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Graphite Deposits from Mt. Psunj in Slavonia (Eastern Croatia)

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Key words: Graphite, Graphite-bearing schists, Palaeozoic, Mt. Psunj

Abstract

In the area of Mt. Psunj graphite occurrences and mineral deposits are found in greenschist facies metamorphic rocks. The graphite occurrences and mineral deposits originated by the regional metamorphism of coal. Graphite belongs to anthracite and graphite d_2, respectively, as determined by X-ray and thermal analyses.

1. INTRODUCTION

Mineral deposits and occurrences of graphites and graphite bearing schists are found in Croatia within the metamorphic complex of the Slavonian Mountains Psunj and Papuk. The graphite deposits were mined in these mountains during the period from 1947 to 1971. In the area of Mt. Psunj, the Brusnik, Sivornica and Brezovo Polje graphite deposits were mined, and in the area of the southern Papuk, mining also occurred within the Kaptol deposits. All these mines gave a total annual production of about 1,000-1,500 tons with the maximum of 17,780 tons in 1961. The graphite was used in metallurgy for steel production.

Detailed exploration was focused on the area of Mt. Psunj where three separate graphite-bearing zones are developed.

The area of Brezovo Polje and Sivornica was mapped in detail and the boundaries of graphite-bearing zones were indicated by geophysical exploration. The types of graphite and genetic mineralization were determined from laboratory data.

2. DATA ON PREVIOUS RESEARCH

Despite voluminous data obtained by numerous detailed geological investigations and exploration of the Slavonian graphites, only a few scientific papers have been published.

KIŠPATIĆ (1892) was the first to give information on the occurrences of graphites, black graphite-bearing phyllites and graphite-bearing chloritoid schists from the area of Brusnik and Rogolji in Mt. Psunj. The graphite samples, collected by Kišpatić in the area of Hambarište and Rogolji in the western part of Psunj, were analyzed by KOCH (1899) who determined a C content of 55%.

Organizing geological exploration in all Slavonian graphite deposits between 1955-1961, Šinkovec produced numerous surface and underground data on structural, tectonical and mining-geological features of the graphite ore bodies and associated metamorphic rocks, as well as on the quality and reserves of the graphites. Summarizing and compiling all available data obtained through the exploration of graphite, JURKOVIĆ (1962) studied the genesis and age of the graphite. According to his opinion, the Slavonian graphite deposits originated by regional metamorphism during the Variscan orogeny; original Silurian pelitic and psammitic sedimentary rocks were metamorphosed into low-grade parametamorphic rocks. Original bituminous or coal-bearing pelites produced during this metamorphism graphite occurrences associated with graphite-bearing schists. Tectogenesis played a very important role during the graphite generation, i.e. in the enrichment of graphitic substance.

The exploration activity stopped after 1962, but the exploitation carried on during the next ten years. ŠINKOVEC (1983) gave a summarised presentation of the deposit types of graphites and graphite-bearing schists from the area of Croatia, Bosnia and Serbia.

In the geological interpretation of the area around Mt. Psunj which was based on the geological mapping (scale 1:100.000) JAMIČIĆ et al. (1989) separated the graphite deposits into two chronostratigraphic groups. "Primary" graphite occurrences related to graphite-bearing schists are found in the series of chlorite-sericite schists of Precambrian age from the area of the northwestern slopes of Mt. Psunj and smaller occurrences in gneisses from the western parts of Mt. Psunj. The second type of deposit is Early Carboniferous in age; the graphite is located in metagraywackes and originated by weathering and redeposition of older graphite deposits.

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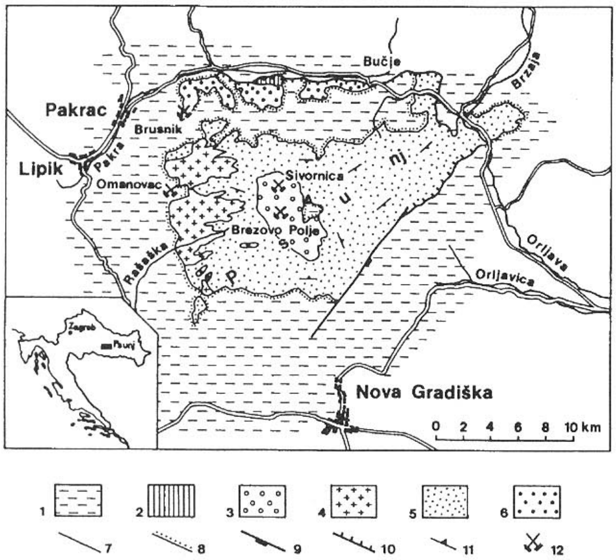

Fig. 1. Generalized geological map of Mt. Psunj based on data of ŠPARICA et al. (1984), JAMIČIĆ (1988) and PAMIĆ & LANPHERE (1991). 1 - Tertiary and Quaternary sediments of the Pannonian Basin; 2 - Mesozoic sediments; 3 - Hercynian weakly metamorphosed complex with metabasic igneous rocks and graphite deposits (Brezovo polje-Sivornica zone); 4 - Granites; 5 - Metamorphosed complex, mostly amphibolite facies; 6 - Metamorphosed complex, mostly greenschist facies (Brusnik zone); 7 - Contact line; 8 -Unconformity; 9 - Normal fault, subsided block; 10 - Reverse fault; 11 - Foliation; 12 - Abandoned graphite mines.

