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*Marian BANAŚ *, Jan JAROSZ **, Witold SALAMON **

THUCHOLITE FROM THE PERMIAN COPPER-BEARING ROCKS IN POLAND

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Abstract. Copper-bearing zone of Zeichstein rocks in Poland was investigated. In the ore samples of sandstone, dolomite and shale, assemblages of thucholite were found. Thucholite forms disseminated spheroidal or irregular bodies. It consists of two components: isotropic and anisotropic one, containing polygonal grains of uraninite. Both thucholitic mass and uraninite have been examined using electron microprobe analysis. It may be suggested, that carbonaceous matter formed from colloidal sapropel was later penetrated by active hydrocarbons and uranium-organic complex. Radiation caused polymerization and partial graphitic preorientation of the uranium-bearing organic material. Secondary ore mineralization was superimposed on the thucholite concretions.

INTRODUCTION

The carbonaceous matter with an anomalously high uranium content called thucholite (terms: uraniferous asphaltite carburan, carbon antraxolite were also used) has been first described in nature by Ellsworth (1928) from Ontario, Canada. Then it was found in the Witwatersrand deposit of gold- and uranium-bearing conglomerates (Davidson, Bowie 1951, Ramdohr 1955, Liebenberg 1955, Schidlowski 1966a, 1966b). The authors cited gave precise data on the geological setting, mineralogical and chemical composition and the genesis of thucholite. It has been also identified by Schüller (1959) in Zechstein copper-bearing rocks near Mansfeld, GDR, by Lenoble and Gangloff (1958) in Permian shales, sandstones and dolomites from Lodève, Massif Central, France (described as carbonised uraniferous product — carburan), by Uytenbogaardt (1960) from pre-Cambrian quartzites of Västervik, Sweden and others. Recently an anomalously high uranium content has been noted in Zechstein copper-

* Institute of Geology and Mineral Deposits, Academy of Mining and Metallurgy, Cracow (Kraków, al. Mickiewicza 30).
** Mineralogical Laboratory, Lubin Copper Combine.

-bearing rocks in Poland (Kanasiewicz, Uberna 1961; Grabczak, Niewodniczański 1962; Kanasiewicz 1966; Machon 1968). Detailed laboratory analyses carried out on sample petrographic material permitted to separate carbonaceous matter (Jarosz, Zaczek 1966) which revealed the characteristics of thucholite (Banaś, Jarosz 1972).

Several samples collected during the investigations of the deposit were subjected to microscopic examinations, infrared absorption and spectroscopic emmision analyses, X-ray analysis, electron microprobe and macro- and microradiographic analyses. On their basis mineralogical and chemical character of the thucholitic substance was determined.

The investigated thucholite concentrations from Polish Zechstein rocks are of uneconomic grade.

THUCHOLITE OCCURRENCE IN THE LITHOLOGICAL PROFILE

Thucholite has been noted in the geological profile of the boundary zone of Rotliegendes and Zechstein rocks. The thucholite-bearing rocks are sandstones and marly shales (Fig. 1). In the overlying carbonate rocks no thucholite occurrences have been practically recorded.

Sandstone with thucholite overlies the Rotliegendes laminated sandstones which form alternating, rhytmical, white-grey and grey bands. It consists of fine-grained quartz sand with psammitic or aleuritic-psammitic texture and random structure. Locally, it shows the effects of oxidation manifesting themselves as red spots (Phot. 1). Quartz grains are the dominant constituent of the detrital material of the sandstone (70—80%), feldspars constitute about 10%, the remaining part are rock fragments. The cement of sandstone is differentiated. Near the contact with shale it has a basal character consisting mainly of calcite with subordinate dolomite. About 30 cm below the contact it changes into argillaceous cement, continuing in this form downwards. Two varieties, differing microscopically in colour, may be distinguished within the sandstone discussed. Just below the shale a light-grey, Lingula sandstone occurs, 5—10 cm in thickness, containing thucholite concretions (Phot. 1). Below, its white-grey variety may be noted. Compared with the latter, the light-grey variety is microscopically characterized by considerably finer grain size and a lower degree of rounding of quartz grains. The whole sandstone frequently shows substantial mineralization with copper sulphides. Ore mineralization is predominantly due to infiltration processes, especially when the s.c. boundary dolomite, separating the copper-bearing shales from sandstones is not developed.

Aggregates of thucholitic carbonaceous matter occur in the light-grey Lingula sandstone. They are confined to a single level at a distance of 1—3 cm from the shale. It has been found that irregular polygonal grains of carbonaceous matter showing no optical anisotropy and free of uraninite partly replace the cement in the thucholite-bearing sandstone. Locally, they make up about 10% of the sandstone cement. Thucholite gradually disappears in the underlying white-grey sandstone and its fine grains, discernible only under the microscope, are very scarce. Down to

the bottom, in the underlying laminated sandstones, no thucholite occurrences have been noted.

In the shales overlying the sandstones thucholite appears in each variety of these rocks in greater or lesser amounts. It has been recorded successively in the clay-sandy shale (1—5 cm thick), in the boundary dolomite (2—10 cm), in the clay-organic (smearing) shale (5—20 cm) and in thin-bedded, clay-dolomitic shale (5—15 cm). The overlying compact, clay-dolomitic shale is barren (Fig. 1).

The shale rocks are characterized by different quantitative ratios of the main rock-forming components. The most common of them — clay minerals — which are the main constituent of smearing shale, disappear towards the top and so does organic substance, the largest concentrations of which have been noted in the smearing shale, too. The content of carbonates (calcite and dolomite), on the other hand, tends to increase towards the top. The whole profile of shales is mineralized with copper sulphides and minerals of accessory metals. The largest concentration of ore minerals has been recorded in the clay-organic shale. In the discussed shale bed thucholite concentrates primarily in the thin-bedded, clay-dolomitic shale and in the clay-organic shale (Fig. 1).

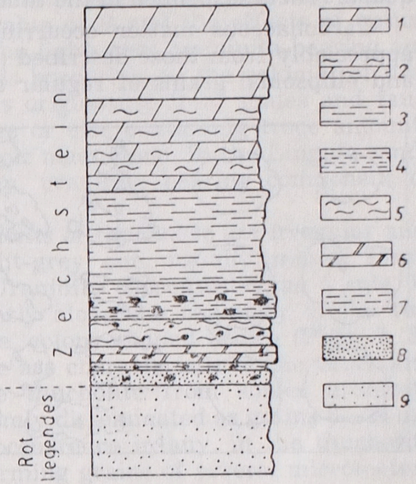

Fig. 1. Lithological profile of copper-bearing zone with the thucholite occurrences (black points)
1 — grey dolomite, 2 — dark-grey, clay dolomite, 3 — dolomitic-clay shale (compact), 4 — clay-dolomitic, thin-bedded shale, 5 — black, clay-organic shale (smearing shale), 6 — boundary dolomite, 7 — clay-sandy shale, 8 — Lingula sandstone, 9 — white-grey sandstone

Substantial amounts of thucholitic substance have been noted in calcite veinlets that cross-cut the boundary dolomite. The veinlets run almost vertically and are up to 7 cm long and 0.5 cm thick. Thucholite grains have been also encountered in the surroundings of the calcite veins in the boundary dolomite itself.

Moreover, certain amounts of thucholitic substance have been found in fault zones.

FORMS OF THUCHOLITIC CONCENTRATIONS

Thucholite exhibits different structures, depending on the place of occurrence. It usually tends to form string-like concentrations concordant with the bedding of the host rock. Such concentrations nearly always consist of spheroidal bodies, sometimes discoidally flattened. Thucholite grains are susceptible to chipping, leaving imprints in the rock (Phot. 2).

In sandstone thucholite forms grains 1—12 mm in diameter the shapes of which depending on the open space between quartz grains. It appears then that thucholite partly replaces the sandstones cement forming irregular bodies with rugged boundaries (Phot. 3), considerably differentiated in size. On account of small grain size, several concentrations of the thucholitic grains are detectable only under the microscope. It may be observed that development of larger concentrations frequently proceeds by thucholitization, i.e. quartz resorption. This is evidenced by quartz relicts suspended in the thucholitic mass.

Carbonaceous matter occurring in shales forms bodies that differ appreciably from those described (Fig. 2). These are, as a rule, spheroidal and ellipsoidal grains of regular shape. They are outlined by the shale

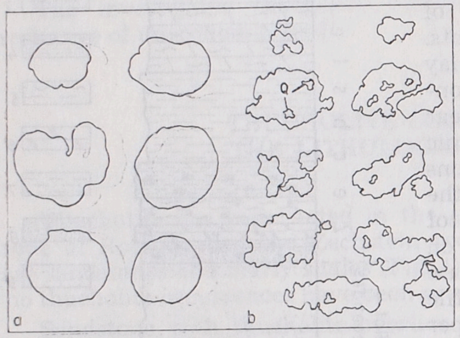

Fig. 2. Forms of thucholite grains typical for shale (a) and for sandstone (b) with the relicts of quartz grains (Q) after the thucholitization process

structures enclosing thucholite grains which gives an impression of eye textures (Phot. 4). The size of thucholite grains in the shales varies from 1 to 5 mm. Some smaller concentrations, 0.08—0.7 mm in size, are visible only under microscope.

In calcite veins thucholite forms irregular, sometimes spheroidal or ellipsoidal bodies, 0.02—5.0 mm in size (Phot. 5). In boundary dolomite thucholite grains are spheroidal, sometimes surrounded by atoll structures of chalcopyrite (Phot. 6). Carbonaceous matter forming sharp-edged polygonal bodies frequently containing hardly discernible uraninite grains also fills the interstices between grains in the coarse-grained dolomite.

Thucholite grains derived from fault zones are, as a rule, disseminated in the material of tectonic origin, forming sharp-edged polygonal bodies which suggest an association with cataclastic processes.

MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF THUCHOLITE

Macroscopically, thucholite is of pitch-black colour with greasy luster. It is characterized by great hardness but shows simultaneously considerable brittleness. Microhardness measured by the PMT-3 microhardness tester is 232—362 kG/mm^2 (2 275,9—3 551,2 N/mm^2) in Vickers scale which gives the values of hardness 4.3—5.0. The measurements were carried out applying a load of 200 G (19.62 N) for 15 s and obtaining the trace of a diamond pyramid with a diagonal of 32—40.5 μm.

