MINERALOGY OF THE MADENBELENITEPE (SOĞUKPINAR-BURSA) TIN MINERALIZATION

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ABSTRACT. — Tin mineralization occurs in the greisenized granite porphyry in Madenbelenitepe area. Stannite is the major tin mineral. Cassiterite is found in trace amounts. Associated minerals are arsenopyrite, pyrite, sphalarite, fahlerz (tennantite-tetrahedrite), galena, chalcopyrite, bournonite, boulangerite, rutile and pyrrhotite. Gangue minerals are represented by quartz, muscovite, sericite and minor amounts of apatite.

To the East of Madenbelenitepe mineralization, scheelite, wolframite and molibdenite occurs in granite, greisenized granite and granite porphyry. Pyrite, arsenopyrite, cosalite, scheelite, wolframite (partly altered to scheelite), molibdenite, specularite, sphalarite, tennantite, chalcopyrite and tourmaline occurs in hydrothermal quartz veins intersecting granites and metamorphic schists.

Madenbelenitepe tin mineralization shows many features similar to those observed in the upper zones of other tin mineralizations found throughout the world, and the mineralization described here, is seemingly a «hydrothermal quartz greissem type formed at high temperatures.

INTRODUCTION

The use of tin minerals in Asia Minor dates back to times immemorial, and although some believe that at least for the past 4,000 years tin has been used by the inhabitants of this part of the globe, opinions regarding the origin of the tin minerals used are contradictory (Kaptan, 1976). The writers of the present work believe that the study of tin mineralization occurring in Madenbelenitepe area shall contribute to the understanding of whether tin minerals used by the inhabitants of Asia Minor were extracted from local sources or brought to the region from sources outside.

Madenbelenitepe tin mineralization, outcropping on the southern flanks of Handeresi valley, occurs in Soğukpınar village, Keles, Bursa Province (Fig. 1). The area was first sampled by A. Çağatay in September 1979, during a trip made within the framework of Project (Exploration Project for Polymetils, Wolfram in particular, in Northwest Anatolia), and with other personnel associated with this Project. During this trip, several other deposits and mineralized areas were visited and samples were collected for preliminary investigations. The area was visited again in April 1980, as abundant stannite and other minerals as well, were determined during polished section studies of the samples collected from the area. During the second trip made to the area by the writers of the present work and the project personnel, the mineralized area and its surroundings were studied and samples were collected for further studies.

Field observations, microscopic studies and the results obtained from the analyses indicate that Madenbelenitepe tin mineralization has some potential value. The purpose of the present work, which describes tin minerals and other associated minerals occurring in the area, is to show that the area under investigation is a favorable environment in terms of tin mineralization.

