture and also contains plagioclase and uralite porphyrites. The amphibolite just north of the Orijärvi mine forms the western edge of an extensive homogeneous amphibolite zone and represents the metamorphic variety of a formerly basic sill. The biotite amphibolites occur as interbeds in the leptites.

The mined-out Orijärvi deposits was in a tremolite skarn host rock between the cordierite-anthophyllite rock and the homogeneous amphibolite mentioned above. The disseminated or brecciated mineralization also occurs partly in cordierite-anthophyllite rock (»hard ore»). Westwards, the prevailing chalcopyrite-sphalerite-galena mineralization grades over to a pyrite-pyrrhotite mineralization, which is still to be seen around the old pit »Nygruva». The other old mines of the field lie south of the small lake, Iilinjärvi, in a sericite-quartz schist zone, which is evidently a bleached biotite leptite. The mineral assemblages contain galena, sphalerite, chalcopyrite, pyrrhotite and rarely pyrite (mostly secondary) in silicious wall rock.

Geology of the Aijala field

The field consists of a contact zone of leptite and amphibolite as shown in Fig. 3. The several diopside skarn intercalations in the amphibolite indicate their calcareous sedimentary origin, but the abundant uralite and plagioclase porphyrite interbeds as well as the agglomeratic structures suggest that the amphibolite is mainly volcanic in origin. The leptites have numerous skarn interbeds. Biotite-rich leptites, which approach the mica gneisses as well as the biotite-cordierite leptites and andalusite leptites occur near the contact zone of leptite and amphibolite. An almost NW-SE fault zone cuts the zone.

The ore deposits lie in the leptite-amphibolite contact zone. The exhausted Aijala deposit contained copper ore with chalcopyrite, pyrite, sphalerite, pyrrhotite and minor galena as the prevailing assemblage. Metsämonttu is a lead-zinc ore deposit containing several ore shoots. Galena and precious metals occur in some of the ore bodies and sphalerite in others. An almost horizontal fault divides the deposit into two parts.

Between Aijala and Metsämonttu there are two small ore showings which were mined out long time ago. The western, Aurums Aijala, was a lead deposit in skarn and marble containing mainly galena with some sulphosalts. The other, Hopeamonttu (»Silver pit»), contained a low-grade lead and silver mineralization in cordierite-biotite gneiss. There is still one small sulfide showing about 300 m NE of Aijala, containing mainly pyrite and pyrrhotite.

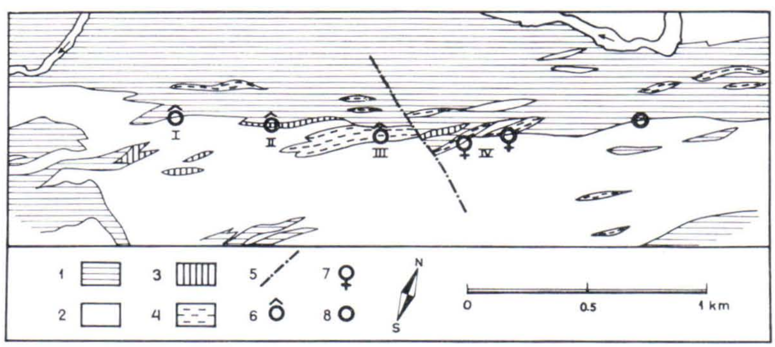

FIG. 3. Geology and ore deposits of the Aijala field, 1. amphibolite, 2. leptite, 3. skarn, 4. biotite and/or cordierite rich leptite, 5. fault, 6. zinc-lead ore, 7. copper ore, 8. pyritic ore deposit. I. Metsämonttu, II Aurums-Aijala, III. Hopeamonttu, IV Aijala.

GEOCHEMISTRY

Base metal distribution in the Iilinjärvi and Aijala fields

The distribution of Cu, Zn, Pb, As, Co, Ni, Mo, Hg and S in different rocks are examined as deviations from background. The background values are presented as arithmetic and geometric means and medians. Geometric means are considered the most suitable parameters for the background, since the frequency distributions of the contents are generally positively skewed.

The geometric and arithmetic means for mercury in the Aijala field are about 41 ppb and 150 ppb, respectively whereas in the Iilinjärvi field these values are below the limit of reliable detection which is about 40 ppb. The means of the other analysed elements (Tables 1 and 2) shows that in the Aijala and Iilinjärvi fields the geometric

TABLE 1

Average contents of S, Cu, Zn, Pb, As, Co, Ni and Mo in the rock types of the Iilinjärvi fied.

