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Tlf: (081) 40500
Telex: 64065 SUA-N

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Forfatter: <u>RAI</u> KISHANLAL	Ant:
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Tittel: A GEOCHEMICAL APPROACH TO THE GENESIS OF THE CALDONIAN SULPHIDE MINERALIZATION AT SULITJELMA, NORWAY
(NORSK GEOL. TIDSSKR. 57 361-78)

Fordeling
Sulitjelma:

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X1:	Y1:	Z:
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Sulis koord:		
X3:	Y3:	Z:
X4:	Y4:	

Resyme:
MED BRUK AV SPOR-ELEMENT GEOKJEMI
OG SVØVEL-ISOTOP DATA, FORFATTEREN
PRESENTERER GENETISK KONSEPTER
OM MALM-DANNELSE. SPOR-ELEMENT
INNHOOLD AV MALMEN ER DISKUSERT MED
EXAMPLER FRA GIKEN, CHARLOTTA,
HAMK., BURSI OG JAKOBSBAKKEN.
(COBALT OG NICKEL BL. A.)

(ENGÆLSK TEKST)

Andre:

Kommentar:

A GEOCHEMICAL APPROACH TO THE GENESIS OF THE CALEDONIAN SULPHIDE MINERALIZATION AT SULITJELMA, NORWAY

KISHANLAL RAI

Rai, K. L.: A geochemical approach to the genesis of the Caledonian sulphide mineralization at Sulitjelma, Norway. *Norsk Geologisk Tidsskrift*, Vol. 57, pp. 361-378. Oslo 1977.

Systematic geochemical studies on the Sulitjelma ores bring out their basic igneous parentage, confirm that the massive pyritic and disseminated ore-types belong to the same pulse of ore-forming fluids, and support the earlier contention that the massive pyrrhotitic ores are of paligenetic origin. The composition of ores/minerals, though broadly uniform on the deposit-scale, exhibits small yet consistent differences from one ore-body to another. The overall observations are best explained by volcanic exhalative mode of ore-genesis which is supported also from the study on isotopic fractionation of sulphur in the deposit.

K. L. Rai, Department of Applied Geology, Indian School of Mines, Dhanbad-826004, India

The pyritic copper-zinc ore deposit of Sulitjelma (67°10'N, 16°E) in northern Norway represents a small and isolated, yet important, subprovince of the larger well-known Caledonian metallogenetic province of Scandinavia. It is a typical strata-bound, massive sulphide mineralization, exhibiting close spatial association with volcanic rocks that seem to have originated during the early stages of development of the Caledonian geosyncline. The deposit seems to have undergone regional metamorphism from biotite to kyanite-grade conditions (Henley 1968, 1970), possibly isofacially with its enclosing rocks, thereby presenting a complicated picture that is susceptible to varied genetic interpretations.

Views and hypotheses, advanced from time to time in the past to explain the genetic mode of this famous Caledonian mineralization, range widely from magmatic-injection (J. H. L. Vogt 1894, Brøgger 1901, Th. Vogt 1927) through hydrothermal-replacement (Sjøgren 1894, Carstens 1935, Kautsky 1953, 1958) to exhalative-sedimentary (Oftedahl 1958) and syngenetic-sedimentary (Stelzner 1891, Stutzer 1906, Middendorf 1914, Krause 1956) processes. A survey of the relevant published contributions makes it abundantly clear that most of these views and hypotheses are based exclusively upon general field studies of the deposit and its geologic environment, while others seem to be extensions of the theories evolved primarily for the sulphide mineralizations in Scandinavian Caledonides in general. Contributions made so far in the field of ore geology relating to this deposit seem to be surprisingly few. As stated in his monograph on the geology of Sulit-

jelma region, Th. Vogt (1927) had planned to write another monograph dealing with the ore geology of the Sulitjelma deposit, but this was unfortunately never done owing to his sad and untimely demise. Ramdohr (1938) described the antimony-rich paragenesis from the Jakobsbakken ore body of the deposit. J. H. L. Vogt (1894), Th. Vogt (1927), and Kautsky (1953) presented their views regarding the geological setting of this famous deposit, as parts of their respective studies on the geology of the region. Recently, Wilson (1973) reviewed the present state of knowledge in this connection and gave his own assessment of the setting in the light of his detailed structural studies in the area. However, systematic and detailed studies covering many other aspects of the mineralization, particularly the geochemical studies, have been long awaited.

It has been the author's contention that, in view of the highly complex geologic history of this deposit, the only way to throw light on the primary mode of sulphide genesis in this region is to undertake an exhaustive chemical and geochemical study of its ores and the associated geologic environment. The present contribution represents but a test case of such a contention. Accordingly, greater stress has been laid in this paper on the genetic evaluation and other implications of the geochemical study of the deposit, while the methods, procedures, and results thereof have only been summarized briefly.

Geology of the deposit

The metasedimentary environment of the ore deposit belongs to the lower part of the Caledonian (Ordovician) succession of eugeosynclinal rocks and comprises a varied sequence of calcareous and aluminous pelitic-schists, quartzites, amphibolites etc. All these rocks are intruded by a huge gabbroic

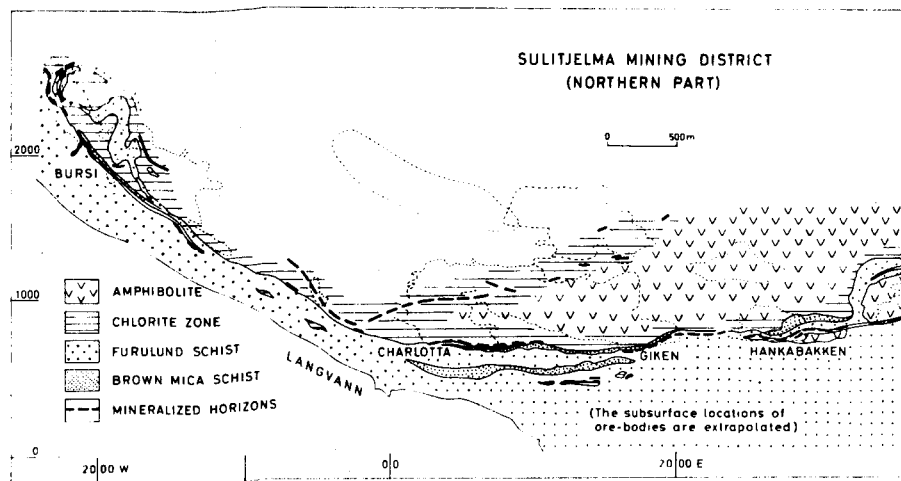


Fig. 1. Geological map of Sulitjelma mining district (northern part), Nordland, Norway. (Modified after Fr. Carlson, 1926-30).

