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TUNGSTEN IN METABASIC ROCKS OF EDOUGH MTS. CRYSTALLINE COMPLEX (NE ALGERIA)

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Abstract: Mineralogical-paragenetical, geochemical as well as previous petrogenetic studies (Hovorka and Ilavský 1991) carried out in the Edough Mts. indicated the presence of tungsten mineralization of intramagmatic ores in pyroxenites, plagioclasites and pegmatites. Subsequent metamorphism caused the alteration of primary disseminated mineralization into impregnation to stockwerk type. At the same time it has been confirmed that all analogous effusive rocks from the Edough Mts. are according to their WO_3 contents perspective as far as tungsten and other metals are concerned.

Key words: tungsten mineralization, metabasic rocks, Edough Mts., Algeria.

Introduction

Scheelite mineralization in the Edough Mts. (northeastern Algeria) exploited during World War II (Beauregard et al. 1958) was in that time considered to be of hydrothermal origin, related to Tertiary granitoids (Hilly 1962). They were considered to be stratiform mineralizations in metamorphic formations by Aissa (1986), however, Glaçon (1973) thought their genesis to be uncertain.

Latest studies of Ilavský and Hovorka (1991) as well as results presented in this paper have shown that scheelites occur in rocks of pyroxenite, plagioclasite, basalt and pegmatite types. Therefore we aimed our mineralogical-paragenetical studies also at their chemical composition in relation to individual rock types.

These studies allowed to define the W-mineralization as intramagmatic, of dissemination-stockwerk type, occurring in plagioclasites to pegmatites in several stratigraphic horizons of Edough Mts. crystalline complex.

The mineralization was after its primary magmatic formation several times metamorphosed, which even stressed its impregnation-stockwerk character (Routhier 1963; Guild 1972). From the viewpoint of morphology it belongs to "strata-bound type" (Wolf et al. 1968–1973) and it occurs in several eruptive horizons belonging to the Ordovician, Devonian to Carboniferous (Hovorka and Ilavský 1991).

Scheelite mineralization in Edough Mts.

The problems of tungsten mineralization in Edough Mts. have been dealt with lately by Aissa (1986), who distinguished here:

1. The deposit Karézas, lying west of the town Annaba (ex-Bône) on northern slopes of Belélieta Mts. in schist formation (or "série des alternaces") northwest of the Annaba University and the metalurgic plant El Hadjar (Figs. 1, 2, 3 in Hovorka and Ilavský 1991).

2. Tin-tungsten deposit of Bouzizi lying in the central part of Edough Mts. in the Seraidi gneiss complex.

3. Polymetallic veins related to Miocene granitoids in the northern and northwestern parts of Edough Mts.

4. The last type is tungsten mineralization studied by the authors, the results of which are presented below; it is related to the uppermost crystalline complex of Edough Mts., i.e. to the Voile Noire Group, or amphibolite series, characterized by Ilavský and Snopková (1987), and scheelites were found in them by one of the authors of the presented paper (J. Ilavský) in the year 1984.

Since the three above types of W mineralization (1, 2, 3) are related to amphibolites to pyroxenites, we shall present the principal characteristics of their structures, textures and mineral composition on the example of the deposits Karézas and Voile Noire.

Structures, textures and chemical composition of W-mineralization Karézas

On the basement of the pyroxenites of the deposit Karézas there are often dispersed or disseminated, sometimes even thin-bedded pyrite-pyrrhotite concentrations with rare contents of arsenopyrite and scheelite (Fig. 1). The thicknesses of these beds, which occur repeatedly two times, are several centimeters to tens of centimeters (Figs. 2, 3). Above these beds, in pyroxenites, there are more abundant grains of chalcopyrite, scheelite, löllingite, while pyrite and pyrrhotite are rare. These are also disseminations, nests to small veinlets in cleavage fissures of the rocks. Tungsten mineralization with scheelite, löllingite and accessory bismuthinite occur in other

