ON THE GENESIS AND MINERALIZATION OF THE TUNGSTEN DEPOSIT ULUDAĞ

Province of Bursa - Turkey *

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ABSTRACT — The tungsten deposit of Uludağ is closely linked with a late tectonic Paleozoic intrusion of a granodiorite - granite - batholith into a series of crystalline rocks and marbles.

The deposit is located in a marble syncline folded into the granite. It is the tectonic structure of this syncline that controlled the location and the shape of the deposit.

The mineralization took place after the granite of the border-zone was more or less solidified. High temperature solutions and volatiles acted with the wall-rock along cracks, bedding-and shearing-planes and resulted in the formation of tungsten-bearing sheets of tactile in the marble syncline and in the mineralization of a brecciated zone on both sides of the contact between marble and granite.

The sequence of mineralization is discussed.

INTRODUCTION

In the summer of 1954 the author investigated the tungsten deposit of Uludag-Turkey, and its geological relationship, on behalf of the Mineral Research and Exploration Institute (Maden Tetkik ve Arama Enstitüsü), Turkey.

It is on this field-work, the information gathered from underground mapping, detailed core logging closely linked with subsequent microscopical work including thin - sections and polished specimens which were mainly taken from drill cores, that this paper is based. The author wishes to acknowledge the kindness and the scientific cooperation which he received from Dr. Sadrettin ALPAN who was in charge of the exploration and drilling operations. In particular, acknowledgement is made to Dr. P. de WIJKERSLOOTH who studied the polished specimens. Stimulating discussions with the latter aided in shaping the conclusions presented herein. This paper is presented by the kind permission of the former general director of M. T. A., Prof. Dr. Hamit Nafiz PAMİR, who promoted this investigation.

HISTORICAL SUMMARY OF EXPLORATION

In 1951, on the northern slope of the summit region of Uludağ, two outcrops of scheelite-bearing tactile (skarn) and large boulders of the same rock in the bordering moraine were discovered by Raşit TOLUN and N. DANIŞMAN (7). During the following years some exploration work was done. In 1953 a report by Galip SAĞIROĞLU (6) threw light on the mineral assemblage, of the deposit.

A campaign of deep diamond-core drilling was commenced in 1954. This last period of exploration resulted in the disclosure of a large tonnage tungsten deposit of moderate - grade ore.

The results of this campaign were laid down in a report by the author - (2) and a report by Sadrettin ALPAN (1).

A separate paper on the concentration of the ore was given by Raşit TOLUN (8). A new mineral —Bursaite— discovered in the deposit, was discussed by Raşit TOLUN (9) and by P. de WIJKERSLOOTH (10).

GENERAL GEOLOGY

Location. — The tungsten deposit Uludağ in the province of Bursa-Turkey is situated in a «cirque» cut out in marble, about 3/4 km NE of the summit (2487 m) and lies from 2200-2300 m above sea level. It is almost 15 km SE from the town of Bursa (150 m) (compare sketch-map showing location of tungsten deposit - fig. 1.) During winter until the beginning of June the summit region is snow-covered.

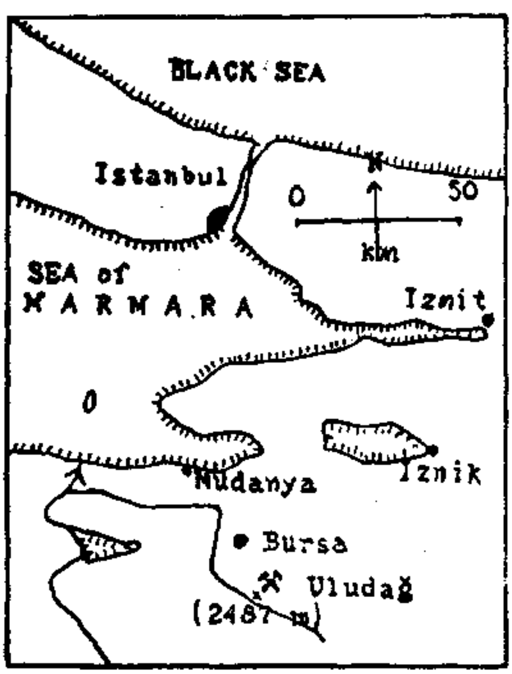

Fig. 1 - Sketchmap showing location of tungsten - deposit Uludağ

Geology. — In 1947 the Uludağ area was the subject of a thorough description by KETİN (4). In his paper he mentions the older mostly geomorphological literature on the area by A. PHILIPPSON (1913), W. PENCK (1918 and 1924), E. CHAPUT (1936) and A. ARDEL(1944). For details regarding the geology of the Uludağ the reader is referred to these papers.