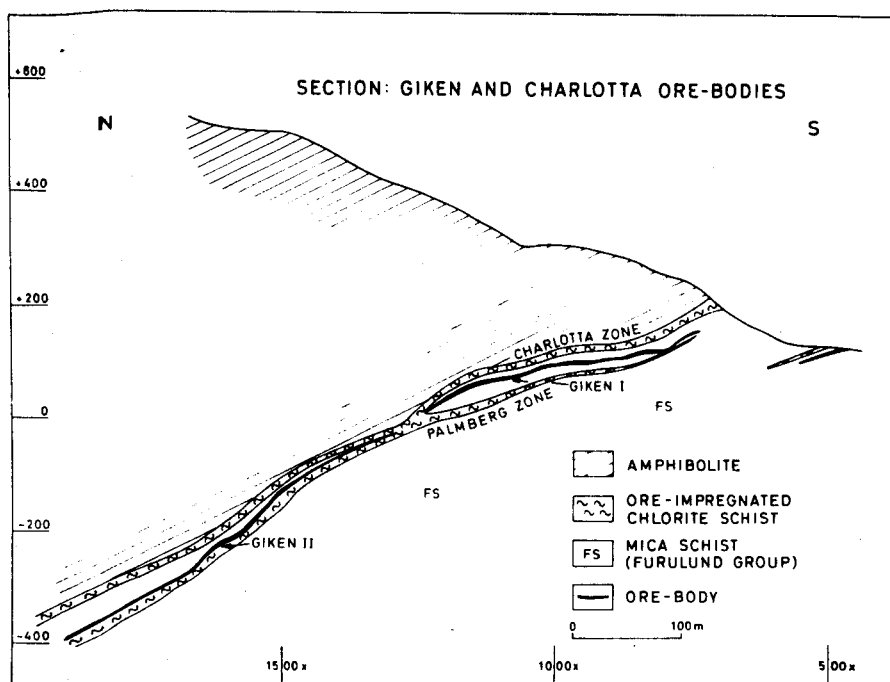


Fig. 2. Geological section of Sulitjelma mining district: The Giken and Charlotta ore bodies.

mass that constitutes the famous Sulitjelma gabbro phacolith, exposed to the north (Fig. 1). According to J. H. L. Vogt (1894) and Th. Vogt (1927), the ore bodies lie closely connected to the strongly altered lower layers of this phacolith, the largest deposit lying concordantly in the Furulund schists immediately below. Kautsky (1953), on the other hand, contends that the localization of ores in the region has taken place in or near the thrust planes underlying the Caledonian nappes of the area. Recent work by Wilson (1973) has shown that Kautsky's postulations need some modification as the ore bodies lie well within a single structural unit of the area.

The ore deposit comprises a series of elongate, ruler-shaped, tabular ore bodies that exhibit remarkable concordance with the enclosing metasediments throughout the region and are often arranged en echelon along a narrow mineralized zone (Fig. 2). This zone is traceable for about a hundred km in the region, but the workable ore bodies seem to be preferentially concentrated in only about 8 km of its strike length on the northern side and in about 15 km of its strike length to the southern side of the lake Langvatn. Current mining operations are confined to the ore bodies occurring north of Langvatn; those to its south (including Jakobsbakken) were abandoned long ago.

In general, the ore bodies consist of at least three different morphologic/

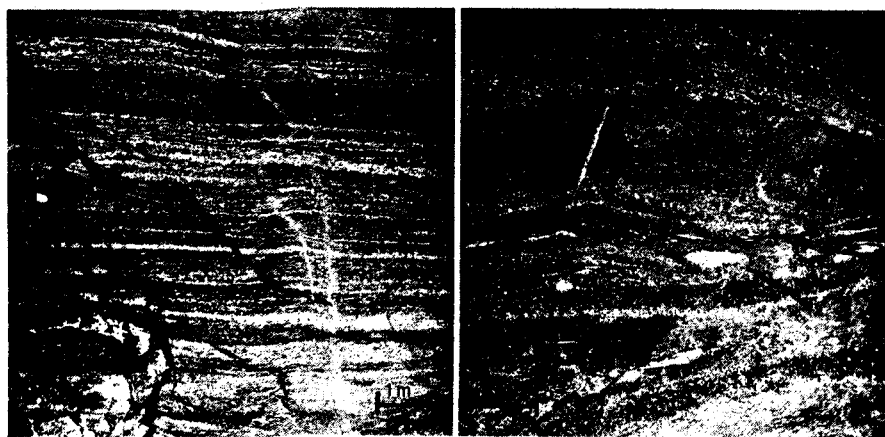


Fig. 3 (A). Typical disseminated pyritic ore exhibiting layered structure. Hankabakken ore body, Level 361 west.

Fig. 3 (B). Layers and bands of massive pyritic ore interstratified within Furulund mica schist, Giken ore body, Level-61 west.

mineralogic types of ores: the massive-pyritic ore, disseminated ore, and the pyrrhotite-chalcopryite ore. The three ore types tend to be assimilated or intermixed in widely variable proportions in the different ore bodies. Figs. 3 and 4 exhibit some of the commonly observed physical and morphological characteristics of these ores in their subsurface expositions or in a representative hand specimen.

The mineralogy of the ores is, in general, remarkably simple. Varying proportions of pyrite, pyrrhotite, chalcopryite, and sphalerite constitute the bulk of the different ore types. A number of minor and rare minerals,

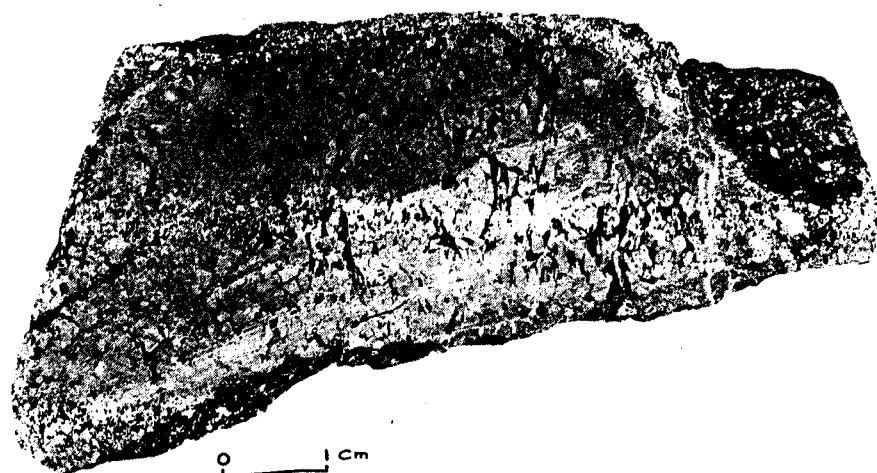


Fig. 4. Specimen photograph of typical coarse-grained massive pyritic ore from Giken ore body. Several lenticles of sericite-schist may be seen interstratified within the ore.

constituting hardly 2–3 % of the ore mass, are observed sparsely distributed in the ores; these include galena, arsenopyrite, tetrahedrite, molybdenite, mackinawite, bournonite, and many other sulpho-salts. The occurrence of a multitude of Cu-, Pb-, Ag-, As-, and Sb-sulphides and sulphosalts, and silver, gold, and antimony as native metals, was reported by Ramdohr (1938) from an antimony-rich paragenesis in Jakobsbakken ore body. The observed textures and structures in ores show that they have generally undergone varied effects of high-grade regional metamorphism.

