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OCCURRENCES OF Fe MINERALIZATION IN THE VICINITY OF TRSINO AND PEKLJANI, VINICA (EASTERN MACEDONIA)

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Abstract: The latest field and laboratory examinations of the Fe mineralization in the vicinity of Trsino and Pekljani offered a new understanding of the mineralization associated with the quartz-chlorite sericite schists and metamorphosed granites. The hosts to iron mineralization are hematite, specularite, magnetite and martite. Latest microscopic studies carried out, in part in electron microprobe, made possible a more complete understanding of the characteristics of the major ore minerals. These studies determined, for the first time, the composition of the major as well as some new minerals. Structural-textural features of ores were also studied in detail for the first time and made it possible to define the successive order of mineralization and the genetic type of ore mineralization. Macroscopic and microscopic studies of samples from Trsino and Pekljani distinguished striped and stockwork-vein-impregnated textures, the most common structures being those of replacement type (corrosive, pseudomorphic and metacrystalline).

Key words: ore occurrences; ore minerals; structures; textures; magnetite; hematite

INTRODUCTION

The iron ore occurrences at Trsino and Pekljani occupy the central parts of the Serbo-Macedonian massif. Spatially, they are located in the western slopes of Mount Golak some 10 km from Vinica.

The geological composition of the ore occurrences of Trsino and Pekljani and their vicinity have been studied by many researchers. The works of Rakićević et al. (1969, 1973), Hristov et al. (1969), Kovačević et al. (1973) during the creating of the sheets for Strumica, Štip, Kjustendil and Delčevo gave important data about the area. Detailed studies of the ore occurrences were carried out by Denkovski (1975) as part of the geological-geophysical investigations of iron. The most complex investigations on the metallogeny have been carried out by Spasovski (doctoral thesis).

GEOLOGICAL CHARACTERISTICS

The Trsino–Pekljani close vicinity is composed of Precambrian and Riphean–Cambrian metamorphic rocks, granitoid rocks and Upper Eocene and Neogene sediments (Fig. 1). A review of individual rock types and their geochronological succession will be presented later in the paper. Riphean–Cambrian rocks which are the most common rock types are the most important for localization of Fe mineralization.

Precambrian metamorphic rocks are the oldest members discovered. They are present as grain-porphyroid gneisses and micaschists.

The largest part of the *grain-porphyroid gneisses* are contingent to the Riphean–Cambrian rocks and their contact is tectonic, whereas the contact with micaschists is sharp (Fig. 1). Their texture differs from other gneisses because they are grain-like and the striped texture is less common. Their structure is similar to the Delčevo granitoids. They are quartz-feldspatic rocks in which quartz, potassium feldspars and plagioclases are important minerals and muscovite is less frequent. The grain size is variable so rocks sometimes grade into real augen gneisses resembling, also, to granitoid rocks.

Micaschists do not occur frequently and are discovered as a small stripe in the north-west part of the area (Fig. 1). They contain two-mica gneisses, amphibolites and amphibolitic schists as thin stripes and lenses with which they show certain transition. Their structure is lepidogranoblastic with relics of blastopsamitic and folding texture.

The mineral composition is fairly simple and consists of quartz, most commonly muscovite and biotite. Feldspar varies from 0 to 25 %. Garnets pointing to retrograde metamorphism with transformation into chlorite are the most common minor component parts.

In terms of iron mineralization the most important are the quartz-sericite-chlorite schists and epidote-amphibole-chlorite schists of Riphean-Cambrian age. These rocks occupy the middle parts of the area (Fig. 1). They occur as elongated stripes of NW–SE strike.