In 1954, at the end of the exploration work, a detail mapping in the vicinity of the tungsten deposit was carried out by F. RONNER (5). His report gives valuable local information.

According to KETIN (4), the oldest rock type in the area consists of crystalline schists as amphibolites and gneisses which are overlain by marbles. These marbles are locally schistose and sometimes a well-developed banding is preserved. Then follows a series of mica-schists and semi - marbles. These metamorphic rocks are overlain, probably in unconformable position, by non-metamorphic Carboniferous and Permian beds. These strata consist of conglomerates, arkoses, limestone breccias, sandstones and limestones.

The metamorphic sequence was intruded by a late - tectonic granitic batholith, probably of late - Paleozoic age. In the last stage of the intrusion, the sequence was folded in an anticline and partly overturned to the SSW.

In the south, marbles and crystalline schists are folded in the granite. They form the core of a special syncline of the partly overturned anticline mentioned previously (compare cross-section of Uludağ after KETİN - fig. 2). These infolded marbles build up the summit region of Uludağ and form a conspicuous range, more than 25 km in length and 2 km in width.

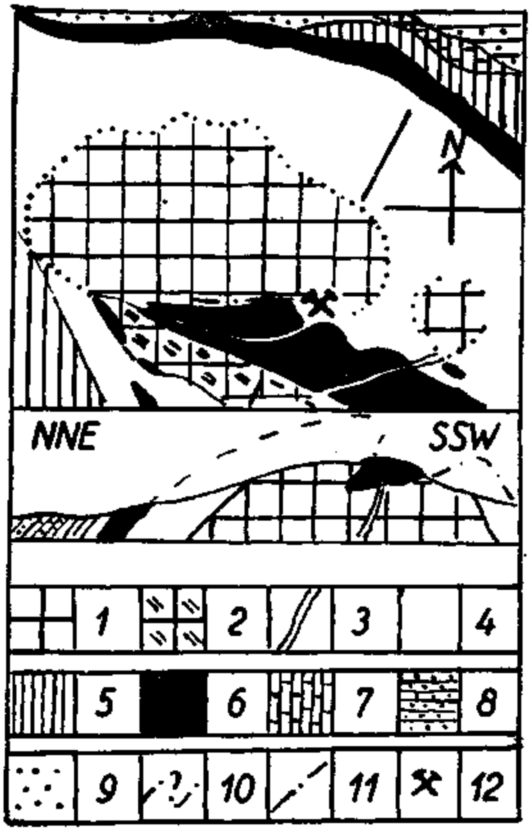

Fig. 2 - Geological map and profile of the Uludağ granite - batholith and *its* surroundings (simplified after İ. KETİN - 1947)

(1) Granite and granodiorite, (2) Granitic-gneiss, (3) Granodiorite porphyry, (4) Gneiss and amphibolite, (5) Mica-schist and phyllite, (6) Marble, (7) Semi - marble, (8) Carbon. - Permian, (9) Pleistocene, (10) Folding, (11) Fault, (12) Tungsten - deposit.

Their structure is of special interest for the tungsten deposit. The general strike is WNW-ESE.

On the southern side of the range the dip is always to the north, on the northern side the dip changes from south to north according to the overturning of the anticline.

Towards WNW, directly west of the tungsten deposit, the range is cut off by granite in an E-W fault. The axis of the range seems to plunge weakly to the ESE.

The marble range was injected by numerous aplites as well as by a granodiorite - porphyry, which intruded along fault planes. The marbles rise steeply from the enclosing granite and crystalline schists. The summit region is rather flat. At the northern side of the range, many steep «cirques» were carved out during the Pleistocene by small glaciers. At the foot of these glaciers local moraines and their debris were deposited. They cover large parts of the contact - zone between granite and marble, making exploration work difficult.