Optical properties of thucholite were defined only in reflected light because it is opaque even in thin section.

Thuholite consists usually of two components: light-grey, anisotropic and grey, isotropic ones. The former mainly occures in thucholites originating from sandstone in which a substantial amount of uraninite has been noted. It appears from Ramdohr (1975) that uraninite may not only make the surrounding carbonaceous matter anisotropic but may also increase its reflectance. An increased value of R and the effects of optical anisotropy may be observed both in the light-grey, uraninite-bearing and grey components in the form of bands bordering on the colonies of uraninite grains. The thucholite varieties originating from shales and fault zones and beeing either uraninite-free or else containing trace amounts of this mineral consists of grey, isotropic mass alone. In the Lingula sandstone casual concentrations light-grey, uraninite bearing component of mosaic anisotropy have been recorded.

The boundaries of the two components of thucholite are irregular and, as seen on Phots 7 and 8 the light-grey one, usually minor, forms elongated, curved, amoebic shapes. Uraninite concentrates, as a rule, in the light-grey substance, predominantly along the boundary of the two components, thus forming chaink-like, colony-shaped bodies (Phot. 7, 8). Those oriented structures of uraninite are characteristic of the thucholite originating from sandstones. In the thucholite from shales uraninite appears in trace amounts, being randomly disseminated as grains 8—24 μm in size. It shows a similar mode of occurrence in any, in the thucholite from fault zones and calcite veins, forming grains of several micrometers in size in the latter.

Uraninite reveals untypical textures. There are neither colloform individuals nor their relicts which would suggest the presence of pitchblende. Under the microscope, the grains resemble polygonal forms with profoundly altered edges (Phot. 9). A question arises whether or not they represent a stage of U_3O_8 recrystallization.

Uraninite grains vary from 4 to 12 μm in size. The mineral is grey, isotropic, hard with reflectance of the order of 17%. Its relief is markedly higher than that of surrounding thucholite. Microhardness has not been measured due to very small grain size. The mineral in question covers on the average 1—5% of the area of thucholite.

Data obtained from microscopic examinations of thucholite and uraninite were supplemented by additional analyses.

The radioactive character of the thucholitic substance was confirmed by macro- and microradiographic analyses. Macroradiographic effects were obtained using highly sensitive photographic paper. One-day exposure was enough to produce weak but visible blackening of the emulsion. Distinct radiographs were obtained after 30 days of exposure. Dark marks corresponding to thucholite grains showed clearly more intense blackening in the samples derived from sandstone (Phot. 10). This is due to the abundance of highly radioactive uraninite in these samples. Radiographic analyses carried out under the same conditions on samples derived from shale have revealed a positively lower degree of emulsion blackening. The blackening was hardly perceptible on the radiographs of thucholite originating from fault zones. In the two latter cases insignificant amounts of U_3O_8 had been noted before.

Microradiographic analyses made on specially prepared nuclear plates with 50—60 μm thick emulsion have revealed further characteristic of the substance under investigations. Samples exposed for 1—9 days gave microradiographes with interpretable concentrations of alpha-particles. Selected radiographs point to a regular distribution of uranium in the thucholitic substance. Uraninite grains recorded in the samples appeared as dense, rosette-like, radial concentrations of alpha-particle tracks (Phot. 11). The absolute length of these tracks is usually below 40 μm, being indicative for the presence of uranium. Only few tracks longer then 40 μm belong to thorium.

Chemical analyses of thucholite and accompanying uraninite were carried out by electron microprobe *. The two components of thucholite together with uraninite were analysed to determine content of U, Th, Pb and some accesory elements, mainly copper. The results for samples derived from Lingula sandstone are listed in Table 1. It is interesting to note the variable content of uranium both in the light-grey and grey variety of thucholite. Lead content is relatively low, which is confirmed by the lack of galena. This fact together with insignificant amount of radiogenic lead may attest the young age of uraninite. Thorium content

Table 1

Results of quantitative chemical analysis of thucholite and uraninite from sandstones determined with electron microprobe

Number of sample	Lithology	Component of thucholite	Elements, weight %		
			U	Pb	Cu
2/L LW	Light-grey Lingula sandstone	light-grey component	0.3— 0.5	l.d.*	l.d.
		grey component	0.6—20.1	up to 0.6	l.d.
		uraninite	about 85	0.3—0.9 average 0.6	0.1—0.2 average 0.15
189/S PW	light-grey Lingula sandstone with copper sulphides mineralization	light-grey component	6.4—11.1	0.3—0.6	0.9
		grey component	3.9— 7.1	0.1—0.3	—
		uraninite	74.9—84.9 average 78.3	1.6—2.8 average 2.4	1.5—0.7 average 1.1

* Limite of detection.

* Analyses were made by L. Kubica in the Institute of Non-Ferrous Metals, Gliwice on the *JXA-3* electron microprobe using accelerating voltage of 25 and 35 kV and electron beam of 1 μm diameter. Samples were coated with 50 A (5,0 nm) thick layer of aluminium and carbon. LiF, SiO_2, mica, KAB and barium stearate crystals were used.

varies from 0.53—1.25% in uraninite from thucholite sample derived from the fault zone. These values do not permit to define explicitly the analysed material as pitchblende or uraninite. According to Ramdohr (1975), a ThO_2 content below 0.5% is characteristic of the pitchblende varieties of U_3O_8. On the other hand, increased contents of Ta, W, Si, Ti and V are the case for uraninite rather then pitchblende nature of the mineral. In the thucholite samples derived from shale, no Ta, W, Mn, Fe, V, La, Mo, Y, Nb, Ce, Re have been recorded; Th and Pb have also been found to be missing. In both varieties of thucholite trace, if any, amounts of uraninite have been noted.

From the data yielded by electron microprobe analysis of thucholite a clear picture energes of increased U, Pb, Ta, Ti and W contens, reflecting the presence of uraninite in the sample (Phots 14—18). Thucholitic substance shows, in turn, the presence of considerable amounts of Cu, Fe, Zn and S between the uraninite grains (Phots 19—22), which would be evident for the presence of sulphides.

Table 2

Content of some elements in thucholite, determined with electron microprobe (weight %)

Point	Fe	Cu	Ni	Mo	Au	Ag	Hg	Pb	V	S
1	0.1	3.0	0.1	0.1	0.3	0.1	0.3	0.3	0	0.2
2	0	0	0	0	0	0	0	0	0.5	0.1
3	0.4	0.9	0	0	0.4	0.9	0	0	0	0.3
4	0.6	0	0	0	0.3	0	0	0	0	0

The quantitative data on the content of Fe, Cu, Ni, Mo, Au, Ag, Hg, Pb, V and S calculated from microprobe analyses at 4 points of thucholite originating from the boundary dolomite are presented in Table 2. Besides the above mentioned elements also As, Bi, Pd, Pt, Al, and Si are present in detectable amounts.

Infrared absorption analyses indicate that the uranium-bearing, carbonaceous matter of sapropelitic character is highly carbonized since it consits of aromatic rings. On the other hand, peaks characteristic of the side bonds of aromatic and hydrocarbon rings are absent.

Thucholitic substance was subjected to X-ray diffraction analysis *. The grey component appeared to be amorphous while the light-grey one was partly recrystallized. Its diffraction pattern showed some distinct but diffused reflections that failed to be identified. As suggested by Ramdohr (1975), it may represent a stage of recrystallization with gra-

* X-ray diffraction analysis was made by J. Kubisz on the TUR *M61* diffractometer using Ni- and Fe-filtered CuK and CoK radiation together with standardized 114.3 and 57.5 cylindrical cameras. The film was inserted asymmetrically after Straumanis-tevins method. Interference lines were measured with accuracy of ±0.05. Reflection intensity was estimated visually.

phitic preorientation. It is worth noting that in Zechstein copper-bearing shales small amounts of graphite have been recorded as isolated, tabular grains oriented concordantly to the bedding.

X-ray diffraction analysis * was also carried out on two uraninite samples separated from the largest concentrations of thucholite in sandstone. The X-ray powder patterns display highly diffused reflections (Table 3)

Table 3

X-ray powder data for uraninite

Sample nr *2/L* sandstone from Lubin		Synthetic UO_2 after Frondel et al. (1956)		Sample nr *189/S* sandstone from Polkowice	
I	dÅ	*I*	dÅ	*I*	dÅ
8	3.14	*10*	3.14	*8*	3.124
2	2.726	*5*	2.73	*4*	2.714
3	1.923	*8*	1.926	*6*	1.9171
2	1.639	*9*	1.645	*4*	1.6280
		4	1.574		
		3	1.365		
1	1.254	*6*	1.251		
		6	1.220		
		6	1.115		
		7	1.051		
		4	0.966		
		7	0.924		
		5	0.911		
		6	0.864		

which permit, however, to define the mineral structure as typical of uraninite with the two characteristic reflections 3.14 (8d) and 1.9171 (6d). As evident from Table 3, the X-ray diffraction patterns of the two analysed samples are similar to those of synthetic uraninite (Frondel *et al.* 1956).

SECONDARY MINERALIZATION OF THUCHOLITE

Microscopic examination of the concentrations of thucholitic matter reveals the occurrence of secondary mineralization of different composition and textures, both depending on the location.

Most intensly mineralized are carbonaceous concrettions from shales. Forms of the mineralization resemble fissure fillings or septarian veinlets. These veinlets strike in different directions, filling the volume of thucholite nodules, sometimes locating themselves in the marginal zones of these bodies. Rarely sulphide veins are oriented. Local bulgings of sulphide aggregates imply metasomatic development.

* See note on the page 9.

Mineralization consists of bornite, chalcocite, chalcopyrite and minor amounts of digenite and covellite (Phot. 23). Thucholites originating from fault zones are mineralized with chalcopyrite, bornite and tennantite. Several fissures are also filled with calcite. Occasionally, the mineralization forms the cement of broken carbonaceous matter fragments resembling microbreccia structures (Phot. 24).