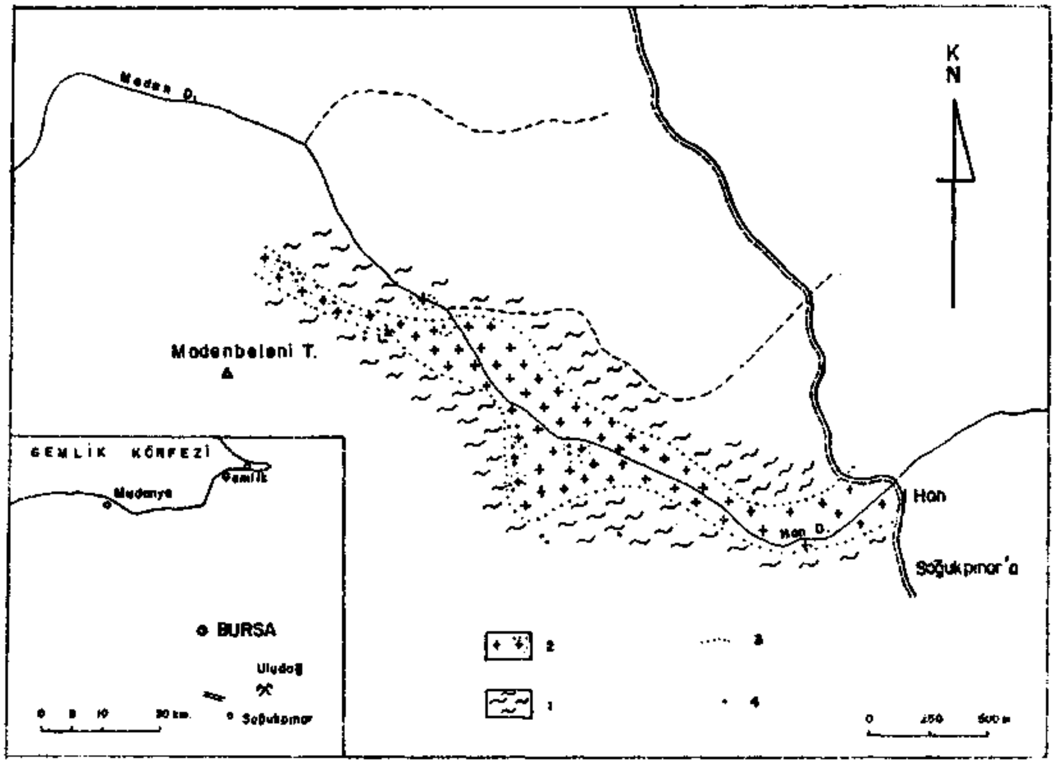

Fig. 1 - **Location and Geological Map of the Area.**
1 - Metamorphic rocks; 2 - Granite, granite porphyry (local greisenization); 3 - Contact; 4 - Sample locations.

FIELD OBSERVATIONS

Madenbelenitepe tin mineralization occurs in the Handeresi Valley, extending E-W to the south of Uludağ granite and within the granite porphyry outcropping S of the valley and along the granite porphyry contact. Granite porphyry outcropping in a narrow belt between the metamorphic schists (mica-quartz schist, epidote-actinolite-quartz-chlorite schist and calc schist) and marbles on the southern flanks of Handeresi valley (Fig. 1 and 2), locally grade into two-mica granite in the east and lower parts. Madenbelenitepe mineralization may be traced in a narrow zone, as much as 500 meters long, in the greisenized portions of the granite porphyry. The same is also true for the outcrops and ancient adits and trenches. Adits and other passages, partly favoring entrance, are known to have been opened in the near past for zinc and lead production. In the lower horizons, however, several workings have been observed, which may have been ancient adits and trenches.

Granite porphyry, on the whole partly altered, has been subject to strong hydrothermal alteration (i.e. greisenization) effects, in mineralized areas. To the W of the mineralized area, greisenization is characteristically in the form of an internal greisenization» (Scherba, 1970; Smirnov, 1976). Mineralization in this part of the area, is essentially in the form of stockworks and fills in the fissures and fractures developed, within the greisenized granite porphyry. According to Tischendorf (1969, 1970 and 1973) and Stemprok (1971), this type of mineralization is closely related to granotoids. Hydrothermal quartz, arsenopyrite, pyrite, sphalarit eand galenite may be seen in the veins, even with the naked eye. To the east of the mineralized area however, the grain size of these minerals is typically smaller and epidotization, chloritization, hematitization and silicification is very common along the contact between the granite porphyry and metamorphic schists.

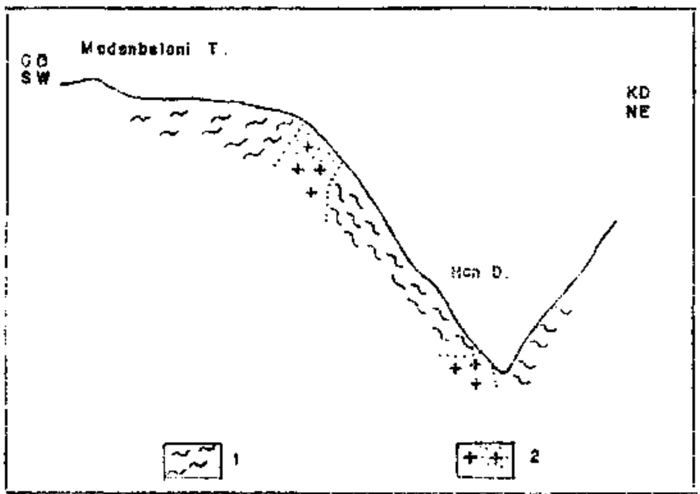

Fig. 2 - Diagramatic Geological Section.
1 - Metamorphic rocks; 2 - Granite, granite porphyry (local greisenization).

Further to the east of Madenbelenitepe tin mineralization, granite porphyry, granite and abundant hydrothermal quartz veins, of varying thickness and intersecting the former two, can be observed. Quartz veins, as much as 1-2 m locally, form elevations on the land surface due to their hardness and occur widely dispersed throughout the area as a result of their breaking and disaggregation. Ore minerals are common in the authoctonous and allochtonous quartz veins and fragments, these will be treated in detail in the chapter on the Microscopic Study of Hydrothermal Quartz Veins.

Recrystallized limestones occurring along the granite porphyry contact to the W and S of the mineralized area, have been altered into hornfels as a result of silicification, and form elevations on the land surface and may occur in the form of boulders.