3. GEOLOGICAL FEATURES OF THE GRAPHITE-BEARING FORMATIONS FROM MT. PSUNJ

In the area of Mt. Psunj, three separate zones of graphite-bearing formations can be distinguished (Fig. 1):

1) The Brusnik zone or the Northern zone;
2) The Brezovo Polje zone or the Central zone, and
3) The Rašaška-Omanovac zone or the Western zone.

1) The Northern zone stretching from Brusnik in the west to Bučje in the east, can be traced along strike for about 10 km. Here, graphite formations occur within the series of metamorphic rocks represented predominantly by chlorite-sericite schists, quartz metasandstones, and quartzites grading into graphite-bearing schists. The width of the graphite-bearing series varies from 70 to 120 m. The outcrops of graphite-bearing schists and metasandstones are found in deeply eroded valleys of the Brusnica, Tisovac, Rakovac and other rivers. The neighbouring slopes, ridges and hills of the northern Psunj close to the Pakra River are covered by Miocene (Helvetian and Tortonian) sedimentary rocks which for the most part mask the graphite-bearing series.

The largest graphite body of the Northern zone crops out in Brusnik. It has a lensoid shape, generally dipping towards the west at angles of between 45-70°. It can be traced allong strike for about 40-70 m and along the depth of occurrence for about 100 m (Fig. 2).

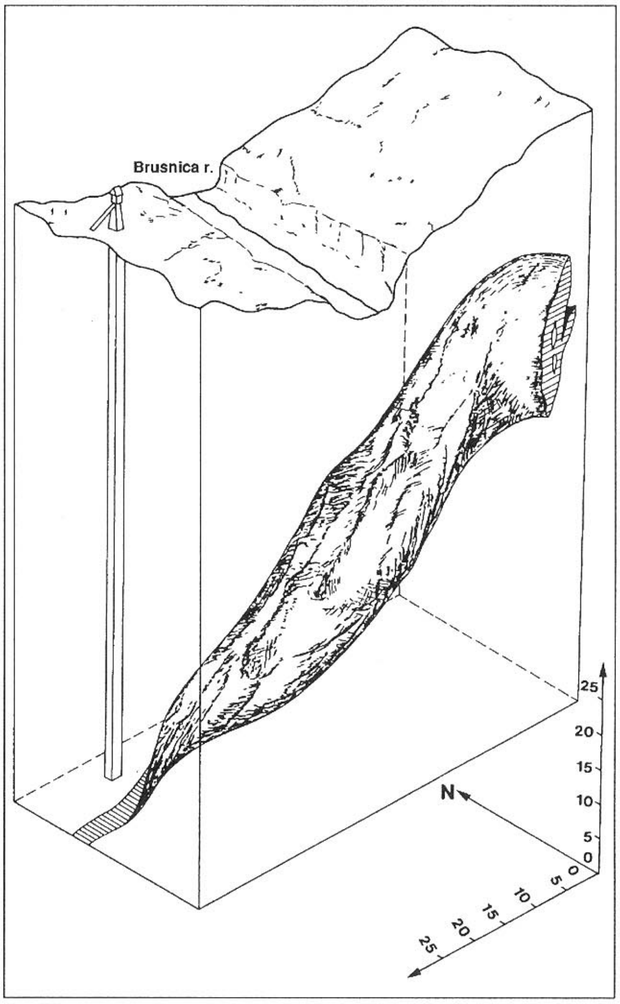

Fig. 2. Block-diagram of the large ore body in the Brusnik graphite deposit (scale in m).

The largest body was almost entirely mined and it gave about 10,000 tons of graphites which contained 35% to 88% C, the average content being 55%.

This graphite bed and numerous smaller lenses are found in the series of graphite-bearing schists which are more than 20 m thick and contain on average 10 to 24% C. On the basis of surficial and underground structural measurements, graphite-bearing schists and graphite-bearing metasandstones, generally, have an east-west strike which is conformable with the strike of the whole Northern graphite zone of Mt. Psunj. The same can be observed in the area of Rakovac, east of Brusnik, where, generally, the graphite series shows east-west to northwest-southeast trends. In the same area, several graphite occurrences were found during earlier exploration; a bed 60 cm thick contained 31.8% C. Recently detected outcrops of graphite-bearing schists in the valleys of the Tisovac and Rakovac rivers suggest that due to tectonics, the extension of the main Brusnik graphite-bearing zone might be located a little further to the south within the Psunj Massif, i.e. in the area where no exploration activity for graphite has occurred.