Method of study

The geochemical investigation was carried out on the selected samples of ores and their constituent monomineralic sulphide-mineral fractions. The samples for the study were collected according to definite sampling schemes from four of the principal ore bodies of the deposit, namely Giken, Hanka-bakken, Charlotta, and Bursi. The ores from Jakobsbakken ore body lying in the now-abandoned southern part of the mining district have been studied only to a limited scale.

Analytical work on major, minor, and trace elements in the ores/ore minerals and host rocks was accomplished principally by the atomic absorption spectrophotometric method following well-tested techniques of Langmyhr & Paus (1968, 1970) in their own laboratory at Kjemisk institutt, Universitetet i Oslo, Norway. A high degree of accuracy of results was ensured from numerous replicate analyses of selected samples and available international standards.

Sulphur isotopic analyses were kindly undertaken by Prof. M. L. Jensen at Laboratory of Isotope Geology, University of Utah. A precision of ± 0.2 permil in the analytical results was obtained.

Results

In the major-elemental composition of ores, it is principally the analytical results of copper and zinc and their varying ratios that seem to have significant genetic implications. These are presented in Figs. 5 & 6.

The abundance of several minor and trace elements was determined in about 350 samples of different sulphide minerals from ores representing various ore types and ore bodies of the deposit.

The elements that were looked for in the various typomorphic minerals of ores and were determined quantitatively included Co, Ni, Mn, Mo, Cr, Ti, V, Ga, Cd, Ag, and Pb. A few others, such as Zn, Cu & Fe, were determined in selected major mineral fractions as a final check on the purity of analysed samples. As, Sb, Bi, Sn, and Se were determined semi-quantitatively. The results of all these analyses have already been presented earlier in detail (Rai 1971, 1972). Only a few critical results having significant genetic implications are presented in this paper. Fig. 7 depicts the distribu-

tion of cobalt and nickel in the pyrite and pyrrhotite fractions of ores from Charlotta and Bursi ore bodies, while Figs. 8A and 8B bring out the patterns of cobalt-nickel relations in different ore types and ore bodies of the deposit. The abundance of different elements in pyrites from different ore types/ore bodies are summarized in Table 1, while Table 2 summarizes the distribution-ratios of selected trace-elements among the typomorphic sulphide phases of various ore-types from different ore-bodies. Figs. 9 and 10 depict the patterns of partition-distribution of various trace-elements in different mineral pairs of the ores.

The results of sulphur-isotopic study of the deposit are shown in Figs. 11 and 12.

Discussion

Major element composition of the ores

The Sulitjelma ore, in general, represents a rich massive concentration of iron sulphides with subsidiary amounts of copper and zinc. All the other metals, notably lead, arsenic, antimony, tin, gold, silver, etc., tend to occur in minor to trace amounts.

Marked differences are observed in the base-metal composition of ores from different ore bodies of the deposit. The relevant results in this connection, as depicted in triangular diagram in Fig. 5A, show that a wide range of zinc-rich to zinc-poor ore bodies is represented in this deposit. No systematic trend in the spatial distribution of such ores or ore bodies is, however, discernible. Observed wide variations in base-metal composition of ores in different ore bodies of the deposit that are located so close to each other in the same geologic environment appear difficult to explain by observations made in the field. The distribution pattern of copper and zinc in the deposit (Fig. 5A) indicates some sort of progressive metal differentiation in the ore-forming fluids following different paths, most probably prior to the deposition of the ores itself. The observed pattern compares remarkably well with that reported for the basic rocks (Fig. 5B) by Sandell & Goldich (1943). Following Wilson & Anderson (1959), such an observation may be suggestive of primarily basic igneous parentage of the ore-forming fluids referred to above.

The various ore types show minor, yet distinctive, differences in their major metal values. The pyrrhotitic ores appear to be generally richer in base metals, particularly in copper, as compared to the massive-pyritic ores. The massive and disseminated pyritic ores, although differing markedly in their absolute content of copper and zinc, exhibit remarkably similar trends in their frequency distribution of $\text{Cu}/(\text{Cu} + \text{Zn})$ ratios (Fig. 6). This observation seems to be in significant contrast to that noted by Wilson & Anderson (1959) at Geco mine deposit of Canada, where the trends of Cu : Zn ratios for massive and disseminated ores are distinctly opposed to each other and are attributed to different pulses of ore-forming fluids. The two