MICROSCOPIC STUDIES

Granite, greisenized granite, granite porphyry, and greisenized granite porphyry closely related to mineralization and ore and hydrothermal quartz veins occurring in the area were studied in detail.

Granite-greisenized granite

The rock characterized by crystalline, sub-idiomorphic texture comprises of quartz, oligoclase, microcline, orthoclase, biotite and muscovite and accessory minerals such as scheelite, rutile, apatite, topaz and pyrite (Plate I, fig. 1).

Quartz is hypidiomorphic and shows interlocking texture. Feldspar, mostly idiomorphic and sub-idiomorphic, consists of oligoclase and minor microcline and orthoclase. Perthitization, sericitization and argillization can be observed in places. Mica is represented by brown colored biotite and muscovite. Biotite, however locally, has been altered to muscovite along the cleavage planes. Minute rutile needles and apatite crystals are common. Accessory minerals are represented by scheelite, coarse rutile crystals, apatite and sparse topaz (Plate I, fig. 1).

Granite is greisenized in places (Plate I, fig. 2) and contains quartz and muscovite. Quartz is hypidiomorphic and shows interlocking texture, while muscovite occurs as aggregates. Greisenized granite also contains minor amounts of orthoclase, microcline, sparse biotite and apatite, rutile, pyrite and molibdenite as accessory minerals.

Granite porphyry and greisenized granite porphyry

Granite porphyry samples collected outside the mineralized area, are typically porphyritic and contain quartz, feldspar and muscovite phenocrysts (Plate I, fig. 3).

Quartz crystals, idiomorphic, sub-idiomorphic and hypidiomorphic, have been locally effected by magmatic corrosion. Feldspar is composed of oligoclase and minor orthoclase and sericitization is widespread. Muscovite, an alteration product of biotite, contains rutile needles and crystals along the cleavages planes (Plate I, fig. 4).

Matrix is composed of microcrystalline quartz, feldspar and sericite. Accessory minerals are rutile, apatite and pyrite.

Effects of hydrothermal alteration, commonly observed in the granite porphyry, are stronger near the ore zone, where the rock consists of quartz, muscovite and sericite, occurring as gangue minerals associated with the ore.

Ore minerals

Samples collected from Madenbelenitepe area contain stannite group minerals, i.e. stannite, isostannite, hexastannite, minor cassiterite and other metallic minerals such as arsenopyrite, pyrite, sphalarite, galenite, fahlerz (tennantite-tetrahedrite), bournonite, chalcopyrite, boulangerite, rutile and pyrrhotite. In the following chapters, tin minerals shall be described in detail, whereas others shall be treated only briefly.

Tin minerals

Stannite group covers a wide range of similar minerals. Studies carried out on this group of minerals by various writers (Levy, 1956,1957,1966; Moh, 1960,1961,1969,1971; Ramdohr, 1975) indicate that the minerals belonging to this group, are hard to distinguish on the basis of their microscopic features only. In the present work, such tin minerals as stannite, isostannite and hexastannite were determined in the samples collected from the area under investigation and these will be classified and treated as stannite.

Stannite. — Stannite, formed after arsenopyrite and pyrite, replaces the latter (Plate I, fig.5; Plate II, fig. 2), and occurs as hypidiomorphic crystals in the interstices between arsenopyrite and pyrite. Stannite crystals may be as much as 1-1.5 mm, and may show linear arrangement along the smooth edges, due to anisotropism (Plate I, fig. 5).

As the crystal structure of stannite has many similarities to that of sphalarite, intergrowing is a very common feature. Stannite may form exsolutions (Plate I, fig. 6) and inclusions (Plate I, fig. 7), in sphalarite along certain crystallographic directions; sphalarite in turn may form exsolutions arranged along certain crystallographic directions and inclusions as well, enveloping stannite exsolutions. Stannite developing simultaneously with sphalarite, replaces and is replaced by the latter.

Fahlerz and galenite, younger than stannite, intersect the latter. The same is also true for chalcopyrite, although rarely. Sub-rounded stannite inclusions are very common in the fahlerz and galenite veinlets. Very minute chalcopyrite exsolutions (hardly distinguishable at 500 x magnification) may sometimes be observed in stannite.

Very thin and parallel twinning laminae are not uncommon in stannite, which shows distinct reflection pleochroism and anisotrophy under polarized light (Plate I, fig. 5). Stannite, formed at relatively high temperatures, has been altered to isostannite and hexastannite, owing to decreases in temperature; and as a result isostannite and hexastannite may occur as intergrowths. Isostannite and hexastannite intergrowths are very common in and around sphalarite and they may sometimes occur interlocked with ordinary stannite. Stannite, formed as the alteration product of isostannite and hexastannite, however, occurs in lesser amounts compared to ordinary stannite.

