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THE ORIGIN OF URANIUM MINERALIZATION IN THE KARKONOSZE-IZERA MASSIF (SUDETES)

(Fig. 1)

Geneza mineralizacji uranowej bloku karkonosko-izerskiego

(*Fig. 1*)

Abstract. In the region of the Karkonosze-Izera massif uranium mineralization occurs, developed during four stages. The first stage represents formation of the mineralization as a result of pneumo-hydrotermal processes causing the regional leucocratization. The second stage corresponds to formation of the mineralization genetically related to the Karkonosze granite, of Carboniferous age. The third stage is a hydrothermal activity taking place during the Variscan orogeny; the fourth stage corresponds to formation of the mineralization due to exogenic processes in the Paleocene, Eocene and Oligocene.

The massif of the Karkonosze and Izera Mountains is a tectonic unit built of a Variscan intrusion of the Karkonosze granite, surrounded by metamorphic rocks (Fig. 1). This unit is characterized by occurrences of various ore mineralization. Ore deposits and occurrences reveal diversity of development and mineral parageneses, due to a complicated geological history of the region. Uranium mineralization occurring there is also of a heterogeneous character. Uranium compounds were found in various mineral assemblages; their structures are not uniform. This points to different origin of mineralization, dependent upon respective geological processes taking part in development of the Karkonosze-Izera massif.

The main stages of rock formation and evolution, connected with mineralization, are shown in Table I. However, only the area within Poland's territory was considered, i.e. the northern and north-eastern part of the structure under discussion.

The oldest geological process in geosynclinal sedimentation, followed by a regional metamorphism of the amphibolite facies (Oberc, 1960; Szałamacha, 1974) or, using the terminology of Turner and Verhoogen — the amphibolite-almandine facies (Teisseyre, 1973). These processes were

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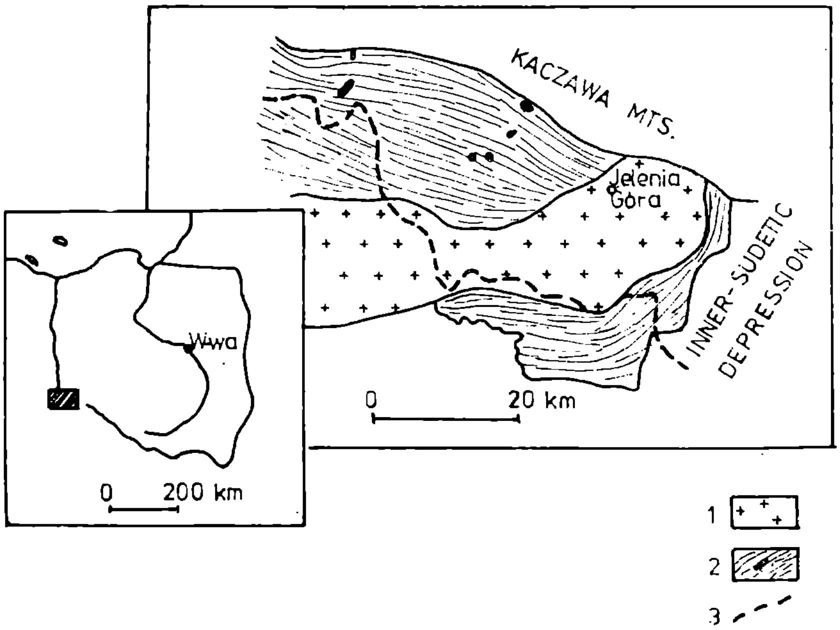


Fig. 1. Geological sketch of the Karkonosze-Izera massif. 1 — Karkonosze granite, 2 — metamorphic cover of the granite (black spots — basalt), 3 — state boundary
Fig. 1. Szkic geologiczny bloku karkonosko-izerskiego. 1 — granit Karkonoszy, 2 — metamorficzna osłona granitu (czarne plamy — bazalty), 3 — granice kraju

accompanied by rock granitization and, selectively, complete homogenization (Oberc, 1965, Kozłowska-Koch, 1965; Teisseyre, 1973); Smulikowski, 1972). Locally in the Izera metamorphic complex, mainly in the northern part, metasomatic processes took place as leucocratization and, in places, greisenization of rocks (Smulikowski, 1958; Heflik, 1964; Pawłowska, 1966, 1968; Kozłowska, 1956; Karwowski, 1973). Oberc (1965) related the regional metamorphism in the Izera metamorphic complex to Precambrian, distinguishing the Early and Late Assyntian folding. According to this author, leucocratization would take place during Late Assyntian folding and, according to Kozłowska-Koch (1965) — during Eocambrian. The Caledonian and later movements caused only a local deformation of the formerly developed rock. Smulikowski (1972) suggested that metamorphic processes observed in the region of the Izera Mts. and the Izera Upland took place in the period from Precambrian to Ordovician, while the metasomatosis resulting in formation of leucogranites should be related, according to Smulikowski (1958), to the Caledonian orogeny. Other authors (Heflik, 1964; Karwowski, 1975) accepted the Variscan age for both leucocratization and greisenization.