ARITHMETHIC MEANS

Number of samples	Rocks	%	ppm						
		S	Cu	Zn	Pb	As	Co	Ni	Mo
8	Granodiorite	.035	15	96	21	10	12	11	21
10	Contact rock *)	.041	19	56	16	11	13	12	27
15	Amphibolite	.065	84	49	23	16	21	26	27
49	Banded amphibolite	.062	77	54	27	17	23	25	33
14	Biotite »	.14	84	130	33	30	20	19	19
6	Diopside »	.063	44	96	51	20	24	32	22
43	Leptite	.13	30	140	40	23	17	23	33
10	Intermediate leptite	.14	42	76	25	66	22	58	32
16	Biotite »	.43	110	170	88	47	21	34	21
13	Andalusite »	.10	32	82	27	13	18	17	27
6	Calcareous »	.093	24	83	25	10	15	14	28
35	Cord.-Antoph. rock	.13	52	150	69	33	19	22	25
225	Total	.12	56	100	40	25	19	24	28

GEOMETRIC MEANS

Number of samples	Rocks	S	Cu	Zn	Pb	As	Co	Ni	Mo
8	Granodiorite	.028	12	65	20	10	11	10	15
10	Contact rock *)	.028	15	50	15	10	12	12	26
15	Amphibolite	.040	54	44	22	13	20	23	22
49	Banded amphibolite	.037	58	48	26	14	22	23	23
14	Biotite »	.069	25	78	25	17	18	17	13
6	Diopside »	.047	32	66	41	10	23	26	14
43	Leptite	.067	16	79	25	14	14	18	20
10	Intermediate leptite	.070	29	70	25	21	19	29	21
16	Biotite »	.084	43	110	52	22	18	24	13
13	Andalusite »	.061	14	78	23	11	16	16	20
6	Calcareous »	.073	22	60	23	10	14	14	24
35	Cord.-Antoph. rock	.069	23	110	41	15	18	19	19
225	Total	.054	28	71	28	14	17	19	20

MEDIANS

Number of samples	Rocks	S	Cu	Zn	Pb	As	Co	Ni	Mo
49	Banded amphibolite	.038	65	46	25	6	21	22	28
43	Leptite	.059	14	71	24	9	14	16	29
35	Cord.-Antoph. rock	.070	20	97	33	10	18	17	19
225	Total	.049	28	67	25	9	17	18	28

*) Contact variety of granodiorite

TABLE 2.

Average contents of S, Cu, Zn, Pb, As, Co, Ni and Mo in the rock types of the Aijala field.

Number of samples	Rocks	%	ppm						
		S	Cu	Zn	Pb	As	Co	Ni	Mo
	ARITHMETIC MEANS								
1	Peridotite	.040	17	75	34	20	26	15	10
2	Granodiorite	.010	4	57	6		7	7	130
7	Pegmatite	.043	10	12	22	86	8	11	11
3	Amphibolite	1.25	120	120	85	110	33	38	10
48	Banded amphibolite	.054	63	37	27	72	27	23	25
157	Biotite »	.17	62	56	86	200	30	28	20
29	Diopside »	.19	63	59	41	350	30	29	16
266	Leptite	.19	41	120	89	28	14	13	23
41	Intermediate leptite	.11	44	62	30	41	21	21	43
4	Biotite »	.75	81	390	100	30	34	68	68
9	Andalusite »	.75	110	390	280	58	16	12	12
58	Calcareous »	.36	81	120	59	69	21	18	18
2	Limestone	.12	10	87	95		35	34	34
23	Diopside skarn	1.14	970	490	2 200	370	19	27	27
2	Cord.-Antoph. rock	2.64	260	5 000	7 700		16	14	140
2	Sulphide ore	12.8	1.6 %	3.7 %	820		11	19	72
3	Others	.035	9	57	17	27	13	11	45
657	Total	.27	140	240	180	110	20	20	24
	GEOMETRIC MEANS								
7	Pegmatite	.032	8	10	16	4	8	10	13
48	Banded amphibolite	.027	54	32	25	10	25	20	19
157	Biotite »	.054	49	42	29	22	28	22	16
29	Diopside »	.083	52	41	32	42	28	24	15
266	Leptite	.053	20	57	27	9	13	12	17
41	Intermediate leptite	.034	31	57	23	10	19	15	28
9	Andalusite »	.50	55	170	120	24	15	12	22
58	Calcareous »	.11	34	57	42	11	19	17	21
23	Diopside skarn	.42	110	100	130	28	18	21	20
657	Total	.062	33	53	31	13	18	16	18
	MEDIANS								
48	Banded amphibolite	.024	52	31	26	14	27	20	19
157	Biotite »	.049	56	38	29	26	27	21	10
29	Diopside »	.069	60	40	35	44	26	21	18
266	Leptite	.049	17	53	26	15	13	11	10
41	Intermediate leptite	.020	29	57	28	16	22	17	19
58	Calcareous »	.11	29	49	37	15	19	18	19
23	Diopside skarn	.30	83	140	71	26	18	19	18
657	Total	.050	31	48	29	16	19	15	14