An interesting type of secondary mineralization has been noted from the thucholite concentrations occurring in calcite veins from boundary dolomite and in their vicinity. They are mineralized with bornite, chalcopyrite, electrum, palladium arsenides, rammelsbergite, safflorite, chloantite, tennantite, molybdenite, castaingite and wittichenite. These minerals occur in following forms:

Table 4

Chemical composition of some sulphides determined with electron microprobe

Mineral	Elements, weight %										Total
	Cu	Fe	Mo	Bi	Ag	Au	Pb	Sb	As	S	
Chalcopyrite	32.1	30.2	·	0.3	0	0	·	·	·	33.0	95.6
Wittichenite	41.4	0	·	35.4	0	0	·	·	·	23.2	100.0
Bornite	44.5	12.2	·	0	10.3	4.5	·	·	·	30.2	101.7
Tennantite	34.7	0	·	0	12.5	2.4	·	3.0	14.0	34.8	101.4
Tennantite	49.7	1.2	·	0.3	0	0	·	0	19.4	31.7	102.3
Castaingite	16.2	2.9	38.4	0.6	1.2	0	2.5	·	·	40.9	102.7
Castaingite	15.0	2.1	38.1	1.5	3.6	0.4	1.8	·	·	37.1	99.6

— fissure fillings in thucholite which concerns especially bornite and chalcopyrite,

— irregular inclusions of chloantite, electrum, palladium arsenides and tennatite, sometimes filling interstices between thucholite grains (Phot. 25),

— dispersive structures impregnating the thucholitic mass with ore pelite composed mainly of electrum and Pd-arsenides (Phot. 26).

Castaingite forms, as a rule, atoll-like rims round the thucholite concentrations.

Thucholite from sandstone reveals poor mineralization in the form of copper sulphide veinlets, several dozen micrometers in size. Aggregations of ore minerals resembling sunflower textures have been also noted round thucholite grains.

In vertical cross-section mineralization in thucholites is markedly differentiated. In shales and tectonic fissures simple copper sulphides are present whereas below, in boundary dolomite, the mineralization is of polymetalilc character, presumably redeposited and chemically sorted. In the underlying sandstones ore minerals appear in trace amounts.

Some of the ore minerals found in thucholite or in its vicinity were subjected to microprobe quantitative analysis. The resultant data for chalcopyrite, bornite, tennantite, wittichenite and castaingite are given in Table 4. It is interesting to note the high Ag and Au content in tennantite nad bornite. Violet, silver-bearing bornite has already been noted several times in other sulphide parageneses found in Fore-Sudetic copper deposits. The chemical composition of electrum is shown in Table 5. The chemical composition of minerals of Pd-arsenides series is presented in Table 6. It is significant that they all are silver- and gold-bearing.

Table 5

Chemical composition of electrum from thucholite, determined with electron microprobe

Sample	Elements, weight %					Total
	Au	Ag	Cu	Hg	As	
1	54.7	43.4	0.4	2.3	0.3	101.1
2	50.8	44.3	0.3	2.4	0.0	97.8
3	44.9	50.5	0.3	2.2	0.3	98.2

Table 6

Chemical composition of palladium arsenides from thucholite, determined with electron microprobe

Approximative chemical formula	Elements, weight %				Total
	Pd	As	Ag	Au	
$PdAs_2$	37.5	56.2	4.8	2.0	100.5
Pd_5As_2	69.4	21.7	9.2	1.1	101.4
Pd_5As_2	69.9	18.4	7.7	2.2	98.2

DISCUSSION AND GENETIC INFERENCES

Field observations and laboratory analyses yielded the following data on the occurrence and characteristic features of the uranium-bearing, carbonaceous matter:

1. Thucholite occurrences in the deposit are of local character.
2. Thucholite concentrations have been found in a part of the copper-bearing profile only. This zone, about 50 cm thick, comprises the top of sandstone, the boundary dolomite and the bottom and middle part of the shale. Single thucholite concentrations have also been noted in epigenetic calcite veinlets and fault zones.
3. As appears from detailed field investigations, thucholite concretions tend to be confined to definite horizons. In general, however, thucholite exhibits disseminated structures.

4. Thucholite is most abundant in the horizon rich in organic matter, i.e. in the bottom part of the copper-bearing shale and in immediately underlying rocks.
5. Rocks enclosing the uranium-bearing, carbonaceous matter exhibit diagenetic alterations and deformations caused by descending solutions, recrystallization, metasomatism, secretion, crumpling and faulting.
6. Thucholite forms isolated, spheroidal and ellipsoidal bodies in shale and irregular ones in sandstone and in calcite veinlets.
7. Thucholite consits, as a rule, of light-grey, anisotropic mass and grey, isotropic variety.
8. The light-grey, minor constituent forms irregular aggregates and contains colony-like uraninite concentrations mainly along boundaries.
9. Uraninite contains more than 0.5% Th and reveals increased contents of other elements.
10. Thucholitic substance, especially its light-grey, anisotropic variety shows an increased uranium content. Moreover, considerable admixtures of several heavy metals have been recorded. Electron microprobe analyses have revealed variations in concentrations of those elements.
11. Thucholite reveals secondary mineralization with ore veinlets displaying untypical changes due to metasomatism. Ore minerals also form impregnations in thucholite and atoll-like structures round its concretions.
12. Apart from common copper sulphides, which are typical of uranium-free carbonaceous matter, Bi, Cu, Mo, Au, Ag, Pd, Ni and Co minerals have been detected in thucholites and in their vicinity. Thucholites originating from the boundary dolomite show the most diversified mineralization.

Before entering upon the genetic discission, it is worth noting that numerous concretions of coaly substance up to 20 cm in diameter have been encountered both in the thucholite-bearing rocks and beyond them. However, they do not contain uranium and their mineralization is frequently presented only by traces of copper sulphides and pyrite.

Another fact significant in the genetic discussion is the occurrence of hydrocarbons in Permian of Fore-Sudetic area in amounts that encourage oil and gas exploration in some places. Pierce *et al.* (1958) suggest a possible role of compounds related with petroleum in forming of uranium-bearing mineraloids. The enrichments of copper-bearing beds in organic coal of sapropelic nature is also a fact of consequence.

Finally, the last observation essential for the genetic considerations is the facial distribution of heavy metals, including uranium, in the deposit.

Colloidal sapropel and, to some extent, fluid (gaseous and liquid) hydrocarbons circulating in large amounts in Permian rocks were an aboundant source material for the subsequent concentrations of coaly substance. At least two factors were responsible for an increase in a degree of their carbonization. The most effective were diagenetic processes which led to the condensation of aromatic rings and gave rise to large, coaly concentrations. Simultaneously, organometallic bonds were broken, resulting in remobilization of a number of cations. Clay minerals that form structures encircling the spheroidal coaly aggregates evidence their concretional origin.

The other factor involved in solidification of the original hydrocarbons into coal-like substance was alpha-radiation emmited by uranium. Radioactive background of Zechstein rocks, notably shales, is fairly high (Grabczak, Niewodniczański 1962), indicating the source of uranium which, was redeposited in the carbonaceous matter due to diagenetic processes.

The genetic process of formation of the thucholite concretions in Zechstein copper-bearing rocks cannot be identified with the phenomena reported by Schidlowski (1966*a*, *b*) from the Witwatersrand deposits in which terrigenic uraninite was subjected to thucholitization. In the Mansfeld deposit (Schüller, 1959) pitchblende was supposed to have been dissolved in asphalt-like substances, leaving relicts of U_3O_8.

From the foregoing discussion it is evident that the possibility of existence of terrigenic uraninite in the Fore-Sudetic copper deposits must be discounted. This statement is substantiated by the occurrcence of U_3O_8 with thucholite in the calcite veins from boundary dolomite and the structures formed by uraninite in the thucholite. It seems hardly feasible that the process of thucholitization of uraninite would leave such structures as shown on Phots 7, 8 and 9. Moreover, it is worth noting that the grain size of the terrigenic material in sandstone and of the detritus (rock fragments, quartz, feldspars, heavy minerals) in clay and carbonate rocks varies from 0.02 to 0.5 mm. Therefore, the hypothetical terrigenic uraninite would have to be much larger in size, attaining even 10 mm, which seems improbable in view of the high degree of sorting of the detrital material.

In view of the data presented, it must be assumed, that both the uraninite present in thucholite and the accompanying ore mineralization are epigenetic.

Both the barren and the uranium-bearing carbonaceous matter formed in at least three stages. The first stage took place presumably during early diagenesis giving rise to spheroidal, coal-like concretions. The source material might have been colloidal sapropel which was then subjected to transformation. The attendant volumetric changes manifested themselves in numerous fissures.

The second stage, proceeding also during diagenesis, involved an intense mobilization and migration of very mobile uranium which was then sorbed mainly in the clay-organic shale during sedimentation of Lower Zechstein. After Katayama (1960, p. 10) *uranium must have been co-precipitated together with carbonaceous material*. Simultaneously, hydrocarbons were activated. Uranium migrated presumably in the form of organometallic complexes. Such compounds were concentrated mainly in the partly consolidated sapropelitic substance in shale, boundary dolomite and sandstone (gravitational infiltration). The penetration of coaly concretions by the uranium-organic complexes was facilitated by their fissuring, so that not only fissures were filled but also the older sapropel (now the grey, isotropic component of thucholite) was resorbed. The uranium-bearing organic matter (hydrocarbons) underwent polymerization and partial graphitic preorientation, as well as became optically anisotropic and its reflectance increased. In consequence, these processes gave rise to the light-grey component of thucholite. Its organic origin is evidenced by its present-day asphalt-like nature whereas the coaly component, grey and isotropic, has the characteristics of sapropel.

At the boundary of those two substances revealing different physico-

-chemical features uranium has been released from organometallic complexes and crystallized as uraninite. Its polygonal grains formed bead and chain-like colonies.

The evolution of thucholite, involving condensation of aromatic rings, was presumably affected by two factors: diagenesis and alpha-radiation. Radiation emitted by colonies of uraninite grains is responsible for partial crystallization (and anisotropy) of the grey component that formed bands along the contact with the light-grey constituent, although diagenetic processes can also cause optical anisotropization of the uranium-free, coaly substance.

