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Thucholite (Ö).

Thucholite was encountered during the mapping of the Boliden mine in the year 1936. It could not be identified and in the general description of the deposit it was simply called »graphitic matter».[1] Later on Aminoff gave a number of detailed specifications and established that the mineral was a radioactive, bituminous substance of the thucholite type, which he, because of a considerable content of titanium, called titano-thucholite.[2]

The mineral is jet black on the surface but on fractures it has a dull blackish colour. It seems to occur mainly in the andalusite rock on the deeper levels (192—570 m) of the mine. In the quartz-free type of this rock the thucholite appears on fissures and stringers sometimes filled with coarse sericite (1 cm^2). It also occurs in veins or narrow gash veins of quartz in the quartz-bearing type of the andalusite rock. In one case, in stope 61 on the 250 m level, the thucholite occurred on a quartz lens in a small body of Bi-telluride-bearing rutile rock. Another interesting occurrence of thucholite from the 570 m level is reproduced in Fig. 1. It is here present as small nodules in quartz-lenses cutting a body of andalusite rock. The latter is also impregnated with a number of metallic minerals of the second mineralization stage, *e. g.* gold, tetrahedrite, a Bi-telluride (tellurobismuthite?), »selenokobellite» (containing lead!), galena, bournonite, and chalcopyrite, occurring together with a coarse sericite in veinlets or irregular formations. The association with coarse sericite is especially noteworthy in view of the appearance of thucholite in similar sericite veins.

The thucholite is never crystallized but occurs in rounded, reniform or botryoidal formations, generally of the size of a pea or a walnut (Fig. 2). Rarely they attain larger dimensions, then sometimes assuming a fantastic shape (Fig. 3). The surface of the thucholite nodules is often very rugged and wrinkled, the wrinkles frequently being filled with sericite scales. The hardness of the mineral is about 3 and the sp. gravity, in two determinations, 1.512 and 1.66 (in view of the varying composition of the mineral the sp. gravity is also likely to vary). Even when but slightly heated the mineral gives off much gas and finally it

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[1] Ödman, Olof H.: Geology and ores of the Boliden deposit. Geol. Surv. of Sweden, Ser. C, No 438, 1941, p. 36.

[2] Aminoff, G.: A titano-thucholite from the Boliden mine. Geol. För. Förh., Vol. 65, pp. 31—36, 1943.

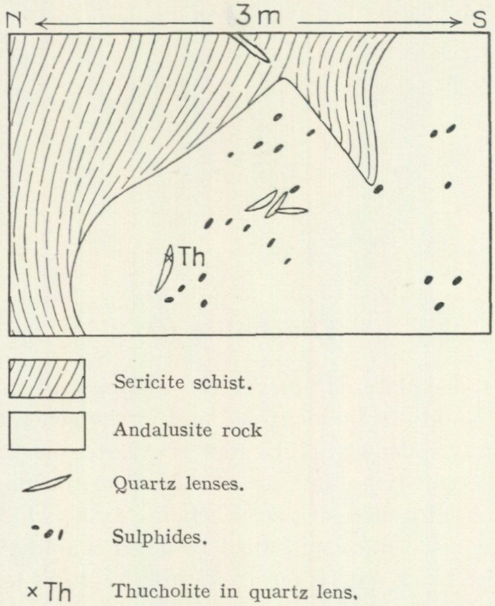

Fig. 1. Vertical section through body of andalusite rock with impregnation of metallic minerals and quartz lenses with thucholite. 570 m level. (Grip 1944).

burns, leaving an amount of ash that varies from case to case (9—19 % were found in several ignition tests according to Aminoff).

As regards the chemical composition of the thucholite the following figures are quoted from Aminoff's paper (Tables 1—3).

Table I. Chemical composition of thucholite.

Sample	II[1] %	V[1] %
Ash	16.4	n. d.
U	6.14	5.7
Th	0.68	0.8
Pb	0.47	n. d.
SiO_2	—	1.9
TiO_2	—	4.5
Al_2O_3	—	1.6
Fe_2O_3	—	0.4

Combustion Analyses	A	B
C	65.17 %	67.90 %
H	2.11	2.65
Ash	23.7	23.3

[1] 250 m level.

In the table opposite another analysis of thucholite, executed by Miss Th. Berggren and Mr. O. Alvfeldt of the Boliden laboratories, is given. The latter determined the rare earths by X-ray spectrographic methods. The analysed material came from stope 60 on the 410 m level. The content of ash is unusually high as is the percentage of TiO_2. Unfortunately nothing remains of the analysed material, and it has not been possible to ascertain whether rutile was present in a sufficiently large amount to correspond to the amount of TiO_2. Of further interest is the presence of 1.18 % S and the high percentage of PbO (4.53 %).

Table II. Analysis of thucholite.

	%
Moisture	1.14
S	1.18
Ash	30.15

Analysis of the ash:

	%		%
U_3O_8	39.70	Er_2O_3	0.130
ThO_2	6.24	Tm_2O_3	0.025
Y_2O_3	1.37	Yb_2O_3	0.144
La_2O_3	< 0.01	Cp_2O_3	< 0.01
CeO_2	0.058	PbO	4.53
Pr_2O_3	< 0.01	TiO_2	37.26
Nd_2O_3	0.122	SO_3	3.10
Sm_2O_3	0.108	SiO_2	2.20
Eu_2O_3	< 0.01	Al_2O_3	1.68
Gd_2O_3	0.144	Fe_2O_3	1.22
Tb_2O_3	0.040	MnO, CaO, MgO	0.00
Dy_2O_3	0.252	Na_2O	0.21
Ho_2O_3	0.032	K_2O	0.23
			98.84

Sp. gr = 1.66.

