SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:o 447.

ÅRSBOK 36 (1942) N:o 4.

THE TELLURIDE-BEARING ANDALUSITE-SERICITE ROCKS OF MÅNGFALLBERGET AT BOLIDEN, N. SWEDEN

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ERLAND GRIP AND OLOF H. ÖDMAN

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Preface.

Since a number of years the authors have had occasion to study the andalusite- and telluride-bearing rocks from Mångfallberget in the vicinity of Boliden. As the investigations show that in several respects there exist some striking similarities with Boliden, it has been found worth while to publish the observations in a joint paper. The chapters in the present paper marked (G) have been written by Grip, whereas Ödman is responsible for those marked (Ö).

The authors wish to express their gratitude to Mr O. Falkman, Director of the Boliden Mining Company, for his kindly permitting them to publish the paper and to Dr. P. Geijer, Director of the Geological Survey, for allowing it to be printed in this Series.

Boliden and Stockholm, Sweden, May 1942.

Erland Grip. *Olof H. Ödman.*

Introduction (G).

During detailed geological mapping, which I carried out for the Boliden Mining Company in 1934, I found an outcrop with disseminations of sulphides at Mångfallberget, a hill about 2 km N of Boliden (Fig. 1). The outcrop rose a few metres above the surrounding ground and had a smoothly rounded shape.

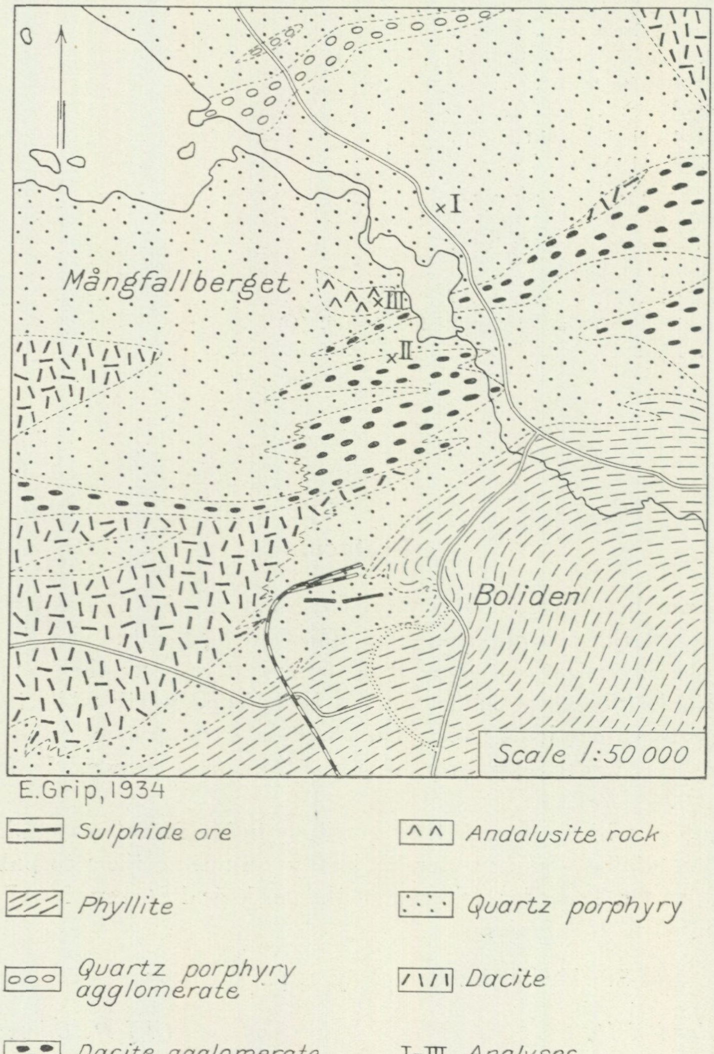

Fig. 1.

An investigation revealed that it was composed of an andalusite-rich, corundum-bearing rock, at the contact towards a sericite rock strongly impregnated with sulphides. Among the latter were noticed pyrite, chalcopyrite, tetrahedrite, and aggregates of a silver-white mineral which later proved to consist of two tellurides, *viz.* tellurobismuthite and tetradymite. The geological survey was followed by a detailed electrical survey of the impregnated zone, which gave some weak indications. The electrical reconnaissance survey had not given any

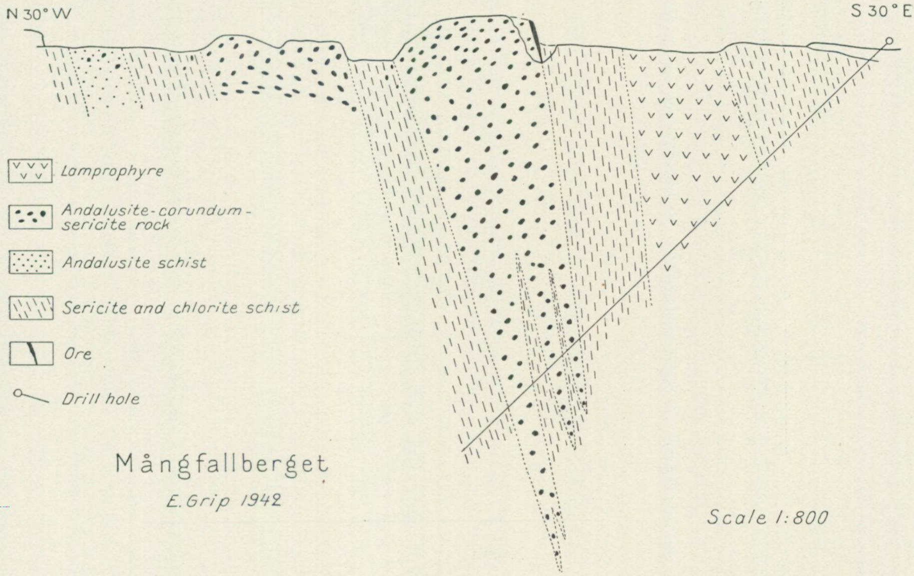

Fig. 2.