means of the ore forming elements: Cu, Zn, Pb, As and S are quite similar. The arithmetic means of these elements, however, are higher in the Aijala field than in the Iilinjärvi field. This differences between the arithmetic means are chiefly due to the fact that there are more samples with very high concentrations of the ore elements from the Aijala field than from the Iilinjärvi field. Such differences do not exist between the arithmetic means of the non-ore forming elements: Co, Ni and Mo.

An examination of the means according to rock types shows that in the Iilinjärvi field the contents of lead and zinc are above average both in biotite leptites and cordierite-anthophyllite rocks, which is natural, because in the Iilinjärvi field these two rock types occur together and are known to be related to the ore (e.g. Eskola 1914). In the Aijala field, the ore metals are concentrated within two rock types in particular: in diopside skarn and in andalusite leptite. The relationship between the skarns and the ore deposits is wellknown. The andalusite leptites and the sulfide deposits occur in the same leptite-amphibolite contact zone. It shoulds also be noted, that in the Aijala field, the abundance of copper in amphibolites is higher than in other rocks.

The dispersion of S, Cu, Zn, Pb, Hg and As in the Iilinjärvi field are depicted in Fig. 4. The contents of lead and zinc are in general higher in acid leptites than in basic rocks. The high copper values are usually found within the basic rocks. The dispersion of arsenic and mercury does not appear to specify rock types in the same way. The distribution of the high arsenic contents seem to be more dependent on the particular contact zones between amphibolite and leptite than on the ore deposits, as is also copper if the high background values of the amphibolite zone are excluded. The lithogeochemical differences, especially the arsenic content, between the Iilinjärvi and Orijärvi deposits reflect the variation in bulk composition of the deposits.

The dispersion of S, Cu, Zn, Pb, Hg and As in the Aijala field are illustrated in Fig. 5. The variations are generally larger than in the Iilinjärvi field. It is characteristic of the leptites of this field that the contents of sulfur, zinc and lead exceed the background, whereas high copper and arsenic contents are associated with amphibolites, although arsenic values exceeding the background are also encountered in the leptites. In the Aijala field the high contents of the ore elements are found more close to the ore deposits than those in the Iilinjärvi field. Copper, zinc and lead, in part also arsenic, are the most distinct indicators of ore. The appearance of the indicator elements as coherent anomalies is evidently due to the rather simple geology of the Aijala field: amphibolites and leptites are the two main rock types and they have a straight contact zone, where the ore deposits are situated. As a whole the geochemical image of the area gives the impression of an endogenous halo around the ore deposits. However, this geochemical picture does not show any clear zoning of the elements in a manner similar to that of the known ore types (see p. 10). This may be due to the varying frequency of outcrops, which made it impossible to investigate the environment of the ore deposits everywhere at an equal sampling density. The most extensive mercury anomaly lies S and SW of the Aijala deposit. This anomaly does