THE INTRUSIONS, THEIR RELATIONSHIP TO METAMORPHISM AND TUNGSTEN MINERALIZATION

G r a n i t e. — According to KETlN (4), the batholith in the centre is more granodioritic and finer - grained and somewhat younger than the granite of the border zone. The granite that underlies the marble in the area of the deposit is a medium to coarse-grained biotite-granite, passing towards the margin into finer-grained leucocratic muscovite-granite. The essential minerals are quartz-orthoclase, albite-oligoclase, muscovite and biotite. Accessory minerals are apatite and magnetite. Its texture is hypidiomorphic. The unaltered granite is barren of tungsten mineralization. The granite itself is very seldom in direct contact with the tungsten-bearing tactile sheets.

A p l i t e. — Aplites and tongues of granite are known in the area and also the amphibolites and gneisses in the ,neighbourhood are injected by numerous aplites. They represent end-stage products of the granite-intrusions and are almost contemporary with the formation of tactile. The aplites are fine - grained and extremely leucocratic. They have the same composition as the leucocratic muscovite - granite but are sometimes rich in apatite. Their texture is allotriomorphic to microporphyritic. Traces of scheelite occur in the aplites which are situated within the marble and tactite. The emplacement of the aplites has certainly participated in the process of tungsten migration and accumulation. Especially within the tactite sheets, the aplites are sometimes strongly epidotized.

Granodiorite -porphyry.— A dike of granodiorite - porphyry cuts the summit region along fault planes. It has no direct relationship to the tungsten mineralization. The rock is strongly porphyritic and consists of phenocrysts of quartz, brown biotite, strongly zoned andesine and a little potassium - feldspar in a felsitic ground - mass of quartz and feldspar.

Metamorphism of granite.— In the marginal zones of the granite, as known from diamond - core drilling, metamorphism has been active. The granite borders are strongly cataclastic and are characterized by a zone of alteration which is from 3-10 m thick. The alteration becomes more pronounced nearer to the border of the granite. The feldspars become sericitized and kaolinized, the rock solidified and impregnated by pyrite.

The greatest friction and resulting deformation during folding and intrusion was located near the contact between marble and granitic rock. In this zone shearing was intensified and favoured the subsequent tungsten mineralization. It seems that the silicification is contemporaneous with the concentration of tungsten. Not far from the deposit a scheelite-bearing quartz vein occurs in barren granite and so is also the case with the tactite where quartz veins often are rich in scheelite (compare plate II-fig. 3). From the above it is obvious that mineralization and metajnorphism of the granite took place after the granite was more or less solidified. It resulted from deep-seated aqueous solutions and volatiles from below the solidified border-zone of the granite and belongs to the aftermath of the acidic intrusion.

Metamorphism of marble.— The solutions and volatiles rich in Si, Al, Fe, F, W, S, and H_2O reacted with the wall-rock and especially the limestone was acting as a selective precipitant. The solutions and volatiles penetrated along fracture- and shearing-zones. The tactite is not a product of thermal metamorphism in the strict sense of the word. This is evident from the concordant sheet-like replacement of sterile marble by tactite, as well as the long distance from the contact. This process of metamorphism was largely favoured by local structural factors. KERR (3), who studied many tungsten deposits in the U.S.A., arrived at the same conclusions. He also points out that for the formation of contact - metamorphic minerals, argillaceous limestones or limestones rich in silica are not required. These minerals may also form in pure limestones. The marble of Uludağ is generally pure, although sometimes it contains intercalations of tremolite - marble, forsterite-marble, veins of epidote and thin veinlets of calcite with traces of scheelite. Banding is locally well preserved and is stressed through a rapid alternation of white and greyish marble.

THE DEPOSIT

Structural Control.— As mentioned above, the tungsten deposit is situated directly east of the E-W fault that cuts off the marble range towards

WNW. In the area of the deposit the anticline is overturned and the infolded marbles form a special syncline. The axial plane of this syncline dips about 20° towards NE and its axis has an average SE plunge of 20°.

During the folding the upper part of the marble was detached from the infolded marble syncline by a horizontal fault-plane. Morphologically, this upper part is conspicuous as a steep cliff rising above the «cirque» of the deposit (compare simplified cross-section - fig. 3).

to the NE. The length of the shorter axis is about 230m. (compare fig. 4a).

The longer axis of these sheets follows the folding axis of the syncline (compare fig. 4b). This axis strikes NW-SE and pitches about 20° to the SE.