indications of ore. A survey was then carried out with the Boliden gravimeter and distinct gravity anomalies appeared above the heavy andalusite rock. A drill-hole was put through the electrical indication and some trenching was done, guided by the gravity indications, in order to establish the extension of the aluminum-rich rock. A large sample was taken from the impregnated zone and the whole andalusite deposit was carefully sampled. The deposit is owned by the Boliden Mining Company.

Geological Setting (G).

The andalusite-rich rock, containing more than 50 % Al_2O_3, forms two lump-shaped bodies, about 20 m in diameter (Fig. 2). They are separated by a band of sericite schist, some metres wide. The bodies are stratigraphically right above one another and neither of them seems to have any notable extension in the direction of strike. Towards the footwall, *i. e.* in the north as well as in the direction of strike, the content of andalusite decreases successively, while the

Table 1.

	Analysis No. I		Analysis No. II	
	%	Mol.prop.	%	Mol.prop.
SiO_2	73.54	12 244	52.37	8 720
TiO_2	0.31	39	0.75	94
Al_2O_3	12.35	1 212	15.04	1 475
Fe_2O_3	0.38	24	1.86	117
FeO	3.73	519	5.78	805
MnO	0.08	11	0.20	28
Mg	1.17	290	3.20	794
CaO	1.78	317	9.40	1 676
Na_2O	2.85	460	4.08	658
K_2O	2.24	238	1.53	162
$H_2O+105°$	0.20	111	0.81	450
$H_2O-105°$	0.06		0.08	
CO_2	0.85	193	4.57	1 039
ZrO_2	nil		nil	
P_2O_5	0.07	5	0.11	8
Cl	0.01	3	0.01	3
F	0.02	11	0.04	21
S	0.08	25	0.10	31
BaO	0.03	2	0.03	2
SrO	0.01	1	0.04	4
	99.76		100.00	

Norm		Norm	
Q	42.6	Q	7.1
Or	13.3	Or	9.0
Ab	24.1	Ab	34.5
An	2.9	An	16.7
C	4.2	C	0.5
Σ sal	87.1	Σ sal	67.8
Hy $MgSiO_3$ 2.9, $FeSiO_3$ 6.0	8.9	Hy $MgSiO_3$ 8.0, $FeSiO_3$ 8.0	16.0
Mt	0.6	Mt	2.7
Il	0.6	Il	1.4
Ap	0.2	Ap	0.3
Cc	1.9	Cc	10.4
Py	0.2	Py	0.2
		F	0.1
Σ fem	12.4	Σ fem	31.1
H_2O +	0.2	H_2O +	0.8
	99.7		99.7
Alsbachose			

I. Felsite quartz porphyry. Bastunäs, 800 m NE of Mångfallberget.

II. Tuffaceous agglomerate. Strömfors, 400 m SE of Mångfallberget.

Analyst: Miss Th. Berggren.

hanging wall of the andalusite-rich rock is formed by a fault against the sericite schist above.

The andalusite deposit occurs in the porphyry series of the Skellefte District and is surrounded by quartz porphyries and their pyroclastic sediments (Fig. 1). Stratigraphically it belongs to the oldest horizons of the porphyries. The strike of the bed-rock around the deposit is about E—W and the dip 80—90° S. The pitch of the deposit coincides with the linear schistosity and not with the main axis of folding (1) and is about 73° in S28°E.

The bed-rock in the footwall and in the direction of strike from the deposit consists of quartz porphyry either carrying small phenocrysts of quartz or quite felsitic. The chemical composition of a sample of the rock, collected at a locality 800 m NE of the deposit (Fig. 1), is given in Table 1 (Analysis No. I). The rocks in the hanging-wall are made up of alternating felsitic quartz porphyry and tuffaceous agglomerate with inclusions of felsitic quartz porphyry in a calcareous and often amphibolitic base. A sample of the agglomerate taken 400 m SE of the deposit (Fig. 1) has been analysed (Table 1, Analysis No. II). This agglomerate, which often shows very beautiful primary features, is in the same stratigraphical horizon as the limestone further to the east (cf map in (1)).

The rocks in the immediate vicinity of the deposit are strongly sericitized and sometimes also chloritized. This is particularly so in the hanging-wall.

A number of dykes occur in the deposit and in its environs. The following types have been established: 1) Amphibolite with stringers of quartz and occasionally tourmaline (originally a lamprophyre), 2) quartz porphyry, occurring together with the amphibolite and forming a composite dyke with it, 3) tourmaline with or without quartz and sometimes with chromiferous mica (mariposite), and, finally, 4) quartz. Secondary andalusite and kyanite, sometimes also sillimanite, and sulphides occur as fissure fillings.

Description of the Rocks (G).

The quartz porphyry in the footwall is widely distributed. In hand specimen it is a dark gray rock with or without phenocrysts of quartz, generally of a small size and thinly scattered. A flow structure is occasionally noticeable and one often observes a ropy structure as on the surface of lava flows. Lithophysae have also been seen. Under the microscope the phenocrysts are strongly corroded and occur in a microgranoblastic base of quartz, plagioclase, biotite, sericite, chlorite, and accessory ore, titanite, and apatite. In some localities, *e. g.* where Analysis No. I was taken, there occur tiny spots of calcite and scattered grains of clinozoisite. The plagioclase is normally an albite but close to the deposit there appears, as at Boliden and Malånäset (2, p. 21 and 3, p. 100), a secondary formation of bytownite.