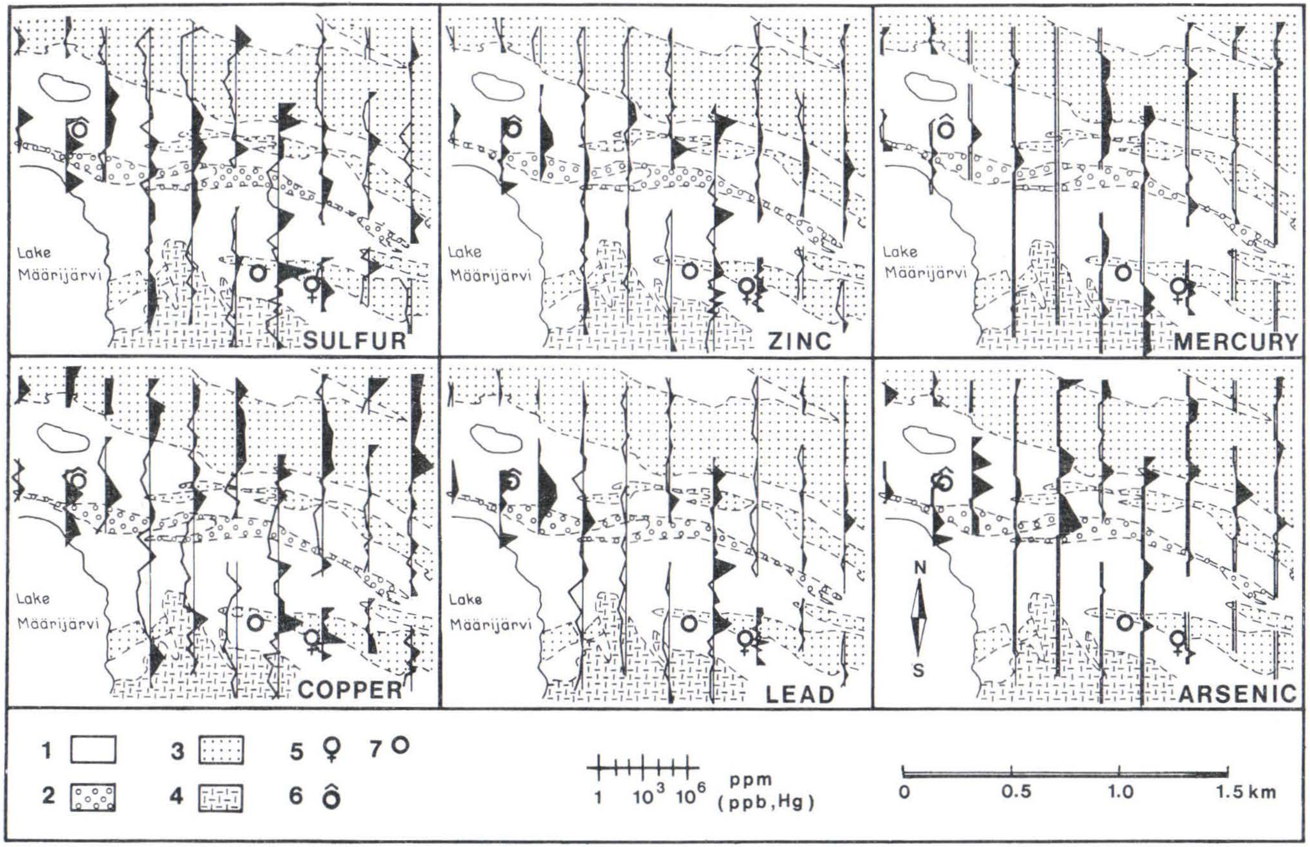

FIG. 4. Distribution of S, Cu, Zn, Pb, Hg and As in the Iilinjärvi field. The geometric mean for each element (see Table 1. p. 11) coincides with the sampling profile and the higher values correspond to the geometric scales given in the figure. 1) leptite, 2) porphyritic leptite, 3) amphibolite, 4) granodiorite, 5) Orijärvi Cu-Zn deposit, 6) Iilinjärvi Zn-Pb deposit, 7) Nygruva pyritic ore deposit.