The two tactite outcrops represent also the outcropping of this axis to the NW. Along this direction the tactite sheets could be followed by means of surface diamond drilling towards the SE over more than 500m. The tactite is

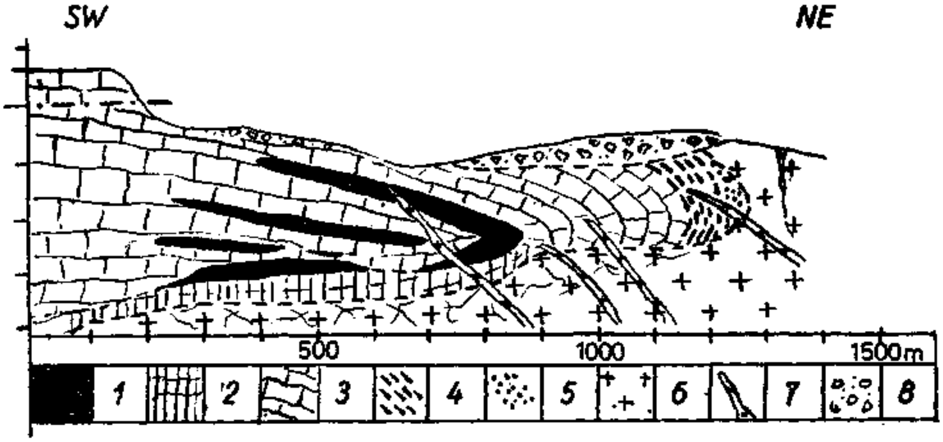

Fig. 3 - Simplified cross-section of tungsten - deposit Uludağ

1. Tactite (skarn) sheets.
2. Tungsten - bearing bottom-zone.
3. Marble.
4. Amphibolite.
5. Gneiss.
6. Granite.
7. Aplite and quartz vein.
8. Debris and moraine.

Several sheets of tungsten-bearing tactite are situated in the lower apex and in the core of the special syncline in shearing zones concordant with the banding of the marble. These sheets show a gradual thinning off at the limbs of the syncline. The thickness is therefore variable. Together the total maximum thickness of these sheets is about 58 m.

The shorter axis of these sheets strikes NE-SW and dips in the upper limbs to 30°, in the lower limbs to 10°

almost certain to continue in this direction. Probably the lower part of the NE-outcropping end is cut off by the post - granitic E-W fault, mentioned above.

It is evident that the longer axis of the productive area is parallel to the trend of the marble range. In this trend brecciated border zones between marble and granite, and brecciated tactite zones bordering the marble foot wall were highly receptive to tungsten mineralization. The genesis of this brecciated border zone (bottom-zone) has already been

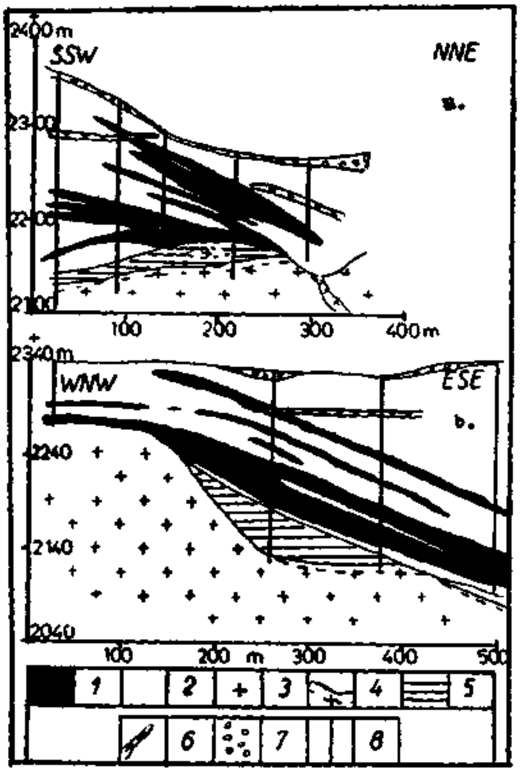

Fig. 4 - Typical cross and longitudinal section of the tungsten - deposit Uludağ

1. Tactite (skarn) sheets, (2) Marble, (3) Granite, (4) Tungsten - bearing granite, (5) Bottom - zone, (6) Aplite, (7) Debris and moraine, (8) Drillhole.

discussed above. A typical cross and longitudinal section of the deposit is shown in fig. 4.