Tuffaceous agglomerate interbedded with quartz porphyry forms the hanging-wall of the deposit. The agglomerate contains inclusions of the felsitic quartz porphyry described above. The base between the often sharp-edged in-

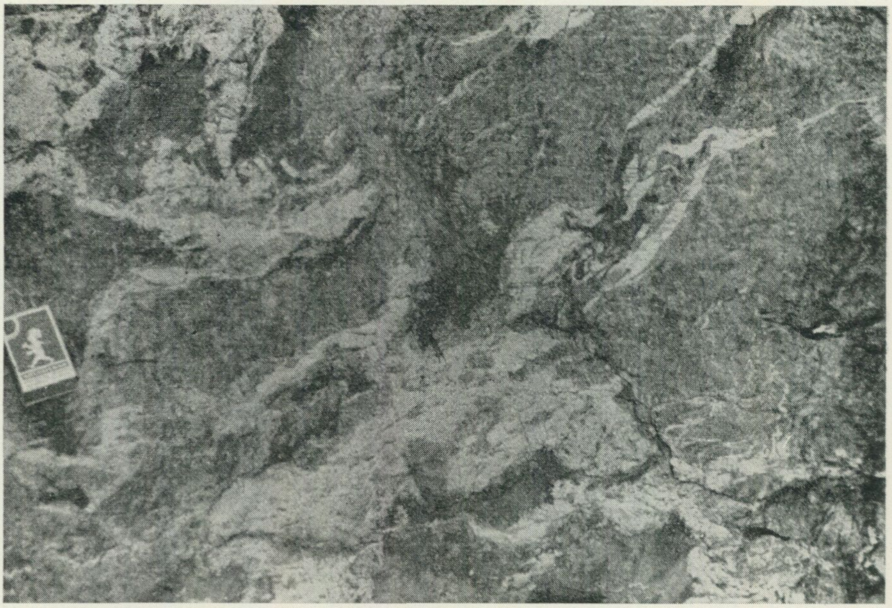

Fig. 3. Brecciated andalusite-sericite rock. The dark spots are sericite rock with porphyroblasts of andalusite. The white stringers consist of andalusite. Scale 1 : 5.

clusions is as a rule more basic. The analysed sample (Analysis No. II), taken 400 m SE of the deposit, has a well marked parallel structure caused by stringers of amphibole, calcite, and sulphides. The hornblende shows pleochroism in straw yellow and bluish green and appears in needles and bunches. Biotite occurs

Fig. 4. Crystals of corundum in fine-grained sericite. Ord. light. Scale 62 : 1.

in scattered foils among the amphibole grains. Fine-grained quartz and irregularly flamy grains of a medium acid plagioclase form the rest of the groundmass. Closer to the deposit the base of the agglomerate is poorer in calcite and amphibole.

The altered rocks described below were formed from the quartz porphyry, including tuff and agglomerate. They may be divided into the following types:

The andalusite-corundum-sericite rock has a peculiar granular texture. The even-grained rock has a grayish yellow colour which

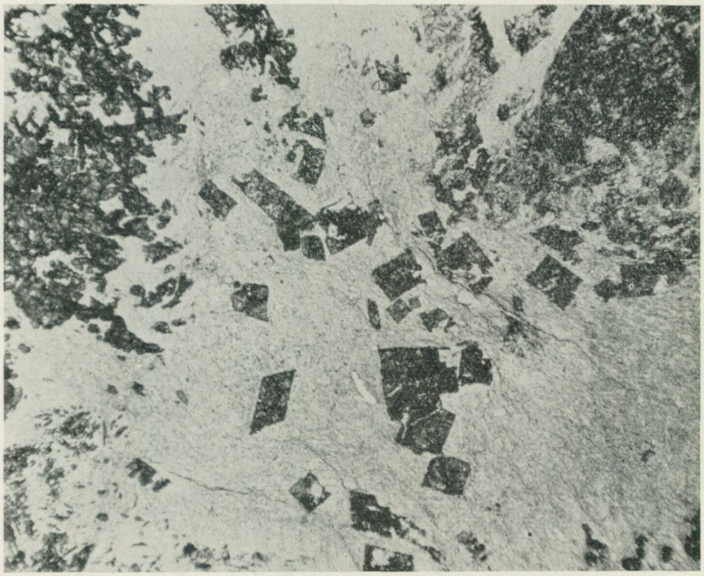

Fig. 5. Pseudomorphs after andalusite, consisting of hydrous alumosilicates. Scale 7 : 1. Ord. light.

turns grayish blue when there is a higher content of corundum. On the glaciated outcrops the outlines of the sharply idiomorphic andalusite crystals stand out nicely. In the portions where the content of Al_2O_3 is about 50 % sericite and rutile often form stringers, but portions still richer in Al_2O_3 are as a rule quite massive. Where the content of Al_2O_3 is lower (30—50 %), the rock is brecciated with a cement of secondary andalusite and occasionally also sillimanite, kyanite, and sulphides (Fig. 3) filling the interstices in the breccia.