Aminoff gave the mineral a careful spectrographic and chemical test, partly in order to »use the values of U, Th, and Pb to calculate the maximum geological age».[1] When Ödman handed over the material first found to Aminoff, it had been only cursorily studied under the microscope and it was thought suitable for an investigation of the purpose just mentioned.

Altogether Aminoff gives five determinations of the age of the thucholite. Three of these were made on material from the 250 m level and gave an average value of 517 M. Y. The remaining two refer to thucholite from the 410 m level, the average value here being 811 M. Y. (*i. e.* 294 M. Y. higher than in the former case). The figures are rather startling and Aminoff cautiously says that even if it is tempting to use them for geological speculations, »the data available would appear too scanty to allow of conclusions of a geological character».[2] Unfortunately, in spite of these words of caution, the figures have already been misused in certain geological speculations by Backlund when discussing *i. a.* the age relations of the Boliden ores and the Varuträsk pegmatite.[3]

In view of this and the lack of agreement in Aminoff's age figures the present author undertook a more careful microscopic study of the thucholite in order to see if any inhomogeneities in the material could be made responsible for the discrepancies in question. Fourteen polished sections in all were studied, representing several different finds of the mineral.

The microscopic study showed that the thucholite is composed of two separate, major components and a few others of less importance. One of the main components is a carbonaceous mineral, evidently corresponding to the thucholite s. str. of the American authors, who have described this mineral

[1] Aminoff, op. cit., p. 34.
[2] Aminoff, op. cit., p. 35.
[3] Backlund, H.: Einblicke in das geologische Geschehen des Präkambriums. Geol. Rundschau, Bd. 34, pp. 79—148, 1943.

from some Canadian pegmatite localities. The term thucholite will, however, be retained for the mixture in the present case.

The other main component is a semi-opaque mineral, in polished sections showing yellowish brown internal reflexions. It has not been identified but it very likely consists of a uranium-thorium mineral. This is strongly supported by the fact that a sample of thucholite from the quartzose andalusite rock, which contained only 7.66 to 8.8 % ash,[1] under the microscope was found to be poorest in the mineral in question of all the sections studied. Generally the ash content and, as a consequence thereof, also the amount of the U-mineral present is much higher. Under the microscope the mineral is of a medium gray colour. The colour is not uniform and the surface has a moiré lustre with a bluish hue. Neither pleochroism nor anisotropism could be seen. The internal reflexions have a patchy appearance.

The carbon mineral cannot be definitely identified with any known mineral but broadly speaking it seems to be comparable to the American thucholite s. str. It probably changes composition from case to case. Aminoff states that on one occasion he obtained graphite lines in an X-ray photogram. At the request of the author Mr Alvfeldt of the Boliden Laboratories kindly undertook an X-ray test of a sample of thucholite from the 410 m level, richest in the carbon mineral, but no lines were obtained at all. Graphite is therefore present only in some cases. The gas content indicates that a certain quantity of hydrocarbons is present. Under the microscope the mineral has a fairly strong reflexion pleochroism in yellowish brown (O) and brownish black (E). As compared to pure graphite the pleochroism is weaker and the colours not so bright. The anisotropism is fairly strong but without any marked colour effects.

The mineral has a peculiar mode of appearance. It often forms veinlets about 0.06—0.12 mm thick, cut by tiny gash veins at right angles to the walls and either empty or filled with a gray gangue (Figs. 4 and 5). In the centre of the veinlets one occasionally observes a narrow fissure. The veinlets are not always continuous but are often interrupted and sausage-shaped (Figs. 5 and 6). The mineral may also assume the shape of beads (Fig. 7). The thucholite from the quartz-bearing andalusite rock is more homogeneous, although no individual grains are developed. The veinlets and related formations of the carbon mineral often show a rhythmic structure which is noticeable in the pleochroism or in the interference colours as a banding (Figs. 5 and 6). More rarely does the extinction in the veinlets disclose that the coal grows out bilaterally from the narrow central fissure. The outline of the veinlet is in those cases somewhat lobate. An irregular spherulitic structure is developed in the bead-shaped particles of the coal mineral as shown by their behaviour in polarized light.

The veinlets form a kind of irregular net-work which surrounds areas built up of more or less complex intergrowths of the carbon mineral and the U-mineral (Figs. 4 and 8). The latter may occur as typical irregular replacement remnants »bitten into» by the carbon mineral (Figs. 5 and 6). Generally the latter forms

[1] Aminoff, op. cit., p. 35. These figures are the lowest values of the ash content which have been obtained.

a fine fabric in which are enclosed extremely small remnants of the U-mineral. Sometimes the fabric of the carbon mineral is built in a concentric, dactyloscopic or plumose fashion (Figs. 7 and 9). On the other hand also the reverse conditions have been met with, and rounded, bead-shaped bodies of the carbon mineral have been found surrounded by an extremely fine net-work of the U-mineral. The carbon particles are sometimes so densely crowded that no intervening portion of the U-mineral is visible, the demarcation between the carbon particles being just a dark line. The quantities of the two minerals vary within wide limits, the sample richest in the carbon phase being the thucholite from the quartzose andalusite rock.