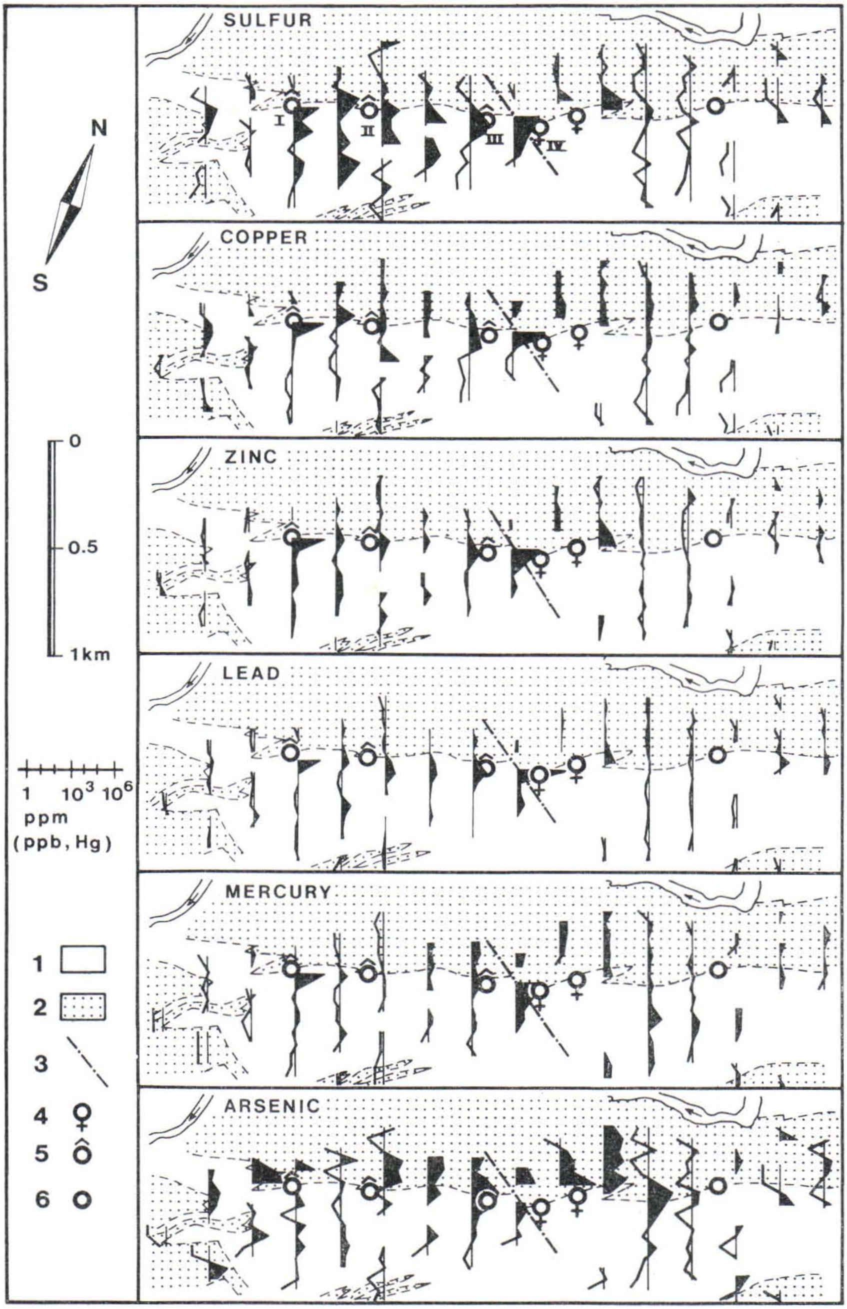

FIG. 5. Distributions of S, Cu, Zn, Pb, Hg and As in the Aijala field presented in the same way as in Fig. 4. Because of the irregular sampling grid the values of profiles were computed as averages of the samples falling within a 50 × 200 m rectangle around the profile point. 1) leptite, 2) amphibolite, 3) fault, 4) copper ore, 5) zinc-lead ore, 6) pyritic ore. The ore deposits: I. Metsämonttu, II. Aurums-Aijala, III. Hopeamonttu, IV. Aijala.

not correlate well with the distribution of the other elements. The cause of the anomaly is not known for certain, although it can be assumed that mercury migrated along a strong fault and breccia zone south of the abovementioned ore deposit.

Factor analysis

The aim of the factor analysis was to establish the characteristic associations between the analyzed elements. The factor analysis was based on the logarithms of the concentrations. Orthogonal rotation was carried out by Varimax method. The correlation and factor matrices are given in tables 3 and 4, respectively.

The correlation matrix of the Iilinjärvi field (Table 3) indicates high positive correlation between the element pairs Zn-S, Cu-Pb, Pb-Ag, Cu-Co whereas Hg and Mo do not show significant correlation with other elements. The correlation

TABLE 3

Correlation and factor matrices based on 225 samples from the Iilinjärvi field.

	S	Cu	Zn	Pb	Ag	Hg	As	Co	Ni	Mo
S		.31	.46	.38	.21	.04	.31	.18	.15	.00
Cu	.31		.16	.41	.28	.08	.17	.43	.20	.03
Zn	.46	.16		.64	.27	.17	.32	.15	.14	.02
Pb	.38	.41	.64		.48	.02	.23	.31	.28	.05
Ag	.21	.28	.27	.48		.01	.18	.25	.21	.19
Hg	.04	.08	.17	.02	.01		.05	.07	.10	.10
As	.31	.17	.32	.23	.18	.05		.30	.34	.03
Co	.18	.43	.15	.31	.25	.07	.30		.70	.01
Ni	.15	.20	.14	.28	.21	.10	.34	.70		.14
Mo	.00	.03	.02	.05	.19	.10	.03	.01	.14	

Factors	1	2	3	4	5	6	7	Comm.
S	.69	.02	.14	.14	.46	.17	.31	.85
Cu	.10	.22	.03	.10	.89	.22	.01	.91
Zn	.88	.09	.05	.18	.08	.19	.11	.88
Pb	.68	.20	.14	.03	.20	.52	.04	.84
Ag	.16	.09	.17	.03	.15	.88	.12	.87
Hg	.07	.07	.07	.97	.06	.03	.04	.97
As	.16	.22	.02	.05	.03	.11	.93	.96
Co	.06	.87	.06	.02	.29	.12	.09	.87
Ni	.10	.91	.14	.07	.02	.04	.16	.89
Mo	.04	.06	.97	.07	.02	.12	.01	.96
Eigenv. %	31.3	14.6	11.5	10.0	9.1	7.4	6.2	
Principal loading ...	Zn Pb S	Ni Co (Cu) (As)	Mo	Hg	Cu S (Co)	Ag Pb (Cu)	As (S)	