Host rock. — Commercial tungsten mineralization occurs only in :

1. The brecciated border-zone which will be called bottom-zone.

2. The tactite sheets (skarn sheets).

Traces of scheelite mineralization are to be found in marble, in aplite and in quartz veins cutting through barren marble.

Ad. 1. Bottom-zone. — On both sides of the margin of marble - granite is a broad tungsten-rich zone. It does not outcrop and is known only through surface diamond drillings. In this marginal zone scheelite is found widely disseminated and it is rich enough to be used as ore. Here scheelite is intimately associated with wolframite, the crystals of which are invaded and partly replaced by scheelite (-compare plate I-fig. 1, 2). This zone is very promising as it contains millions of tons and its boundaries are not yet known. Its thickness varies between 5 and 55 m, and is greatest in the troughs of the granite. The grade of tungsten ore in this zone varies from traces to over 3% WO_3. The average tungsten content is estimated at 0.8% WO_3. This bottom-zone may be divided into :

a. A zone of metasomatic brecciated marble with apophyses of granite and aplites on top of metasomatic granite. In a few places scheelite is associated with zones rich in magnetite.

Mineral compositon : Quartz, calcite, pyrite, magnetite, scheelite, wolframite, feldspars, with minor constituents such as fluorite, sphalerite, apatite, spinel, sericite, rutile. It should be stressed that contact minerals such as diopside and garnet are missing.

b. A zone of metasomatic granite, also strongly brecciated, on top of unaltered barren granite.

Mineral composition: Orthoclase, quartz, acidic - plagioclase, calcite, pyrite, magnetite, spinel, muscovite, sericite, kaolin scheelite, wolframite, apatite, rutile.

Ad. 2. Tactite sheets. — Genesis and in fluence of structural control on the origin of tactite sheets have been discussed above. Within the tungsten-bearing zones large scheelite - free areas occur, but also here large parts are rich enough to be counted as ore. Scheelite is widely disseminated but seems to be more concentrated in brecciated zones bordering the marble foot wall of the sheets. Here, bands rich in scheelite are arranged parallel to the strike and dip of the foot wall marble. Cross-fractures in the tactile are usually filled by quartz veins sometimes rich in scheelite and pyrite. Also parts rich in fluorite and scheelite have been observed (compare plate II-fig. 1,2,3). This tactite area is even larger than the bottom zone, but poorer in tungsten. Its grade of tungsten varies from trace to 5 % WO_3. The average tungsten content is estimated at about 0.4 % WO_3

Mineral composition :

Silicates : Diopside, hedenbergite, garnet, tremolite, actinolite, quartz, sillimanite, epidote, sericite, chlorite.

Oxides and metallic,-sulfides : Magnetite, hematite, pyrite, chalcopyrite, sphalerite, cubanite, valleriite, pyrrhotite, bismuthinite, bursaite.

Other minerals: Calcite, scheelite, fluorite, bismuth, graphite, apatite.

Table I - Ore zone minerals, their relative abundance and sequence of deposition

Phase of mineralization			
Minerals	*Magmatic*	*Pneumatolitic*	*Hydrothermal* *High..........Low*
Feldspar	xxx xxx xxx	xx xx x	....
Quartz	xxx xxx xxx	xxx xxx xxx	xx xx xx xx x x
Biotite	xx xx xx	....	....
Muscovite	xx xx xx	x x x	....
Apatite	(x) (x) (x)	(x) (x) (x)	....
Magnetite	.... xx	xx xx xx	....
Spinel	.... (x)	(x) (x)	....
Wolframite	....	x x x	....
Diopside	....	xxx xxx xxx	....
Hedenbergite	....	x x x	....
Hematite	....	.... x x	x x x ....
Scheelite	....	.... x xx	xx xx ....
Fluorite	... .	....	xx xx ....
Garnet	....	.... xxx	xxx x ....
Pyrite	....	.... x	xxx xxx xx ....
Tremolite	....	....	xxx xxx ....
Actinolite	....	....	x x
Epidote	....	....	..... xxx xx xx ....
Sphalerite	....	....	..... xx x x ....
Chalcopyrite	....	....	x x x x ....
Cubanite	....	....	.... (x) (x) (x) ....
Valleriite	....	....	.... (x) (x) (x) ....
Pyrrhotite	....	....	.... (x) (x) (x) ....
Bursaite	....	....	(x) (x) (x) (x) ....
Bismuth	....	....	.... (x) (x) (x) ....
Bismuthinite	....	....	.... (x) (x) (x) ....
Calcite.	....	....	.... xx xx xx xx

Legend :			
	xxx very abundant	xxx abundant	xx common
	x not common	(x) rare	(x) very rare

S u p e r g e n e - m i n e r a l s: Covel-Hte, malachite, azurite, limonite, psilomelane, chalccdone.