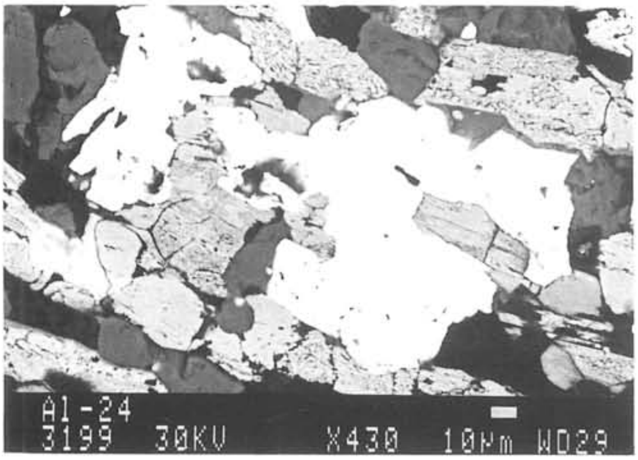

Fig. 1. Sample A1-24-3198. The occurrence of disseminated scheelite (white grains) in pyroxenite-type rocks. Belélieta Group – mine Karézas. Photo: F. Caño, J. Beňka.

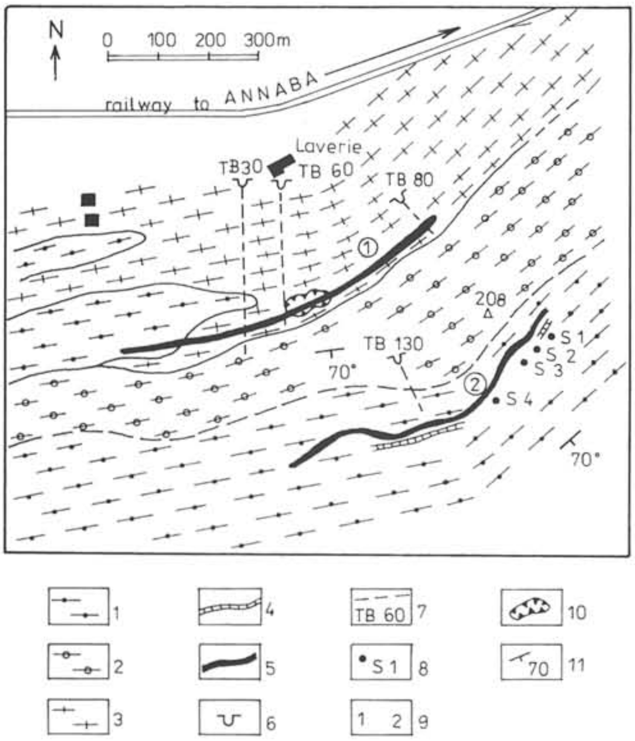

Fig. 2. Schematic geological map of the As-W deposit Karézas at Annaba (according to Sonarem 1969, in Aissa 1986).
1 – two-mica gneisses; 2 – augen gneisses; 3 – tourmaline gneisses; 4 – beds of crystalline limestones; 5 – mineralized pyroxenites; 6 – adit endings; 7 – TB-60, the starting cross-cut of the horizon 60 *m* above sea level; 8 – surfatial drillings and their numbers; 9 – ore bodies No. 1 and 2; 10 – surfatial quarries and exploitation on outcrops of the As-W deposit; 11 – strike and dip of gneiss schistosity.

bodies of amphibolite, garnet schists, carbonates, or "aplites" (albitites), as well as in pegmatites, which are usually situated in the upper parts of the mineralized beds.

The most noteworthy mineral of the deposit is scheelite the grains of which are usually finely dispersed and they attain sizes from 10 microns to 0.5 *mm*. They are associated with plagioclases, pyroxene and sulphides. The oldest ore mineral is wolframite, which is usually surrounded by scheelite. Löllingite forms larger needle-like or xenomorphic grains. Pyrrhotite and arsenopyrite are younger and they frequently form margins around scheelite (Fig. 5).