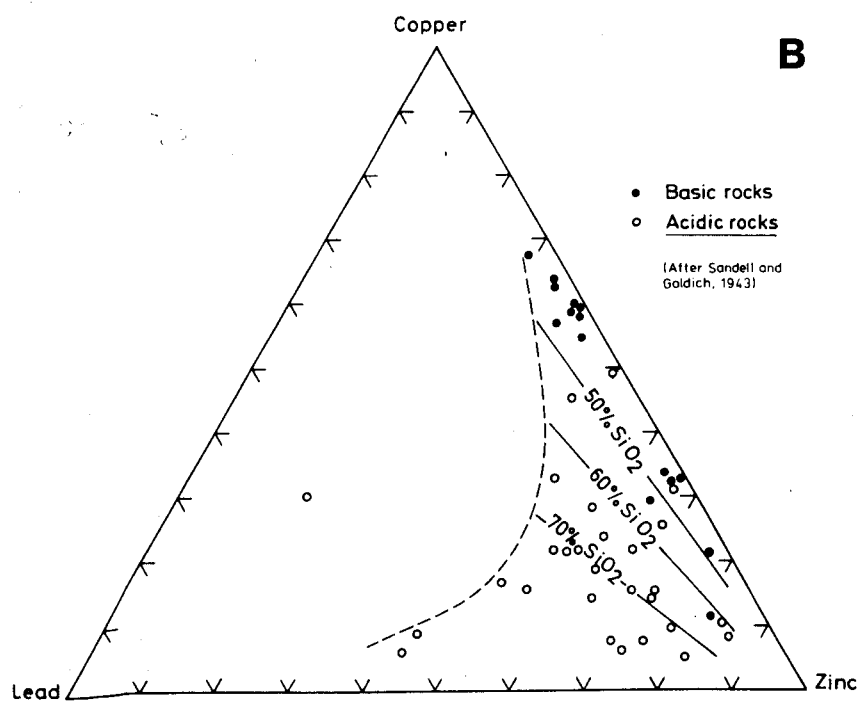
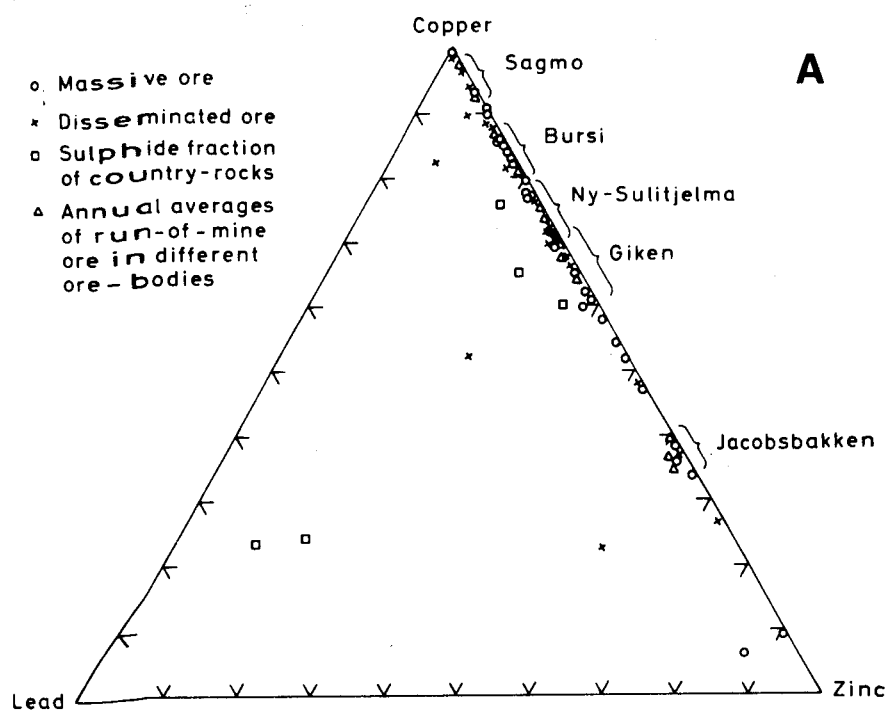


Fig. 5 (A). Copper, zinc and lead ratios in average ores of different ore bodies of Sulitjelma deposit.

Fig. 5 (B). Copper, zinc, and lead ratios in some igneous rocks. (After Sandell & Goldich 1943).

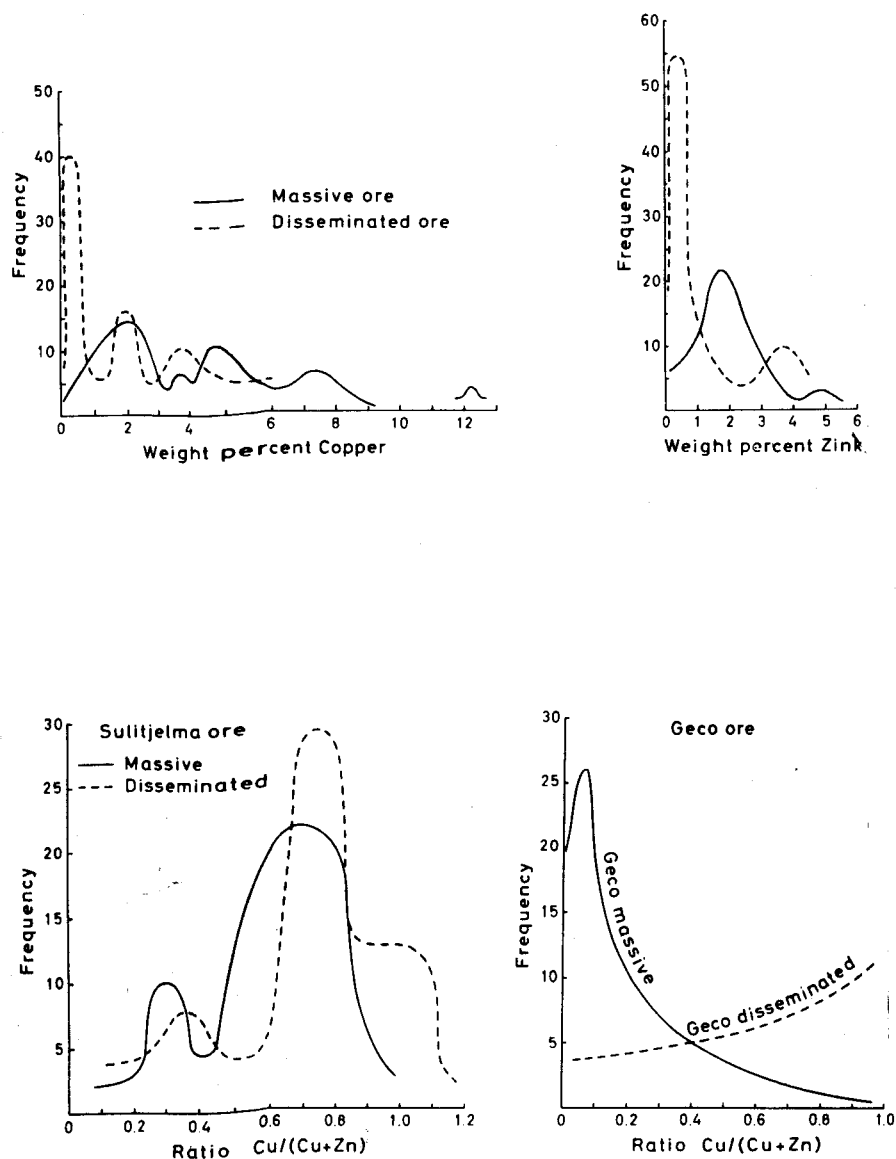


Fig. 6. Frequency distribution of copper: zinc ratios in the massive and disseminated ores of Sulitjelma deposit compared with that in Geco deposit, Canada.

ore types at Sulitjelma, by comparison, appear to be closely related to each other belonging, by and large, to the same pulse of ore-forming fluids.

Minor and trace-element composition of the ores

Abundances and patterns of distribution of various minor and trace elements in the ores and their typomorphic sulphide minerals representing various ore types and ore bodies have been described and discussed earlier in detail

Table 1. Trace-elements in pyrite from different ore types and ore bodies of Sulitjelma deposit. All values given below are in parts per million (ppm). Ore-type A corresponds to massive pyritic-ore, B to disseminated ore and C to pyrrhotitic-chalcopyrite ore.