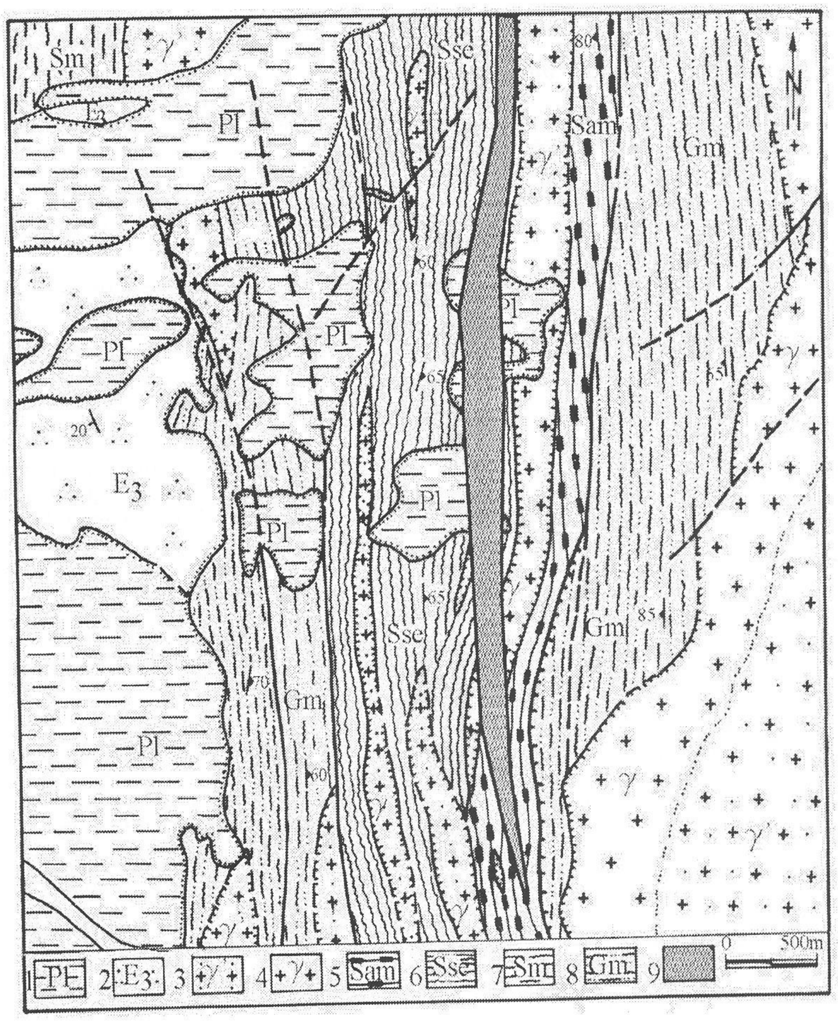

Fig. 1. Geological map of the Trsino–Pekljani ore occurrence (after Denkovski 1975, modified by Spasovski 1998). 1. Pliocene sediments, 2. Eocene sediments, 3. granites, 4. granite porphyry, 5. epidote-amphibole-chlorite schists, 6. quartz-chlorite-sericite schists, 7. micaschists, 8. gneisses, 9. area of Fe mineralization

Quartz-chlorite-sericite schists of NW–SE strike occupy the central parts of the terrain. They are hosted by grain porphyroid gneisses. Locally, plate-like quartz-sericite schists and quartz-chlorite schists can be found. Intruded vein-like leucocratic aplitoid granate porphyry can be seen in them as well. The relationship between epidote-chlorite-amphibolic schists and feldspatized chlorite-muscovite schists is gradual and they alternate facially. The rocks are characterized by phyllitic appearance, grey-greenish colour and perfect schistosity. They possess lepidoblastic, occasionally, non-metablastic to lepidoblastic structure. The most important components are sericite, quartz, chlorite, epidote, zoisite and limonite material.

Epidote-chlorite-amphibole schists are characterized by grey-greenish colour and phyllite appearance. Their structure is lepidoblastic to granoblastic and the texture is laminated to schistose. Major component parts consist of epidote, zoisite, hornblende, chlorite, seldom quartz and sericite. Feldspatization (albite) can be observed at the contacts with granodiorites. Magnetite, titanomagnetite, garnet, pyrite and limonite occur as minor components.

Two-mica porphyroblastic gneisses overthrust the schists in the eastern sector of the south-eastern parts of the terrain, whereas from the west the relationship to the leucocratic schistose granites and two-mica gneisses is tectonic.

Granitoid rocks are widespread in the eastern and southeastern parts of the terrain (Fig. 1). They are present as cataclysmized granite-porphyry, cataclysmized leucocratic granite-porphyry and granites. The rocks cross-cut Precambrian high grade metamorphic rocks and Riphean-Cambrian rocks. Paleogene and Neogene sediments transgressively overlie granitoid rocks.

The mineral composition is fairly simple and consists of quartz, potassium feldspar (microcline and orthoclase), plagioclases, seldom biotite and muscovite. The rocks are characterized by their alotriomorphic grain-like structure.

The most important among the granitoid rocks are meta-granite porphyries because of their association with poor magnetite-martite-hematite mineralization. It should be mentioned that some authors (Denkovski, 1975) affiliate the quartz feldspatic rocks that are associated with richer hematite-magnetite mineralization with this group as well.