Cassiterite. — Cassiterite has been identified in a limited number of samples taken from the area, as idiomorphic crystals, as much as 10-20 microns in size, and in trace amounts. Cassiterite occurs in the fahlerz veinlets intersecting stannite, and has been formed as a result of element exchange between these minerals (Plate II, fig. 1). During the element exchange, copper present in the composition of stannite has been used by fahlerz, remaining tin forming Cassiterite. Ramdohr (1975) reports that such Cassiterite formations are common in areas where chalcopyrite intersects the stannite.

Other ore minerals

Arsenopyrite. — Arsenopyrite, occurring very widespread and as idiomorphic crystals (Plate II, fig. 2), is the oldest ore mineral following pyrite I, present in trace amounts, and rutile. The coarsest arsenopyrite crystal contained in the samples collected from the area under investigation, has been measured to be 0.8 x 0.4 mm. Rutile and pyrite I inclusions are common in arsenopyrite, which occasionally shows cataclastic texture and occurs either as inclusions in other ore minerals or being entirely replaced by the latter.

Pyrite. — Pyrite shows two distinst modes of formation. Pyrite I, occurring in trace amounts and as idiomorphic crystals, is the oldest mineral after rutile. Pyrite II, however, younger than rutile, pyrite I and -arsenopyrite, is older than other ore minerals. Pyrite II crystals, generally idiomorphic or sub-idiomorphic, may be as much as 2 mm, and show cataclastic texture in places (Plate II, fig. 3). Pyrite II, encloses rutile, arsenopyrite and however rarely, pyrrhotite inclusions. Other minerals replacing Pyrite II, occur as grains and veinlets in the latter (Plate II,.fig. 3).

Sphalarite. — Occurring as hypidiomorphic crystals in the interstices between idiomorphic quartz, arsenopyrite and pyrite crystals, encloses stannite and to a lesser degree, chalcopyrite exsolutions (Plate II, fig. 4). Stannite and chalcopyrite exsolutions enclosed along certain crystallographic directions in sphalarite, are indicative of a zonal growth. Chalcopyrite exsolutions, generally envelope coarser crystals compared to stannite exsolutions, and may be interlocked with the latter. It may thus be concluded that sphalaritfc is contemporary with stannite and chalcopyrite, younger than rutile,. arsenopyrite and pyrites and older than other minerals. Fissures and minute fractures developed in sphalarite, showing cataclastic texture, are filled by fahlerz, galenite (Plate II, fig. 1),chalcopyrite and carbonate minerals. Sphalarite can also form exsolutions in these minerals.

Fahlerz (tennantite-tetrahedrite). — Like sphalarite, hypidiomorphic fahlerfc crystals occur between idiomorphic quartz, arsenopyrite and pyrite crystals. Fahlerz, younger than sphalarite and stannite, replaces arsenopyrite, sphalarite and stannite along the fissures (Plate II, fig. 1). Such reaction minerals as bournonite and boulangerite are common along the contact, where fahlerz has been replaced by galenite; such relationship may sometimes lead to the formation of a myrmekitic texture also (Plate II, fig. 5), and arsenopyrite, pyrite, quartz, sphalarite and stannite inclusions and galenite intrusions are therefore, not uncommon in fahlerz. Chalcopyrite contained in minor amounts is presumed to have been formed contemporary with the fahlerz.

Galenite. — Since galenite is the youngest mineral following chalcopyrite, which replaces the former, replaces all other minerals and encloses them as inclusions. Minute grains of boulangerite and bournonite, formed partly as a result of replacement of fahlerz by galenite, are very common and abundant in galenite. Galenite has been altered to sericite along the cleavage planes and grain margins. Native silver grains, as much as 3-5 microns, have been identified in the samples collected from the stockwork ores occurring to the W of Madenbelenitepe mineralization.

Chalcopyrite. — Chalcopyrite occurring in minor amounts, may be divided into three age groups - the oldest chalcopyrite is represented by those (Plate III, fig. 4) enclosed in sphalarite and stannite as minute inclusions and exsolutions. These are believed to have been formed simultaneous with the sphalarite and stannite, whereas chalcopyrite occurring as minute grains in fahlerz are contemporary with fahlerz. Chalcopyrite veinlets intersecting galenite and other minerals in Madenbelenitepe mineralization, on the other hand, is the youngest mineral.