Oberc (1965) suggested the Precambrian age for most of the eastern and south-eastern parts of the metamorphic cover of the Karkonosze granite, similarly as for the Izera metamorphic complex. According to this author, only a very insignificant part of the Early Paleozoic of the southern Karkonosze Mts. is found in the territory of Poland. However, not all authors investigating this region accept this age of rocks. M. and J. Szałamacha (1967) distinguish three units these: the Precambrian Leszczyniec unit, the Cambro-Silurian Niedamirów unit, and the pre-Silurian Kowary unit. The latest paper of Teisseyre (1973), concerning the eastern part of the metamorphic cover, attributed generally an Early Paleozoic age to the rocks found in that area, and a Proterozoic age only to, so called, Kowary Gneisses group. In the eastern part of the Karkonosze metamorphic cover this author distinguished four stages of folding, and jointed three of them, of pre-Variscian age to the Caledonian orogeny. The pre-Variscan evolution of metamorphic rocks shown in Table I is oversimplication: detailed studies revealed a much more complicated structure of this area, and pointed to more complex and often controversial geological processes which were responsible for formation of rock series. Further opinions on the above problems can be found in the cited literature, mainly in the papers of Smulikowski (1972) and Teisseyre (1973). The present study discusses only these points which may be important for the genesis of mineralization.

According to the opinions on the rock series surrounding it, Karkonosze granite intruded into completely metamorphosed rocks with symptoms of local diaphthoresis. The absolute age of the intrusion is about 300 million years (304 m.y.K/Ar, 292 m.y.Rb/Sr — Przewłocki et al., 1962).

The influence of granite upon the surrounding rocks appears in formation of contact zones of hornfelses (Borkowska, 1966), and occasionally in formation of skarns. The hydrothermal activity, connected with the Variscan folding, took place considerably later. Other processes observed in the Karkonosze-Izera massif region are of an exogenic character. Ore mineralization occurs in minor amount within the granite and accumulates mainly in metamorphic rocks of cover. In the northern, eastern, and south-eastern parts of the discussed structure the following types were found: Sn mineralization, impregnation with pyrite, magnetite deposits, polymetallic mineralization with prevailing copper minerals, polymetallic deposits with prevailing arsenic minerals, polymetallic deposits with uranium and almost monometallic uranium occurrences, traces of Mo, W, Th minerals, and thorium mineralization. Table I shows the relation of respective types of mineralization to the distinguished stages of development of the Karkonosze-Izera massif, on the basis of the most recent data concerning these deposits (Jaskólski, 1964, 1976; Zimnoch, 1961, 1976; Mochnacka, 1966, 1967, 1975; Banaś, Kucha, 1975; Gajda, 1960 a, b; Szałamacha, 1974; Pawłowska, 1966; Lis et al., 1965; Lis, Sylwestrzak, 1977; Karwowski, 1973, 1975; Jęczmyk, Kanasiewicz, 1973; Metallogenetic Map, 1976.

REVIEW OF URANIUM OCCURRENCES IN THE KARKONOSZE-IZERA MASSIF

In the Karkonosze-Izera massif region several types of mineralized zones can be distinguished, differing in development and in mineral assemblages. These are: 1) disseminated mineralization with uraninite in the Karkonosze granite; 2) traces of Nb and Ta minerals together with thorium and uranium ones in pegmatites, and richer concentrations of thorium mineralization; 3) concentrations of brannerite in quartz vein; 3) almost monometallic uranium mineralization in the form of impregnation, with nests and small veins of secondary uranium minerals, apparently spatially related to leucogranites; 5) vein-and-nest mineralization, chiefly with pitchblende (nasturan), almost monometallic, partly impregnating, with minor amount of accompanying sulphides in the Izera metamorphic complex; 6) vein polymetallic mineralization with uranium in the south-eastern part of the Karkonosze granite cover, and similar occurrences with poorer parageneses of ore minerals.

Uraninite disseminated in the Karkonosze granite

This mineral was found in the zone where granite enrichment with uranium has reached 90 ppm (Lis, Sylwestrzak, 1977). Uraninite was accompanied by pyrite only (Table II). The structure and the mode of occurrences of this mineral prove that it is syngenetic with granite (Table I). Therefore, it might be the highest-temperature form of uranium compounds occurrence, genetically connected with the Karkonosze granite.