This study included eight analyses on quartz-chlorite-sericite schists and meta-granite porphyries. The results are shown in Table 1.

The chemical analyses indicate that the rocks containing from 51.52 to 73.00 SiO_2 are placed into two groups. Analyses nos. 3, 5 and 8 are characterized by increased contents of SiO_2 , lower CaO and K_2O contents, as well as slightly higher Na_2O (2.16 to 4.52 %) content.

Table 1

Chemical composition of the metamorphic rocks from the Trsino and Peklajni occurrences (in %).

Components	1	2	3	4	5	6	7	8
SiO_2	56.72	51.52	70.26	67.74	70.05	66.73	57.18	73.00
TiO_2	1.43	1.54	0.54	0.57	0.46	0.33	1.61	0.26
Al_2O_3	16.53	17.07	16.26	17.90	16.80	18.70	15.72	15.45
Fe_2O_3	10.08	9.96	3.37	3.63	6.82	3.72	10.03	5.41
MnO	0.22	0.06	0.04	0.12	0.03	0.20	0.20	0.02
MgO	4.57	6.64	3.04	1.29	0.51	3.94	4.72	0.63
CaO	2.17	4.14	0.37	1.30	0.31	0.37	5.31	0.19
Na_2O	3.62	3.86	3.14	2.16	4.47	3.44	1.18	4.52
K_2O	0.56	0.99	1.41	2.65	0.27	0.52	0.61	0.06
P_2O_5	0.31	0.31	0.25	0.07	0.03	0.02	0.07	0.02
Loss mer.	3.07	3.22	1.22	1.58	0.30	1.21	3.07	0.29
Σ	99.28	99.31	99.90	99.01	100.05	99.28	99.70	99.85

Analyses nos. 1–4 are from the Trsino ore occurrence, nos. 5–8 are from the Pekljani ore occurrence. Total Fe is given as Fe_2O_3; X-ray fluorescence method. Analyst: E. Karaivanova.

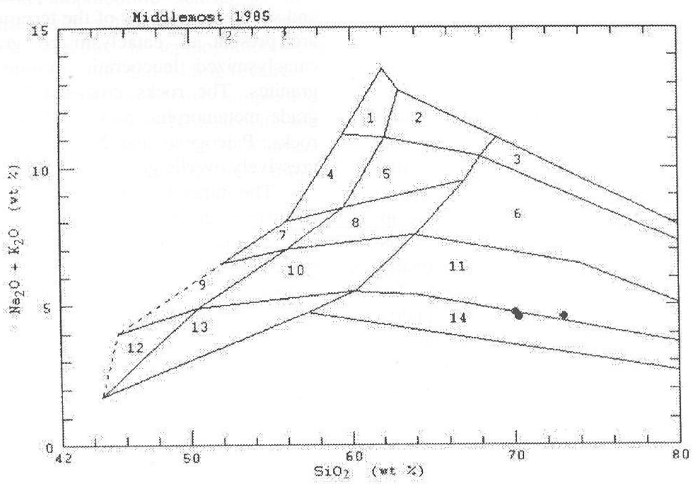

Fig. 2. Classification of granitoid rocks from the Trsino and Pekljani occurrences accordings to the Middlemost diagram (1985). 1. alkali feldspar syenites, 2. alkali feldspar quartz syenites, 3. alkali feldspar granites, 4. syenites, 5. quartz syenites, 6. granites, 7. monzonites, 8. quartz monzonites, 9. monzonite-diorites, 10. quartz monzonite-diorites, 11. granodiorites, 12. diorites and gabbros, 13. quartz diorites, 14. tonalites

The present study is an attempt to classify the granitoid rocks on the basis of a diagram for classification of plutonic rocks after Middlemost (1985).

The diagram (Fig. 2) illustrates that one analysis falls into the granodiorite field. One analysis falls into the boundary between granodiorites and tonalites, and one into the tonalite field. Such grouping in the bordering part between the two fields of the diagram is due to their similar characteristics or the samples studied are very close in terms of their chemical composition. It should be mentioned, however, that the number of analyses is rather small. Deeper and precise conclusions demand a large number of studies.

The remaining five analyses are characterized by their lower SiO_2 (51.52 to 73.00 %), increased CaO (of 0.31 to 5.31 %), low K_2O and conformable Na_2O contents. These rocks were classified as quartz-chlorite-sericite schists based on their chemical and mineralogical composition as well as structural and textural characteristics.

Paleogene and Neogene sediments were also found in the area under consideration.