The final stage involved mineralization of the carbonaceous and thucholitic concretions thus formed. It was presumably a catagenetic process brought about by remobilization and redeposition of selected metallic and organometallic compounds in the deposit. These processes was most intense in shales where heavy metals were in abundance. Veinlets and metasomatic concentrations of sulphides were formed. They mineralized the uranium-free and thucholitic carbonaceous concretions or cemented their broken fragments in fault zones. A certain amount of mineralizing solutions descended to the underlying boundary dolomite, impregnating it mainly with noble metals such as Au, Ag or Pd and with Cu, Mo, Bi, Hg, Ni and Co minerals. Thucholite concentrations found in the sandstone contain practically no ore minerals. A reducing environment favourable for polymetallic mineralization of the thucholitic substance may has been caused by the evolution of bitumens, involving condensation of aromatic rings.

The presented hypothesis on the genesis of the mineralized coaly and thucholitic concretions certainly has several shortcomings and further data are required to test the conclusions.

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Marian BANAŚ, Jan JAROSZ, Witold SALAMON

THUCHOLIT Z PERMSKICH UTWORÓW MIEDZIONOŚNYCH W POLSCE

Streszczenie

W profilach cechsztynu miedzionośnego na obszarze dolnośląskim stwierdzono podwyższone anomalie zawartości uranu, a badania mineralogiczne strefy okruszcowania przeprowadzone w strefach anomalii potwierdziły obecność skupień thucholitu.

Występowanie tej substancji w złożu ma charakter lokalny. Idąc od spągu strefy złożowej, thucholit stwierdzono: w stropowej części piaskowca (piaskowiec lingulowy), w dolomicie granicznym, w łupku ilasto-organicznym (tzw. łupek smolący) oraz w łupku dolomitowo-ilastym, razem w pakiecie skał miąższości około 50 cm (fig. 1). W stropie serii złożowej w utworach węglanowych thucholitu nie spotkano. Śladowe jego ilości oznaczono natomiast w niektórych strefach uskokowych.

W łupkach thucholit tworzy rozproszone i izolowane formy kuliste lub dyskoidalne wykazujące cechy konkrecji (fot. 2, 4, fig. 2*a*). W dolomicie granicznym gromadzi się w żyłkach kalcytowych. W piaskowcach ujawnia on nieprawidłowe struktury (fig. 2*b*), które noszą zwykle cechy metasomatycznego zastępowania (thucholityzacji) ziarn kwarcu (fot. 3).

Thucholit jest czarny, smolisty, bardzo kruchy, o twardości 232—362 kG/mm² (2275,9—3551,2 N/mm²), 4,3—5,0 w skali twardości. Obserwowany pod mikroskopem kruszcowym ujawnia dwa składniki: 1) jasnoszary, optycznie anizotropowy oraz 2) szary, izotropowy (fot. 7). Składnik jaśniejszy tworzy nieprawidłowe, amebowate formy i zawiera głównie na obrzeżeniach sznurowate skupienia ziarn uraninitu (fot. 8).

Przy dużych powiększeniach w mikroskopie kruszcowym uraninit ujawnia struktury poligonalne (fot. 9) i typowe cechy optyczne. W badaniach rentgenowskich metoda proszkowa wykazuje strukturę UO_2 (tab. 3). Analizy w mikroobszarze ujawniły w nim: małe ilości Pb (radiogeniczny), 1,25% Th oraz podwyższone anomalie zawartości Ta, Ti i W (tab. 1, fot. 15, 16, 17, 18).

Radioaktywność skupień thucholitu wraz z zawartym uraninitem potwierdzono za pomocą badań radiograficznych (fot. 10, 11).

Thucholit jest wtórnie zmineralizowany żyłkami kruszców o charakterze septariowym, które lokalnie wykazują objawy zgrubień metasomatycznych (fot. 23). Okruszcowanie to, w postaci pospolitych siarczków miedzi, jest najliczniejsze w thucholitach lub bezuranowych konkrecjach węglistych występujących w łupkach (fot. 4). Bardziej urozmaicony charakter ma ono w niżej leżących dolomitach granicznych. Oznaczono tam minerały: Cu, Mo, Ag, Au, Pd, Bi, Ni i Co (fot. 25, 26). Analizy w mikroobszarze ujawniły w thucholicie podwyższone ilości Cu, Fe, Zn i S (fot. 19, 20, 21 i 22) oraz Ag i Au (tab. 2).

Geneza thucholitu jest dyskusyjna. Przypuszcza się, że w stadium diagenetycznym zostały utworzone z koloidalnego sapropelu konkrecje substancji węglistej. W dalszym etapie były one penetrowane wzdłuż szczelin spękań przez aktywne węglowodory i organiczne kompleksy uranowe. Uranonośny materiał organiczny pod wpływem promieniowania radioaktywnego ulegał rekrystalizacji i anizotropizacji optycznej. Wytworzył się w ten sposób jaśniejszy składnik thucholitowy ujawniający asfaltopodobny charakter, podczas gdy składnik ciemniejszy, izotropowy, nosi znamiona sapropelu. Uwalniany z połączeń organometalicznych na granicy obydwu składników uran krystalizował w postaci uraninitu. Na tak utworzone skupienia węgliste oraz thucholitowe nałożyło się wtórne okruszcowanie katagenetyczne. Znaczniejsze nasilenie okruszcowania widoczne jest w łupkach, w których istniał dostatek ilościowy metali ciężkich. Pewne wyselekcjonowane ilości roztworów kruszconośnych infiltrowały głębiej i były źródłem mineralizacji kruszcowej dolomitu granicznego oraz zawartego w nim thucholitu. Thucholit w leżącym niżej piaskowcu nie został już okruszcowany.

Na zakończenie rozważań genetycznych należy podkreślić, że w złożu nie znaleziono dowodów na terygeniczne pochodzenie uraninitu zawartego w skupieniach thucholitowych, jak to określono w przypadku złoża Witwatersrand (Schidlowski 1966 *a*).

Ilości uranu i metali towarzyszących, oznaczonych w thucholitach z rud miedzi na monoklinie przedsudeckiej, nie przedstawiają wartości praktycznej.

OBJAŚNIENIA FIGUR

Fig. 1. Profil litologiczny strefy miedzionośnej z wystąpieniami thucholitu (czarne punkty)

1 — dolomit szary, 2 — dolomit ilasty ciemnoszary, 3 — łupek dolomitowo-ilasty, (zwięzły), 4 — łupek ilasto-dolomitowy, cienkopłytkowy, 5 — łupek ilasto-organiczny, czarny

(smolący), 6 — dolomit graniczny, 7 — łupek ilasto-piaszczysty, 8 — piaskowiec lingulowy, 9 — piaskowiec białoszary (szary spągowiec)

Fig. 2. Formy ziarn thucholitu typowe dla łupku (*a*) i dla piaskowca (*b*) (Q) — relikty ziarn kwarcu po procesie thucholityzacji

OBJAŚNIENIA FOTOGRAFII

Fot. 1. Występowanie thucholitu (Tl) w stropowej części piaskowca miedzionośnego

Fot. 2. Kuliste ziarna thucholitu i ich odciski rozproszone w łupku ilasto-dolomitowym

Fot. 3. Nieprawidłowe skupienia thucholitu (Tl) w piaskowcu lingulowym.
Widoczny proces thucholityzacji, czyli zastępowanie kwarcu substancją thucholitową. Światło odbite, 1 N

Fot. 4. Konkrecyjna forma materii węglistej (Cm) otoczona laminami ilasto-organicznymi.
Wewnątrz struktury widoczne liczne żyłki siarczków miedzi. Skała otaczająca (łupek) ujawnia liczne żyłki i rozproszone ziarna siarczków (białe plamki). Światło odbite, 1 N

Fot. 5. Thucholit (Tl) w żyłkach kalcytowych (Ca) przecinających dolomit graniczny (Bd)

Fot. 6. Nerkowate ziarna materii węglistej (Cm) w dolomicie granicznym (Bd)
Białe plamy — chalkopiryt, czarne — odciski po skupieniach thucholitu. Światło odbite, 1 N

Fot. 7. Fragment ziarna thucholitu w piaskowcu lingulowym
W masie thucholitu dostrzegalne dwa składniki: szary (G) i jasnoszary (L) tworzący amebowate formy. Wzdłuż granicy obydwu składników widoczne są łańcuszkowate skupienia uraninitu (czarne plamki); Q — kwarc, Sp — siarczki miedzi zastępujące spoiwo piaskowca. Światło odbite, 1 N

Fot. 8. Dwa składniki thucholitu
Składnik jasnoszary (L) tworzy nieprawidłowe, amebowate formy w masie składnika szarego (G). Wzdłuż granicy obydwu składników dobrze widoczne są łańcuszkowate skupienia ziarn uraninitu. Światło odbite, 1 N

Fot. 9. Poligonalne ziarna uraninitu (Ur) rozmieszczone w jasnoszarym składniku thucholitu (L) wzdłuż granicy ze składnikiem szarym (G)
Światło odbite, 1 N

Fot. 10. Radiogram skupień thucholitu w piaskowcu lingulowym. Czas naświetlania 3 miesiące

Fot. 11. Skupienia torów cząstek α na fragmencie mikroradiogramu thucholitu
Radialno-rozetkowe ich koncentracje wskazują ziarna uraninitu. Czas ekspozycji 8 dni

Fot. 12. Obraz absorpcji elektronów thucholitu
G — składnik szary, L — składnik jasnoszary

Fot. 13. Obraz absorpcji elektronów powiększony z fragmentu pokazanego na fot. 12
G — składnik szary, L — składnik jasnoszary z ziarnami uraninitu (czarne plamki), *A-A* — linia profilu analizy skanningowej

Fot. 14—16. Selektywne obrazy rozmieszczenia U, Pb, Ta w thucholicie i uraninicie

Fot. 17—19. Selektywne obrazy rozmieszczenia Ti, W, Cu w thucholicie i uraninicie

Fot. 20—22. Selektywne obrazy rozmieszczenia Fe, Zu, S w thucholicie i uraninicie

Fot. 23. Materia węglista (C_m) zmineralizowana wtórnie *septariowymi* żyłkami bornitu (Bo) i chalkopirytu (biały) tworzącego pręcikowate skupienia na obrzeżeniach żyłek
Lokalne zgrubienia nagromadzeń siarczkowych wskazują na ich rozwój metasomatyczny. Światło odbite, 1 N

Fot. 24. Zbrekcjonowana materia węglista (Gm) scementowana chalkopirytem (Ch)
Światło odbite, 1 N

Fot. 25. Wrostki elektrum (El) i drobne ziarna uraninitu (Ur) w masie thucholitowej pochodzącej z żył kalcytowych w dolomicie granicznym
Szczelinki wypełnione kalcytem (Ca). Światło odbite, 1 N

Fot. 26. Elektrum (El) i arsenki palladu (Pd) impregnują masę thucholitową
Bo — żyłki bornitu. Światło odbite, 1 N

Мариан БАНАСЬ, Ян ЯРОШ, Витольд САЛАМОН

ТУХОЛИТ ИЗ ПЕРМСКИХ МЕДНОРУДНЫХ ОТЛОЖЕНИЙ В ПОЛЬШЕ

Резюме

В профилях меднорудных отложений цехштейна на территории Нижней Силезии обнаружено аномально повышенное содержание урана, а минералогические исследования зоны оруденения в зонах аномалий подтвердили присутствие скоплений тухолита.