Mineralization in pegmatites

Traces of uranium mineralization in pegmatites were found in a few places, both in the neighbourhood of granite and in metamorphic rocks near the northern boundary of the Karkonosze granite. These are chiefly niobium-tantalum, occasionally lithium pegmatites. Apart from pyrite, arsenopyrite and siderite, ore minerals occurred in the pegmatites in small amounts (Table II). In the heavy fraction, obtained during sample enrichment, a few grains of uraninite and a more frequently occurring thorite were traced (Gajda, 1960 a, b).

Thorium mineralization is another example of pegmatite radioactive mineralization in the north-western part of the Karkonosze-Izera massif (Banaś, Kucha, 1975). Pegmatite veins occur in tectonic zones within granitoids belonging to the north-western part to the metamorphic cover of the Karkonosze granite. These are titanium- and niobium-bearing pegmatites of zonal structure. Their central parts are mineralized. Ore zones are developed as nests consisting of feldspar breccia with veinlets, and as aggregates of thorium-bearing mineralization (Table II).

In this region thorium mineralization was superimposed on originally potasium pegmatites. It seems that this type of pegmatite mine-

Table 1

Evolution of the Karkonosze Izera massif and some occurrences of ore mineralization

Tabela 1

Ewolucja bloku karkonosko-izerskiego i ważniejsze wystąpienia mineralizacji kruszcowej

Table I

		EVOLUTION OF THE ROCKS	ABSOLUTE AGE	OCCURRENCES OF ORE MINERALIZATION	STAGES OF U-MINERALIZATION
		weathering of the rocks and ore deposits		alluvial concentrations of cassiterite and Au zones of weathering of ore deposits	EGZOGENIC STAGE
POST VARISCAN OROGENY			70^6 years nasturan from Kowary		
VARISCAN OROGENY		hydrothermal processes	265^6 years nasturan from Kowary	hydrothermal deposits and occurrences of ore minerals - polymetallic mineralization with U /Kowary/ - U-mineralization /N part of the metamorphic cover/ x/ - polymetallic mineralization with As /Czarnów/ - polymetallic mineralization with Cu /Miedzianka/ - small concentrations of sulphides /whole region/	HYDROTHERMAL STAGE
VARISCAN OROGENY	CONTACT METAMORPHISM	metasomatic processes } formation of skarns and hornfelses intrusion of the Karkonosze granite	$\sim 300^6$ years granite	sulphides, cassiterite, magnetite / E part of metamorphic cover/ traces of Li, Th, Nb, Ta, U, Mo-mineralization in pegmatites Th, Nb-mineralization in pegmatites U-mineralization /uraninite/ in granite	MAGMATIC AND PEGMATITIC STAGE
PREVARISCAN OROGENY	REGIONAL METAMORPHISM	local diaphtoresis metasomatic processes } formation of greisens, formation of leucogranites		Sn, W-mineralization /N part of metamorphic cover/ x/ U-mineralization /N part of metamorphic cover/ U-mineralization /brannerite/ /SE part of metamorphic cover/ xx/	PNEUMO-HYDRO-THERMAL STAGE
PREVARISCAN OROGENY	REGIONAL METAMORPHISM	granitization, formation of rocks belonging to the amphibolite facies, folding folding antecedent to granitization		metamorphic ore deposits - magnetite deposit /Kowary/ - impregnation with pyrite /Wieściszowice/ - impregnation with cassiterite /Krobica - Gierczyn/ x/	
		geosynclinal sedimentation		ferruginous sediments sediments enriched with cassiterite	

x/ origin discussible

xx/ according to Lis et all. /1965/ occurrence of brannerite belongs to metasomatic mineralization connected with the Karkonosze granite