Scheelite belongs paragenetically to the oldest ore minerals. The grains are usually locally cracked and sometimes inclusions of rock-forming minerals can be observed in them (Fig. 6). It is probably the older scheelite generation I. The substantial part of grains is however homogeneous, without inclusions of surrounding rock-forming minerals and they belong probably to the younger scheelite generation II, which could have formed also during metamorphism. This younger scheelite generation II is accompanied also by younger sulphide generations: löllingite, pyrite II and III, pyrrhotite and arsenopyrite.

Pyrite is usually similarly dispersed in pyroxenites as scheelite and it appears in several generations. The oldest pyrite generation I is usually represented by the largest number of grains. It is strongly corroded and mechanically destructed. Pyrite II is younger, more idiomorphic. Its grain-size is 1–2 *mm*. Pyrite III formed as the product of pyrrhotite disintegration, around which it forms chain-like margins with grain-size of 0.1–0.3 *mm*.

Pyrrhotite is less frequent than pyrite. It replaces scheelite and is itself replaced by löllingite as well as magnetite spots (nests), which form at oxidating conditions (Ramdohr 1962).

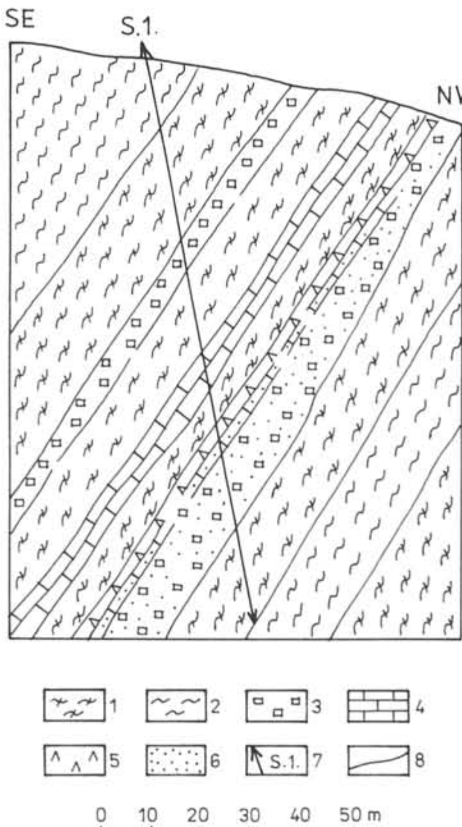

Fig. 3. Detailed geological section across the strata-bound deposit of As-W ores Karézas at Annaba (after Sonarem 1969, in Aissa 1986).
1 – augen gneisses; 2 – banded gneisses; 3 – pyroxenites; 4 – crystalline limestones and dolomites; 5 – amphibolites to pyroxene gneisses; 6 – As-W mineralization in pyroxenites; 7 – survey drillings; 8 – boundaries between lithologic rocks types.

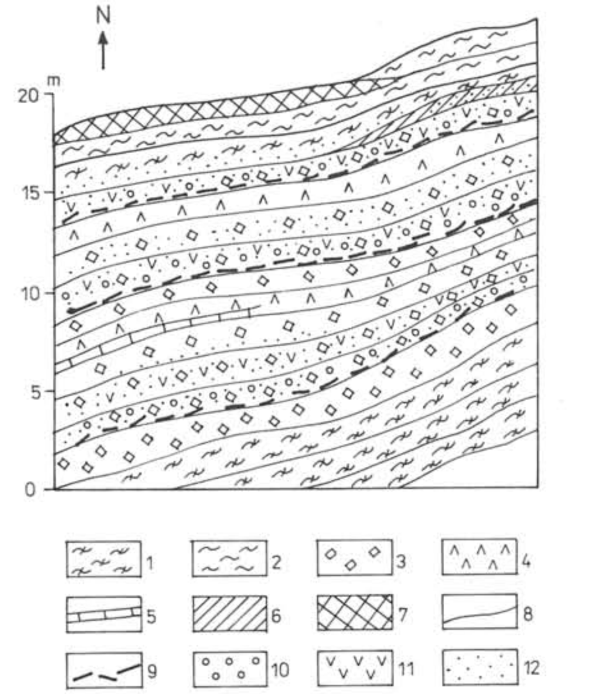

Fig. 4. Detailed geological section across the As-W deposit Karézas at Annaba (in the Belélieta Group).
1 – augen gneisses; 2 – banded gneisses; 3 – pyroxenites; 4 – amphibolites; 5 – crystalline limestones and dolomites; 6 – albitites (aplites); 7 – pegmatites (pegmatitites?); 8 – bedding cleavage; 9 – pyrrhotite, pyrite (with segregations of Ni-pentlandite); 10 – chalcopyrite, cubanite; 11 – löllingite and arsenopyrite (with Bi); 12 – scheelite and wolframite.