GEOCHEMICAL CHARACTERISTICS OF QUARTZ-CHLORITE-SERICITE SCHISTS AND META-GRANITE PORPHYRIES

The geochemical characteristics of the rocks can be obtained, in some respect, from the contents and distribution of microelements in the rocks. Elements and admixtures important to the explanation of the geochemical characteristics of the rocks and Fe mineralization associated with them are those of Ti, Cr, Ni, Co, V, Mn, Sc, etc.

Samples were collected from the rocks and determination of elements as admixtures was made using X-ray fluorescence method in order to get a more complex and thorough understanding of the geochemical characteristics of quartz-chlorite-sericite schists and meta-granite-porphyries associated with ore formation. The results obtained are shown in Table 2.

Table 2 shows that the Fe elements (Ti, Cr, Ni, Co, Mn, V, etc.) occur in higher contents compared with their mean contents in the same rock types. The relationship between the Fe group of elements is probably due to Fe mineralization in the rocks.

Table 2

Contents of microelements in quartz-chlorite-sericite schists and meta-granite porphyries from the Trsino and Peklajni occurrences (in %)

Elements	1	2	3	4	5	6	7	8	9	10
Fe	7.05	6.96	2.36	2.54	4.77	2.60	7.01	3.78	4.8	1.83
Ti	0.86	0.92	0.32	0.34	0.27	0.20	0.96	0.16	0.38	0.17
Mg	2.75	4.00	1.83	0.78	0.40	2.37	2.85	0.40	1.50	0.33
Ca	1.55	2.56	0.26	0.93	0.22	0.26	3.79	0.13	2.00	1.12
Mn	0.17	0.05	0.03	0.09	0.02	0.15	0.15	0.01	0.08	0.04
V	0.021	0.023	0.009	0.020	0.003	0.006	0.027	0.006	0.013	0.004
Cr	0.003	0.003	<0.003	0.003	0.003	0.003	0.003	<0.003	0.009	0.001
Ni	0.003	0.002	0.001	0.001	0.005	0.004	0.002	0.002	0.007	–
Co	0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.004	0.002	–
Zn	0.009	0.005	0.003	0.008	0.002	0.004	0.005	0.005	0.008	0.004
Ga	0.002	0.002	<0.002	0.003	0.002	0.002	0.002	<0.002	0.002	0.002
Ba	0.009	0.015	0.044	0.067	0.009	0.012	0.009	0.005	0.058	0.084
Rb (ppm)	15	20	50	77	<10	<10	43	15	140	210
Y (ppm)	35	31	12	19	51	243	30	8	26	40
Sr (ppm)	333	623	84	146	78	89	289	71	300	110
Zr (ppm)	246	296	206	212	280	234	151	211	160	180

Note: Analyses nos. 1, 2, 4, 6 and 7 are quartz-chlorite-sericite schists. Analyses 3, 5 and 8 are meta-granite porphyries. Analyses 9 and 10 are mean contents of elements studied in rocks after Beus (1975).

GENERAL CHARACTERISTICS OF MINERALIZATION

The Fe magnetite hematite mineralization in the vicinity of Trsino and Peklajni occurs within rocks of Riphean-Cambrian age as an ore series of N–S strike with a slope to the east. The ore series was explored in an 3.200 m long and 75 to 200 m thick area that occupies some 0.5 km^2.

Quartz-feldspar, chlorite-sericite schists and metasandstones were distinguished in the series in addition to the mineralized and cataclysmized granite porphyries present. The series of quartz-feldspar, chlorite-sericite schists and metasandstones is a host to a large volume of hematite and poor magnetite-hematite mineralization, whereas the cataclysmized metagranite porphyry is a host to poor magnetite-martite-hematite mineralization.

Four mineralized layers (horizons) are distinguished in the ore-bearing series. It was also discovered that there is continuous surface and deep-seated dissemination of mineralized horizons. The horizons are represented by iron quartz and feldspar stripes. The ore stripes are divided by unmineralized quartz-feldspar layers and quartz-feldspar-chlorite schists. The ore stripes contain numerous interbeds of hematite, magnetite and martite, whose thickness ranges from 0.1 mm to 2 cm in size, whereas horizons are up to 5 meters thick. Iron mineralization occurs as hematite-specularite, idiomorphic magnetite and martite crystals. Other minerals are of mineralogical importance representing only component parts of the mineralogical paragenesis in these occurrences. The cataclysmized metagranite porphyry also contains poor magnetite-hematite mineralization. The Fe content in mineral layers ranges from 8.13 to 35.17%.