Bournonite. — Bournonite, has been formed at the contact between fahlerz and galenite, at least partly replaced by the former, as a reaction product. Bournonite, occurring as intergrowths with galenite and fahlerz, forms myrmekitic texture with galenite (Plate II, fig. 5). In some bournonite crystals, parallel twinning laminae may be observed (Plate II, fig. 6).

Boulangerite. — Occurs as sub-rounded, worm-like grains in galenite, rod-like grains in the gangue and as a reaction product along the galenite-fahlerz contact.

Rutile. — Rutile is the oldest ore mineral, and occurs in minor amounts and different forms. Minute rutile needles and rods occur along the cleavage planes developed in muscovite and as inclusions enclosed in the pyrite and arsenopyrite crystals. Rutile needles may be as much as 60x12 microns. Idiomorphic to sub-idiomorphic rutile crystals, showing cataclastic texture and rarely as much as 100-200 microns, were also observed. Parallel twinning laminae, generally developed in one and rarely in two directions are not uncommon.

Pyrrhotite. — Occurs in small amounts and as minute and sub-rounded inclusions in pyrite.

Hydrothermal quartz veins

Samples collected from the hydrothermal quartz veins contain hypidiomorphic quartz, minor sericite, tourmaline, scheelite and opaque minerals. Opaque minerals are represented by cosalite, wolframite, which is altered to scheelite along the margins, molybdenite, pyrite, sphalarite, arsenopyrite, fahlerz, chalcopyrite, specularite and covelline.

ANALYSES

Microprobe analysis

Results obtained from microprobe analyses of the stannite crystals identified in the samples collected, confirm microscopic observations. Studies carried out on stannite (Plate II, fig. 7), have shown that major constituents are Cu, Fe, Zn, Sn and S; Ag, present in trace amounts is accessory mineral. Quantitative microprobe analyses on stannite however, could not be made, due to the unavailability of necessary standard solutions. Results obtained from qualitative microprobe analyses, i.e. Cu K a, Fe K a, and Sn K a, made on a stannite crystals are given in Plate II, figures 8,9 and 10.

Semi-quantitative optical spectrographic analyses

Semi-quantitative optical spectrographic analyses were made on four seperate samples, containing stannite (Table 1).

Table 1 - Results of semi-quantitative optical spectrographic analysis

Samples		*I*	*II*	*III*	*IV*	*Dedection limits*
Elements (%)	Sn	0.2	0.1	0.04	0.2	
	Fe	$>4, \cong 10$	$>4, \cong 7$	$>4, \cong 7$	$>4, \cong 10$	
	Cu	0.3	0.3	0.1	0.4	
	Zn	$>1, \cong 2$	>1	>1	>1	
	Pb	$>1, \cong 3$	0.4	0.4	0.2	
	As	>1	>1	>1	>1	
	Sb	G	G	G	G	0.02
	Bi	G	G	G	G	0.02
	Ti	0.03	0.04	0.02	0.04	
	Cd	0.02	0.04	0.1	0.03	
	Ag	0.015	0.02	0.01	0.015	
	Au	G	G	G	G	0.002
	Li	G	—	—	G	0.1

CONCLUSIONS

Results obtained from the mineralogicai-petrographical studies of the samples collected fron Soğukpınar Madenbelenitepe mineralization may be briefly described as follows:

1. Greisenization (i.e. hydrothermal alteration) is typical in the granites and granite porphyry outcropping extensively throughout the area. As Deer et al. reports (1962), biotite has been altered to muscovite and as a result of this alteration process, Ti present in the crystal structure of biotite has been released and very minute rutile needles and rods have been formed along the cleavage planes developed in muscovite. Fe released during the alteration process has been used in the crystal structure of pyrite and arsenopyrite.

2. Based on the results obtained from the mineralogical-petrographical study of the samples collected from Madenbelenitepe mineralization, the sequence of formation of the minerals contained is as follows:

Muscovite (alteration product of biotite), sericite (alteration product of feldspar), rutile needles
Quartz (hydrothermal origin), sericite, pyrite I
Arsenopyrite, sericite, quartz
Pyrite II, quartz
Sphalarite, stannite, chalcopyrite
Fahlerz, chalcopyrite, carbonate
Galenite, bournonite, boulangerite
Chalcopyrite

3. Madenbelenitepe mineralization extends over an, area of 500-600 meters. Tin minerals, are relatively more abundant in the stockwork type of ore occurring in the western part of the mineralized area; they occur in lesser amounts in the eastern part of the area under investigation. Fahlerz and bournonite, in particular, increase from west to east.