Löllingite usually forms separate, spear-like grains or it replaces scheelite.

Arsenopyrite is associated with pyrite I. It is relatively scarce. Chalcopyrite has been found rarely in the studied polished sections. However, it is more abundant in the lower parts of the deposit.

WO_3 contents on the deposit Karézas range according to Beauregard et al. (1958) from 0.7 to 1.5%. Marginal parts of the deposit, which were not exploited in the sixties, had WO_3 contents of 0.15 to 0.20%. and they were considered at that time unrentable and unexploitable. Gold contents varied about 1 *g/t* and they were bound to löllingite.

According to our studies, WO_3 contents in individual host rock types are as follows:
- in underlying augen-gneisses 1.22% WO_3, or 0.96% W;
- in basal parts of pyroxenites 3.26% WO_3, or 2.58% W;
- in plagioclasites lying above the pyroxenites 2.06% WO_3, or 1.63% W;
- in coarse-grained pegmatites 1.18% WO_3, or 0.93% W;
- in fine-grained aplites (or albitites) 2.36% WO_3, or 2.08% W.

These results are in accordance with Fig. 4.

From the above data it follows that economically exploitable deposit is at present-day conditions much thicker that it was in the sixties.

Scheelite contents increase from basal members – pyroxenites, in which W contents are the highest, upwards to pegmatites and albitites. It is a result of magmatic differentiation of ultramafic rocks.

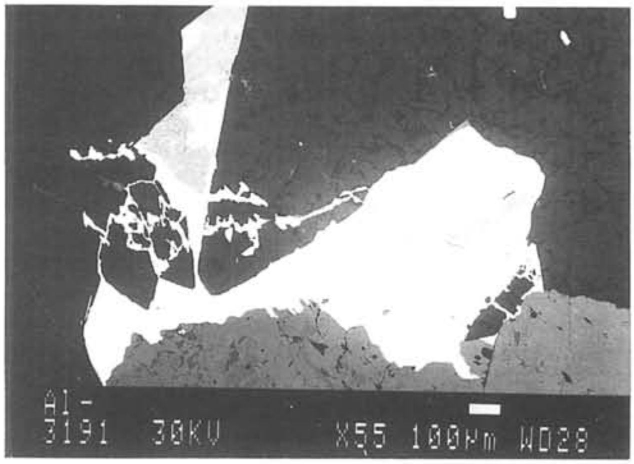

Fig. 5. Sample A1.3191. Scheelite (white) is replaced by pyrrhotite (light grey) and by arsenopyrite (dark grey). All minerals are in pyroxenic rocks. Belélieta Group – mine Karézas.
Photo: F. Caño, J. Beňka.

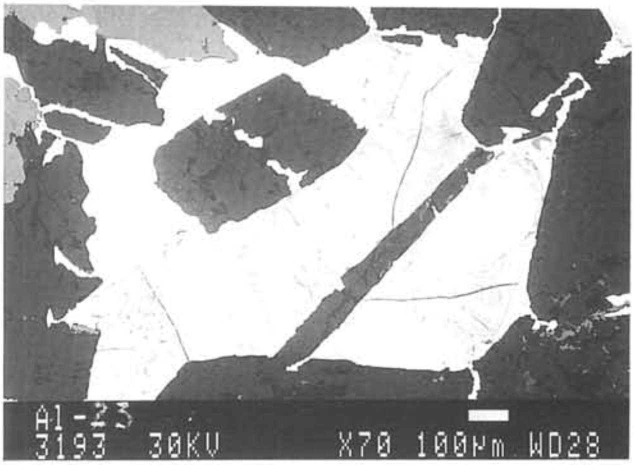

Fig. 6. Sample A1-23-3193. Scheelite (white), replaced by pyrrhotite (light grey) with alteration products – dark spots (nests). Tiny grains on the upper left side of the figure are pyrite III. The surrounding rock is pyroxenite. Belélieta Group – mine Karézas.
Photo: F. Caño, J. Beňka.