Among the more uncommon components we note the following minerals.

S e r i c i t e is present in stringers along the edge of the thucholite nodules and may also penetrate into their interior. Nothing definite can be said of the age relation but the impression is that sericite is younger. It is definitely so in one case, where the thucholite is cut by a thin veinlet composed of pyrite and sericite.

R u t i l e has been noticed in almost every section in the shape of small, irregularly rounded grains. It is found in the carbon mineral as well as in the U-mineral. The presence of rutile fairly likely accounts for the content of TiO_2 in Aminoff's analyses. Whether all the TiO_2 of the analyses enters into the rutile or if part of it is contained in the two major components of the thucholite, as Aminoff thinks, cannot be ascertained. The prefix »titano» in the mineral name does not, however, seem appropriate.

P y r i t e has only been found in the veinlet mentioned above. — A questionable grain of c o b a l t i t e has been noticed once. The grain was too small for an accurate determination. — C h a l c o p y r i t e was observed in thucholite from the 570 m level (Fig. 1) and appeared as small blebs.

The carbon mineral and the U-mineral contain also two other m e t a l l i c m i n e r a l s which could not be determined because of the small size of the grains (max. 0.02 mm but generally only about 0.005 mm, see Figs. 6, 7, and 9). The more common one is a pure white, seemingly isotropic mineral. It is probably a sulphide, its reflexion power being of the same order as that of galena. It occurs in small irregular grains fairly uniformly distributed. Its appearance along the centre of the carbon mineral veinlets or as the tiniest specks in the U-mineral is rather characteristic. In two of the sections there were also seen small grains of an unknown gray mineral, probably also a sulphide. The combined percentage of these two minerals is very small, hardly 1 %.

Thucholite is chiefly known from a few localities in Canada, having been described by Ellsworth from Parry Sound, Ontario and Buckingham, Quebec,[1] and by Spence from Parry Sound and from Pied des Monts, Quebec.[2] The mineral from Boliden has many qualities in common with the thucholite from the

[1] Ellsworth, H. V.: Thucholite, a remarkable primary carbon mineral from the vicinity of Parry Sound, Ontario, and Thucholite and uraninite from the Wallingford mine near Buckingham, Quebec. Am. Min., Vol. 13, pp. 419—439 and pp. 442—448, 1928.

[2] Spence, H. S.: A remarkable occurrence of thucholite and oil in a pegmatite dyke, Parry Sound, Ontario. Am. Min., Vol. 15, pp. 499—520, 1930.

Uraninite and thucholite from Pied des Monts, Quebec. Am. Min., Vol. 25, pp. 711—718, 1940.

Canadian occurrences, the main difference being that all the latter are pegmatites. In all the Canadian places quoted the thucholite s. str. is intimately associated with and replacing uraninite. A microscopic picture of the Parry Sound thucholite, given by Spence, reminds one very much indeed of the replacement of the U-mineral by the carbon in the Boliden thucholite. Further points of similarity could be demonstrated but to save space the reader is referred to the original texts.

As seen from the above description, the Boliden thucholite, as most other minerals of the same kind, is not homogeneous but composed of mainly two components. One may be justified in asking whether a »mineral»[1] of this character can be used in calculating the age. For several reasons the question may be answered in the negative. Let us first consider the circumstance that the U-mineral has been replaced by the carbon substance. It seems very probable that during this process the proportion Pb/U may have been disturbed and that, consequently, discrepancies in the age of the mineral are likely to appear. As regards the content of uranium it can be suspected that this element, which is of a migratory nature, has been partly brought into solution and carried away. The Pb content has occasionally also been influenced by the introduction of small amounts of »common» lead in connection with the introduction of sulphide minerals. This is particularly evident at the locality on the 570 m level described above (p. 3), where the thucholite appears in the closest relationship to a number of metallic minerals, three of which are Pb-minerals. An average content of 0.02 % Pb was found in a chip sample across the portion of andalusite rock in Fig. 1, in which place the thucholite occurred.

If the problem is considered from a paragenetic point of view it can be pointed out that the thucholite has the same appearance and the same occurrence throughout the levels where it has been encountered. The only difference is that on some occasions the mineral appears on veins of coarse sericite and on other occasions on quartz lenses or veins. It may further be stated that the detailed study of the mineralization in the mine definitely pointed to only one single period of U-mineral formation, namely in connection with the second or tourmaline stage of mineralization. Thus there is not the slightest evidence of two generations of thucholite as widely separated as by 300 M. Y.

If we now turn to Backlund's speculations referred to above, we find that in order to explain the lower age (517 MY) of the thucholite from the 250 m level, he compares it with the Rb-feldspar from Varuträsk (SE of Boliden), the age of which Hahn in 1942 found to be 530 MY, and assumes that the formation (by regeneration) of the younger thucholite »könnte zu einer Wärmeeinwirkung der Molassebasalte eines algonkischen Tektogens (mit einem Alter von etwa

[1] The thucholite from Boliden is, strictly speaking, not a mineral but a mixture. Some of the thucholites from Canada must also be considered mixtures as they contain more or less uraninite. It has been seen in the Boliden thucholite that sometimes the amount of the U-mineral is very insignificant and that the replacement remnants are very difficult to detect under the microscope. The question may therefore be raised whether thucholite should really be considered a true U-Th-mineral or whether the contents of these elements in reality refer to replacement remnants — often extremely small — of uraninite, etc.