Orebody	Ore-type	No. of samples	Co	Ni	Co:Ni	Mn	Mo	Ga	Ag
GIKEN	A	28	302	104	2.9	16	23	17	4.5
	B	16	449	101	4.5	14	20	16	4.3
	C	19	943	90	10.5	14	27	17	6.0
GIKEN	average	63	533	99	5.6	15	23	17	5.0
CHARLOTTA	A	7	1271	123	10.3	12	19	16	6.4
	B	15	1318	134	9.8	11	10	16	5.2
	C	12	1397	119	11.7	10	15	15	4.7
CHARLOTTA	average	34	1332	127	10.5	11	15	16	5.2
HANKABAKKEN	average B	11	711	117	6.1	13	17	17	5.6
STURRE	B	2	592	115	5.2	22	7	14	5.0
BURSI	average B	11	1589	89	17.8	9	26	14	5.4
JAKOBSBAKKEN	C-I	1	1875	60	31.2	87	5	15	8.5
	C-II	1	4000	90	44.5	38	8	20	6.0

(Rai 1971, 1972). Only the generalized observations of this study are presented here.

In general, the various types of ores exhibit much the same suite of minor and trace elements throughout their occurrence in the deposit. The abundance of a minor or trace element in a particular typomorphic mineral generally displays almost regular and uniform pattern on the broad scale of the deposit. Elements like Ni, Mn, Ga, Ag, As, and Sb exhibit fairly

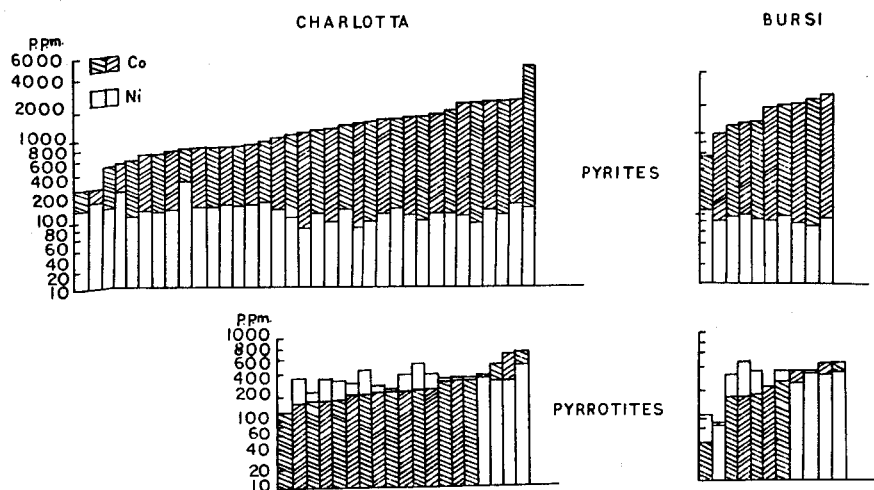


Fig. 7. Distribution of cobalt and nickel in pyrites and pyrrhotites from Charlotta and Bursi ore bodies.

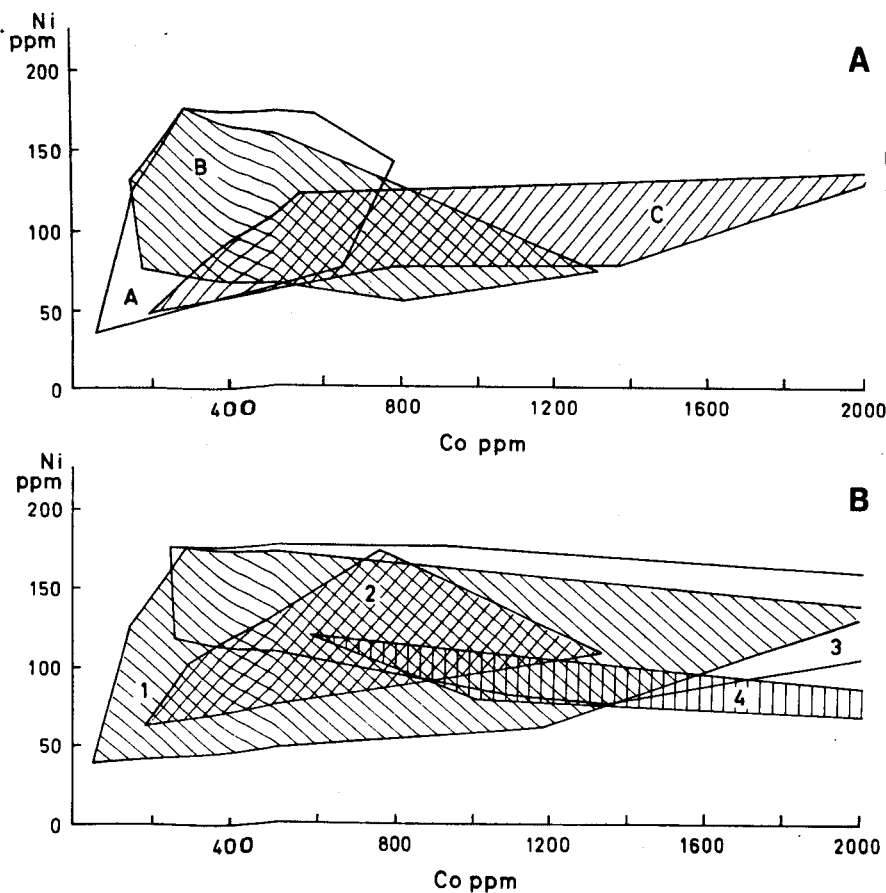


Fig. 8 (A). Fields demarcating cobalt-nickel relations in pyrites belonging to various ore types of Giken ore body, Sulitjelma deposit. (A stands for massive pyritic, B for disseminated and C for pyrrhotitic ore types).

Fig. 8 (B). Fields demarcating cobalt-nickel relations in pyrites belonging to the various ore bodies of Sulitjelma deposit. 1. Giken, 2. Hankabakken, 3. Charlotta, and 4. Bursi.

consistent behaviour (Table 1). The erratic behaviour of elements like cobalt may be attributed to its extraordinary sensitivity to post-depositional events such as metamorphism, recrystallization, and remobilization of the ores. General consistency of element concentration in a particular mineral phase is better pronounced on the scale of an individual ore body, and is further refined considering a particular ore type belonging to it (Table 1, Fig. 7). Extensive geochemical studies on the sulphide deposits of different modes of origin from the Western and Little Carpathians and other parts of the world by Cambel & Jarkovsky (1967, 1968) have shown that the geochemical regularities of the type noted as above are generally diagnostic of primarily the sedimentary or volcanic-exhalative type of sulphide genesis. They are in distinct contrast to the abundance pattern of minor and trace elements in the typomorphic minerals of magmatic and hydrothermal deposits. The geo-

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chemical picture of the later type of deposits, according to them, is generally variable and irregular, the visible variance being caused by influences of wall-rocks, temperature of ore solutions, periodicity of mineralization, and several other factors.