Based on the mineralogical composition, lithological environment and structural-textural characteristics inference can be drawn that the Trsino and Pekljani occurrences are of metamorphogenic origin except for the mineralization within the cataclysmized granite porphyry.

REVIEW OF THE MORE IMPORTANT MINERALS

The latest ore microscopic studies and microprobe investigations (carried out by the present authors) offers new information about the mineral composition and unravels some features related to the chemical composition and occurrence mode of more important ore minerals. It was determined that these Fe occurrences are composed of hematite, magnetite, martite, mushketovite, ilmenite, limonite, lepidocrocite, rutile, pyrite, pyrrhotine, heazlewoodite, magnesio-alumoschrome magnetite, etc. A look at their occurrence mode shows that most of the mineral kinds occur as minerals. The most common minerals are iron oxides (hematite, magnetite, martite, mushketovite, etc.) of which hematite and magnetite are the most abundant.

Hematite is the most abundant ore mineral often occurring as specularite. It is often intergrown with magnetite pointing to their common origin. Hematite occurs as very fine needle-like and rod-like shapes impregnated in the quartz mass. It often develops vein, stockwork and pseudoimpregnated structural shapes with magnetite. Locally, it also occurs as coarse-grained and plate-like shapes. It often develops striped mineralization in which dark hematite quartz stripes and light quartz rutile stripes alternate. In individual parts it is affected by oxidation processes that yielded secondary minerals such as limonite and lepidocrocite.

Magnetite occurs as coarse and idiomorphic metacrystals metasomatically developed along cracks. Octahedrons are the most common shape of metacrystals. Idiomorphic magnetite crystals occur as relics within the hematite aggregates that were affected by replacement processes.

These processes are developed along cleavage directions or the periphery of the idiomorphic magnetite metacrystals. Some magnetite crystals are completely metasomatically replaced by martite. This magnetite is intimately intergrown with hematite indicating to their common origin. Specularite which is microfolded and forms microboudinage can be observed round coarse octahedron magnetites.

In addition to coarse-grained magnetite, magnetite as very fine, fresh and isolated grains, probably representing a younger phase, can also be observed.

One of the important characteristics of the magnetite and hematite from Trsino and Pekljani is that they are fairly pure with regard to their chemistry. They also contain small amounts of Mn and Cr as admixtures. The chemical compositions of magnetite and hematite are shown in Table 3.

The table shows that the compositions of hematite and magnetite in these occurrences are close to the theoretical ones (Чвилева, 1988).

Table 3

Quantitative X-ray microanalyses of magnetite and hematite from the Trsino and Pekljani (in %)

Elements	1	2	3	4	5	6
Fe	74.09	73.6	70.95	74.1	73.9	69.6
Mn	0.1	0	0.18	0.22	0.19	0.15
Mg	0	0	0	0	0	0
Al	0	0	0	0	0	0
Cr	0.08	0.16	0.13	0.1	0.12	0.1
Ti	0	0	0	0.07	0	0
Ca	0	0	0	0	0	0
Si	0	0	0.06	0	0	0
O	24.29	24.87	28.22	24.1	25.2	29.1
Σ	98.56	98.63	99.54	98.59'	99.41	98.95

Analyses nos. 1, 2, 4 and 5 are magnetite, analysis 3 is hematite, analysis 6 is hematite (martite) performing pseudomorphosis of magnetite

Specularite is a common mineral occurring as bundle-like, clearly elongated crystals of 0.1–0.2 mm in size. Locally, it also occurs as fine-grained mineral with complete magnetite replacement by martite. It often occurs as microboudinage round octahedron magnetite.

Martite often occurs as pseudomorphosis along coarse-grained octahedron magnetite crystals particularly along cleavage direction or along periphery of magnetite crystals. Complete pseudomorphosis or replacement of magnetite by martite is observed in some magnetite grains.

Limonite and lepidocrocite are often found as secondary minerals in these occurrences. The two minerals developed due to magnetite, hematite and specularite oxidation.

Ilmenite and rutile occur as titanium minerals. They seldom occur and when found they are present as fine irregular grains in purely quartz feldspatic stripes.

Chalcopyrite and pyrite are the most common sulphide minerals. They are not abundant since they occur in several fine and irregular grains. Chalcopyrite and pyrite are important supplements to the paragenesis of these ore occurrences.

TEXTURES AND STRUCTURES OF ORES

Macroscopic and microscopic studies distinguished several morphological and morphogenetic types of structures and textures.