The development of the large graphite ore body which was exploited by the underground works of the

Brusnik Mine represents evidence that graphite-bearing formations of the Northern zone can have a significant depth of occurrence.

According to our exploration data, the fragmentarily preserved Norhern graphite-bearing zone represents a whole series in terms of formations. Chronostratigraphically, according to JAMIČIĆ et al. (1989), most of the metamorphic rocks from the northern slopes of Mt. Psunj belongs to the Precambrian. PAMIĆ & LANPHERE (1991) included these rocks into the progressive metamorphic complex, mostly of greenschist facies and, on the basis of radiometric data, they concluded that the main phase of metamorphism took place during the Variscan orogeny.

2) The Central graphite-bearing zone stretches in a north-south direction in the highest parts of Mt. Psunj (Brezovo Polje). The zone is in some places intruded by metadiabases and covered by Miocene clastic sedimentary tocks. The graphite-bearing zone, which is about 3 km wide, can be traced along strike for about 7 km. Graphite-bearing schists and metasandstones with graphite beds and lenses are associated with greenschist facies rocks. The northern part of the zone, where the Sivornica and Brezovo Polje Mines were located, was strongly enriched in graphite. These formations were ascribed to the Devonian-Carboniferous by JAMIČIĆ et al. (1989). PAMIĆ & LANPHERE (1991) included these rocks in the weakly metamorphosed complex with metabasic igneous rocks which also belong to the Variscan orogeny.

Because the Northern zone of Mt. Psunj represents an area of higher potential, it was explored in detail. The geological map (Fig. 3) presents the northern parts of the Central graphite-bearing zone of Mt. Psunj in the area of Brezovo Polje and Sivornica.

The oldest amphibolite facies metamorphic rocks of Mt. Psunj are represented by gneisses, mica schists and amphibolite schists. On the basis of structural and textural features and mineral composition, several varieties of gneiss can be distinguished. They are interlayered with amphibolites and amphibolite schists. All these metamorphic rocks are in tectonic contact with the graphite-bearing series which consists mostly of metagraywackes and chloritoid schists. Within these, the zones with graphite-bearing schists and graphite-bearing quartz metasandstones occur, with beds, ore bodies and lenses of graphites. On the basis of prospecting in the field, geophysical prospect data and underground geological maps of the abandoned mines, the graphite-bearing zones were distinguished.

In the area of Sivornica and Brezovo Polje, greenschists and metadiabases, which occur within the weakly metamorphosed complex, are very common. The youngest formations of the research area are represented by Miocene (Helvetian) sedimentary rocks, mostly clayey silt and sandstones. These rocks which represent an erosional relic, originally covered the whole area of Mt. Psunj.

Most of the contact lines between different lithologies are characterized by faults. Four main fault systems can be identified in the region of the ore field. The faults with the Dinaridic trends are hardly noticable. The north-south trending faults and the perpendicular ones characterise the rocks of the Variscan, weakly metamorphosed complex as distinguished from the rocks of the surrounding progressively metamorphosed complex. Southwest-northeast directed faults are the youngest, and together with those above give rise to a "parquet" structure. Ore bodies and, generally, the graphite-bearing zones stretch in west-east and west-