While the geochemical regularities, in a relatively broader sense, characterize the Sulitjelma deposit in general, certain minor, yet appreciably characteristic differences among its different ore types and ore bodies appear noteworthy. Such differences, magnified to different scales by different elements, are best represented by elements like cobalt and nickel. The geochemical data presented in Table 1 and Fig. 8 show this clearly. Other typomorphic minerals – namely pyrrhotite, chalcopyrite and sphalerite – show exactly similar behaviour regarding their elemental abundances. It seems very significant to note that a particular ore type generally exhibits slightly, yet characteristically different levels of concentration of an element in a particular mineral in different ore bodies of the deposit, while exhibiting remarkable consistency in the abundance of that element in the mineral on the scale of an ore body. Such definite and consistent differences in the minor and trace element composition of ores in different ore bodies of the deposit, coupled with the kind of observed differences in their base metal composition (Fig. 5A), seemingly reflect primary differences in the overall composition of ores in different ore bodies of the deposit and are possibly explained by relatively small changes of genetic, thermodynamic, and other conditions of ore deposition in different ore bodies.

It has been further observed that a particular ore type exhibits closer and rather interdependent geochemical relations with other ore types associated with it in the same ore body rather than with the same ore type in other ore bodies of the deposit. As evident from the data of Tables 1 and 2, this relationship is best displayed by massive pyritic and pyrrhotitic ore types and indicates an intimate genetic relation between them. The interdependence of the abundance patterns of different elements and of their distribution-ratios in typomorphic minerals in these ore-types offers strong support to the idea of palingenetic mode of origin of pyrrhotitic ores as proposed earlier by several leading Scandinavian workers (Bugge 1948, 1954, Kautsky 1958, Vokes 1962) for the Caledonian pyrrhotitic ores in general.

Statistical studies on the distribution of different trace-elements among the various sulphide-mineral phases of the ores bring out fairly regular and meaningful patterns, particularly for Co, Ni, Mn, and Ag. Average distribution ratios of these elements in pyrite, pyrrhotite, and chalcopyrite from the various ore types and ore bodies of the deposit are given in Table 2, while the patterns of distribution of various elements in different mineral pairs are shown by distribution diagrams in Figs. 9 and 10. On the whole, a good measure of regularity or uniformity seems discernible in the partitioning of an element among the three typomorphic sulphide minerals of ores on the scale of an ore body as well as on the deposit scale. This is borne out also by the definite trends towards linearity of distribution curves

Table 2. Distribution of elements in pyrite, pyrrhotite, and chalcopyrite of Sulitjelma ores.

Element	Ore-type	No. of samples averaged	Giken	Charlotta	Bursi
			Pyritic ore (10)* Pyrrhotitic ore (6)	Pyritic ore (10)* Pyrrhotitic ore (7)	Pyritic ore (8)* Pyrrhotitic ore (4)
COBALT	Pyritic ore	Py.	491	1229	1662
		Po.	107	285	213
		Cpy.	97	111	189
		D.Ratio	4.6:1:0.90	4.3:1:0.4	7.8:0:0.89
	Pyrrhotitic ore	Py.	798	1435	1596
		Po.	149	272	288
		Cpy.	98	121	178
		D.Ratio	5.3:1:0.65	5.3:1:0.44	5.5:1:0.62
NICKEL	Pyritic ore	Py.	117	127	84
		Po.	185	350	288
		Cpy.	42	40	41
		D.Ratio	0.63:1:0.23	0.36:1:0.12	0.30:1:0.14
	Pyrrhotitic ore	Py.	91	115	101
		Po.	186	438	280
		Cpy.	70	81	40
		D.Ratio	0.49:1:0.37	0.39:1:0.18	0.36:1:0.14
MANGANESE	Pyritic ore	Py.	15	9	7
		Po.	93	134	116
		Cpy.	72	43	64
		D.Ratio	0.16:1:0.77	0.07:1:0.33	0.06:1:0.55
	Pyrrhotitic ore	Py.	15	10	9
		Po.	109	112	168
		Cpy.	80	50	71
		D.Ratio	0.14:1:0.74	0.11:1:0.44	0.05:1:0.42
SILVER	Pyritic ore	Py.	3.8	5.9	5.1
		Po.	55	40	28
		Cpy.	131	49	55
		D.Ratio	0.07:1:2.38	0.15:1:1.21	0.18:1:1.94
	Pyrrhotitic ore	Py.	3.0	3.7	5.7
		Po.	53	42	84
		Cpy.	128	50	66
		D.Ratio	0.06:1:2.40	0.09:1:1.19	0.07:1:0.78

* Numericals in the parentheses refer to the No. of samples averaged.

in most of the distribution diagrams pertaining to both massive pyritic and pyrrhotitic ores. A detailed geochemical study on sphalerites belonging to these two prominent mineral parageneses in this deposit (Rai 1977) also brings out a comparable regularity or uniformity of minor and trace-element partitioning between sphalerite and other associated minerals. However, it appears difficult to surmise the implications of these observations in the