Differentiation of metal contents in bodies of ultramafic to intermediary rocks took place also as a result of gradual enrichment of the differentiates by potassium- (pegmatites) and sodium-rich (albitites) components in the overlying parts of the geological section.

The enrichment of the magmatic melt by alkalies affected in a decisive way the solubility of metals. Therefore there are increased tungsten contents in albitites.

The above mentioned regularities of the distribution of ore minerals in the complex of ultramafics, basics or alkalic rocks of NE Algeria are consistent with the results of authors who dealt with these problems (Ramdohr 1962; Routhier 1963; Guild 1972; Wolf et al. 1976).

From the conclusion on the differentiation of scheelite and other mineral contents in ultramafic rocks of Edough Mts. it follows that further prospection for tungsten-bearing and

Table 1. Chemical analysis of ore from Karézas.

WO_3	As	S	Pb	Zn	Cu	Bi	F
1.45	0.25	2.7	0.02	0.12	0.05	0.18	1.5
SiO_2	Al_2O_3	MnO	MgO	Fe	CaO	TiO_2	Na_2O
36.6	17.0	0.2	2.0	13.3	5.8	0.3	2.5
K_2O	Ag	U	H_2O	Total			
0.2	2g/t	5g/t	4.0	100.2			

Table 2. Chemical analyses of scheelite from ore deposits of Karézas and Voile Noire (in %).

metal sample	CaO	WO_3	MoO_3	Ce_2O_3	Y_2O_3	FeO	
	K	a	r	é	z	a	s
Al-24a 3198	19.86	78.42	0.07	0.37	0.03	0.04	98.81
Al-24b 3198	18.82	79.32	0.00	0.43	0.07	0.04	99.70
Al-24c 3200	20.27	78.37	0.04	0.39	0.00	0.70	99.80
Al-22a 2501	19.24	79.17	0.13	0.40	0.11	0.50	99.56
Al-22b 2501	19.59	79.13	0.00	0.39	0.25	0.13	99.51
Al-23a 3102	19.67	79.75	0.03	0.30	0.27	0.08	100.1
Al-23b 3193	19.57	78.98	0.06	0.38	0.19	0.07	99.29
	V o i l e		N o i r e				
Al-8a 3184	19.19	78.30	0.14	0.55	0.00	0.10	98.36
Al-8b 3184	19.46	78.25	0.00	0.37	0.03	0.14	98.27

Electron Microanalyser Super Probe JEOL JCX-703.

other deposits is necessary to carry out on the basis of principles derived from the presented data.

From the above mentioned facts it also follows that economically exploitable deposit is in the view of present economic parameters much thicker that in the sixties, in the period of exploitation by the French colonial administration of Algeria.

The complete chemical analysis of ore exploited from the deposit Karézas, reworked by flotation, according to Beauregard et al. (1958), is listed in Tab. 1.

The thickness of mineralization with tungsten at the deposit Karézas varied from 1 *m* to 4 *m*, while average W content was 1%. Therefore, the thickness of mineralized beds on the deposit, as we have mentioned, should be recalculated on the basic of a detailed sampling of under- and overlying parts of the deposit, including white albitites and pegmatites (Fig. 2).

Chemical composition of scheelite from the deposit Karézas has been studied on homogeneous grains also using electrone microanalyser JEOL Superprobe JXCA-703, where one analysis represents the average of several measurements. We have carried out seven analyses on three of the studied samples (Tab. 2).