The striped texture is characterized by the alternation of dark hematite quartz and light quartz-rutile stripes (Fig. 3). Dark stripes are composed of grey flaky hematite (75%) and fine-grained quartz (25%). The light ones are composed of 95% quartz and 5% rutile. Magnetite in light stripes is fine-grained, very fresh and isolated.

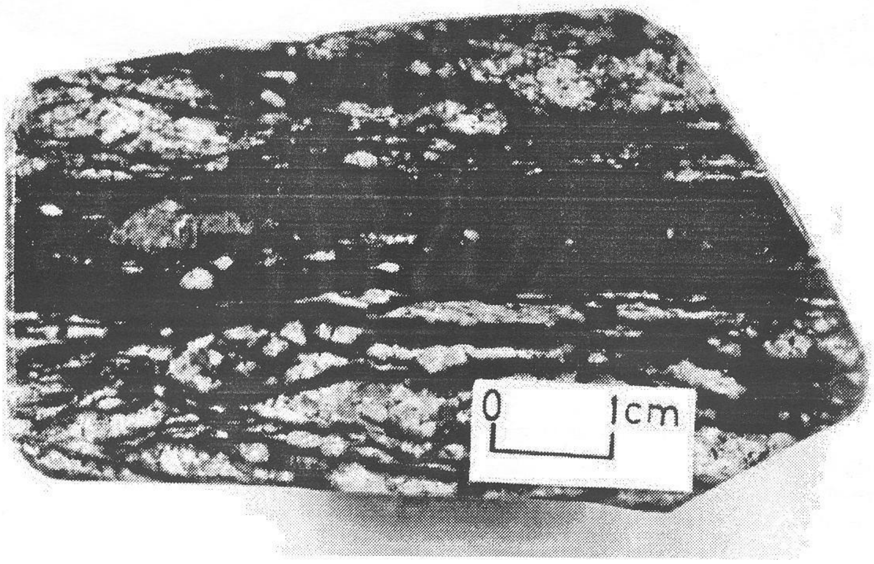

Fig. 3. Striped hematite-magnetite mineralization in quartz-chlorite-sericite schists

Textures and structures formed during the process of filling of vugs and cracks in rocks and ores

Mineral aggregates fill up various vugs, cracks and fissures in rocks formed later by tectonic mineralization processes.

The stockwork lode-like texture is characterized by stringers and lodes of ore minerals along cracks cross-cutting the rock (Fig. 4). Stringers and lodes are of different orientations and form an intersecting texture. The stringers and lodes are much smaller in comparison with the rocks and are characterized by their sharp boundaries. Mineralization is present as magnetite and hematite occurring in meta-granite porphyries.

Mineral aggregates are grained with common occurrences of corrosive and metagrained structures.

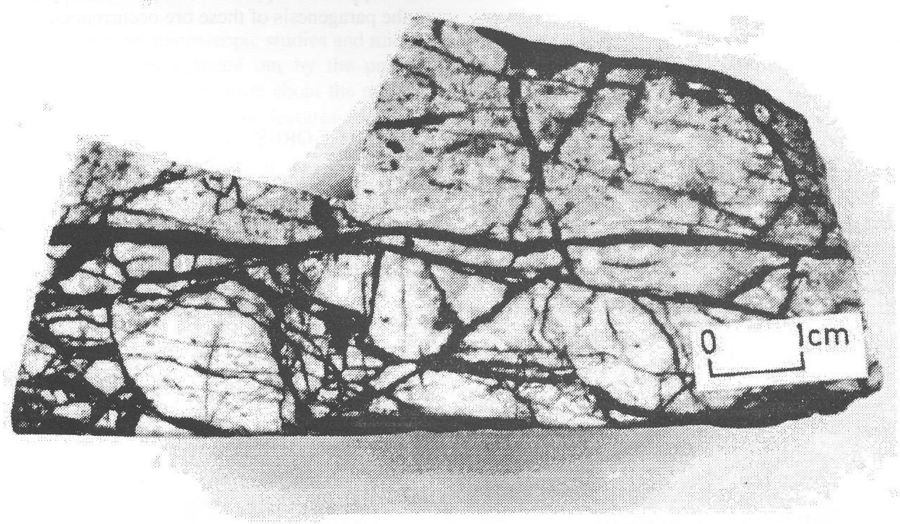

Fig. 4. Stockwork-lode type of magnetite and hematite mineralization in meta-granite porphyry

Textures and structures developed during the replacement process

Three replacement types, developed to a various degree, are determined in the Trsino and Pekljani ore occurrences.