4. Stockwork ores occurring in the greisenized granite porphyry located to the West of Madenbelenitepe mineralization, have been formed by high-temperature hydrothermal solutions. Based on the textural and structural features observed it may be concluded that mineralization occurring in the west, represents relatively higher-temperature conditions compared to the mineralization observed in the east.

5. Skarn minerals such as epidote, chlorite, quartz, garnet, diopsite, magnetite and hematite occur in small amounts along the contact between the granit porphyry and recrystallized limestones, calc-schists and other metamorphic schists.

6. Granite and greisenized granite occurring on the eastern extension of Madenbelenitepe mineralization contain topaze, apatite, molibdenite, scheelite and wolframite; hydrothermal quartz veins, on the other hand, contain tourmaline, molibdenite, scheelite, wolframite (partly altered to scheelite) and cosalite. These minerals occur in association with tin mineralization (Stemprok, 1965; Schrocke, 1968; Baumann et al., 1974 and Yajima, 1979).

7. The abundance of hydrothermal quartz veins, hornfels and quartz-bearing greissen in the area under investigation, is an indication of the presence of SiO_2 -rich granite. This is also true for tin mineralizations found in other countries (Tischendorf, 1969).

8. The occurrence of stannite and stannite group minerals in the outer zones of tin deposits found in other countries (Ramdohr, 1975) and of cassiterite as well in deeper zones (Mulligan, 1975; Aubert, 1969; Burnol, 1974; Fov, 1969; Hosking, 1970; Mitchell, 1974 and Bromley, 1975), may also be true for Madenbelenitepe mineralization.

9. According to a classification made by Mulligan (1975) Madenbelenitepe tin mineralization belongs to «hydrothermal quartz-greissenD type.

ACKNOWLEDGEMENTS

The writers wish to express their gratitude to N. Pehlivan, N. Yüce, A. Kara and M. Yıldırım, associated with the KAWAP project for the accomplishment of the field work. Special acknowledgement is due N. Öztuğ and S. Alparslan for making micrbprobe analyses of stannite; and M. Güler, T. Akyüz and Ş. Taş for semi-quantitative optic spectrographic analyses of samples. The writers are also indebted to Dr. Orhan Özkoçak and Dr. M.Yıldız for giving valuable-assistance for the completion of this work.

Manuscript received Junt JO, 1980

Translated by: Filiz E. DİKMEN

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P L A T E S

PLATE - I

Fig. 1 - Magnification X 50.
Topaz in granite (between biotite crystals); biotite (with cleavage, gray to dark gray colored) containes rutile (black). Quartz and feldspar (light gray) and pyrite (black) in the matrix.

Fig. 2 - Magnification X 50.
Muscovite (with cleavage and as light-colored accumulations) and quartz (light-colored and without cleavage) in granite as a product of greisenization.

Fig. 3 - Magnification x 50, nicol +.
Sericite flakes (upper and lower right corners), quartz phenocrysts (light gray and white), muscovite (in the middle; with cleavage and light to dark gray), rutile crystals (black, in muscovite), small quartz crystals and sericite flakes in the matrix, developed in granite porphyry as a result of greisenization.

Fig. 4 - Magnification x 100.
Rutile needles and crystals (black) developed along the cleavage planes of muscovite which is the alteration product of biotite in granite porphyry, apatite (with high relief, upper left corner).

Fig. 5 - Magnification x 400, in oil, nicol +.
Pyrite (light gray), stannite (gray to dark gray, anisotropic, in pyrite). Arsenopyrite (idiomorphic, in stannite). Gangue and gaps (black).

Fig. 6 - Magnification x 600, in oil.
Stannite exsolutions (light gray) developed along crystallographic directions in sphalarite (gray). Gangue and gaps (black).

Fig. 7 - Magnification x 600, in oil, nicol +.
Stannite (light gray) inclusions and exsolutions in sphalarite (gray). Arsenopyrite (white and idiomorphic).

Fig. 8 - Magnification x 600, in oil.
Iso-stannite (gray) and hexastannite (light gray) formed from high temperature stannite, sphalarite and gangue (dark colored).