matrix of the Aijala field (Table 4) shows that sulfur has high coefficients of correlation with Cu, Zn, Pb and Ag; copper with Zn, Pb, Ag and Co; zinc with Pb, Ag and Hg; lead with Ag; and nickel has high coefficient with Co. Molybdenium has no correlation with the other elements. The highest values of correlation coefficients indicate that the ore-forming elements: Cu, Zn, Pb, Ag and S exist together in the rocks of both areas. In the correlation matrix of the Aijala field the coefficients are generally higher than in that of the Iilinjärvi field. This may be due to the wide variation of the metal contents and to the more coherent anomaly areas around the deposits of the Aijala field. It is noteworthy that the correlation matrices contain only positive coefficients. This may indicate that in this area the ore-forming processes might cause the enrichment of all the ore-forming elements together.

The factor matrix based on the Iilinjärvi data includes seven factors and that of the Aijala data six factors. These account for 90.1 % and 87.2 % of the total variance in the variables of the Iilinjärvi and Aijala data, respectively. The comparison

TABLE 4

Correlation and factor matrices based on 657 samples from the Aijala field.

	S	Cu	Zn	Pb	Ag	Hg	As	Co	Ni	Mo
S		.51	.56	.56	.41	.30	.27	.09	.14	.09
Cu	.51		.43	.49	.56	.31	.33	.43	.40	.07
Zn	.56	.43		.63	.47	.45	.04	.04	.09	.15
Pb	.56	.49	.63		.69	.42	.20	.22	.33	.03
Ag	.43	.56	.47	.69		.35	.19	.17	.23	.15
Hg	.30	.31	.45	.42	.35		.11	.02	.07	.10
As	.27	.33	.04	.20	.19	.11		.34	.36	.06
Co	.09	.43	.04	.22	.17	.02	.34		.68	.14
Ni	.14	.40	.09	.33	.23	.07	.36	.68		.14
Mo	.09	.07	.15	.03	.15	.10	.06	.14	.14	

Factors	1	2	3	4	5	6	Comm.
S	.90	.02	.01	.24	.05	.19	.90
Cu	.47	.46	.13	.19	.10	.41	.86
Zn	.72	.05	.11	.28	.32	.33	.80
Pb	.47	.17	.14	.03	.25	.70	.67
Ag	.19	.11	.12	.07	.11	.93	.83
Hg	.19	.01	.05	.06	.95	.19	.98
As	.09	.25	.04	.93	.05	.09	.94
Co	.04	.92	.05	.11	.02	.04	.82
Ni	.04	.86	.10	.14	.04	.15	.95
Mo	.05	.10	.98	.03	.04	.05	.98
Eigenv. %	37.7	38.4	10.3	7.6	7.2	6.0	
Principal loading	S Zn Cu Pb	Co Ni Cu (As)	Mo	As (Zn) (S)	Hg (Zn) (Pb)	Ag Pb Cu (Zn)	

of the factor matrices of Aijala and Iilinjärvi fields shows them to be very similar. In the Iilinjärvi field, factors 1, 2, 5 and 6 explain the variances of several variables. Of these, factor 1 is a Zn-Pb-S factor, 2 a Ni-Co factor, 5 a Cu-S factor and 6 a Ag-Pb factor. These factors may be interpreted in such a way that factor 1 accounts for the geochemistry of the polymetallic ore formation, 2 the geochemistry of the basic rocks, 5 the geochemistry of copper ore formation and 6 the geochemical association of silver with lead. In the Aijala field, factors 1, 2, 5 and 6 explain the variances of more than one variable. Of these, factor 1 is a Zn-Pb-Cu-S factor, 2 a Co-Ni-Cu factor, 5 a Hg-Zn-Pb factor and 6 a Ag-Pb-Cu-Zn factor. Hence, the most conspicuous difference between the factor matrices is that in the Aijala field the variables tend to be more distributed among the different factors than in Iilinjärvi field. Thus, in that field, factor 1 contains 77 % and 46 % of the variances of zinc and lead, respectively, whereas the corresponding values in Aijala are 52 % and 22 %. On the other hand, in Aijala, factor 1 includes 22 % of the copper variance but in Iilinjärvi only 1 %. These differences are to a great extent due to the fact that in the Iilinjärvi field there are two separate ores in different zones viz. the Orijärvi ore, which is mainly a copper ore and the Iilinjärvi ore, which is a zinc-lead ore. The Aijala field also contains different ore types, but they overlap in same contact