Присутствие этого вещества в залежи имеет локальный характер. Переходя от подошвы залежи, тухолит был обнаружен в: верхней части песчаника (лингуловый песчаник), пограничном доломите, глинисто-органических сланцах (так называемые марающие сланцы) и в доломитноглинистых сланцах, целом в пакете пород мощностью около 50 см (фиг. 1). В верхней части залежи, в карбонатных отложениях, тухолит не был обнаружен. В то же время его остаточные количества были обнаружены в некоторых сбросовых зонах.

В сланцах тухолит образует разновидные и обособленные шаровидные или дископодобные формы, обнаруживающие свойства конкреций (фото 2, 4, фиг. 2*a*). В пограничном доломите аккумулируется в прожилках кальцита. В песчаниках обнаруживает неправильные структуры (фиг. 2*b*), которым обыкновенно присущие свойства метасоматического замещения (тухолитизация) зерн кварца (фото 3).

Тухолит это черное, смолистое, очень хрупкий минерал с твёрдостью 232—362 кг/мм², 4,3—5,0 по шкале твёрдости. В поле зрения микроскопа для изучения руд можно в нём обнаружить два компонента: 1) светлосерый, оптически анизотропный и 2) серый, изотропный (фото 7). Более светлый компонент образует неправильные, амебовидные формы и содержит, в основном по краям, шнуровидные скопления зерн уранинита (фото 8).

При больших увеличениях в поле зрения микроскопа для изучения руд в уранините можно обнаружить полигональные структуры (фото 9) и типичные оптические свойства. В рентгеновских исследованиях методом порошков DSH препаратов обнаруживает он структуру UO_2 (таблица 3). Анализы в микрозоне обнаружили в нём: малое количество Pb (радиогенного), 1,25% Th и аномально повышенные количества Ta, Ti и W (таблица 1, фото 15, 16, 17, 18).

Радиоактивность скоплений тухолита, вместе с содержащимся в них уранинитом, была потверждена при помощи радиографических исследований (фото 10, 11).

Прожилки руд септарного характера вторично минерализуют тухолит. Эти прожилки обнаруживают локально свойства метасоматических утол-

щений (фото 23). Это оруденение, в форме общеизвестных сульфидов ме-
ди, чаще всего присутствует в тухолитах или в углеподобных конкрециях
не содержащих урана, которые находятся в сланцах (фото 4). Более
разнообразный характер этого оруденения обнаруживается в ниже лежа-
щих пограничных доломитах. Отмечено в них присутствие минералов
Cu, Mo, Ag, Au, Pd, Bi, Ni, Co (фото 25, 26). Анализы в микрозоне обна-
ружили в тухолите повышенные количества Cu, Fe, Zn, S (фото 19, 20,
21, 22) Ag и Au (таблица 2).

Происхождение тухолита не установлено. Есть предположение, что
в диагенетической стадии образовались из колоидного сапропеля конкре-
ции углеподобного вещества. В дальнейшем сквозь них по трещинам про-
сачивались активные углеводородные соединения и органические урано-
вые комплексы. Органический материал, содержащий уран, под воздейст-
вием радиации рекристаллизовался и стал оптически анизотропным. Этим
путём образовался более светлый компонент тухолита, у которого обна-
ружены свойства сходные с асфальтом. В то же время более тёмный ком-
понент, изотропный, обнаруживает свойства сапропеля. Освобождаемый
на границе двух компонентов из органометаллических соединений уран
кристаллизовался в форме уранинита. На образованные этим путём угле-
подобные и тухолитовые скопления наложилось катагенетическое вторич-
ное оруденение. Более значительная интенсивность оруденения видна
в сланцах, в которых было достаточное количество тяжёлых металлов.
Некоторые ограниченные количества рудных растворов просачивались
глубже и стали источником оруденения пограничного доломита и содер-
жащегося в нём тухолита. Тухолит в подстелающем песчанике не под-
вергался оруденению.

В заключение генетических рассуждений надо подчеркнуть, что в за-
лежи не обнаружено доказательств тому, что уранинит в тухолитных скоп-
лениях терригенного происхождения, как было отмечено в залежи Вит-
ватерсранд.

Количества урана и сопутствующих металлов, отмеченные в тухолитах
из медных руд, присутствующих во внесудетской моноклинали, не имеют
практического значения.

ОБЪЯСНЕНИЯ ФИГУР

Фиг. 1. Литологический профиль меднорудной зоны, в котором присутствует тухолит (чёрные пункты)
1 — серый доломит, *2* — глинистый доломит, тёмносерый, *3* — глинисто-доломитовый сланец (плотный), *4* — глинисто-доломитовый сланец, тонкопластингатый, *5* — глинисто-органический чёрный сланец (марающий), *6* — пограничный доломит, 7 — глинисто-песчаный сланец, *8* — лингуловый песчаник, *9* — бело-серый песчаник

Фиг. 2. Формы зерн тухолита типичные дла сланцев (*a*) и для песчаников (*b*), (*Q*) реликты зерн кварца после процесса тухолитизации

ОБЪЯСНЕНИЯ СНИМКОВ

Фото 1. Присутствие тухолита (Tl) в верхней части слоя меднорудного песчаника

Фото 2. Шаровидные зерна тухолита и их отпечатки рассеянные в глинисто-доломитовым песчанике

Фото 3. Неправильные скопления тухолита (Tl) в лингуловом песчанке
Виден процесс тухолитизации, то есть замещения кварца тухолитовым веществом. Отражённый свет, 1 николь

Фото 4. Конкреционная форма углеподобного вещества (См), окруженная глинисто-органическими ламинами
Внутри структуры видны многие прожилки сульфидов меди. Окружающая порода (сланец) содержит многие прожилки и рассеянных зерна сульфидов (белые пятна). Отражённый свет, 1 николь

Фото 5. Тухолит (Tl) в прожилках кальцита (Ca) секающих пограничный доломит (Bd)

Фото 6. Почковидные зерна углеподобного вещества (См) в пограничном доломите (Bd)
Белые пятна — халькопирит, чёрные отпечатки скоплений тухолита. Отражённый свет, 1 николь

Фото 7. Часть зерна тухолита в лингуловом песчанике
В массе тухолита видны два компонента: серый (G) и светлосерый (L), образующий амёбовидные формы. Вдоль границы этих компонентов видны цепевидные скопления уранинита (чёрные пятна). Q — кварц, Sp — сульфиды меди замещающие цемент песчаника. Отражённый свет, 1 николь

Фото 8. Два компонента тухолита
Светлосерый компонент (L) образует неправильные амёбовидные формы в массе серого компонента (G). Вдоль границы между компонентами хорошо видны цепевидные скопления уранинита. Отражённый свет, 1 николь

Фото 9. Полигональные зерна уранинита (Ur) расположеные в светлосером компоненте тухолита (L) вдоль границы с серым компонентом (G)
Отражённый свет, 1 николь

Фото 10. Радиограмма скоплений тухолита в лингуловом песчанике
Время экспонирования — 3 месяца

Фото 11. Скопление траекторий α — частиц на части микрорадиограммы тухолита
Их радиально-розеточные скопления показывают на зерна уранинита. Время экспонирования — 8 дней

Фото 12. Изображение абсорпции электронов тухолита
G — серый компонент, L — светлосерый компонент

Фото 13. Изображение абсорбции электронов, являющийся увеличением фрагмента показанного на фото 12
G — серый компонент, L — светлосерый компонент с зёрнами уранинита (чёрные пятна), A—A — линия профиля сканингового анализа

Фото 14—16. Селективные изображения размещения: U, Pb, Ta, в тухолите и уранините

Фото 17—19. Селективные изображения размещения: Ti, W, Cu, в тухолите и уранините

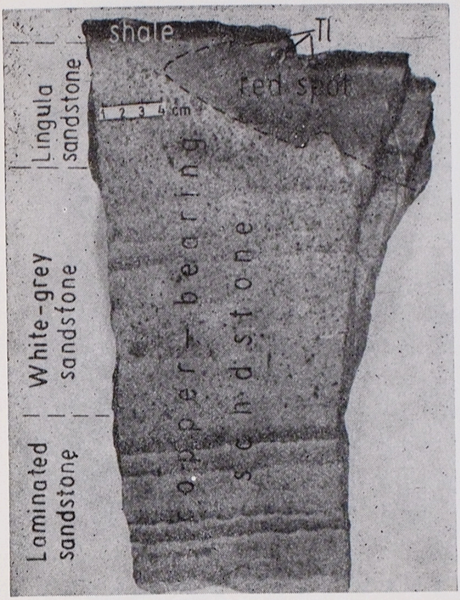
Фото 20—22. Селективные изображения размещения: Fe, Zn, S, в тухолите и уранините

Фото 23. Углоподобное вещество (См) вторично минерализованное септарийны и прожилками борнита (Bo) и халькопирита (белый), который образует полочковидные скопления по окраинам прожилок
Местные утолщения сульфидных скоплений свидетельствуют о их метасоматическом развитии. Отраженный свет, 1 никол