650 M. J.) Beziehungen haben».[1] It is difficult to follow Backlund in this case but the following may be pointed out. Since Hahn published the figure 530 MY in 1942 he has on a later occasion given a much higher value (in a lecture in Stockholm Oct. 1943, see Geol. För. Förh., Vol. 66, pp. 90—97, 1944), and Dr Dahlström, of the Boliden Laboratories, has told the author, in a personal communication, that according to his investigation even the latter value has now been revised and that no figure of the age of the Varuträsk Rb-feldspar can be given at present. As regards Backlund's molass basalt it is even more doubtful, as no basalt of the kind or age referred to is present anywhere at Boliden or in the whole district.

In summing up the author wishes to emphasize: 1) that the age figures obtained from the Boliden thucholite cannot be considered reliable, as the thucholite is a mixture of minerals, formed by the replacement of the U-mineral by a carbon substance, and as it is very likely that changes in the Pb/U ratio did take place, and 2) that the thucholite from Boliden must have been formed during one single mineralization stage, as the mineral appears under the same paragenetic conditions throughout the mine.

Natural Gas in the Boliden Mine (G).

For the purpose of examining the 410 m level in the Boliden mine a long drift has been driven and from it horizontal diamond drillholes have been made on either side. From some of the drillholes in the foot-wall portion of the ore-zone there escapes a colourless gas, which has an intense sickening smell and burns with a blue flame.[2]

The rocks cut by the drillholes discharging gas consist of acid sericite schists with a varying andalusite content and with strips of andalusite rock. As was mentioned in the preceding chapter the andalusite-rich rocks are thucholite-bearing and in the vicinity of the gas-bearing drillholes thucholite has also been found in quartz veins. As the gas comes from thucholite-bearing areas it would seem reasonable to expect the gas to contain helium, formed in the disintegration of the radioactive uranium- and thorium-containing thucholite. This was confirmed by analyses (Table III).

Table III. Natural gas from the Boliden mine.

	A	B	C	D	E	F	G	H	I
CH_4	59.6	68	—	—	—	—	68.7	68.8	62.3
N_2 + inert gases except He	36.6	27.1	—	—	—	—	24.3	22.9	30.1
He	2.3	2.3	5.3	5.2	5.4	3.3	4.3	2.3	2.7
C_XH_Y	0.0	0.0	—	—	—	—	0.3	0.2	0.1
H_2	0.03	1	0.0	0.09	—	—	1.0	0.5	0.6
H_2S	—	—	—	—	—	—	0.0	0.0	trace
CO	0.6	0.7	—	—	—	—	0.1	0.9	1.1
CO_2	0.1	0.1	—	—	—	—	0.1	0.0	0.0
O_2	0.8	0.8	—	—	—	—	1.2	4.4	3.1

[1] Backlund, op. cit., p. 143.

[2] It causes nausea when inhaled in large quantities and its smell clings to the clothes and remains long after the bearer has left the mine.

A.	Drillhole	98	410	m	level	May	30	1941.	8 l/hour.		
B.	»		410	»	»	Oct.	11	1941.			
C.	»	164	410	»	»	Dec.	30	1942.			
D.	»	136	410	»	»	Dec.	30	1942.			
E.	»	136	570	»	»	Dec.	30	1942.			
F.	»	146	410	»	»	Dec.	30	1942.	18 l/hour.		
G.	»	139	410	»	»	Feb.	8	1944.	(14	»	1942)
H.	»	320	570	»	»	Feb.	8	»	4	»	
I.	»	324	570	»	»	Feb.	8	»	3	»	

The analyses were made in the Boliden Laboratory, Stockholm, Nos A—F by R. Sundgren and G—I by I. Ljungberg and L. Selving.

The same gas is discharged from drillholes on the 570 m level, especially where they cut a brecciated zone, and from some fissures in the drifts on the 410 and 570 m levels.

The drillholes yield moderate quantities of water and from the water there is precipitated a yellowish mud with a repulsive cadaverous smell. An examination made in 1941 of mud from borings on the 410 m level yielded:

	West	East
H_2S	traces	
Organic substance	24.8	54.8
P_2O_5	0.38	0.77

Analyst Th. Berggren.

The chief components of the gas in the Boliden mine are methane and nitrogen (see Table III). Gas of this composition arises through the disintegration of sedimentary organic material, *e. g.* sapropel in clay or schist. The disintegration may be brought about by bacteria or chemically by distillation under high pressure.

The Boliden ore is situated in altered volcanic rocks, but stratigraphically under it there is a limestone horizon and minor horizons of graphitic sediments. Over the ore, stratigraphically and tectonically, arches the large series of schist in an anticline dipping steeply towards the east. It consists of mainly quartz-rich sediments, the grain-size of which varies considerably. The series is graphitic and sulphide-bearing, the graphite being especially enriched in the pelitic parts. The graphitic series of schists has quite a considerable extension and extends several hundred kilometres southwards from the Skellefte Field. Undoubtedly the carbon content of the sediments originates from organic material embedded in the sediments when they were deposited.