The composition of the tactite changes rapidly from place to place but in the tactite zone diopside, garnet, tremolite, quartz and calcite make out the bulk of the tactite. Garnet and diopside rocks are common. The sequence of deposition of minerals and their relative abundance - as studied from field observations and thin and polished sections will be listed below in a table. T h i s t a b l e s h o u l d b e c o n s i d e r e d a s a n a t t e m p t t o f i x t h e c o m p l i c a t e d g e n e s i s o f t h e d e p o s i t i n s e q u e n c e o f p h a s e s o f m i n e r a l i z a t i o n. Slight changes in the distribution of some minerals over the phases may be possible. Some minerals will be discussed briefly.

Since most material studied in both zones is relatively incoherent, ordinary methods of mineral determination, such asi examination of thin and polished seotions, have to be supported by heavy mineral separation, thermal-differential - and-X-ray studies. Additional minerals undoubtedly will be found, but only as accessories. Present but not classified in this table are forsterite (x), sillimanite (x), graphite (x), rutile (x), titanite (x), chlorite x, sericite xx, kaolinite xx, limonite xx, psilomelane (x) and chalcedone. Molybdenite and tourmaline, which should be expected, seem to be lacking in the paragenesis of Uludağ. In the concentrate, only very little Mo could be proved to exist as an integral constituent of scheelite. Compare TOLUN (8).

DISCUSSION OF SOME MINERALS AND CLASSIFICATION OF THE DEPOSIT

M a g n e t i t e: Idiomorphic to hypidiomorphic. Characteristic for contact-pneumatolitic origin is the observed zoning accentuated by exsolution-products in the form of tiny crystals of spinel.

PLATE -1

Fig. 1 - Polished section. Wolframite (Wr) is replaced along crystallographic directions by scheelite (SI). In the upper part magnetite (Mt) with high relief. Di = Diopside. (x 120).

Fig. 2 -Thin section. Idiomorphic crystal of scheelite (SI) partly replaced by calcite (Cc). Wolframite (Wr) is replaced by scheelite. Other minerals : quartz (Q and rutile (Ru). (x 36).

Fig. 3 - Thin section. Hypidiomorphic crystal of scheelite (SI) enclosing idiomorphic crystal of apatite (Ap). Opaque mineral is pyrite. The matrix consists of calcite and quartz, (x 120).

PLATE - II

Fig. 1 - Thin section. Broken up crystals of scheelite (SI) are recemented by quartz (Q) other minerals: diopside (Di) replaced by calcite (Cc) and fluorite (Fr). (x 36).

Fig. 2 - Thin section. Hypidiomorphic crystal of scheelite (SI) and fluorite (Fr) replacing diopside (Di). Other minerals: quartz (Q.) and sphalerite (Sph). (x 36).

Fig. 3 - Thin section. Corroded individuals of scheelite (SI), partially replaced by a strongly cataclaslic quartz (Q.). (x 36).

PLATE - III

Fig. 1 - Thin section. Veinlet of garnet (Gr) crossing diopside (Di). Other minerals: quartz (Q). (x 36).

Fig. 2 - Thin section. Nicols X. Shows anomalous birefringence and zoning of garnet, (x 36).

Fig. 3 - Polished section. Bursaite (Bu) with tiny exsolutions of bismuth (B) and bismuthinite (Bi). Other minerals: sphalerite (Sph), fluorite (Fr), garnet (Gr). (x 60).