Table 2

The minerals associated with uranium occurrences in the Karkonosze-Izera massif

Tabela 2

Minerały towarzyszące wystąpieniom uranu w bloku karkonosko-izerskim

type of mineralization	ore minerals	other minerals
disseminated mineralization - uraninite /Karkonosze granite/	uraninite, pyrite	granite-forming minerals
mineralization in pegmatites /N contact of granite and metamorphic cover/	traces of siderite, niobite, kemerezite, monazite, fergusonite, xenotime, thorite, Ag-minerals, uranium minerals, arsenopyrite, Bi-minerals, chalcopyrite, pyrite, tetrahedrite, malachite, wolframite, gadolinite, dumortierite, molibdenite, monazite	
occurrence of brannerite /SE part of metamorphic cover/	brannerite, pyrite, gersdorffite, pharmacosiderite, autunite /?/	quartz, tourmaline, biotite, apatite
mineralization spatially related to leucogranites /Izera metamorphic complex/	autunite, metaautunite, torbernite, metatorbernite, uranophane, gummite, zeunerite, abernathyite /?/, pitchblende /nasturan/, uranothorite, metauranocircite.	quartz, fluorite
pitchblende /nasturan/ mineralization, nearly monometallic /Izera metamorphic complex/	iron oxides, gummite, torbernite, autunite, metauranocircite pitchblende /nasturan/, elacherite, uranopilite	fluorite
polymetallic mineralization with uranium /Kowary deposit/	pitchblende /nasturan/, coffinite, liebigite, arsenopyrite, loellingite, tiemannite, sphalerite, chalcopyrite, pyrite, cinnabar, bornite, covellite, native silver, emplectite, tetrahedrite, smaltite, rammelsbergite, niccolite, galena, haematite, stromeyerite, umangite, aikinite, rittingerite, chloantite, sternbergite, proustite, argentite, pyrargyrite, gummite, skłodowskite, uranophane, schroeckingerite, autunite, uranium black, uranotile, native bismuth/?/, bismuthinite/?/, matildite/?/, schirmerite/?/, native arsenic/?/, malachite/?/, erythrite, annabergite, rutherfordite.	carbonates /calcite, dolomite/, traces of barite, fluorite.

/?/ the minerals determined as uncertain ralization is genetically similar to the traces of mineralization found in pegmatites within the Karkonosze granite, but was formed in a different geochemical environment.

Brannerite in quartz vein

Brannerite, discovered in close vicinity to the Kowary deposit, an interesting mineralogical discovery.

A leucogranite zone was found within gneises in this area. In this zone a quartz vein occurs containing brannerite with a mineral assemblage characteristic of pneumatolitic formations (Table II). Pyrite found in the vein is regarded as a faint reflection of the hydrothermal stage. A close neighbourhood of the Karkonosze granite permits a conclusion about genetic relation of this locality with granite (Lis et all. 1965).

Uranium mineralization spatially related to leucogranites

Localities with uranium mineralization of the Izera metamorphic complex, which display development different from other occurrences, deserve more attention. Uranium minerals are represented almost exclusively by silicates, phosphates and arsenites; in archival materials insignificant amounts of uranothorite and pitchblende were recorded (Table II). Wall-rocks are granitic gneisses, gneisses, leucogranites, mica schists and amphibolites. They are cross-cut by a fault around which a zone of tectonic breccia was formed. This breccia was then transformed into mottled rock. Numerous secondary fractures, quartz and fluorite veins were formed in the neighbourhood.

Ore concentrations occur as lenticular zones of impregnation with uranium minerals. They occur mainly along fractures at the contact of petrographically different rock types.