During the second phase of the folding of the Skellefte Field[1] there occurred an extensive migmatization of the schist series and a mobilization of the elements present. If the organic material of the schists had not disintegrated *inter alia* to gas prior to the folding, due to the influence of bacteria, the disintegration occurred during the folding and the accompanying heat wave. The gas must then have started moving and followed the same channels as the ore

[1] Grip, E.: Die Tektonik und Stratigraphie der zentralen und östlichen Teile des Skelleftefeldes. Bull. Geol. Inst. Upsala XXX, 1941, p. 82.

solutions that penetrated during that time. The gas will have penetrated into the ore area particularly during the second stage of mineralization,[1] the quartz-tourmaline stage, when there was a plentiful influx of boron, fluorine and water. The sericitization of the andalusite rock also occurred under the influence of these solutions, and the gas is now encountered in the andalusite-bearing areas. The fact that the gas occurs most profusely in the andalusite-bearing sericite schists may be attributed to the great brittleness of this rock and to its numerous small fissures.

Next to methane and nitrogen, helium is the richest component of the gas. The helium content amounts to 5.4 per cent. It will undoubtedly be a radioactive disintegration product of uranium- and thorium-bearing minerals. As has already been mentioned, the thucholite occurs in the same parts of the mine as does the gas. Certain parts of the andalusite rock contain as much as 600 g/t of uranium in the thucholite. The mean uranium content of the andalusite-bearing rocks is considerably smaller. Measurements of the radioactive γ-radiation from cores and drift-walls carried out by Dr D. Malmqvist[2] show the mean uranium contents of the gas-bearing areas to be between 10 and 100 g/t U. A uranium quantity of 100 g corresponds to 6 litres of helium formed by the disintegration of uranium during 500 million years, 12 litres during 1,000 million years, etc. The calculation gives an idea of the quantity of helium gas formed by radioactive disintegration and shows that the quantities are so considerable that the gas in the mine may have obtained its helium from that source.

If a hydrocarbon flows past a uranium-bearing mineral, the radioactive radiation causes a polymerization of the hydrocarbon and a solid substance is precipitated from the gas. There being a surplus of gas, the carbonaceous substance precipitated is proportional to the radiation time and the quantity of radioactive element. In the Boliden mine there are both radioactive minerals and a gas rich in hydrocarbon, which latter may come into contact with the former. A substance rich in carbon must then be precipitated. There is thus no doubt but that the thucholite was formed by methane, other hydrocarbons and perhaps to some extent H_2, CO, and CO_2 being polymerized under the influence of radioactive radiation by U-Th-minerals. This formation of thucholite probably still continues.

This theory on the formation of thucholite agrees with that supposed by Spence,[3] Kirsch[4] and Wickman[5] for the thucholite in American pegmatite veins, which opinion is strongly supported by Vernadsky.[6]

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1 Ödman, op. cit., pp. 71—107.
2 Report not published.
3 Spence, op. cit.
4 Doelter, Handbuch der Mineralchemie. IV, 3, p. 984.
5 Wickman, F., Unpublished report.
6 Vernadsky, W. Les Problèmes de la Radiogéologie. Actualités Scientifiques et Industrielles. 201. Paris 1935.

A Comparison between the Gas at Boliden and Other Occurrences (G).

Natural gas containing helium is known above all from North America, where in some places it is discharged in so great quantities and with so high a helium content that helium can be obtained at a small cost. However, in 1935 helium was obtained only at Amarillo, Texas (1.8 % He, 24 % N) and at Dexter, Kansas (0.5—2 % He, 83 % N). Dobbin[1] says of the American natural gas: »Rich helium and nitrogen gas from wells occurs in some formations ranging in age from Cambrian to Tertiary . . . It is significant that natural gas containing noteworthy amounts of helium generally occurs in reservoirs relatively close to the basement rocks. It is believed that this relation strengthens the theory that the helium in some natural gases, at least, is derived from the disintegration of the radioactive elements in the basement crystalline rocks».

The highest helium contents of the American natural gases are 7—8 %, but the helium contents of the sources utilized are barely 2 %. Furthermore the composition of the gas containing helium varies very considerably at different places. Methane and nitrogen are, however, generally the main components. Ethane and carbon dioxide may also occur in considerable quantities.

Besides in America, gas containing helium has been found in many places, but judging from reports in the literature the content of helium is very low (< 1 % He). Some Swedish deposits, however, form an exception. Thus natural gas from the Cambrian strata of Öland contains a noteworthy percentage of helium. Dr Otto Meier has been kind enough to submit some analyses of natural gas from borings in Öland carried out in 1935.[2] They are shown in Table IV.

Table IV Natural gas from the Cambrian strata of Öland.

Locality	Bläsinge	Sandvik	Solliden	Borgehage	Getstaåsen
CH_4	69.0	74.3	82.0		46.3
N_2	29.8	23.4	11.8		47.7
He		0.14	0.85	1.37	1.20
A		0.39	0.0		0.52
C_2H_6	0.7	0.0	0.0		0.0
C_XH_Y	0.0	0.5	0.0		0.0
H_2	0.5	0.0	4.9		1.8
CO	0.0	1.1	0.0		0.0
CO_2	0.0	0.2	0.0		2.5

It will be seen that the composition of the Öland gas greatly resembles that of the Boliden gas, though the helium content is considerably lower.