Fig. 1

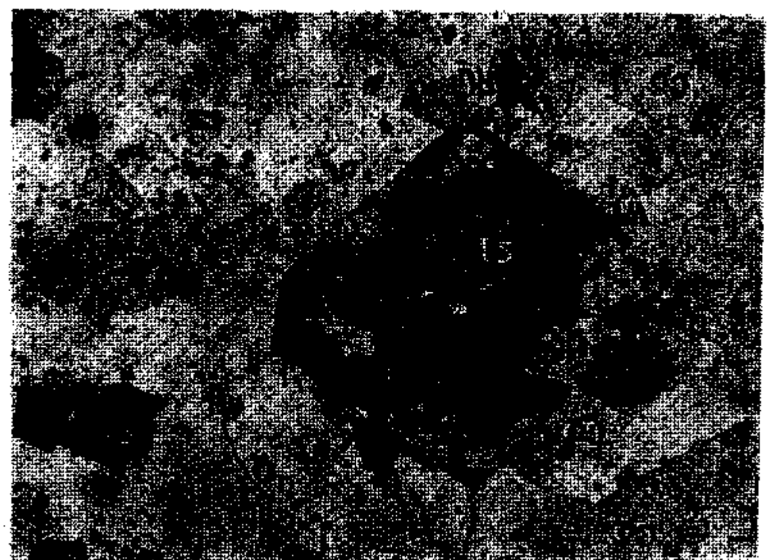

Fig. 2

Fig. 3

Fig. 1

Fig. 2

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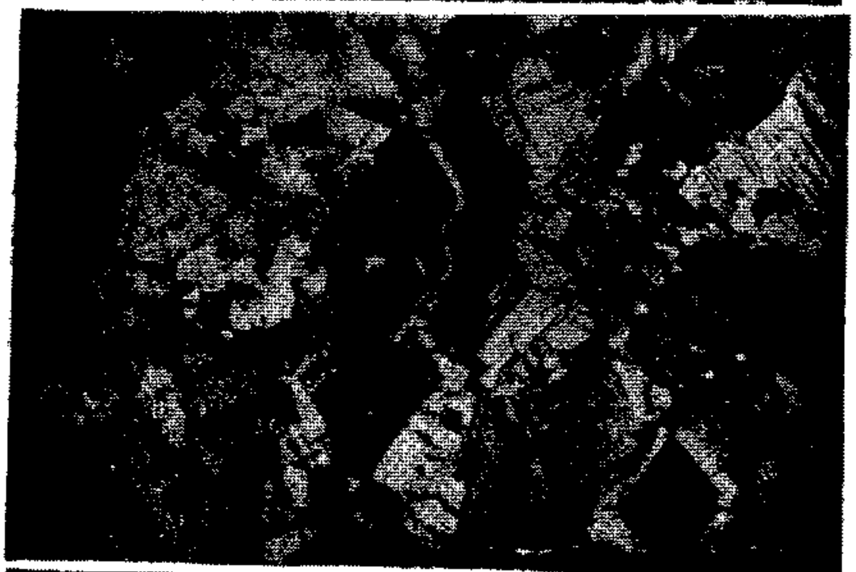

Fig. 2

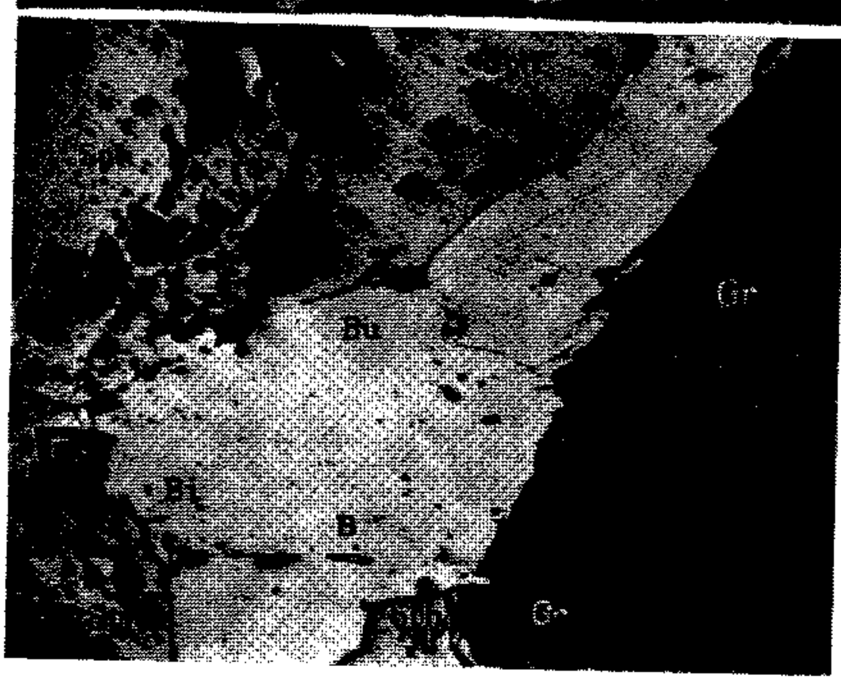

Fig. 3

Very rarely it contains inclusions of pyrite. The magnetite is often cataclastic.