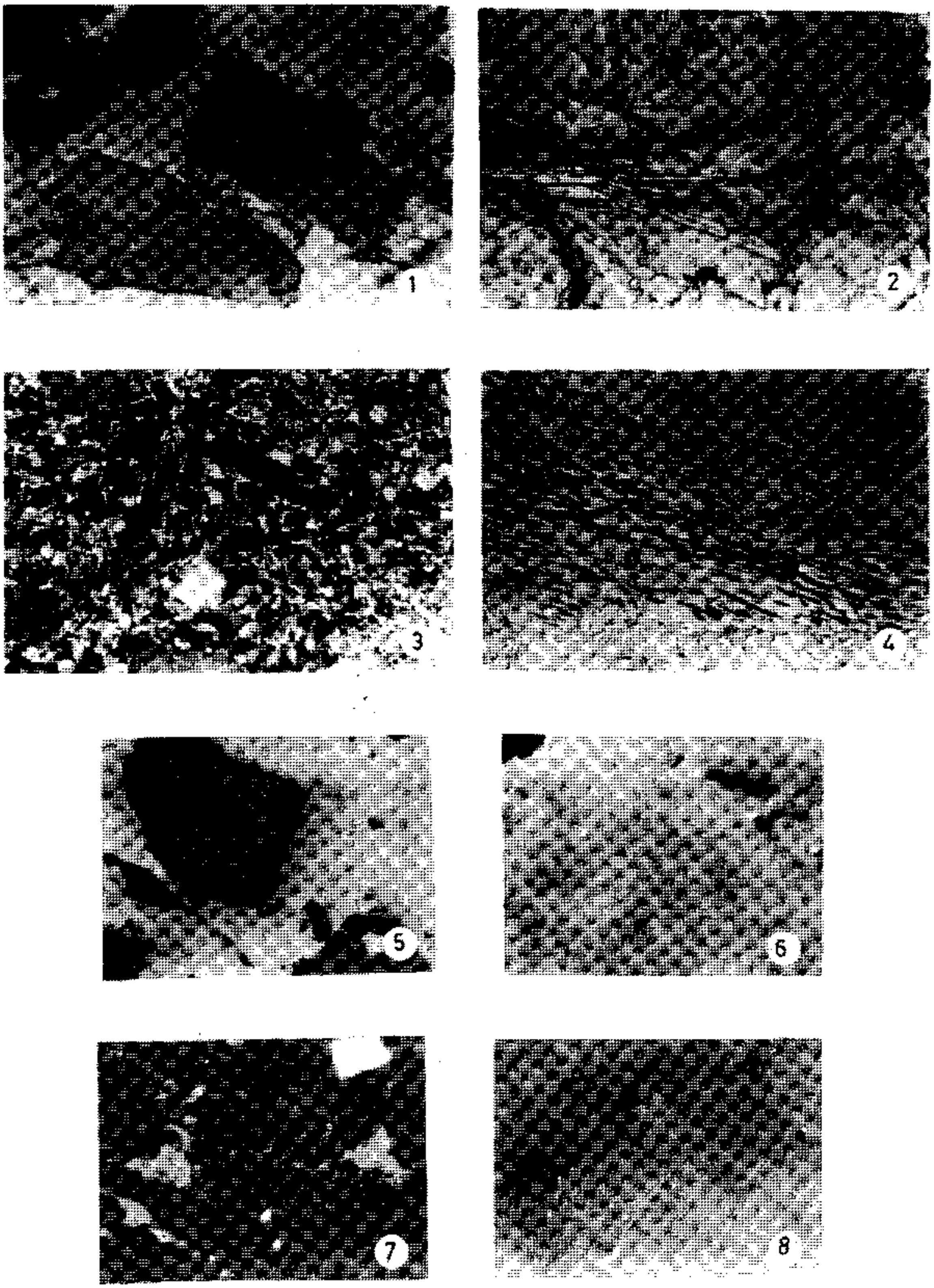
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PLATE - II

Fig. 1 - Magnification x 600.
Cassiterite (dark gray) formed along the fahlerz (lighter gray) veinlets intersecting stannite (light gray) in sphalarite. Arsenopyrite (white and idiomorphic), galenite (white) veinlets intersecting sphalarite with fahlerz. Quartz and gaps (black).

Fig. 2 - Magnification x 200.
Stannite (gray) between arsenopyrite (idiomorphic and white). Quartz (black).

Fig. 3 - Magnification x 400, in oil.
Fahlerz (gray) fills fissures between cataclastic pyrite (light gray), Gangue (black).

Fig. 4 - Magnification x 400, in oil.
Chalcopyrite (white) and stannite (light gray) exsolutions in sphalarite (gray).

Fig. 5 - Magnification x 400, in oil.
Bournonite (gray) forms myrmekitic texture with galenite (light gray). Arsenopyrite (idiomorphic and white), sphalarite (dark gray), gangue (black).