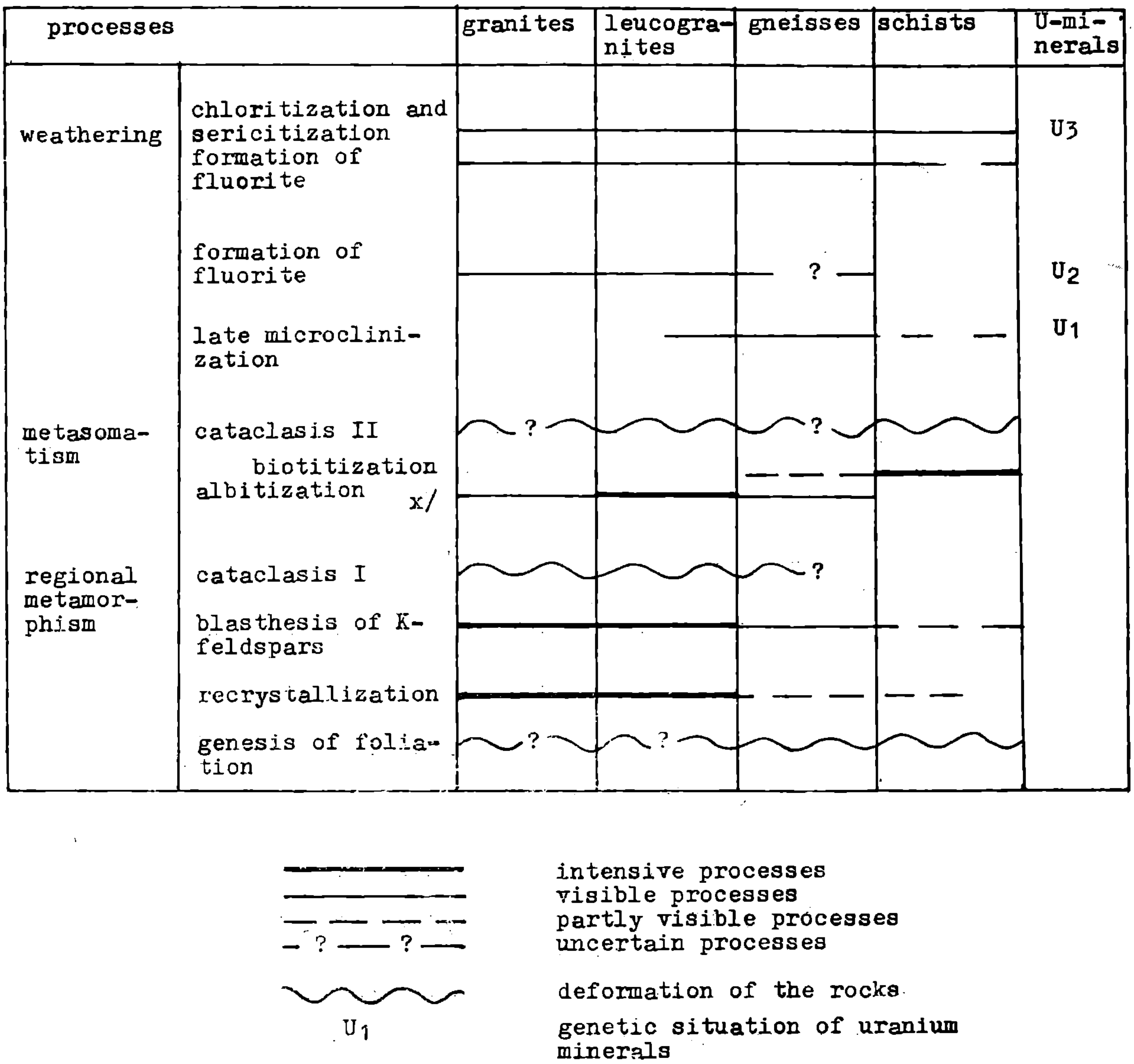
Uranium minerals are accompanied by iron hydroxides only (Table II). Ore minerals occuring in the area under investigation, such as pyrite, pyrrhotite, chalcopyrite, magnetite, arsenopyrite, indicate neither spatial nor genetic relation to uranium mineralization. Earlier papers, however, describe an ore zone consisting of quartz (rock crystal, amethyst, smoky quartz) and of coarse-crystalline fluorite in which, besides uranium minerals, both pyrite and chalcopyrite were found (Table II). Studies of the described mineralization zones pointed to two stages of the formation (Mochnacka, 1975). The first stage is a formation of a primary mineralization as a result of hydrothermal processes; the second one is a mineralization due to exogenic processes. In the area under examination one can find mineralized zones which were formed at both stages, as well as zones formed entirely at the second stage. Hydrothermal processes were a continuation of a high-temperature K-Na metasomatosis, resulting in leucogranite formation. Origin of uranothorite, as well as a genetically younger pitchblende, might be connected with higher-temperature stages.

Table 3

Scheme of rock-alteration and origin of uranium mineralization related to leucocratization

Tabela 3

Schemat przeobrażeń skał oraz powstawanie mineralizacji uranowej o sugerowanym genetycznym związku z procesami leukokratyzacji



x/ albitization and biotitization – processes recognized as contemporaneous.

Petrographic studies of mineralized, partly leucocratized gneisses permit an assumption that formation of some of torbernites is connected with the hydrothermal activity or, more precisely, that they are almost contemporaneous with the second microclinization stage following albitization one. Table III shows succesive processes of rock metamorphosis and determines formation of uranium minerals connected with them. The above data indicate that primary concentrations of uranium minerals in the Izera metamorphic complex were formed as a result of final stages of the regional metasomatosis (Mochnacka, 1975).

The age of this mineralization is the same as the age of metasomatic processes. This conclusion is supported by localization of mineralized zones in close vicinity to the northern boundary of leucogranites which is, according to Szałamacha (1964) an old tectonic zone. This zone might be the circulation patch of solutions causing metasomatic rock alterations (Smulikowski, 1958); at the final stages of their activity these solutions was enriched with uranium.

Secondary zones prevail in the area under investigation. They were formed as a result of weathering of the primary deposit, and due to enrichment with uranium circulating groundwaters. Overlying parts of the primary zones, eroded in Tertiary, might constitute a source of uranium.

According to the classification of Bielova (1968), the oxidation zone can be defined as a silicate-micaceous one. According to the same author, this zone corresponds to oxidation zones of sulphide deposits characterized, however, by an inconsiderable amount of sulphides. The zone thus determined is overlapped by a micaceous zone (a different genetic type) which, according to this author, is formed as a result of conveying uranium compounds by circulating waters.