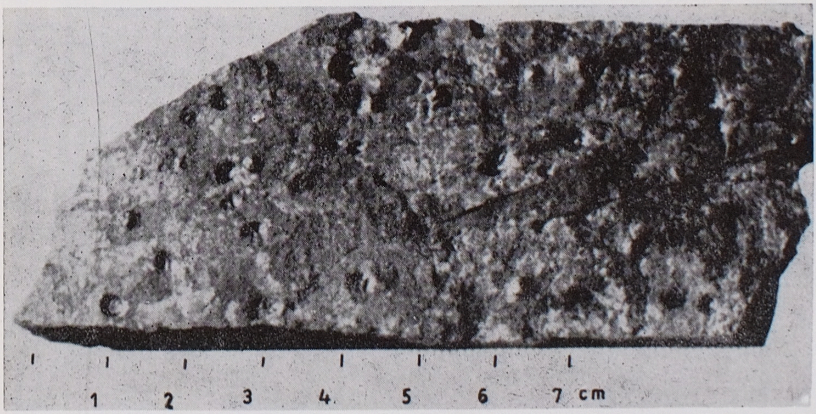
Фото 24. Брекчия из углеподобного вещества (См) сцементированная халькопиритом (Ch)
Отражённый свет, 1 николь

Фото 25. Инклюзии электрума (El) и мелкие зёрна уранинита (Ur) в массе тухолита происходящей из кальцитовых прожилок в пограничном доломите. Трещины заполнены кальцитом (Ca)
Отражённый свет, 1 николь

Фото 26. Электрум (El) и арсениды палладия (Pd) пропитывающие массу тухолита, Bo — прожилки борнита
Отражённый свет, 1 николь



Phot. 1. The uppermost part of copper-bearing sandstone. (Tl) — nodules of thucholite



Phot. 2. Nodules of thucholite and their imprints both disseminated in the clay-dolomitic shale

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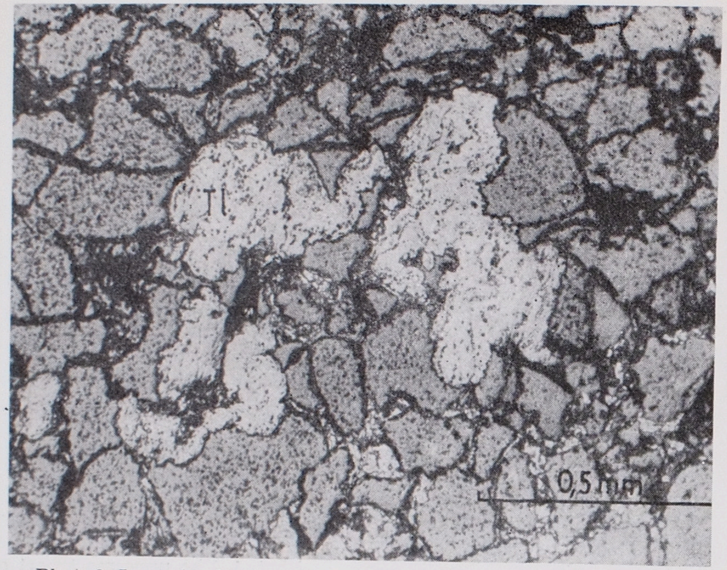
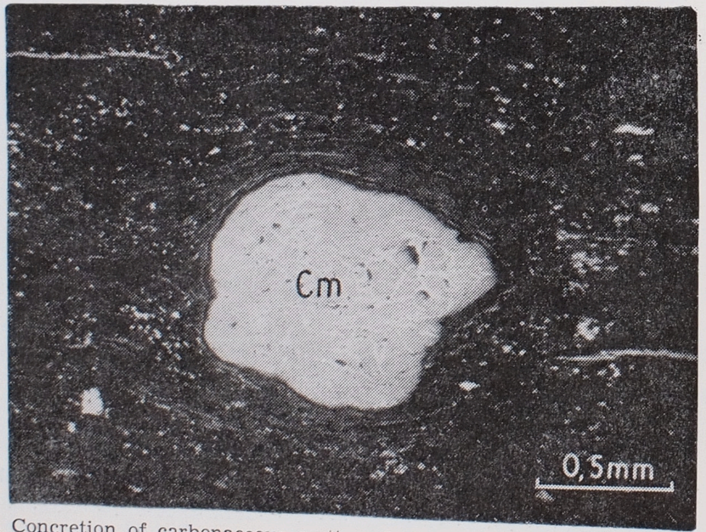


Phot. 3. Irregular bodies of thucholite (Tl) in Lingula sandstone
Process of resorption (thucholitization) of quartz grains is visible. Reflected light, 1 N



Phot. 4. Concretion of carbonaceous matter (Cm) with veinlets of copper sulphides inside, encircled by clay-organic lamines
Host-rock reveals numerous veinlets and disseminated grains of sulphides (white spots). Reflected light, 1 N

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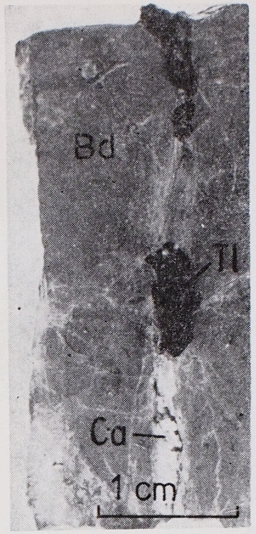
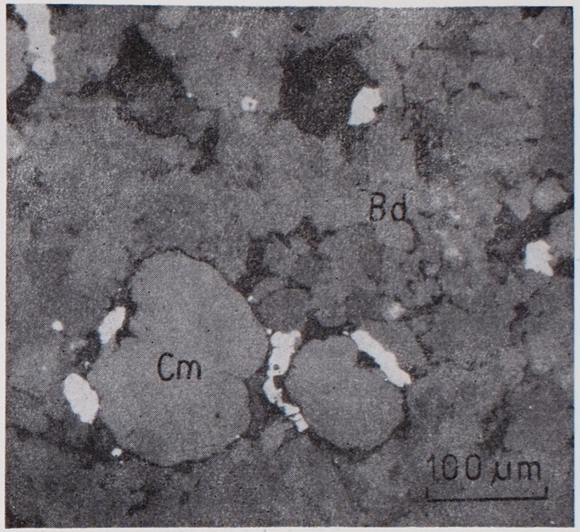
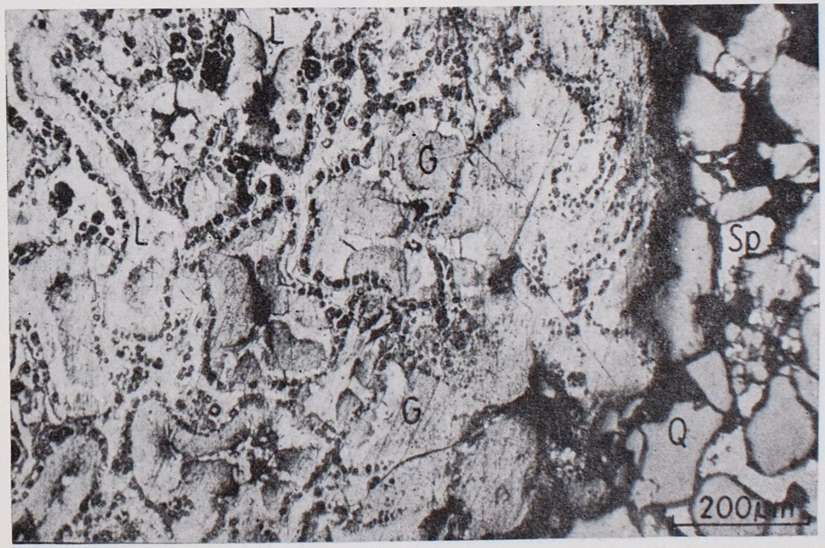


Phot. 5. Thucholite bodies (Tl) in calcite veinlet (Ca) cross-cutting the boundary dolomite (Bd)



Phot. 6. Spheroidal grains of carbonaceous matter (Cm) in boundary dolomite (Bd)
White — chalcopyrite, large black spots — imprints after the thucholite nodules. Reflected light, 1 N



Phot. 7. A fragment of thucholite body in Lingula sandstone
Two components: grey (G) and amoebic-shaped light-grey (L) are visible. Along the boundary of these components chain-like concentrations of uraninite grains (dark points) occur; Q — quartz, Sp — copper sulphides in the cement of sandstone. Reflected light, 1 N

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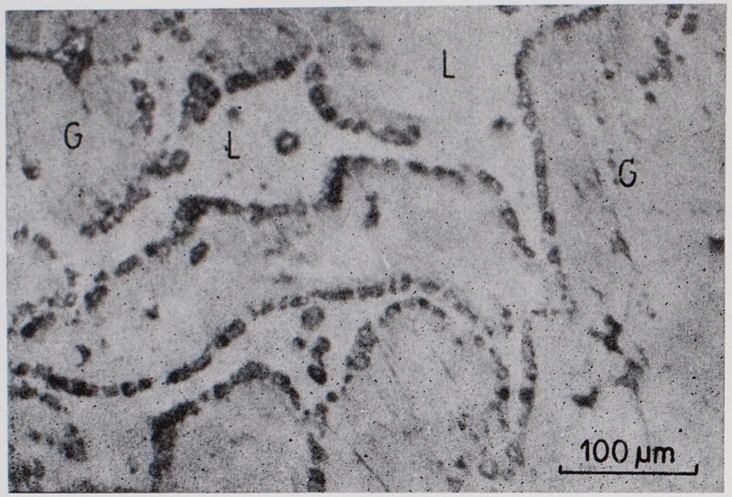
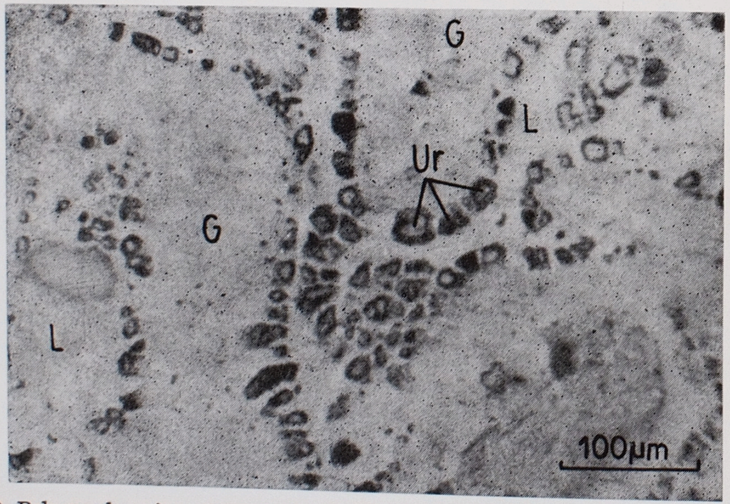
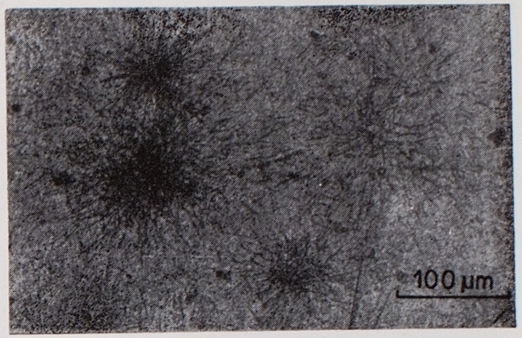