The rock richest in aluminum runs as high as 70 % Al_2O_3 and consists of sericite, which is always present, together with andalusite, corundum, and their alteration products (Fig. 4). Sharply idiomorphic porphyroblasts of andalusite of a maximum size of 1 cm lie in a fine-grained mass of sericite. The porphyroblasts are more or less altered and judging by the content of the pseudomorphs the alteration runs in the direction andalusite → kaolin → corundum or andalusite → corundum → $Al_2O_3 \times nH_2O$. The products of hydration are very fine-grained and it has not been possible to make a definite identification under

Fig. 6. In a mass of sericite lies to the left a swarm of kyanite needles, in the centre a pseudomorph after andalusite, and in the lower right corner fine-grained corundum. Ord. light. Scale 7 : 1.

the microscope (Fig. 5). An alteration in the direction andalusite → kyanite may sometimes be observed. The corundum is generally very fine-grained but occasionally one observes individuals about 2 mm long. Fig. 4 shows the corundum in its typical development. The largest grains are faintly bluish.

Rutile is plentiful (1.2 % TiO_2) and forms a fine pigment which on some

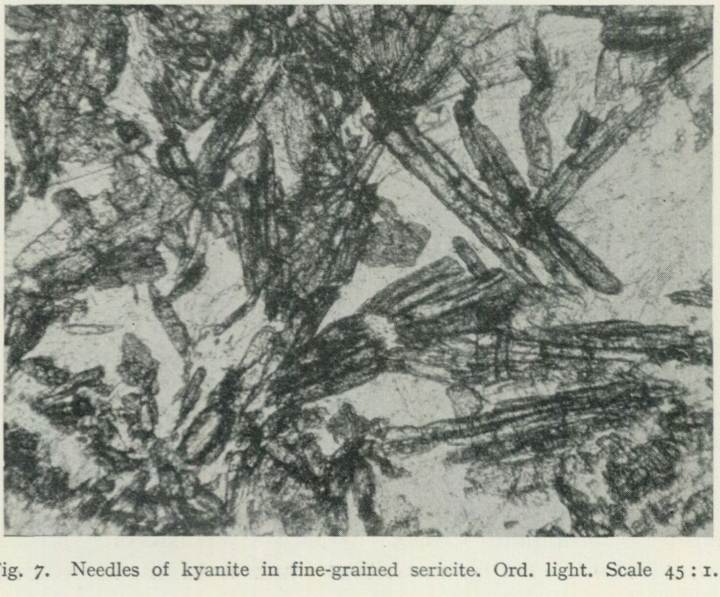

Fig. 7. Needles of kyanite in fine-grained sericite. Ord. light. Scale 45 : 1.

Table 2.

Analysis No.	III.		IV.
	%	Mol.prop.	%
SiO_2	18.50	3 080	21.73
TiO_2	1.17	146	1.05
Al_2O_3	70.23	6 889	72.49
Fe_2O_3	0.45	28	0.21
FeO	0.41	57	0.41
MnO	<0.01	—	nil
CaO	nil	—	nil
MgO	nil	—	0.01
Na_2O	1.11	179	0.36
K_2O	3.85	409	1.43
$H_2O+105°$	3.76	2 087	2.04
$H_2O-105°$	0.08	—	0.16
P_2O_5	nil	—	nil
B_2O_3	nil	—	—
S(sol. in acid)	<0.01	—	0.04
F	0.08	42	0.03
	99.66		99.96
Sp. gr.	3.10		3.046

Analysis No. III. Andalusite-corundum-sericite rock. Mångfallberget.
Analysis No. IV. Andalusite rock. 410 m level, Boliden (2, Analysis 14, p. 39).
Analyst: Miss Th. Berggren.

occasions appears in stringers. Larger scattered grains are not uncommon. Ore minerals only locally appear in rich concentrations; generally the rock is almost devoid of such minerals.

Kyanite is occasionally met with as an alteration product of andalusite and occurs as bundles or bunches or as scattered needles (Figs. 6 and 7). Tourmaline is locally present as fine-grained needles or bunches. Two varieties of this mineral are found: one almost colourless and one showing pleochroism in olive green. The colourless variety may occur as kernels in the coloured one. The chemical composition of this rock is given in Analysis No. III (Table 2). For comparison an analysis of the typical andalusite rock from Boliden is reproduced in the same table (Analysis No. IV) which shows how closely related the rocks are chemically.

The andalusite-sericite rock is a transitional type of rock occurring towards the footwall. The andalusite appears as more or less scattered but sharply idiomorphic porphyroblasts in a fine-grained, scaly mass of sericite. The corundum is here lacking or plays a less important rôle. The andalusite is often altered to a fine-grained mass of kaolin or other hydration products (Fig. 5). It is evident that in this rock the andalusite has been formed by the replacement of sericite. The dark portions in Fig. 3 consist of this rock.

The andalusite schist occurs still further down in the footwall and consists of andalusite, quartz, sporadic small foils of sericite, and a small amount of rutile (Fig. 8). The andalusite forms large poikiloblasts, which sometimes contain needle- or bunch-shaped mineral formations. The individuals have the shape of a string of pearls and have higher refringence and birefringence than the andalusite. An alteration to sillimanite or kyanite is here indicated. The quartz has a granular texture. Its grains are tectonically adjusted with smooth flow lines marking the contours of the andalusite crystals.