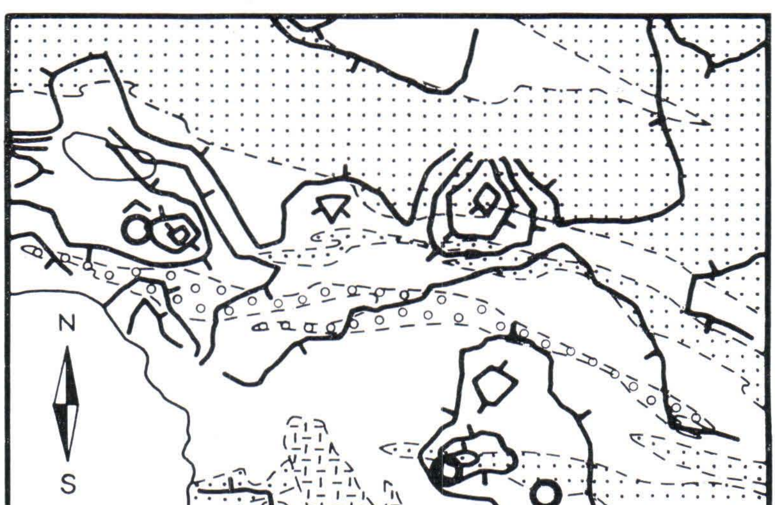

FIG. 6. Iilinjärvi field. Isopleths (1—5) for Zn-Pb-S factor scores. About rock types and ore deposits see Fig. 4.

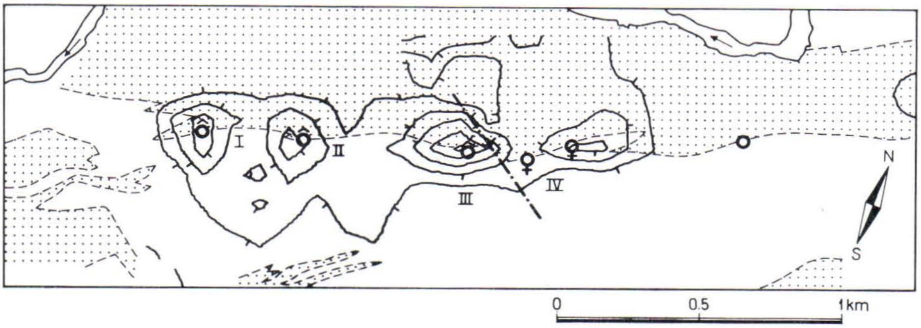

FIG. 7. Aijala field. Isopleths (0—4) for Zn-Pb-Cu-S factor scores. About rock types and ore deposits see Fig. 5.

zone between leptites and amphibolites and are not separated like the ore bodies of the Iilinjärvi field.

In both fields the most interesting factor is factor 1, which could also be called the ore factor. This factor is fairly common. In the Iilinjärvi field it includes 31.3 % and in the Aijala field 37.7 % of the total variance of the variables.

In order to describe factor 1, the factor scores for both the Aijala and Iilinjärvi data were computed. The factor scores are presented with smoothed contours as plotter outputs. The contouring method was as follows: Because the sampling grid was not regular, an arbitrary square grid with 100 m spacing was placed on the map. A weighted mean was then calculated on each new grid point from those sample scores which were inside the 150 m radius circular area around the point by using an inverse value of the distance as weighting factor.

The variations in the factor scores in the Iilinjärvi field are depicted on a map (Fig. 6), which shows that the known ore bodies are well indicated. However, it is important to note that whereas the Orijärvi ore is encircled by a closed anomaly pattern, the Iilinjärvi deposit is part of a long anomaly zone, which cuts the investigation area in a W-E direction. In the Aijala field (Fig. 7) the known ore deposits are situated within a closed oblong anomaly pattern with major axis parallel to the amphibolite-leptite contact. Hence, both in Aijala and Iilinjärvi similar ore represented by similar anomaly patterns as far as the elemental associations and the shapes of the anomalies are concerned.