Corrosive replacement is observed along fine textural-structural orientation in magnetites (cleavage, sutures of twinning and microcataclases) by hematite (martite) (Fig. 5b). During this process narrow reaction rims and martite stringers developed round magnetite grains and aggregates. The rims are bent, circular and rather jagged. The newly developed martite replaces the magnetite groundmass developing lodes or lode-net shapes.

During the replacement process corrosive and elongated striped textures are formed. Morphological types of structures are metagrained, needle-like corrosive and relic.

Pseudomorphic replacement makes possible the development of a new mineral or mineral aggregate which inherits the shape and the composition of the mineral replaced or the aggregate mineral. Sometimes it is hard to distinguish between corrosive and pseudomorphic replacement. Pseudomorphic replacement sometimes leads to a complete loss of primary structure and texture and the newly formed products inherit the textural and structural features of the replaced earlier mineral. An example of this is magnetite replacement by martite which takes place in the periphery parts of magnetite grains (Fig. 5c). The boundaries between magnetite and newly developed martite are usually fairly bent and jagged.

Metacrystalline replacement is characterized by minerals that develop their own shape forming metacrystals or metagrains of idiomorphic characteristics. The possibility for replacement is characteristic of the minerals of high crystallizing ability to grow in solid medium (magnetite and quartz). Metacrystals of quartz have been observed in development zones along cracks. Metacrystals and metagrains exhibit equal growth in all directions. They have a clear and pronounced crystal shape and clear boundaries with surrounding minerals (Fig. 5a).