Sericite and chlorite schists occur in zones in the andalusite-rich rocks as well as in the hanging-wall of the deposit. Besides quartz, sericite

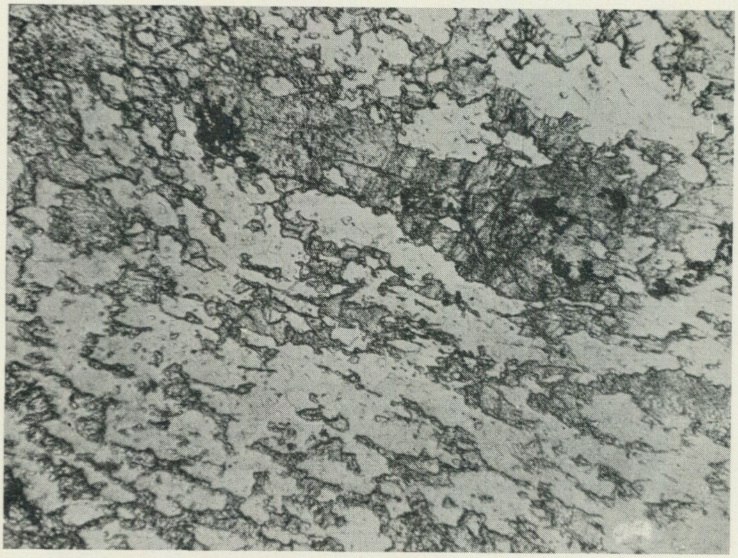

Fig. 8. Andalusite schist. Large andalusite poikiloblasts in a mass of fine-grained quartz. Ord. light. Scale 45 : 1.

is generally the dominating mineral but in some zones chlorite is more plentiful. Sulphides and rutile are accessory minerals.

Sericite and chlorite rock appear in the same way as the schists mentioned above. They may be almost mono-mineralic, the sericite rock containing almost only sericite and the chlorite rock mainly chlorite together with small amounts of plagioclase, sericite, and rutile.

Dyke rocks. Lamprophyre. A 6 m broad zone of amphibolite with stringers of quartz and some tourmaline has been interpreted as an original dyke of lamprophyre. The rock consists of a weakly pleochroitic hornblende in short porphyroblasts enclosed in a mass of chlorite which also contains small amounts of quartz, calcite, clinozoisite, rutile, titanite, biotite, orthite, sulphides, and sometimes also bytownite.

Quartz porphyry occurs together with the amphibolite and seems to have formed a composite dyke with it. The rock sometimes carries phenocrysts of albite which in part has been altered to chlorite. The groundmass is microgranoblastic and consists of quartz, plagioclase, chlorite, sericite, calcite, some biotite, and accessory rutile, ore, and apatite. In one thin section the plagioclase of the base was a labradorite.

Tourmaline in thin needles or bunches forms narrow veinlets or nodules and often occurs together with quartz and sometimes also with mariposite and ore minerals. In hand specimen the tourmaline has a dark green colour. Under the microscope one observes both colourless and coloured tourmaline. The mariposite resembles the sericite as it appears in the sericite rock but has a greenish colour. An analysis showed 0.73 % Cr_2O_3.

Tectonic Features and Metamorphism (G).

As I have shown earlier (1), it is possible to distinguish two orogenic phases in the folding of the Skellefte District, *viz.* an earlier gentle folding along flat folding axes, during which epoch the Jörn granite was intruded, and a later phase of folding which forms the continuation of the former and during which the Revsund granite was intruded. During the first phase the main tectonic features were developed which now appear in the general structure of the Skellefte District. During the second phase the direction of the stress had changed somewhat and lateral movements developed a steeply dipping linear schistosity at the same time as displacements of fault-blocks caused a foliation along zones of various directions.

The development of the zone of sericitic rocks at Mångfallberget may have begun already during the first phase of folding but it became fully developed during the second and the degree of foliation increased during this latter phase. In connection with a down-warping, followed by heating and the formation of fissures during the second orogenic phase, solutions penetrated the bed-rock. Already during the formation of the sericitic rocks an appreciable concentration of Al took place. A particularly strongly fissured portion in the zone of sericitic rocks was more permeable to the solutions and within the sericite rock there occurred a metamorphic differentiation with a strong concentration of Al_2O_3. The texture of the andalusite-bearing sericite rock shows that the andalusite replaces the sericite, indicating that Al_2O_3 has been added, whereas alkalis and silica (silicates of alkali) have been carried away. An andalusite-sericite rock was formed and where the addition of Al_2O_3 was most pronounced also corundum crystallized. The rock thus formed was very hard and during the continued tectonic movements the surrounding sericite schist obtained a foliation which smoothly follows the steep linear schistosity in the area, while the hard and brittle andalusite-sericite rock reacted differently and was brecciated. At the same time andalusite was mobilized and the mineral recrystallized in fissures in the breccia. Towards the end of the epoch of stress a further fissuring took place through the action of lateral movements. In the new fissures a composite lamprophyre- and quartz porphyry dyke was intruded.

It has only been brecciated and is only slightly schisted. At the same time, or somewhat later, complex ore solutions ascended from which not only ore minerals but also tourmaline, mariposite, and quartz were deposited. In connection with the deposition of the ore minerals the andalusite was attacked and to some extent replaced by sericite. Contemporaneously or possibly later the andalusite was decomposed to corundum and hydrous aluminum silicates.

Description of the Ore Minerals (Ö).

Occurrence.

Ore minerals are comparatively rare in the andalusite-sericite rocks at Mångfallberget. They are concentrated to local zones or spots where, however, they may occur in appreciable quantities. This is particularly the case in the hangingwall of the andalusite-sericite rock towards the contact to the sericite rock.

Photo C. Larsson

Fig. 9. Tellurobismuthite (white) and pyrite (mottled gray) brecciating and replacing andalusite rock and a veinlet of sericite, cutting the former. Polished section, ord. light. Scale 11 : 1.