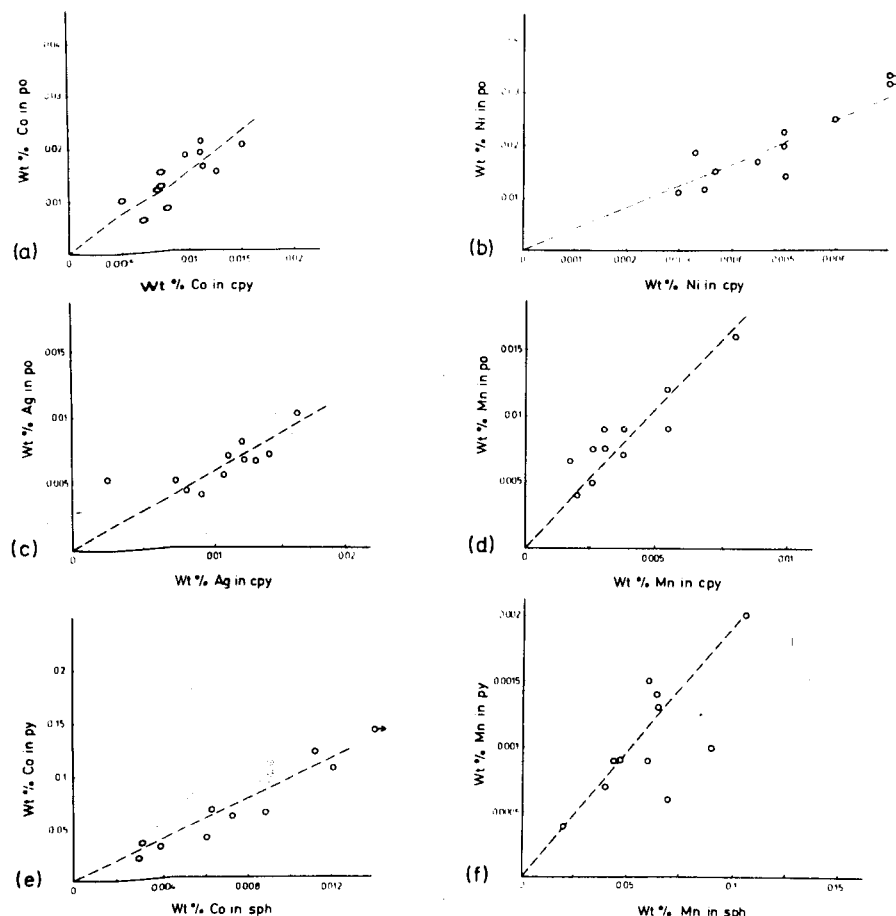


Fig. 9 (a)–(d). Distribution of Co, Ni, Ag, and Mn between co-existing pyrite and pyrrhotite in pyritic ore.
(e)–(f). Distribution of cobalt and manganese between co-existing pyrite and pyrrhotite in pyrrhotite-chalcopyrite ore.

evaluation of equilibrium or disequilibrium of primary depositional conditions in view of the known involvement of the ores in high-grade regional metamorphism.

Isotopic composition of sulphur

The isotopic analyses of sulphur in pyrite fractions of different types of ores from the deposit exhibit an overall spread of 8.55 permil of δS^{34} values in the range of -0.1 permil to $+8.44$ permil with an average value of $+3.57$ permil (Fig. 11). Within this general range, it seems highly significant to find the massive ores (including both pyritic- and pyrrhotitic-types) displaying a much narrower spread of only about 3.5 permil in $+1$ to $+4.5$ permil range. δS^{34} values outside this sub-range seem to correspond exclusively to the disseminated-pyritic ores.

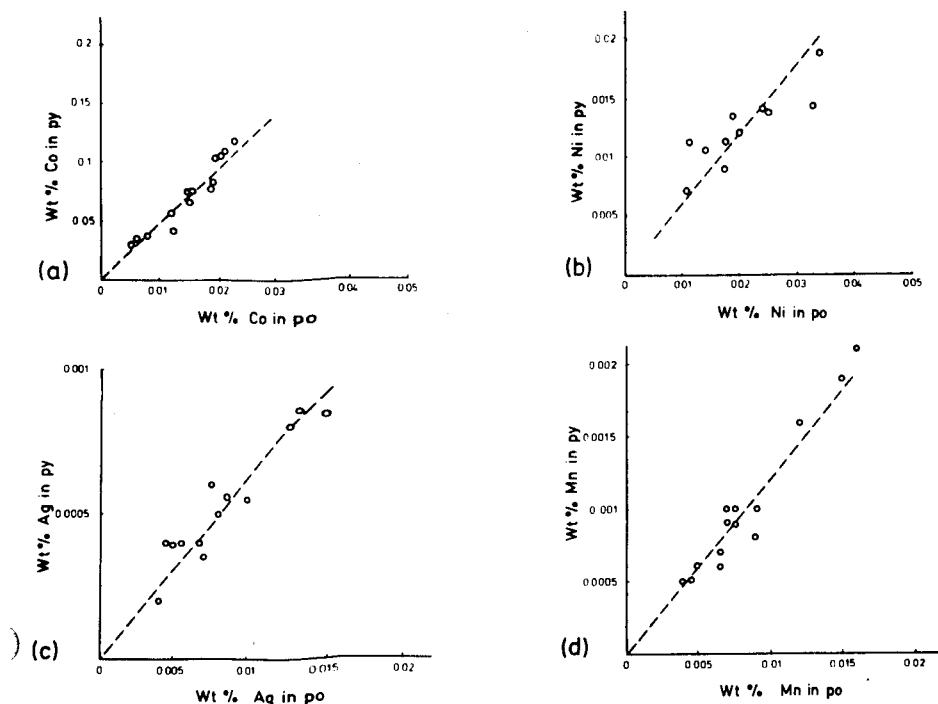


Fig. 10 (a)–(d). Distribution of Co, Ni, Ag, and Mn between co-existing pyrrhotite and chalcopyrite in massive ores.

Notwithstanding these differences in patterns corresponding to different ore types, the overall spread of δS^{34} values seems to be rather narrow and close enough to the value of the meteorite standard. A general enrichment tendency of the heavier stable isotope (S^{34}) is clearly discernible. These observations seem to be meaningful and characteristic enough to suggest essentially a single, almost uncomplex primary genetic process in which the ore fluids might have been derived basically from an independent and fairly homogeneous deep-seated magmatic source. Observed close similarities of the distribution pattern and spread of δS^{34} values in Sulitjelma deposit with those in some of the type deposits of geosynclinal volcanic type – e.g. the Tertiary volcanic ores of Japan (Tatsumi 1965) and the Cambrian ores of Mt. Lyell, Tasmania (Solomon, Rafter & Jensen 1969) – seem to be strongly suggestive of an analogous mode of origin of the deposit.

Synthesis

The overall geochemical picture of the deposit emerging from the present study seems to be appreciably uniform with well-defined and meaningful geochemical characteristics of the ores. In detail, however, minor yet systematic and consistent differences characterize the geochemistry of various ore types in different ore bodies of the deposit.