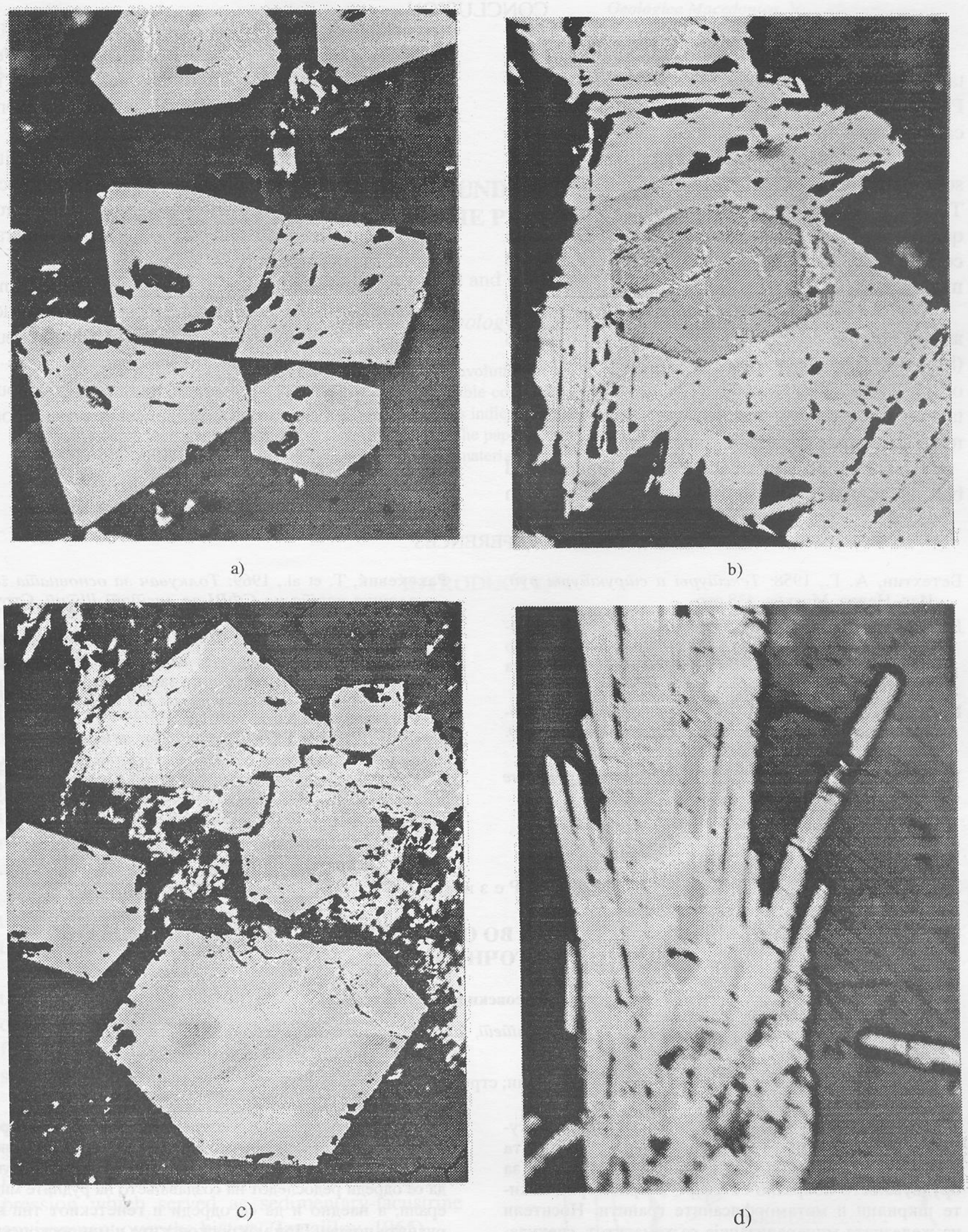

Fig. 5. Some more characteristic types of structures from the Trsino and Peklajni occurrences.
a) Idiomorphic metagrained magnetite structure in quartz groundmass. **b)** Corrosive magnetite structure along hematite. Needle-like development of hematite (white) along cleavage strikes of idiomorphic magnetite (grey) and coarse specularite aggregate (grey-white). **c)** Structure of pseudomorphic replacement. Idiomorphic crystals of magnetie (grey) pseudomorphic replacement by martite (white) and irregular hematite grains (grey-white). **d)** Relic structure. Coarse specularite aggregate (white) with relics of magnetite (grey).

CONCLUSION

Based on earlier information and data obtained during the investigations in the Trsino and Pekljani ore occurrences the following conclusions can be drawn:

– A hematite-magnetite mineralization is present in an area of 0.5 km^2 in size in the vicinity of Trsino and Pekljani. The mineralization is related to quartz-feldspar-chlorite schists of Riphean-Cambrian complex. Poor mineralization related to cataclized meta-granite porphyry is also found.

– Hematite-magnetite mineralization occurs as an ore-bearing series with four mineralized layers (horizons). The ore-bearing series is found in all parts of the terrain. The mineralized horizons exhibit certain continuation in terms of length, slope, thickness, mineral composition and Fe content.

– The south part of the Pekljani mineralized belt is subsided and intruded by younger vein rocks – granite porphyry. It is poorer in Fe, whereas the northern part of the belt (Trsino) is characterized by four mineralized layers – horizons with Fe contents ranging from 8.13 to 35.17 % Fe.

– Hematite, specularite, magnetite and martite are hosts to iron mineralization. Other minerals such as limonite, heaslewoodite, greichite, alumochromium magnetite, pyrite and pyrrhotine are of mineralogical importance only.

The most common textures are striped and stockwork-vein like, whereas the most common structures are of replacement (corrosive pseudomorphous and metacrystalline) type.

– Ore occurrences are of metamorphogenous origin, except for the mineralization in granite porphyry.

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Р е з и м е

ПОЈАВИ НА Fe-МИНЕРАЛИЗАЦИЈА ВО ОКОЛИНАТА НА ТРСИНО И ПЕКЉАНИ, ВИНИЦА (ИСТОЧНА МАКЕДОНИЈА)

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Клучни зборови: рудни појави; рудни минерали; структури; текстури; магнетит; хематит

Со најновите теренски и лабораториски испитувања на појавите на Fe-минерализација во околината на Трсино и Пекљани се добиени нови сознанија за орудувањето поврзано со кварц-хлорит-серицитските шкрилци и метаморфисаните гранити. Носители на железната минерализација се хематитот, спекуларитот, магнетитот и мартитот. Најновите лабораториски испитувања, во прв ред рудномикроскопски, а делумно и испитувања со електронска микросонда, овозможија покомплетно познавање на особините на главните рудни минерали. Со овие испитувања за првпат е одреден составот на главните рудни минерали, а исто така е утврден хемискиот состав на некои нови минерали. За првпат посистематски се проучувани структурно-текстурните карактеристики на рудите, што овозможува да се одреди редоследот на создавањето на рудните минерали, а наедно и да се одреди и генетскиот тип на рудните појави. При макроскопските и микроскопските испитувања на примероци од Трсино и Пекљани се издвоени лентести и штокверкно-жиличесто-импрегнациони текстури, додека од структурите најзастапени се структурите на заменување (корозиони, псевдоморфни и метакристалести).