The ore minerals often appear in veinlets or stringers which cut and replace the wallrock. A more or less spotty and irregular impregnation is also typical. In connection with the deposition of the ore minerals there also takes place an alteration of the andalusite rock. It is to a large extent sericitized or it is recrystallized which may result in the formation of andalusite crystals about 1 cm in length. The sericite often occurs in coarse scales. Also tourmaline is formed during this alteration, either in the shape of needles or in veinlets.

The ore minerals were formed in close connection with this alteration but still they crystallized later than the gangue minerals which are replaced and brecciated by the former (Fig. 9). They also fill the interstices between the large andalusite crystals. Particularly the Bi-tellurides appear in this manner but also *e. g.* pyrite has a similar appearance. Some of these features are best seen under the microscope and one observes here how for instance Bi-tellurides or tetrahedrite penetrate along the cleavage of the sericite and replace that mineral. Also tourmaline is brecciated and distinctly replaced by the ore minerals.

In a vein-like formation of tourmaline and sericite the ore minerals displayed a special tendency towards concentrating in the central part of the vein, giving still more proof of the intimate relationship between gangue minerals and ore minerals.

Paragenesis.

Gold is rare at Mångfallberget and has been observed in one polished section only from a vein-shaped formation of tetrahedrite. It occurred partly as irregular grains in this mineral, partly as inclusions in a grain of arsenopyrite.

Native bismuth is also rare. As a rule it occurs in narrow veinlets cutting the tetrahedrite.

Bi-tellurides are characteristic and comparatively common minerals. They appear in irregular veinlets or as disseminations in the andalusite rock. In the former case they accumulate to coarse scaly masses, the individual foils obtaining a diameter of 1—2 cm and a thickness of 0.5 cm[1].

Under the microscope two tellurides have been observed and one of them has been definitely identified as tellurobismuthite Bi_2Te_3 (antimony-bearing, cf below). The other is in all probability tetradymite Bi_2Te_2S. We may also include another species which could not be identified, however, but which very likely also belongs to the Bi-tellurides (No. 1, p. 17).

On an earlier occasion the author has briefly mentioned the occurrence of antimony-bearing tellurobismuthite from Mångfallberget (2, pp. 101—103). Under the microscope some portions of the mineral in question were quite homogeneous and material could easily be separated for an analysis (cf table below). The analysis shows that Sb has in part been substituted for Bi which indicates that in reality the mineral is an antimony-bearing modification of the true tellurobismuthite. The latter, which occurs at Boliden in a pure state, has not been identified at this locality[2]. In spite of the rather considerable content of Sb the author has not found it appropriate to give this modification a name of its own before its atomic structure has been investigated.

If in the analysis we add Sb to Bi and Se to Te the following proportions are obtained:

$$(Bi + Sb) : (Te + Se) = 254 : 391,$$

which closely agree with the formula Bi_2Te_3.

---

[1] This applies to the tellurobismuthite, the tetradymite is more fine-grained.

[2] The character of tellurobismuthite as a special mineral species has recently been established by C. Frondel (4).

Table 3.

Analysis No.	V.		VI.	
Bi	46.40	222	52.48	251
Te	48.92	384	46.10	362
Se	0.58	7	0.94	12
Sb	3.92	32	nil	—
S	0.13	4	0.18	6
As	0.10	—	0.06	—
Fe	0.03	—	0.04	—
Cu, Ni, Co, Zn, Pb .	nil	—	nil	—
Ag	0.02	—	0.01	—
Au	nil	—	0.04	—
	100.10		99.85	
Sp. gr.	7.061		7.209	

Analysis No. V. Sb-bearing tellurobismuthite. Mångfallberget. Analysis No. 47 in (2, p. 103.)
Analysis No. IV. Tellurobismuthite. 210 m level, Boliden. Analysis No. 46 in (2, p. 103).
Analyst: Miss Th. Berggren.

Under the microscope the Sb-bearing tellurobismuthite is found to form mica-shaped individuals without any real idiomorphism. The cleavage parallel (0001) is sometimes visible and between the foils one occasionally observes interpositions of gangue minerals (sericite in part) (Fig. 10). In oil immersion the mineral shows a very weak pleochroism in cream-white to grayish white. The anisotropism is comparatively strong and has grayish blue to yellowish gray colour effects.

In some of the polished sections there occur together with the tellurobismuthite similar grains of a mineral of a somewhat darker gray colour (Fig. 10), which very likely is tetradymite. The mineral has the same colour and shows the same colour difference in relation to the Sb-bearing tellurobismuthite as the tetradymite at Boliden.

Sphalerite is rare and has only been observed as replacement remnants in chalcopyrite.

Pyrite is, besides the Bi-tellurides, the most common ore mineral. It sometimes occurs in coarsely crystalline masses, in which single crystals may obtain a length of 1 cm. Generally, however, the mineral is considerably more fine-grained. Under the microscope some grains are found to possess a certain degree of idiomorphism, but on the other hand many grains are corroded, for instance by chalcopyrite or Bi-tellurides. Veinlets of pyrite were on one occasion seen cutting a fine-grained mass of tourmaline.

Arsenopyrite has been observed in some sections in the form of small, often corroded crystals in tetrahedrite or chalcopyrite.

Galena, intergrown with bismuth, occurred in small amounts in veinlets through tetrahedrite.

Chalcopyrite is present as disseminations in the andalusite rock but it is also associated with other ore minerals, particularly tetrahedrite. It here forms detached grains which give the impression of being replacement remnants, or narrow veinlets which are definitely younger than the tetrahedrite. — In one of the sections covellite was observed in the chalcopyrite. It has been formed by percolating surface waters.