Inflammable natural gas is also known from several mines in the precambrian of middle Sweden. In most of them, however, the gas originates from decaying wood or mud. According to Nordenström[3] this is not the case with gas in the mines of Åmmeberg and Dannemora.

[1] C. E. Dobbin, Geology of natural gases rich in helium, nitrogen, etc. publ. in H. E. Ley, Geology of natural gases, Tulsa 1935.

[2] Meier, Otto. Förekomsten av jordgas i Ölands och Östergötlands kambrosilur och några geologiska rön därstädes. A lecture. Geol. Fören. Förh. Stockholm, 1935. p. 364.

[3] G. Nordenström, Förekomst av brännbar gas i malmgrufvor. Geol. Fören. Förh. Stockholm, 1896. pp. 637—39.

In the zinc mine of Åmmeberg in 1896 a diamond drillhole was driven from the 200 m level through leptite and zinc-ore. From this drillhole an inflammable gas escaped.

In the Dannemora iron mine in 1893—1896 there escaped inflammable gas with a nauseous smell from a diamond drillhole driven through hälleflinta and limestone on the 209 m level in »Mellanfältet».

Nordenström published analyses of the gas from Dannemora and Åmmeberg. They are quoted in Table V, B and C. In these old analyses the inert gases have not been determined.

A note by A. E. Nordenskjöld about the occurrence of nitrogen in an organic compound associated with the Dannemora iron ore and a suggestion to investigate whether there also was a content of helium, caused the present author to ask the superintendent of the Dannemora mine, Mr E. Berggren, if there now was any natural gas in the mine. There was and Mr Berggren kindly communicated the following data and sent the author a sample of the gas. The inflammable gas is escaping from a diamond drillhole recently driven horisontally 150 m towards the W from the 300 m level in »Sjögruvan». The drillhole cuts hälleflinta and some skarn. An analysis shows that the gas has about the same composition as the Boliden gas, but that the content of helium is a little higher, being 6 %. See Table V, A.

Table V. Natural gases from Dannemora and Åmmeberg.

	A	B	C
CH_4	70	33.6	51.0
N_2 + inert gases except He	19.7	66.4 (N₂ + inert gases + He)	44.8 (N₂ + inert gases + He)
He	6.0		
C_2H_4	—	0	0.5
C_XH_Y	1.2	—	—
H_2	0.4	—	1.0
H_2S	—	—	—
CO	0.8	0	1.2
CO_2	0.1	0	1.5
O_2	1.8	0	0.0

A. Dannemora Sjögruva, 300 m level, 3 l/hour. 1944. Anal. L. Selving, Boliden Laborat.
B. Dannemora Mellanfält, 209 m level. 1894. Anal. C. G. Särnström.
C. Åmmeberg, 200 m level. 1896. Anal. C. G. Särnström.

Both the Åmmeberg and Dannemora mines are situated in areas of metamorphic pre-Cambrian supracrustal rocks, including thick layers of limestones. At Dannemora, graphite has been noted in the ore. This, however, cannot be taken as a parallel to the graphitic schists at Boliden, as the Dannemora graphite is believed to have been formed through the dissociation of iron-manganese carbonate. However, as at Boliden the gas in both the mines mentioned seems to be of fossil nature, and the helium content a product of the radio-active disintegration of minerals.

As regards their helium content, the gases of Boliden and Dannemora are most closely comparable to the American gases richest in helium. Gas containing helium from pre-Cambrian areas does not appear to be described or mentioned anywhere in the literature. The older the rocks the greater are of course the possibilities of a gas there present seeping out in the course of time, and it is possibly under very special circumstances only that the gas can have remained shut in during so long a time. On the other hand the prospects of finding gas rich in helium will be greater in the older areas where the radio-active disintegration has been active for a longer time.

The authors wish to express their gratitude to Mr Erik Bengtson, President of the Boliden Mining Co., for due permission to publish this report.

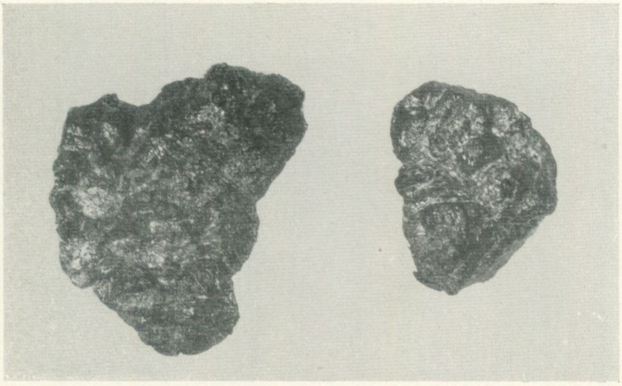

Fig. 2. Reniform nodules of thucholite. Nat. size. 250 m level. (Plate 16, Fig. a in Geology and Ores of the Boliden Deposit. Geol. Surv. of Sweden, Ser. C, No 438, 1941).