Phot. 8. Two components of thucholite
Light-grey component (L) forms irregular, amoebic shapes in groundmass of the grey one (G). Chain-like aggregates of uraninite are visible along the boundary of these two components.
Reflected light, 1 N

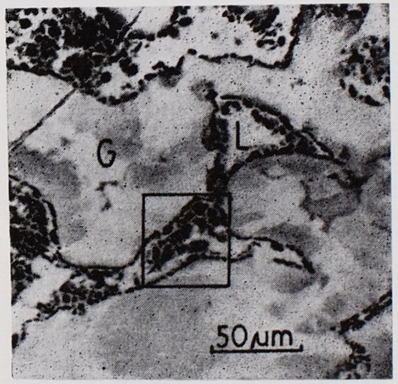


Phot. 9. Polygonal grains of uraninite (Ur) localized in the light-grey component of thucholite (L) along the boundary of the grey component (G)
Reflected light, 1 N

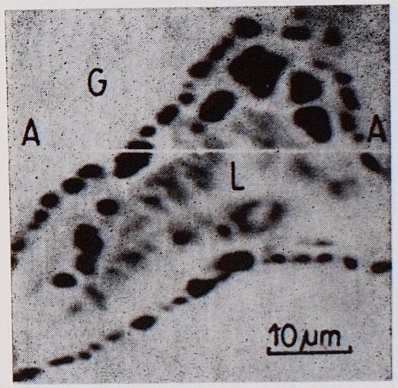
Phot. 10. Radiographs of thucholite bodies in Lingula sandstone
Exposure: 3 months



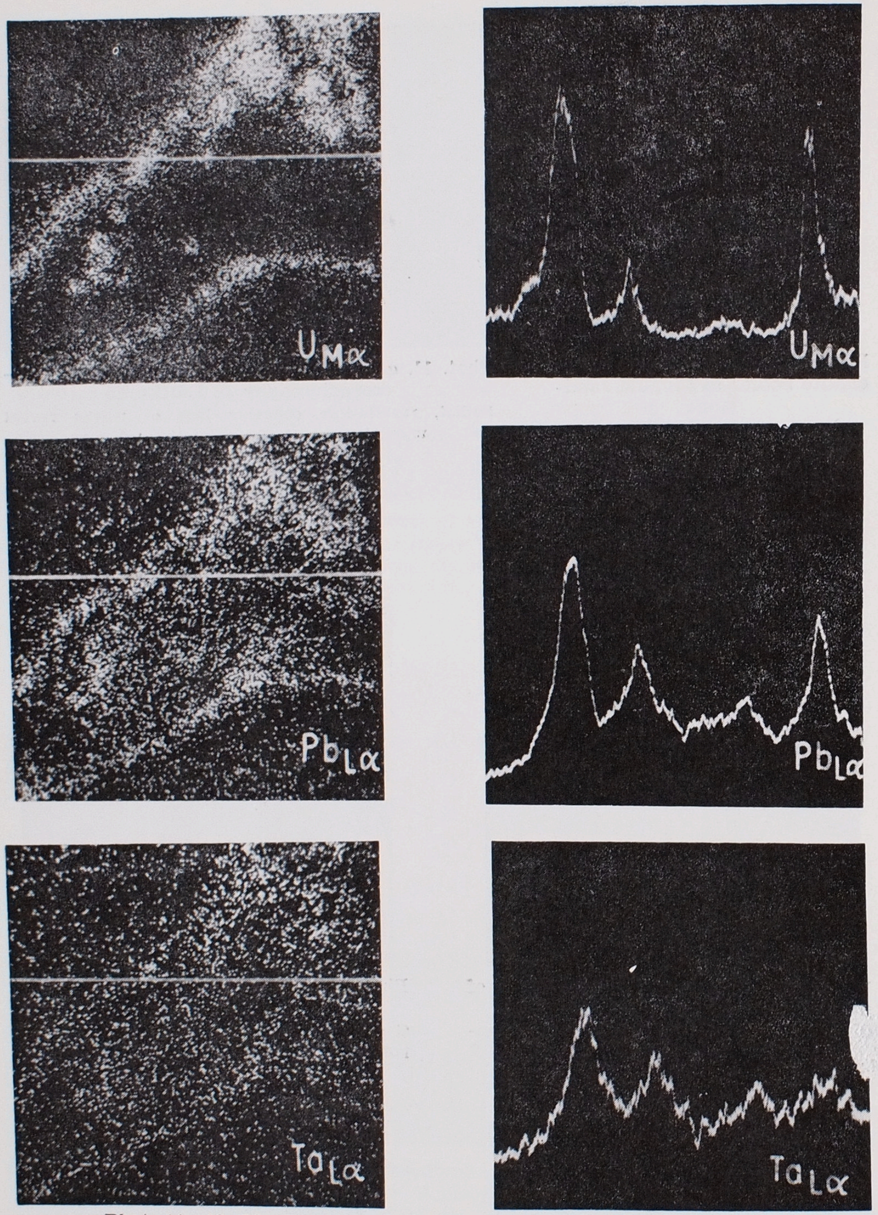
Phot. 11. α — particle tracks upon a part of microradiography of thucholite
Radial, rosette-like concentrations of tracks reveal uraninite grains. Emission time: 8 days



Phot. 12. Electron absorption image of thucholite
G — grey component, L — light-grey component



Phot. 13. Electron absorption image of the area marked on Phot. 12
G — grey component, L — light-grey component with grains of uraninite (black spots), *A — A* — scanning line



Phot. 14—16. Distribution of U, Pb, Ta in thucholite and uraninite

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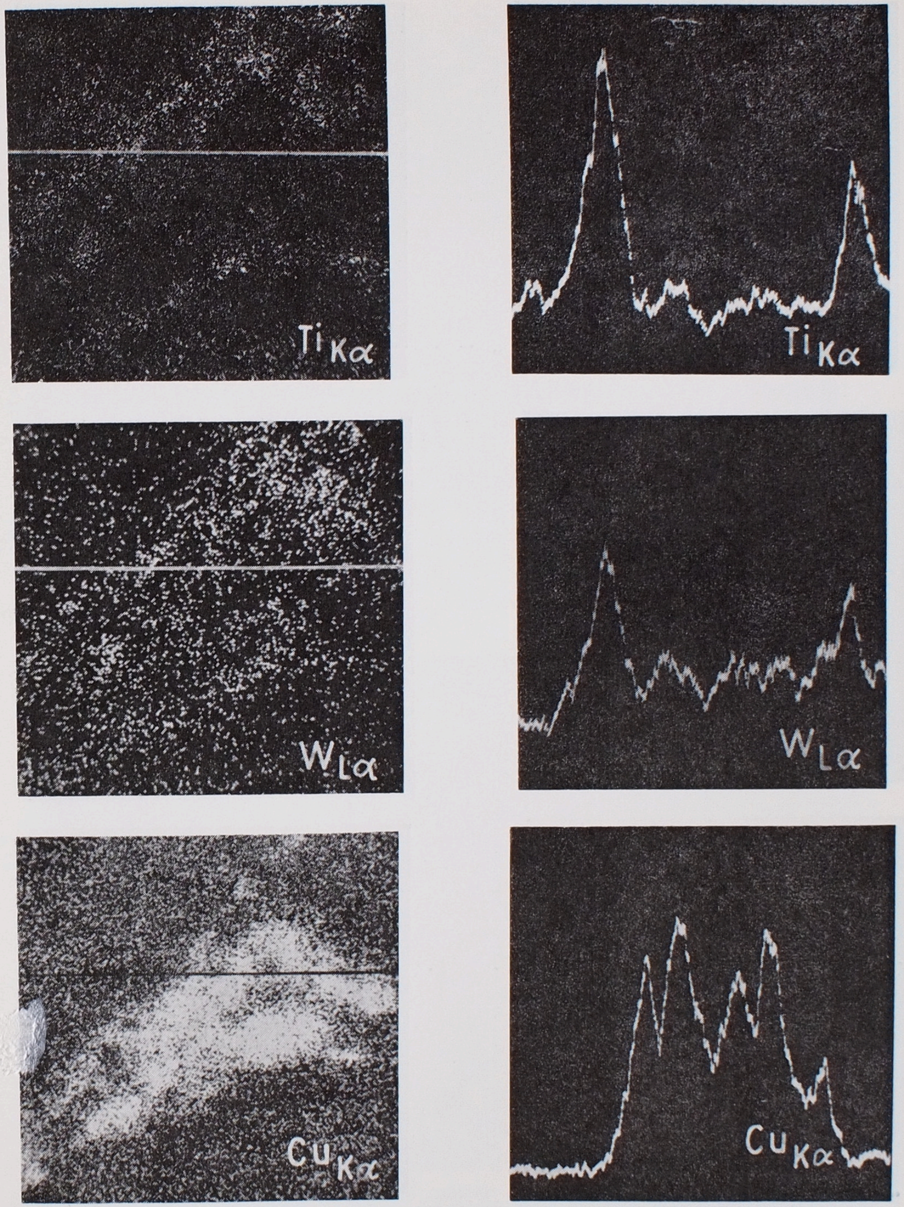