Tetrahedrite is a characteristic mineral in the deposit, sometimes forming massive veinlets in the andalusite rock. It is of interest from a paragenetic point of view as it is the seat of some peculiar intergrowths, unfortunately as a rule of not identifiable minerals (cf below). The tetrahedrite seems to replace

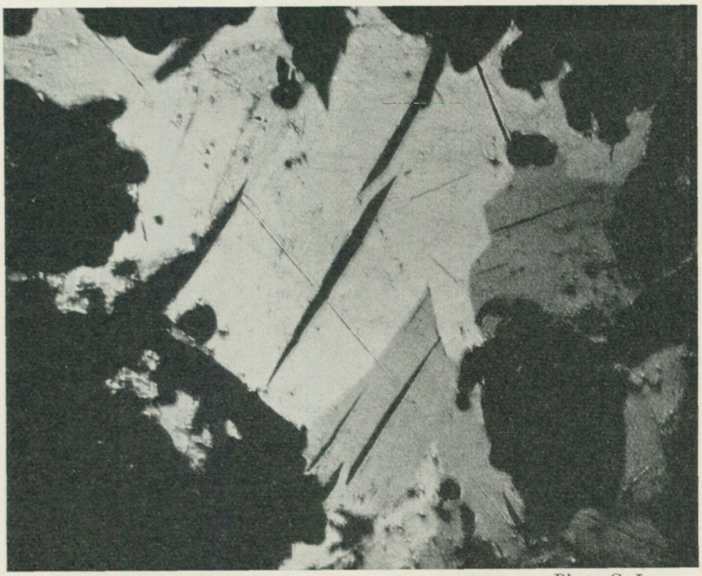

Photo C. Larsson

Fig. 10. Tellurobismuthite (white) and tetradymite (light gray) with interpositions parallel (0001) of sericite. Polished section, ord. light. Scale 120 : 1.

such minerals as arsenopyrite and chalcopyrite but is on the other hand cut by narrow veinlets of bismuth, galena, and chalcopyrite. A not identified mineral (No. 4 below) also appears on these veinlets. In one of the sections the tetrahedrite was replaced by a net-work of a soft, in relation to the tetrahedrite somewhat bluish gray, isotropic mineral of unknown nature (Fig. 11). Very likely the mineral consists of a tetrahedrite of another composition than he host mineral.

Unidentified minerals. Small amounts of four not identified minerals and two complex intergrowths between partly unknown minerals have been observed in the sections. Here follows a brief account of them.

Mineral No. 1. Bluish white mineral, strikingly similar to tellurobismuthite in which it occurs as small rounded or elongated grains. Without doubt it is chemically closely related to tellurobismuthite. Hardness and anisotropism are almost identical with those of tellurobismuthite.

Mineral No. 2. Evenly gray mineral in small irregular grains in the tellurobismuthite. Softer than this. Extremely weak pleochroism but comparatively strong anisotropism in yellow orange.

Mineral No. 3. Small irregular, evenly gray grains in tellurobismuthite. The mineral is somewhat harder than the latter and weakly anisotropic.

Mineral No. 4. Dark gray mineral in veinlets together with bismuth in tetrahedrite or sericite. In colour it is similar to sphalerite. Weakly anisotropic, interior reflections in yellowish brown to greenish.

Intergrowth No. 1. Irregular areas in tetrahedrite. Skeleton-shaped, extremely fine-grained intergrowth between three unknown minerals, one

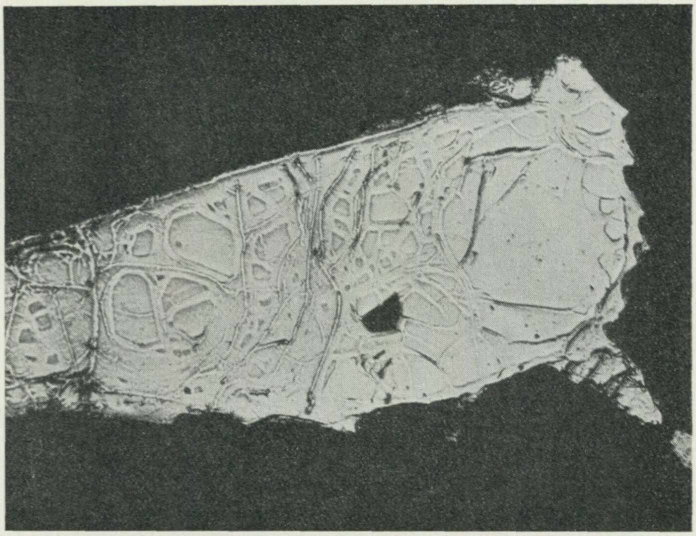

Fig. 11. Tetrahedrite (in coarse sericite; black) veined by a softer mineral of unknown nature (possibly a tetrahedrite of another composition). Polished section, ord. light. Scale 210 : 1.

white and two gray, and some chalcopyrite. The grains of the minerals show a tendency to a lamellate structure. The three unknown minerals are all comparatively strongly anisotropic. The formation reminds of certain decomposed Bi-tellurides from Boliden (2, p. 92). It does not seem unlikely that also here the primary mineral was a telluride.

Intergrowth No. 2. Irregular areas in tetrahedrite or independent formations in coarse sericite. Skeleton-shaped, almost »graphic» and extremely fine-grained intergrowth of two unknown ore minerals, one white and one gray, and some chalcopyrite. An unknown, soft gangue mineral forms the base of the intergrowth. The unknown ore minerals may correspond to the white and one of the gray minerals in intergrowth No. 1. The intergrowth also contains small grains of a pinkish mineral which probably is native bismuth.