NEARLY MONOMETALLIC MINERALIZATION WITH NASTURAN (PITCHBLENDE)

Mineralization in veins, nests and, partly in the form of impregnations with nasturan, with an inconsiderable amount of sulphides, occur in the Izera metamorphic complex. The surrounding rocks are granitogneisses which are red-coloured in the deposit zone. Ore zones are connected with subordinate fissures in the vicinity of the main fault. Primary concentrations consist of fissures-and-cracks fillings by a mineral assemblage composed of fluorite, nasturan (pitchblende) and iron oxides. Moreover, traces of pyrite and disseminations of radiogenic galena in nasturan are also found there. The oxidation zone is characterized by the presence of iron oxides and an assemblage of secondary uranium minerals (Table II). The presence of Co, Ni, Bi which are, according to Jaskólski (1976), traces of parageneses of the five-metallic formation, was determined in nasturan by a spectral analysis method.

According to this author, this mineralization is of an epithermal character and corresponds to the final, fluorite-uranium stage of hydrothermal mineralization. Due to a considerable distance from the Karkonosze granite, the assemblage of five-metallic parageneses was lost.

The mineralization under discussion is similar to some extent to the ore mineralization with an assumed genetic realtion to leucogranites, although the latter rocks lack a well-developed zone with pitchblende. The similarity lies in: poor mineral parageneses practically devoid of a polymetallic assemblage, the presence of metauranocircite, the presence of fluorite as an important mineral accompanying ores, and the neighbourhood of leucogranites. These rock reveals considerably smaller range than in the previous case. However it seems that in this area, as well, leucocratization might be genetically related to uranium mineralization.

POLYMETALLIC MINERALIZATION WITH URANIUM

The Kowary deposit may serve as an example. It belongs to hydrothermal deposits resembling a five-metalic formation. Ore minerals occur together with waste ones- calcite (or dolomite), occasionally with traces of fluorite. At greater depths they are accompanied by quartz. These minerals form veins or nests of veinlets. Ore zones ore situated in close vicinity to the granite, or nearby. They have been found up to depth exceeding 650 m. They occur mainly in the neighbourhood of the main fault in rock assemblage composed of marbles, schists, skarns and erlans, together with magnetite lenticles. The above mentioned rock assemblage is surrounded by gneisses. In the deposit three stages of mineralization overlap one another. These are: stage I, in which a metamorphosed magnetite deposit was formed (Zimnoch, 1961); stage II, in which traces of sulphide mineralization exist, genetically related to skarns; stage III, in which a polymetallic deposit with uranium was formed. In most mineral concentrations nasturan (pitchblende) prevails together with a rich assemblage of Co, Ni, Ag, Se, Cu, Bi, As Hg minerals (Table II) (Mochnacka, 1966, 1967). The amounts of ore minerals accompanying uranium mineralization differs; occasionally they occur in inconsiderable quantities.

The Kowary deposit has been already described several times; therefore only the most important characteristics concerning its structure are given in the present paper.

Occurrences of uranium mineralization found in the close neighbourhood of Kowary should also be included in the same group as the Kowary deposit. They differ in diversified assemblages of ore minerals accompanying pitchblende; moreover, they are usually situated at greater distance from granite. Lack of more detailed data does not permit these occurrences to be included in well-defined formation of uranium deposits.

DISCUSSION

The analysis of the types of mineralization with uranium and thorium in the Karkonosze-Izera massif permits a conclusion that the following processes were involved during its formation: 1) magmatic and pegmatitic apparently genetically related to the Karkonosze granite, 2) hydrothermal processes, whose activity is connected with the Variscan orogeny, without a visible genetic relation to the granite; 3) pneumo-hydrothermal processes, causing the leucocratization of metamorphic rocks of the granite cover; 4) weathering processess.

Uraninite concentrations in the Karkonosze granite, as well as formation of mineralized pegmatites in the granite and the surrounding rocks, are processes unquestionably related to the Karkonosze granite. Uraninite crystals in the granite were formed in the time of the rock formation.

Niobium-tantalum or lithium pegmatites, containing thorium and uranium minerals (with a considerable prevalence of the former minerals), are derivatives of the Karkonosze granite. This is confirmed by the composition of traces of minerals (Gajda, 1960). Considerable concentrations of thorium mineralization in pegmatites of the north-western granite cover may also point to a genetic connection with the Karkonosze granite.