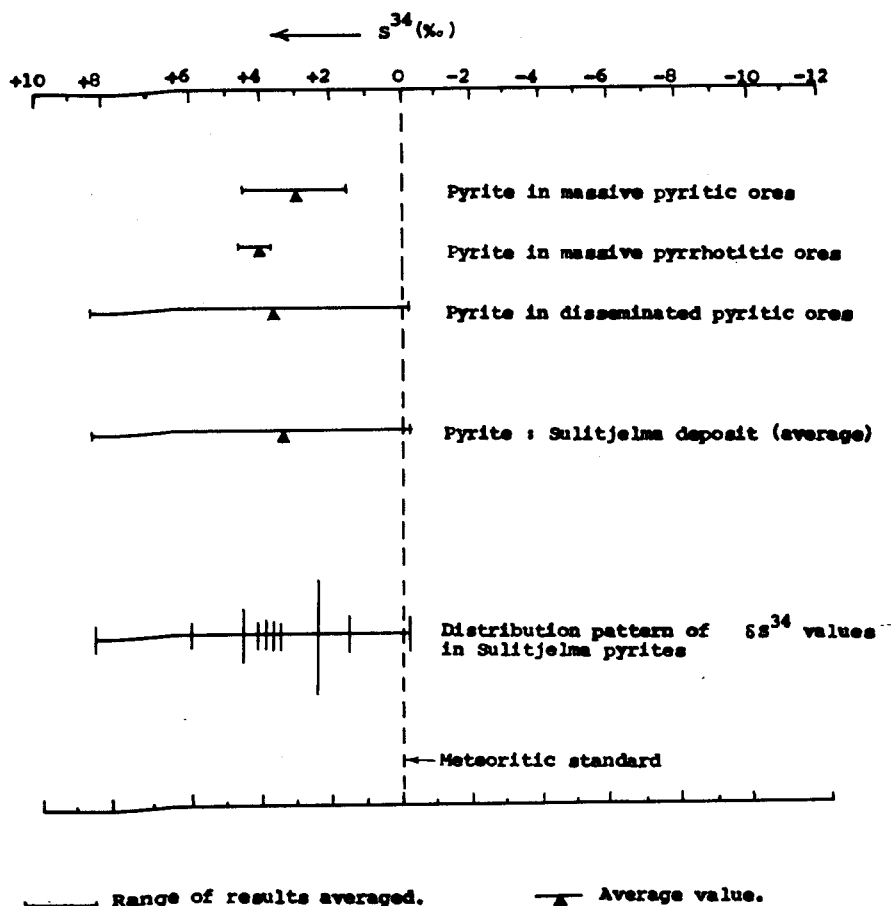


Fig. 11. Pattern of sulphur-isotopic fractionation in pyrites from Sulitjelma.

Studies on the distribution of major metals, particularly copper and zinc, in various ore types and ore bodies of the deposit, bring out certain important aspects of metallogeny in the region. They suggest primarily a basic igneous parentage of the ores and indicate close genetic linkage between massive pyritic and disseminated type of ores, both of them belonging possibly to the same pulse of ore-forming fluids. Some sort of base-metal differentiation in the ore fluids supplying ores to the different ore bodies appears to have taken place.

Detailed studies on the minor and trace elements in various typomorphic minerals of the ores bring out notable geochemical regularities on the scale of the deposit in general and that of individual ore bodies in particular. The palingenetic mode of origin of pyrrhotitic ores, presumably during regional metamorphism of the deposit, is supported by the study. Interpretation of the observed results of minor and trace element study in terms of primary genetic and depositional conditions is circumscribed by the unknown effects of metamorphism on the primary geochemistry of the ores. Minor, yet

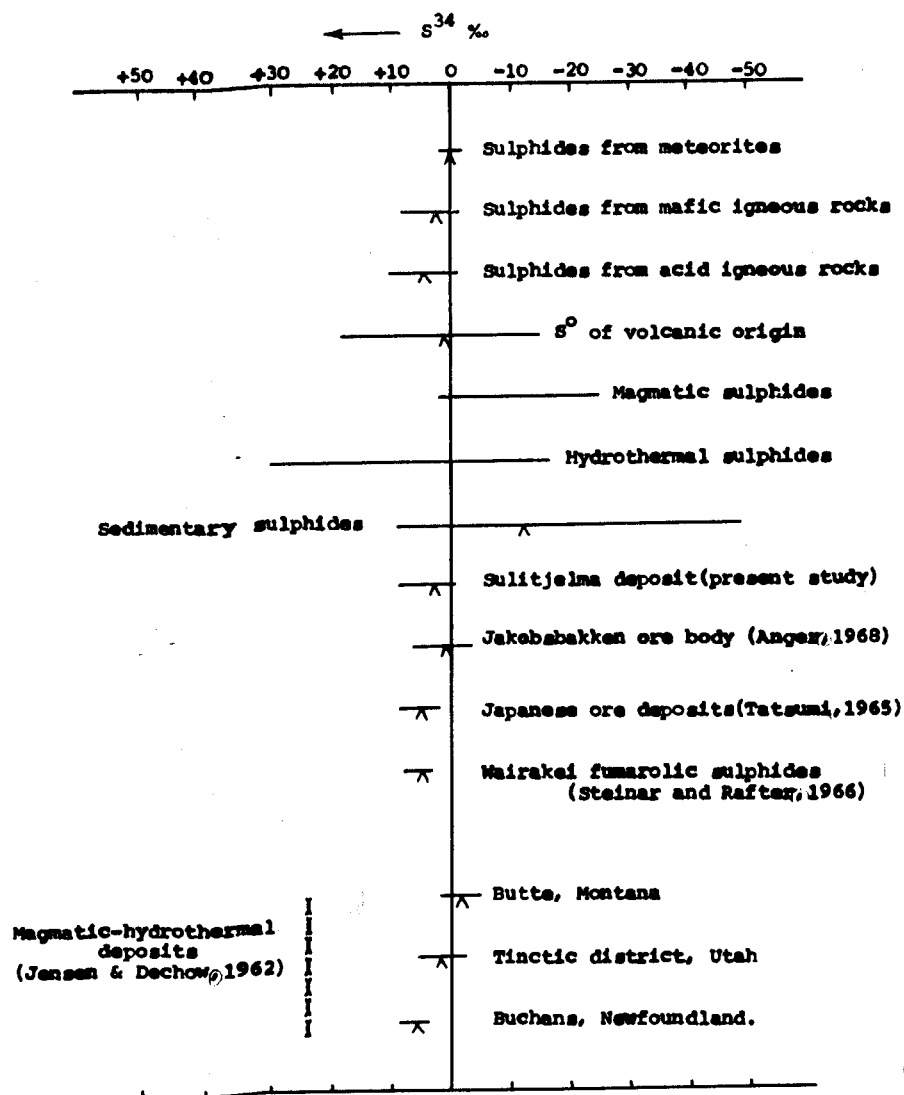


Fig. 12. Sulphur-isotope distribution in Sulitjelma ores compared with that in some typical deposits reported in the literature.

definite and consistent differences in the composition of ores in different ore bodies of the deposit, however, seem to be basically a primary feature of the deposit, which seems difficult to explain by a simple sedimentary or hydrothermal concept of ore-genesis. Although derived primarily from a common source, the ore-forming fluids seem to have undergone some differentiation of their metallic content before the final deposition of ores in different ore bodies. The possibility of existence of small time-lags in the deposition of ores corresponding to the different ore bodies, as may be implied in distinct, though slight differences in their relative positions in

the mineralized zone, cannot be ruled out. The overall observations may be best explained by the volcanic-exhalative mode of ore deposition in the region.

Observations from the study on isotopic fractionation of sulphur in the deposit are characteristic and meaningful enough to suggest essentially a single, almost uncomplex primary genetic process in which the ore fluids were derived basically from an independent, deep-seated magmatic source. Such a source of ore material is compatible with the proposed volcanic-exhalative mode of ore-deposition, which is favoured also by the comparison of the observed pattern of sulphur-isotopic fractionation in the deposit with that exhibited by typical massive sulphide deposits reported in the literature.

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