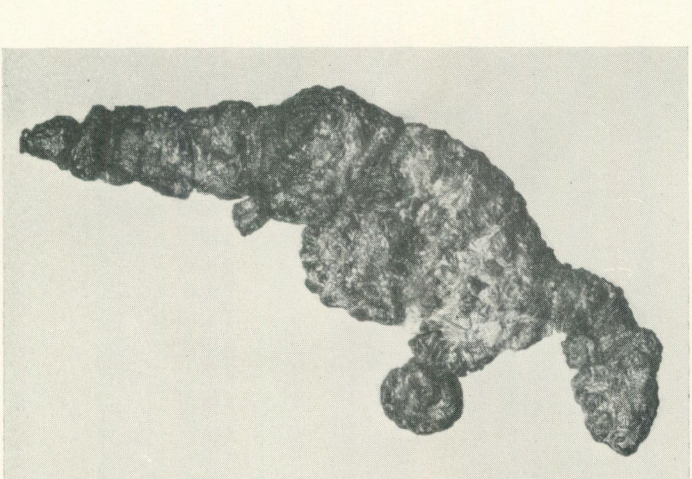

Fig. 3. Odd, dinosaur-shaped nodule of thucholite. 3/5 of nat. size. Stope 60, 403 m level.

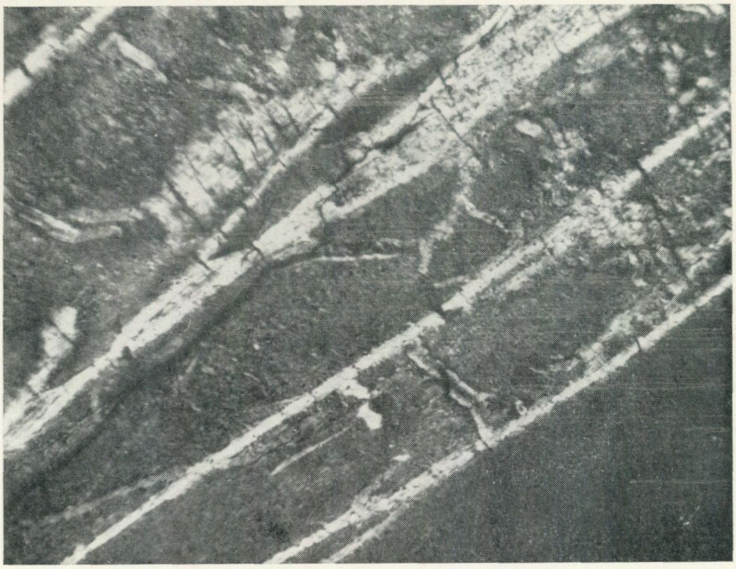

Fig. 4. Veinlets of carbon mineral in massive, fine-grained carbon with almost submicroscopic remnants of U-mineral. N crossed, 45 x. 330 m level, east.

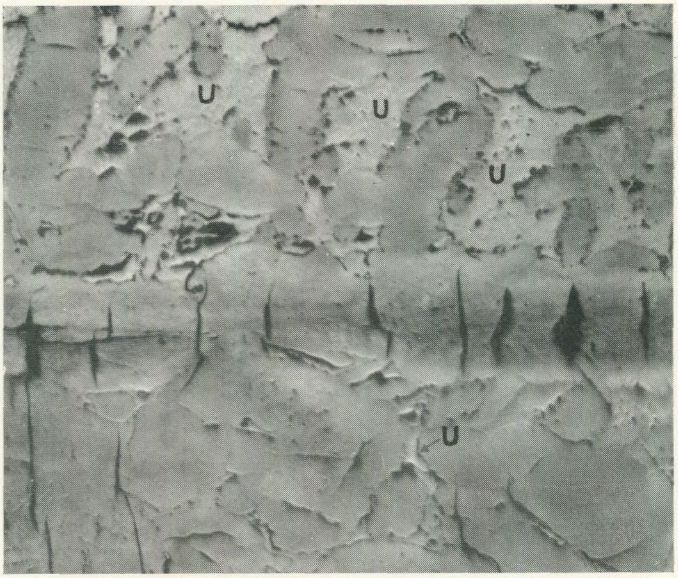

Fig. 5. Veinlets and sausage-shaped formations of carbon mineral. Note gash-veins in central vein. U = remnants of U-mineral. Ord. light, 170 x. 250 m level, centre.

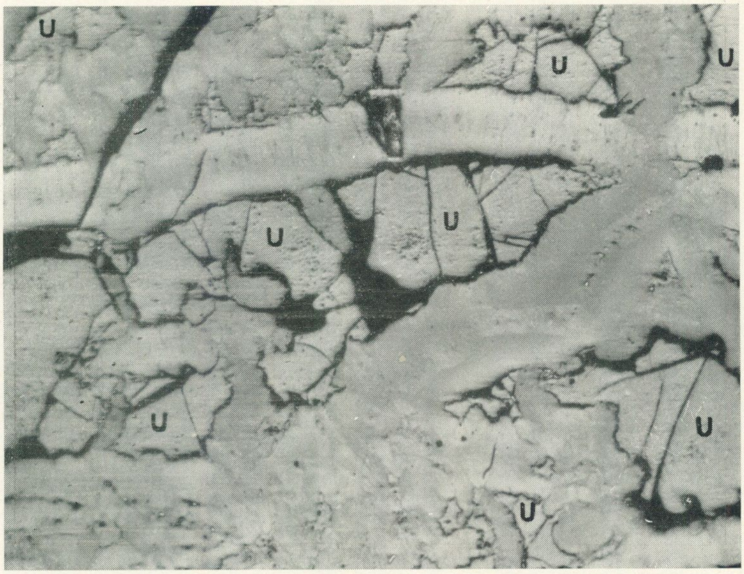

Fig. 6. Veinlets of carbon mineral with remnants of U-mineral (= U). Note structure in the carbon veinlets and specks of unknown white mineral in centre of veinlet to the right. Ord. light, 170 x. 250 m level.