Hydrothermal processes resulting in polymetallic mineralization took place in the period after formation of the Karkonosze granite. Considerable time interval between the formation of granite and of mineralization is supported by geological observations made within the Kowary mine. Veins belonging to the polymetallic stage were found in this deposit. These genetically younger veins penetrate into skarns, the latter rocks being formed directly as a result of contact metamorphism of the granite. Moreover, the skarns reveal intense wall-rock alterations in the neighbourhood of these veins. The above observations were confirmed by determinations of the absolute age of the Kowary pitchblende and the granite. They pointed to differences in the time of formation of the granite and the mineralization, amounting to 35 million years. Similar differences between the absolute age of nasturan and that of granite are observed in Obří Důl (Legierski 1973), which is also situated in the metamorphic cover of Karkonosze granite. The fact that age differences exist between the formation of Variscan granitoids and the formation of uranium hydrothermal mineralization, related spatially to these intrusions, is a common phenomenon observed in a number of Variscan deposits in Europe. For example, age determinations of deposits from the Erzgebirge connected with the Eibenstock massif revealed differences to about 50 million years (Borucki, 1964). In the Bohemian massif uranium deposits are 50 to 100 million years younger than Variscan granitoids occurring in their neighbourhood (Legierski, 1976). As suggested by Legierski (1976), these deposits may be regarded as being connected with respective orogenic phases however, no visible genetic relation to granites can be observed. Probably, the lower is the temperature of mineral formation, the longer are the differences in time between the formation of such deposits and formation of the granite (Borucki, 1964).

The above mentioned time intervals between the granite formation and the age mineralization are differently interpreted by various geologists. Davidson (1960) explains them by the subsequent rejuvenation of pitchblende which, however, primarily origins from Variscan intrusions. An interesting interpretation was given by Bietiechtin (1959), who assumed the presence of a tectonic zone through which both granite magma, forming Variscan intrusions, and uranium-bearing solutions might ascend, from a common, deep-seated source.

According to Smith (1974), the period following the formation of Hercynian granites in Europe was important for the formation of primary uranium veins. This author stated that „deep weathering during the following Permian coated uranium-rich Hercynian granites with thick soil formed in situ within which uranium concentrated in zones of fracturing or high porosity. Some of the uranium became caught in fracture system in the metamorphosed rocks surrounding the granite massifs. None of these uranium deposits stray very far away from the end of the granite bodies". According to the above interpretation, Variscan vein deposits might be of an exogenous character, and rock fractures found in the metamorphic neighbourhood of the granite massifs would only constitute a favourable environment for the accumulation of mineralization.

The existing data on vein mineralization in the region of the Karkonosze-Izera massif are insufficient for determining the source of uranium. Moreover, this problem may only be considered locally, and not with regard to a considerably larger area. Bietiechtin's hypothesis seems to be problematic, whereas that concerning the exogenous origin — very unlikely, yet the latter cannot be excluded, either.

Processes of the pneumo-hydrothermal metasomatosis which caused formation of leucogranites resulted in two types of occurrcences of uranium mineralization.

The first type of mineralization consists of high-temperature occurrences of uranothorite with pitchblende (recorded in archival materials only) in the Izera metamorphic complex and, possibly, of the occurrences of brannerite in the vicinity of Kowary. In the latter case, however according to Lis et all. 1965, a close neighbourhood of granite permits a possibility that it is a high-temperature uranium mineralization stage, genetically related to the Karkonosze granite. It was not developed in polymetallic hydrothermal deposits (Kowary).

The second type of mineralization was formed as a result of lower--temperature processes interelated with late microclinization and, thus, with final, lower-temperature processes of the K—Na metasomatosis. The significance of leucocratization for uranium migration is supported by geochemical studies of alluvial deposits (Depciuch et al. 1976). However, these authors express an opinion that processes of alkaline metasomatosis release uranium from the surrounding rocks, while the neighbouring schist belts play the role of lithogeochemical barriers.

The origin of uranium mineralization with a minor amount of sulphides, which is found in the metamorphic complex, has not been entirely explained yet. According to Jaskólski (1976), the genesis of this mineralization is similar to that of the Kowary one. Nevertheless, when the structure of this occurrence is compared with the mineralisation related to leucocratization, great similarity between these two occurrences can be observed.

In the case of uranium mineralization of the Karkonosze-Izera massif the exogeneous processes are of a twofold character. They are: 1) formation of oxidation zones whose mineral composition is differentiated, and 2) redeposition of mineralization effected by groundwaters, resulting in concentrations of uranium minerals, mainly autunite, in localities where the primary zones are absent.

The age of the uranium mineralization can be assessed by defining the age of geological processes related with them. In some cases this age was determined by means of the absolute dating of pitchblende.

The origin of the mineralization genetically related to the Karkoonsze granite is estimated by the absolute dating of granite at about 300 million years (Przewłocki et al., 1962). The age of formation of hydro thermal concentrations connected with the Variscan orogeny is determined by the absolute dating of the Kowary pitchblende, estimated at 265 and 70 million years (Lis, Kosztelanyi, Coppens, 1971). An approximate value of 277 million years was obtained for the model age of pitchblende from the Obři Důl deposit in Czechoslovakia (Legierski, 1973). The above datings indicate that the pitchblende was formed in the Permian. The age of the Kowary pitchblende, estimated at 70 million years, proves transformation of this pitchblende during the Laramie folding.