The results show except the principal components (CaO, WO_3, MnO, FeO) also the presence of small amounts of MoO_3 (maximally 0.14%), Y_2O_3 (maximally 0.27 %) and Ce_2O_3 (from 0.30 to 0.43%). While the contents of MoO_3, Y_2O_3, and FeO are considerably variable and they can be connected with heterogeneous admixtures of fine sulphides, the contents of Ce_2O_3, CaO and WO_3 are relatively stable.

The above results allow to assume that scheelites were metamorphosed subsequent to their formation, which is indicated also by the structure of scheelite grains.

Tungsten contents of the Voile Noire Group (amphibolite series)

The connection of the scheelite-löllingite mineralization of the deposit Karézas with pyroxenites, plagioclasites, amphibolites and pegmatites of the Belélieta Group initiated our study of tungsten content in the Voile Noire Group, or amphibolite series, on the northern slopes of Edough Mts.

Even though the geological setting of this formation is different from the central parts of Edough Mts., petrographical and petrochemical conditions are similar to those of the Seraidi or Belélieta Group in the sense of Ilavský and Snopková (1987).

Therefore, in the Voile Noire Group we studied with regard to tungsten and other element contents, the following: amphibolites and accompanying pyroxenites, limestones, dolomites, epidotites, albitite-type rocks.

As we have already mentioned (in Hovorka and Ilavský 1991), tungsten is found in the Voile Noire Group in two horizons:

- in the basal part of the amphibolite series, which is lying on the schist series, and
- in the terminal part of the formation.

The scheelite mineralization is in this case also of disseminated type and scheelite forms here grains several microns to milimeters in size. Sometimes they are in clusters elongated in the direction of schistosity. Predominantly they are however isolated, irregular grains, occurring in association with rock-forming minerals – amphibole and plagioclases.

W contents are in the mentioned two horizons very interesting:

- in the lower part W contents reach 0.96% and minimal contents are 4 to 3 *ppm;*
- W contents are in the upper part as high as 0.78%;
- weakly mineralized zones in the amphibolite series have been studied only by orientation samples, their W contents range between 4 and 15 *ppm.*

It has to be said that under the basement of the Voile Noire Group there are rocks of the schist series, which also contain increased amounts of WO_3 – 1.22%, or 0.96% W. The samples represent strongly altered and mylonitized basic rocks of meta-amphibolite to porphyrite type, which occur relatively frequently in the schist series (the Belélieta Group), on various locations.

The chemical composition of scheelite from the Voile Noire Group is listed in Tab. 2 (the last two samples). The contents of principal components are the same as those of scheelites from the deposit Karézas. Slight differences can be observed only in the contents of CaO, WO_3 and FeO. However, there are greater differences in the contents of Y_2O_3 and Ce_2O_3, those in scheelites of Voile Noire being higher in comparison with the deposit Karézas, with the exception of FeO, where the relationship is opposite. However, it is necessary to note that the differences in the contents of principal and secondary elements in scheelites from the two groups with different ages – Belélieta (Ordovician–Devonian) and Voile Noire (Upper Devonian–Lower Carboniferous) – are not more marked that differences within the same complex.

Genesis of rocks with tungsten mineralization

Rocks of pyroxenite, plagioclasite, amphibolite and epidotite type were considered by Beauregard et al. (1958) to be genuine magmatites of basic character, which have been metamorphosed in the pre-Gottlandian period into gneiss, or schist facies. They considered pegmatites to be the principal source of mineralization, ascribing them Tertiary age and considering them related to the assumed granitoids of intrusive type hidden deep in the Kabylides. They derived from them all mineralizations occurring here: W, As, Cu, Fe, Bi etc. They considered them to be of hydrothermal, vein and epigenetic origin. On the basis of these assumptions they solved also the problems of parageneses and succesion, as well as textures and structures of the ores.

Hilly (1962) put forward different concepts, considering all basic rocks of Edough Mts., from pyroxenites and amphibolites to epidotites, to be metamorphogenic rocks, which according to the cited author, should have originated from marly and calcareous rocks. He thought all mineralizations in Edough Mts. to be of hydrothermal origin, epigenetic and related to Miocene magmatism (granitoids).