Phot. 17—19. Distribution of Ti, W, Cu in thucholite and uraninite

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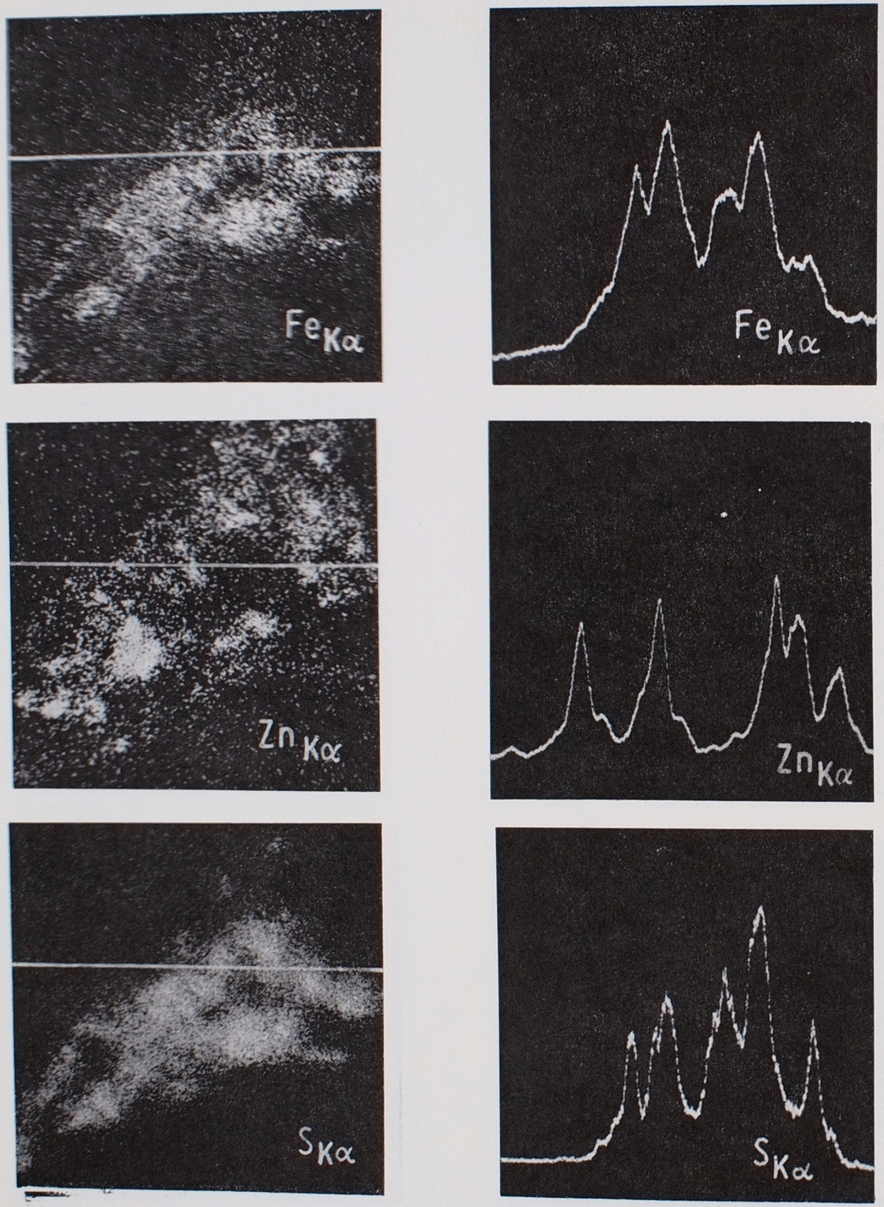
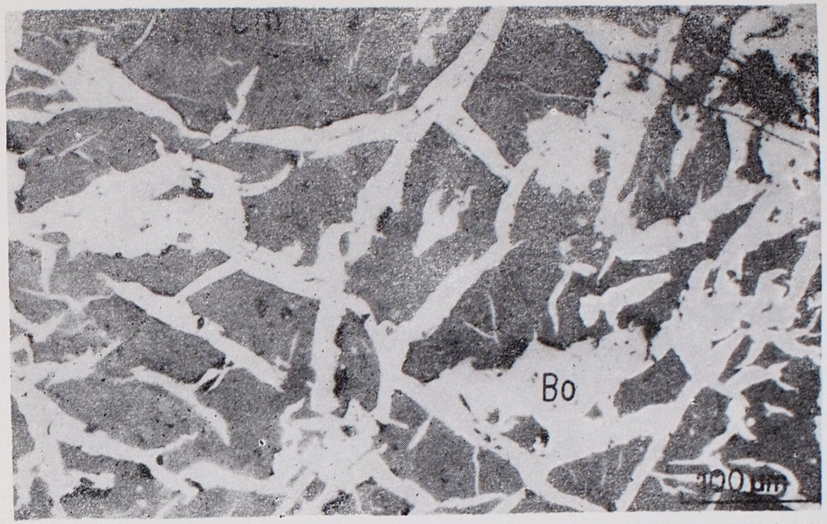
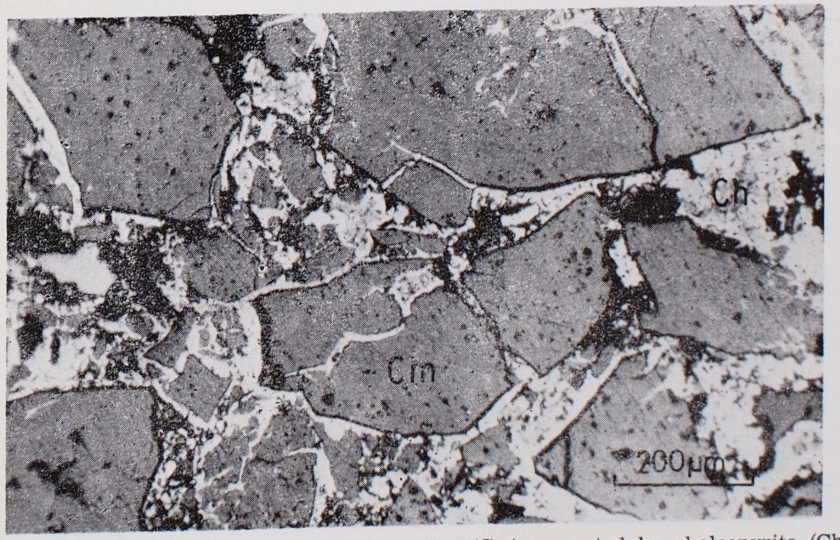


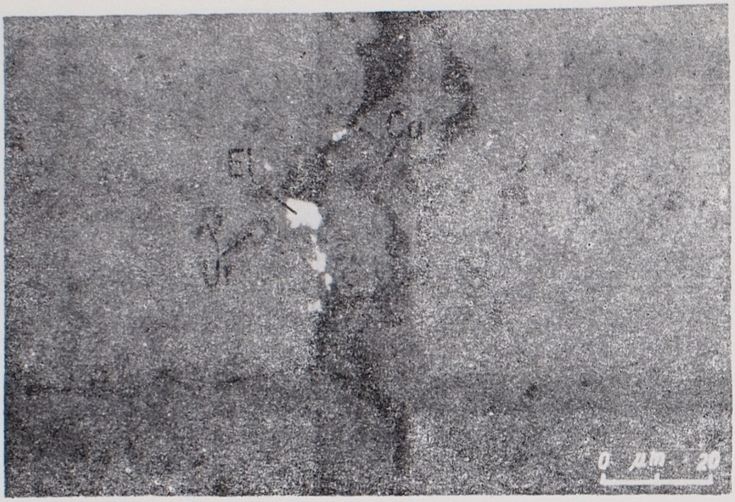
Phot. 20—22. Distribution of Fe, Zn, S in thucholite and uraninite



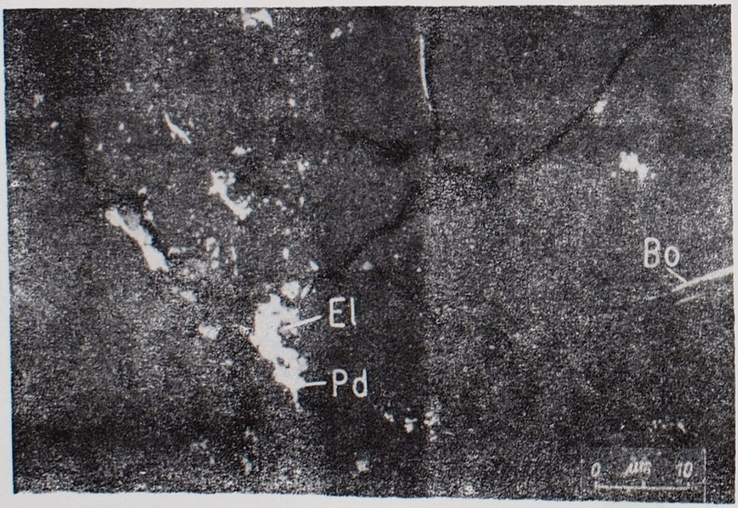
Phot. 23. Secondary mineralization of carbonaceous mater (Cm) by septarian veinlets consisted of bornite (Bo) and chalcopyrite, the latter forming light rims round the bornite
Local bulgings of sulphides aggregates imply metasomatic development. Reflected light, 1 N



Phot. 24. Microbrecciated carbonaceous matter (Cm) cemented by chalcopyrite (Ch)
Reflected light, 1 N



Phot. 25. Inclusions of electrum (El) and minute grains of uraninite (Ur) in the thucholite body from calcite veinlets in boundary dolomite
Cracks filled by calcite (Ca). Reflected light, 1 N



Phot. 26. Electrum (El) and Pd-arsenides (Pd) impregnating the thucholite mass
Veinlets of bornite (Bo) also occur. Reflected light, 1 N