As it has been already stated at the beginning of the present paper, various authors attribute different age (the close of the Assyntian orogeny, determined as Upper Eocambrian, the Caledonian orogeny or the

Variscan orogeny) to the leucocratization to which occurrences of some uranium mineralization of the Izera metamorphic complex are spatially related. The processes of albitization and microclinization with which uranium circulation is connected are generally separated from each other in time and space (Mehnert, 1968). Thus it may be predicted that uranium mineralization took place after the formation of leucogranites, or at the final stages of their formation.

Analysis of the literature concerning the problem under discussion suggests, that it seems unreasonable to join the leucocratization with the Karkonosze granite activity. Therefore, the only conclusion is that the pre-Variscan age should be attributed to this type of uranium mineralization.

Exogenic processes, especially displacements caused by groundwaters, have been taking up to the Recent time. However, the most favourable conditions for the solution and redeposition of uranium existed during Paleocene and Oligocene, when the climate was subtropical and humid and when intensive denudation processes has taken place (Walczak, 1968). Weathering zones of the uranium deposits, characterized by great thickness, are formed under similar conditions (Evsejeva and Perelman, 1962).

As it can be seen from the above discussion, four stages of formation of the uranium mineralization can be distinguished in the history of development of the Karkonosze-Izera massif (Table I). The stages are:

Stage I — pneumo-hydrothermal — related to the regional leucocratization processes, presumably of a pre-Variscan age.

Stage II — magmatic and pegmatitic — took place in the Carboniferous.

Stage III — hydrothermal — falling on the Permian.

Stage IV — exogeneous — most difficult to determine precisely; at this stage the highest intensity of the ore-forming activity falls on the Paleocene, Eocene and Oligocene.

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STRESZCZENIE

Blok karkonosko-izerski (fig. 1) charakteryzują wystąpienia urozmaiconej mineralizacji kruszcowej. Mineralizacja uranowa ma również niejednolity charakter, co spowodowane jest tworzeniem się jej w wyniku różnych procesów geologicznych kształtujących tę jednostkę geologiczną (Tabela I i III). W przedstawionych rozważaniach brano pod uwagę jedynie obszar znajdujący się na terenie Polski, zatem N i NE część bloku karkonosko-izerskiego.

Mineralizacja kruszcowa w znikomych ilościach występuje w obrębie granitu, w dominującej części gromadzi się w skałach metamorficznych osłony. Wyróżnić można kilka typów skupień mineralizacji uranowej i torowej (Tabela II). Są nimi: 1) rozproszona mineralizacja uraninitem w granicie Karkonoszy, 2) śladowe wystąpienia głównie minerałów Nb, Ta z minerałami toru i uranu w pegmatytach oraz bogatsze skupienia mineralizacji głównie torowej, 3) nagromadzenia brannerytu w żyle kwarcowej, 4) mineralizacja uranowa w formie impregnacji, częściowo gniazd i żyłek wtórnych minerałów uranu, prawie monometaliczna, o widocznym przestrzennym związku z leukogranitami w metamorfikum izerskim, 5) mineralizacja żyłowo-gniazdowa, częściowo impregnacyjna, prawie monometaliczna, głównie nasturanowa ze znikomą ilością towarzyszących siarczków w metamorfikum izerskim, 6) żyłowa mineralizacja polimetaliczna z uranem w południowo-wschodniej części osłony granitu Karkonoszy oraz podobne wystąpienia w sąsiedztwie, o uboższych paragenezach minerałów kruszcowych.

Analizując poszczególne typy kruszcowania można wnioskować, że w tworzeniu się skupień minerałów uranu brały udział następujące procesy:

1. magmowe i pegmatytowe o wyraźnym genetycznym związku z granitem Karkonoszy

2. hydrotermalne, których działalność związana jest z orogenezą waryscyjską, bez wyraźnego związku z granitem
3. procesy pneumo-hydrotermalne, przypuszczalnie te same, które powodowały leukokratyzację skał metamorficznych osłony granitu (Tabela III)
4. procesy wietrzeniowe.

W historii rozwoju bloku karkonosko-izerskiego można zatem wyróżnić cztery etapy tworzenia się wystąpień mineralizacji uranowej:

I etap — pneumo-hydrotermalny, przypuszczalnie wieku przedwaryscyjskiego

II etap — magmowy i pegmatytowy który miał miejsce w karbonie

III etap — hydrotermalny, przypadający na perm

IV etap — egzogeniczny, w którym natężenie działalności złożotwórczej przypada na paleocen, eocen i oligocen.