Limonite is a rare component, observed in one case in fissures in chalcopyrite. The fissures continued out into the neighbouring tetrahedrite but they were here empty.

Rutile is a common semi-opaque constituent of the andalusite-sericite rocks but has no connection with the deposition of the ore minerals.

Arsenopyrite and pyrite are probably the earliest crystallized minerals and they are replaced by most of the other minerals, *e. g.* chalcopyrite, tetrahedrite, and Bi-tellurides. The main part of the chalcopyrite is older than the tetrahedrite and is replaced by it, but part of the chalcopyrite is nevertheless later and cuts the tetrahedrite in small veinlets. No direct observations of the position of the Bi-tellurides in the sequence of crystallization have been made but in view of the similarity with the telluride mineralization at Boliden, discussed below, it seems reasonable to presume that the tellurides, as at Boliden, are late crystallizing minerals.

Comparison with Boliden and Origin of the Deposit (Ö).

As was indicated already in the preface, marked similarities exist between Mångfallberget and Boliden and from the description now presented it is evident that as regards geological appearance as well as mineralogical-chemical composition the altered rocks at Mångfallberget perfectly correspond to those on the deeper levels at Boliden. In the description of the Boliden deposit Ödman has dealt with those rocks in detail (2) and the reader is referred to that paper. In the following only certain points of interest as regards these rocks will be treated.

The primary rocks from which the altered rocks have issued were in both localities quartz porphyry and tuffs, besides which, as regards Boliden, also keratophyre should be added. The deposits lie in quite different stratigraphical horizons and Boliden is considerably higher up in the porphyry series.

A first stage in the alteration was in both localities the formation of the almost mono-mineralic sericite rock. Already here an enrichment of Al_2O_3 is in evidence. The continued alteration involved a breakdown of the sericite which was replaced by andalusite. Alkalis and silica are carried away, whereas the content of Al_2O_3 increased. According to Grip a formation of corundum occurs at Mångfallberget already at this stage, whereas at Boliden the development of corundum is by Ödman placed in the stage during which the andalusite rock was sericitized in connection with the quartz-tourmaline stage (2, p. 165). Among other minerals also tourmaline, mariposite, and a second generation of andalusite were then formed.

Besides this early corundum, there appeared at Mångfallberget a later generation of corundum which together with sericite and hydrous aluminum silicates was formed during the ore mineralization. This alteration process thus corresponds to the decomposition of the andalusite rock at Boliden.

Another similarity of some importance is the appearance of lamprophyre dykes of mainly the same type in both deposits. A dissimilitude in this case is, however, that the lamprophyre at Boliden is not known to be accompanied by any quartz porphyry. The lamprophyre dykes contain stringers (gash veins) of quartz and tourmaline. They form at Boliden the immediate forerunners to the ores of the quartz-tourmaline stage. The common appearance of mariposite should also be pointed out.

If we now turn to a comparison between the two deposits in regard to their content of ore minerals, we especially note that the generally rare Bi-tellurides are typical of Mångfallberget as well as of the second mineralization stage at Boliden. It is of particular importance that the Sb-bearing tellurobismuthite occurs at both localities. But for some general features, common to both deposits, no further special paragenetic similarities can be noted. Some dissimilitudes are apparent and among them may be mentioned the absence at Mångfallberget of the Se-Bi-minerals »selenocosalite» and »selenokobellite» (2, pp. 87 and 89) which are so typical at Boliden. Gold, which at Boliden, particularly in association with the Bi-tellurides, is a remarkably common mineral, is very rare at Mångfallberget. Pyrite is common in this locality, whereas pyrrhotite has not been observed; at Boliden the opposite is true and pyrrhotite is there an exceedingly common mineral in the quartz-tourmaline ore, pyrite on the other hand being very rare.

The conditions now related show that one undoubtedly is justified to conclude that the alteration and mineralization at Mångfallberget have their exact counterparts at Boliden and that they are the result of an action of chemically related solutions. The two processes are probably also synchronous. The alteration to sericite rock and its alteration to andalusite rock preceded the mineralization. At Mångfallberget it was initiated by the intrusion of lamprophyre dykes, followed by the alteration of the andalusite rock and a deposition of ore minerals. These processes represent the quartz-tourmaline stage (second stage of mineralization) at Boliden.

At Mångfallberget traces are lacking of the two stages of mineralization which preceded respectively followed the formation of the quartz-tourmaline ores, *viz.* the arsenopyrite stage and the pyrite stage. The quartz-tourmaline ores, together with the lamprophyre dykes which preceded these ores, are at Boliden accumulated to the deeper levels and continue to still unknown depths below the sulphide ore bodies. The same is valid of the andalusite rocks at Boliden.

The mineralization at Mångfallberget has a smaller areal extent than at Boliden and has more the character of a dissemination. The strictly delimited ore veins with sharply cutting contacts to the wall rocks, so typical at Boliden, are lacking at Mångfallberget. This may be explained by the condition that at Mångfallberget the ore solutions were more diluted and thus could more easily migrate into the wall rocks, or that the tectonic conditions were not suitable to the formation of massive ores. In this connection it may be pointed out that the tourmalinization and sericitization, connected with the quartz-tourmaline ores, and the Bi-tellurides at Boliden often appear at comparatively long distances from the compact quartz-tourmaline bodies and, as at Mångfallberget, form disseminations, which would indicate that the solutions on the whole were rather mobile.

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