Regional distribution of mercury

The analysed samples suggest that the abundance of mercury in the bedrock of the leptite zone is low and frequently below the limit of reliable detection which is about 40 ppb. Hence, all tenors with Hg less than 80 ppb are marked on the map

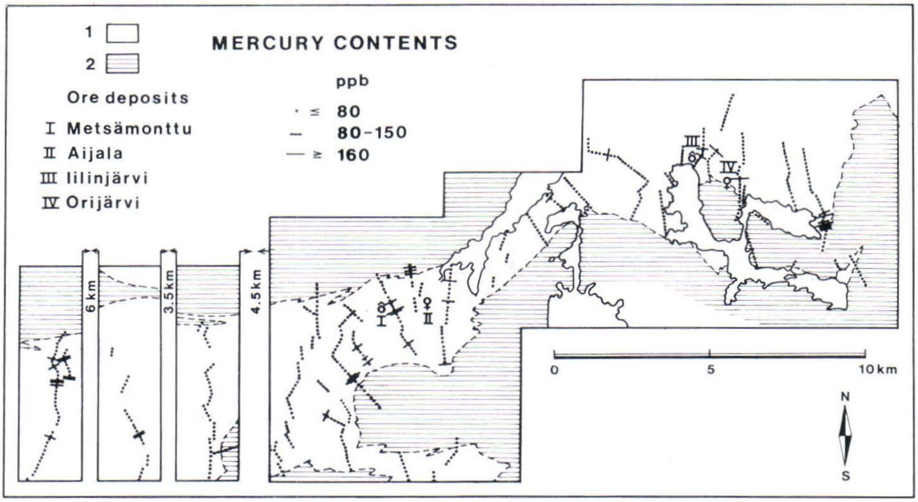

FIG. 8. Mercury contents $\geq$ 80 ppb in the Orijärvi leptite zone. The spacing between the sampling sites along the profiles were normally 40—60 m. 1) leptite zone, 2) intrusive massifs.

(Fig. 8) only with the symbol of a sampling site. Abundances exceeding this anomaly threshold occur in several places in the leptite zone as isolated spots, which, however, tend to concentrate on three parts of the zone. The first is the Iilinjärvi field near the ore deposits of Orijärvi and Iilinlampi, and east of it at the arch-shaped contact of the leptite zone with the granodiorite. Secondly, mercury anomalies occur in the Aijala field, known for its ore deposits, as well as SW of it, in bedrock characterized by cordierite-anthophyllite rocks. Thirdly, anomalous concentrations are met with at the western end of the zone investigated, where there are polymetallic sulphide deposits as well as cordierite-anthophyllite rocks.

As a whole, the study seems to indicate that the points with anomalous mercury abundances are concentrated on those parts of the zone in which there are known ore deposits, or in which there are rocks, e.g. cordierite-anthophyllite rocks, associated with these deposits. In some cases, the mercury anomalies may also be controlled by certain structures of the bedrock.

CONCLUSIONS

1. Present lithogeochemical investigation has been able to reveal zones which are anomalous in relation to the environment. The zones are associated with certain geologic unit. Examples are some of the contact zones between amphibolite and leptite, where anomalous base metal contents occur.

2. Local studies show that the base metals can be enriched in certain aureoles around known ore deposits (e.g. in the Aijala field).

3. The mercury distribution in the bedrock seems to be directly related to ore deposits. In particular the mercury patterns are controlled by petrological or structural properties. However, for the mercury the sampling error is large, and special attention should be paid to the sampling design. Variation in fracture frequency is supposed to be one of the causes for this large error. Possible other causes should be further investigated.

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REFERENCES

ESKOLA, PENTTI (1914). On the petrology of the Orijärvi region in southwestern Finland. Bull. Comm. géol. Finlande 40.

—»— (1915). Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvi-traktens metamorfa bergarter. Summary of the contents: On the relation between chemical and mineralogical composition in the metamorphic rocks of the Orijärvi region. Bull. Comm. géol. Finlande 44. 145 p.

—»— (1922). The mineral facies of rocks. Norsk Geologisk Tidskrift 6: 143—194.

—»— (1950): Orijärvi reinterpreted. Bull. Comm. géol. Finlande 150: 93—102.

—»— (1963). The Precambrian of Finland. Pp. 145—263 in the Precambrian, Vol. 1; ed. by K. Rankama. Interscience Publ. New York.

MIKKOLA, TOIVO (1955). Origin of ultrabasics in the Orijärvi region. Bull. Comm. géol. Finlande 1968: 39—51.

TUOMINEN, HEIKKI V. (1951). Metamorphic concentration of magnesium and iron in the Orijärvi region: a reply. Bull. Comm. géol. Finlande 154: 233—238.

—»— (1957). The structure of an Archean area: Orijärvi, Finland. Bull. Comm. géol. Finlande 177. 32 p.

—»— (1961). The structural position of the Orijärvi granodiorite and the problem of synkinematic granites. Bull. Comm. géol. Finlande 196: 499—515.

TUOMINEN, HEIKKI V. and MIKKOLA, TOIVO (1950). Metamorphic Mg-Fe enrichment in the Orijärvi region as related to folding. Bull. Comm. géol. Finlande 150: 67—92.