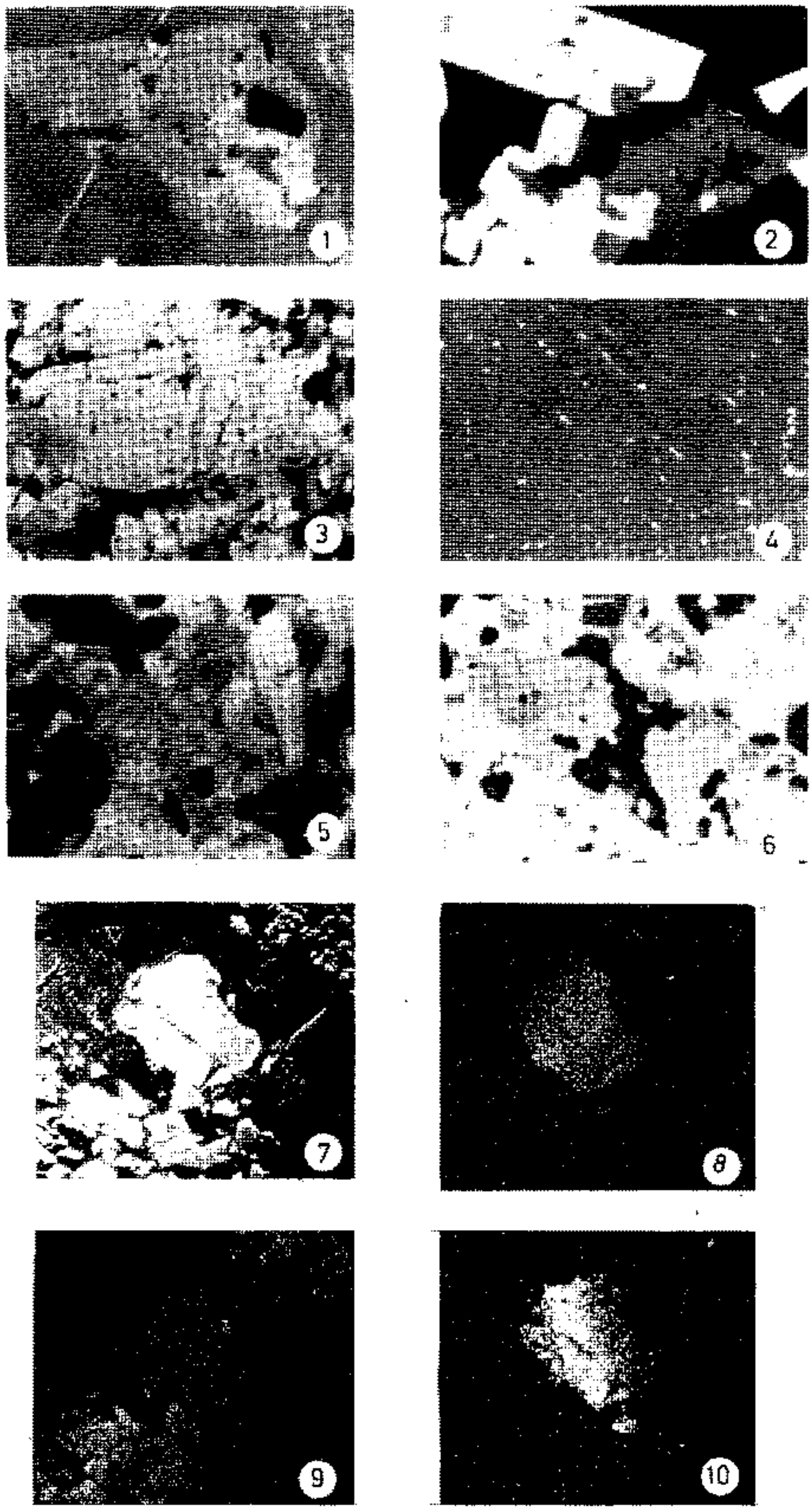
Fig. 6 - Magnification x 400, in oil, nicol +.
Bournonite (in the middle) contains parallel twinning laminae developed in different directions. Galenite (light gray) contains fahlerz (gray), sphalarite (dark grey), arsenopyrite (white) and pyrite (white) and bournonite as well. Quartz (black).

Fig. 7 - Magnification x 100.
Electron image of stannite (in the middle). Arsenopyrite in the matrix. Gangue (black to dark gray).

Fig. 8 - Magnification x 100.
Electron image of Cu K_a of Fig. 7.

Fig. 9 - Magnification x 100.
Electron image of Fe K_a of Fig. 7.

Fig. 10 - Magnification x 100.
Electron image of Sn K_a of Fig. 7.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