Even Glaçon (1973) did not avoid in his critical contribution the idea that Sn-W minerals of Edough Mts. are granitophillic, in spite of the fact that he described the metallogeny of the mountain range as polyphasal and polygenic. E.g., he did not relate mineralizations with löllingite to the granitoids.

However, our studies have shown (and they concern only mineralizations in Edough Mts. crystalline complex) the following:

1. plagioclasites and amphibolites in the Seraidi Group (gneiss series) as well as in the Belélieta Group (schist series, or "série des alternances"), as well as the Voile Noire Group (amphibolite series), are genuine magmatites of effuzive type, this being evidenced by their petrostructures and petrographic character;

2. in the above mentioned metamorphosed eruptive rocks there are examples of gravitational-magmatic differentiation;

3. ultramafic rocks (pyroxenites) are connected above all with mineralizations with pyrite and pyrrhotite, or with segregations of petlandite as well as scheelite. They are dissemination to impregnation-stockwerk types.

Basic members and their differentiates – amphibolites to plagioclasites – contain more disseminated mineralization of chalcopyrite, with lesser amounts of pyrite and pyrrhotite, as well as W-minerals – wolframite and scheelite, locally also bismuthinite.

In overlying rocks – intermediary to alkaline members, i.e. aplites and pegmatites, which alternate with the original sediments of pelite and carbonate type (now schists and marbles) – the most frequent mineralization is that of scheelite, wolframite and löllingite, while chalcopyrite occurs here in negligible quantities.

All ore minerals are spatially and paragenetically bound to originally magmatogenic or metamorphogenic minerals – amphiboles, plagioclases, augite, diopside. Thus, there is no mineral-paragenetic evidence of hydrothermal and epigenetic origin of ore minerals. Although quartz is present in the deposit, or in its mineralized parts, it belongs to metamorphogenic type which formed from the surroundig protolithic rocks.

The general development of mineral associations on the deposits Karézas and Voile Noire in the Edough Mts. crystalline complex indicates:

– close spatial relationships of mineral assemblages with scheelite with the crystallization of ultrabasic to intermediary magmatic rocks in the sense of Routhier (1963);

– textures and structures of the mineralization are of dissemination type, in some places they are banded, indicating thus synchronal formation of ore and rock-forming minerals;

– the genesis of mineralization in pyroxenites, amphibolites, aplites to pegmatites of Edough Mts. is thus polygenic and polyphasal: in the first stage minerals formed in close relationship to magmatic differentiation of rocks, in the second stage, during progressive metamorphism, primary ore minerals were altered to metamorphogenic ones: pyrrhotite, löllingite, pentlandite, bismuthinite, chalcopyrite etc., in the third stage, during retrograde metamorphism, older minerals were altered to low-temperature ones. Schists, chlorite-sericite diaphtorized schists to phyllonites were formed, and at the same time, younger generation of sulphides was mobilised into fissures and veinlets in older minerals.

Conclusions

The study of scheelite mineralization in ultramafic rocks to acid and alkaline differentiates of various formations in Edough Mts. indicates their relatioship to tholeiitic effusives of OFB type, or MORB type of present oceanic basins, even though they are of Lower Paleozoic age (Hovorka and Ilavský 1991).

Scheelite mineralizations with industrial W contents are very intimately related to various magmatic differentiates of tholeiitic magma and the represent, according to Routhier (1963) and Wolf (1979), disseminations to impregnations, or stockwerks, in "strata-bound" structures in which scheelite mineralization occurs.

Multiple repetition of the occurrence ultramafic, basic, intermediary to acid and alkaline differentiates in Edough Mts. from the Ordovician to Devonian provides very perspective conditions for the prospection for further tungsten and other mineralizations.

Scheelites contain the admixtures of molybdenum, yttrium and cerium, which, in the sense of Herrmann and Felscher (1969) indicates very close relationship to tholeiitic magma of oceanic type. However, we have not studied other rare earth elements. They would deserve further investigation, which would be necessary not only from theoretical, but also practical point of view.

Translated by K. Janáková

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