W o l f r a m i t e: Seems to be concentrated in the bottom zone; it is of fine or medium grain. It could be proved that in various places it is later than magnetite. It is replaced along crystallographic directions by scheelite (compare plate I - fig. 1, 2).

D i o p s i d e: Together with garnet it is the most important contact-mineral and is replaced by various minerals such as tremolite, metallic sulfides, quartz, along crystallographic directions. Fractures in diopside are recemented by garnet (compare plate III-fig. 1).

S c h e e l i t e: Idioblastic to hypidioblastic, coarse to fine-grained. The pure white scheelite is mostly of too fine grain to be recognized macroscopically, but it yields a bluish-white fluorescence with ultraviolet light which greatly facilitates its recognition. In Uludağ it is rather pure and contains only minor amounts of powellite. It replaces wolframite (compare plate I - fig. 1,2, 3,).

Microscopical evidence indicates contemporaneity of fluorite and scheelite (compare plate II - fig. 1,2). The scheelite seems to be in part formed earlier than garnet, but later than diopside.

F l u o r i t e: A white variety. Violet colours are very rare in Uludağ, making its macroscopical recognition difficult, though it is rather common. The fluorite indicates the role played by fluor in the process of mineralization.

G a r n e t: Together with diopside the most important contact-mineral. Colour brown. It is a member of the grossulare-andradite series. It is replaced by chlorite. Coarse to fine-grained. Mostly idioblastic to hypidioblastic. Zoning common. In thin sections anomalous birefringence is always observed between crossed nicols (compare plate HI-fig. 2).

E pi d o t e : Coarse to medium-grained. It is represented by the strong pleochroitic variety pistacite. Zoning common. It is of about the same age as pyrite.

P y r i t e : Idiomorphic to hypidiomorphic, fine to coarse-grained. Cubic crystals up to 4 cm in diameter are observed. In places it is of the same age as magnetite, but in general it is younger. Sometimes it is also younger than garnet and hematite. It appears, however, that pyrite was earlier formed than the other sulfides, because it is replaced by them.

M e t a l l i c s u l f i d e s: With the exception of pyrite they were all introduced in a somewhat later epoch of mineralization.

Microscopical evidence as intergrowth of iron-rich sphalerite (marmatite), chalcopyrite with cubanite, valleriite, pyrrhotite and some bismuth minerals indicate essential contemporaneity of these minerals. The presence of cubanite and valleriite denotes a high - temperature genesis. The metallic sulfides are especially concentrated in the tactite sheets. Of these minerals, the cristallization of the idiomorphic bursaite may have begun somewhat earlier.

Bursaite was concentrated by Dr. RAŞİT TOLUN and analyzed at the chemical laboratory of M. T. A. The mineral was described by TOLUN (9), the morphological and optical properties were given by WIJKERSLOOTH (10).

According to them, bursaite is a Pb-Bi-sulfosalt in between cosalite - lillianite.

Characteristic are exsolutions of bismuth and bismuthinite (compare plate III-fig. 3).

Galcite: Is partly of later origin than the metallic sulfides. In some places of the tactile sheets it shows a red fluorescence under ultraviolet light, probably due to a small manganese content.

From the above it is concluded that the tungsten deposit Uludağ is to be classified as a pneumatolytic-high-temperature-hydrothermal deposit in the neighbourhood of the granite contact.

A certain temperature zoning in mineralization has been observed.

1. Wolframite is only observed in the bottom zone.

2. Larger concentrations of magnetite are also restricted to this zone.

3. Concentration oftungsten is more intensive in the bottom-zone than in the tactite sheets.

4. The metallic sulfides, with the exception of pyrite, are concentrated in the tactite sheets.

5. The contact-minerals—garnet and diopside—are restricted to tactite sheets which in part are found at a long distance from the granite contact

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