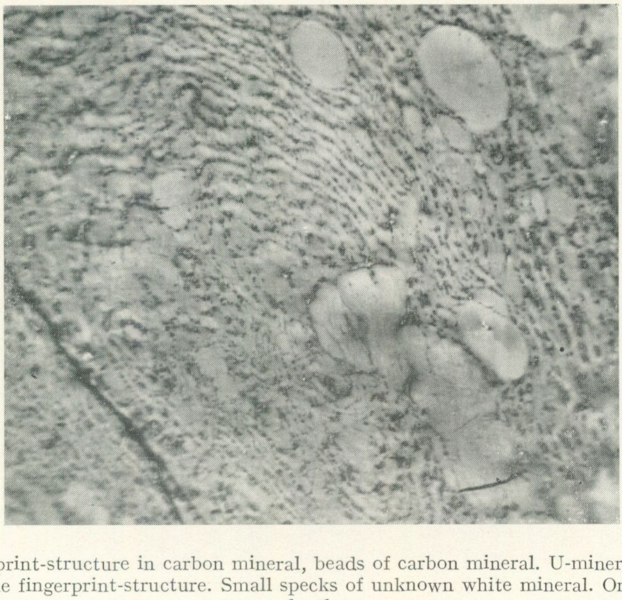

Fig. 7. Fingerprint-structure in carbon mineral, beads of carbon mineral. U-mineral in small particles within the fingerprint-structure. Small specks of unknown white mineral. Ord. light, 220 x. 250 m level, centre.

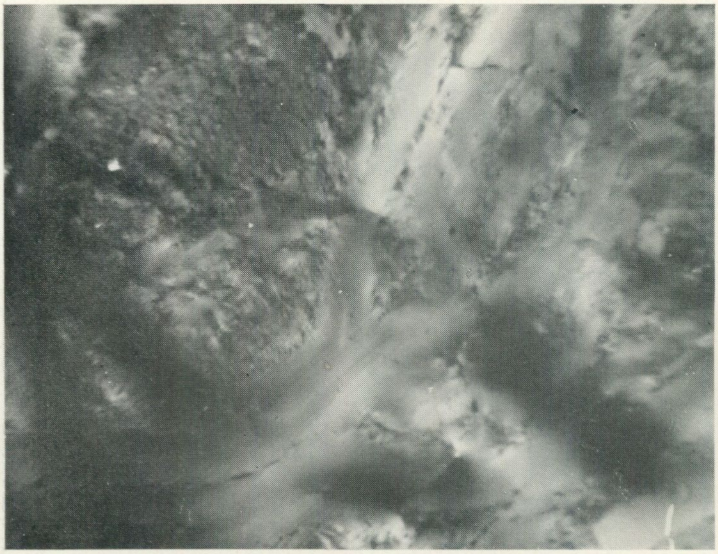

Fig. 8. Flamboyant veinlets of carbon mineral in massive, fine-grained carbon with almost submicroscopic remnants of U-mineral. N crossed, 220 x. 410 m level.

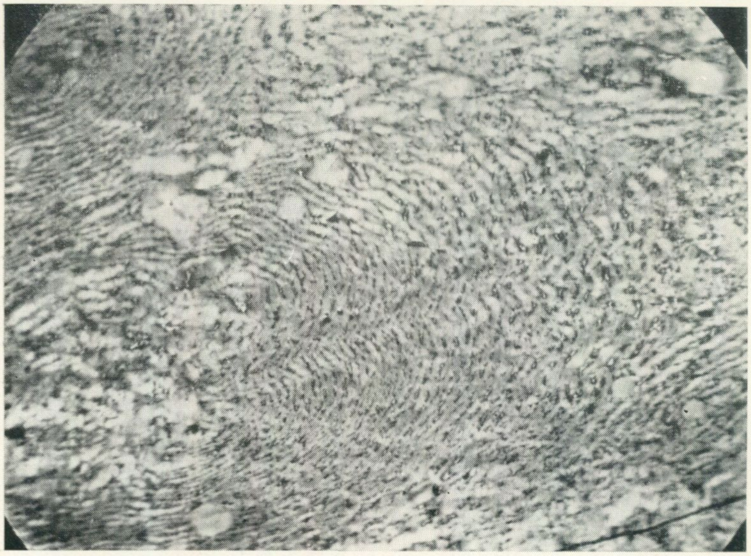

Fig. 9. Fingerprint-structure in carbon mineral. U-mineral in small particles within the fingerprint-structure. Ord. light, 220 x. 250 m level.

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