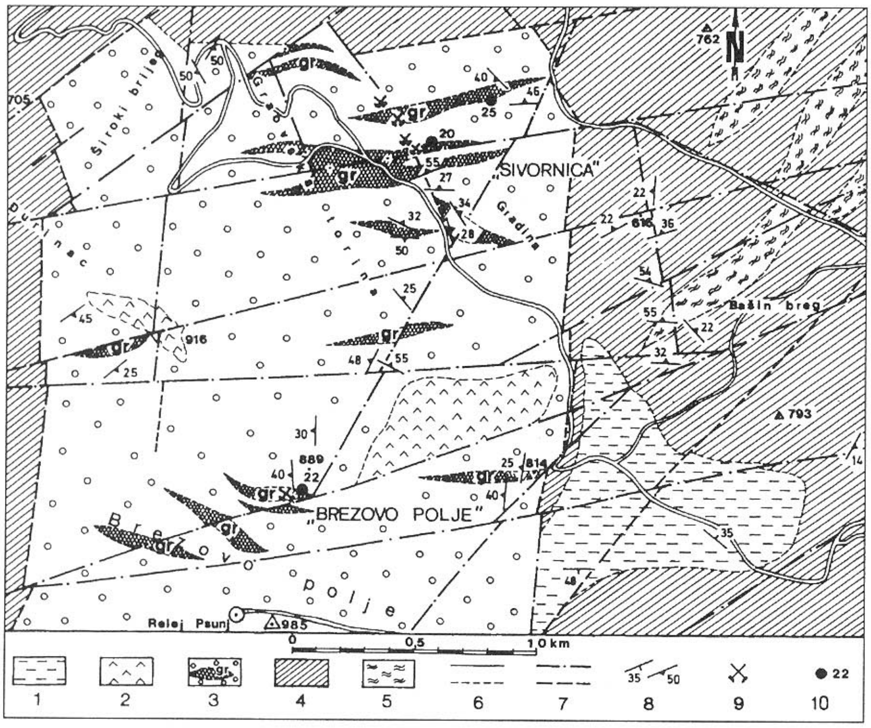

Fig. 3. Geological map of the area Brezovo polje - Sivornica. 1 - Helvetian beds: siltstones and sandstones; 2 - Metadiabases; 3 - Weakly metamorphozed complex with the zones of (gr) graphite bearing schists and graphites; 4 - Metamorphosed complex, mostly gneises; 5 - Amphibolites and amphibolite schists; 6 - Normal contact line and inferred contact line; 7 - Fault identified by photogeology and inferred fault; 8 - Dip of beds and foliations; 9 - Abandoned graphite mines; 10 - Sample locations.

southwest-eastnortheast directions which correspond to the directions of younger tectonic strikes.

Graphite ore bodies are of much smaller dimensions in the area of Brezovo Polje-Sivornica than in the area of Brusnik. The former are represented by smaller lenses and lenticular beds as well as by irregular blocks originating from the tectonic crushing of larger ore bodies (Fig. 4).

The average carbon content in the ore from Brezovo Polje was approximately the same as in the Brusnik ore and it varied from 50% to 55% C. The Sivornica graphite body had in some places an increased content higher than 60% C with a maximum of 87% C; the average content was 56.22% C. The associated graphite-bearing schists are represented by numerous varieties, grayish to black in colour with distinct foliation and different layering. The carbon content in the Sivornica graphite-bearing schists varies from 0.5% to 24.9% and the average is 8.45%.

The known graphite occurrences from the area of Sivornica and Brezovo Polje have the form of bedded, elongated and wedging lenses. This area is well covered and for that reason it is very probable that there are more graphite bodies which could not be registered on the presented map.

3) The Western graphite zone occurs in the form of a narrow north-south trending belt. The zone is located along the contact between gneisses and amphibolites with granites of the progressive metamorphic complex in the east and Miocene sedimentary rocks in the west. The potential of this graphite zone, which can be traced for about 4 km from Rašaška to Omanovac, geologically is not quite clear, particularly towards the west where the Western graphite zone is covered by Helvetian and Tortonian sedimentary rocks.

In the area of Rašaška, in the southern part of the Western zone, black graphite-bearing metasandstones are found. The graphite-bearing schists grade towards the north into quartz metasandstones and yellowish slates. Graphite-bearing thinner or thicker interlayers occur either in the sandstones or the yellowish slates. In the area of Omanovac, a graphite bed about 25 cm thick with a C content of 33.58% was detected in 1956 by underground exploration-exploitation works. In the area of Rašaška, an analyzed graphite sample from a small occurrence gave a 47.6% C content. In the area of Hambarište (KOCH, 1899) a graphite sample from the same zone contained 55% C.

Graphite type	d_{002}	ÅI/H (on 1/2 I)
Graphite with ordered structure	3.35-3.36	30
Graphite d_1	3.35-3.36	3 - 15
Graphite d_{1A}	3.37-3.44	3 - 15
Graphite d_2	3.45-3.55	0.5 - 1
Graphite d_3	3.50-3.75	0.5

Table 1. Graphite classification scheme (LANDIS, 1971).

JAMIČIĆ et al. (1987) are of the opinion that the graphite-bearing formations from the western part of Mt. Psunj are Precambrian in age, whereas JURKOVIĆ (1962) ascribed a Silurian age to all Slavonian graphites.

4. THE PRESENTATION OF ANALYTICAL RESULTS

A coal-graphite substance named graphite, graphitoid, graphitite, graphite d, shungite, subgraphite and meta-anthracite occurs in many metamorphic rocks of different ages and of different degrees of metamorphism. The quantity of the coal-graphite substance of these rocks amounts to only a few percent. Only exceptionally do the rocks contain a few tens of percent of carbon and become graphite ores.

A continuous transition from coal to graphite with a completely ordered structure as proved by X-ray and thermal data has been described in the literature.

FRENCH (1964) studied the coal substance in the rocks affected by progressive contact metamorphism and found out gradational changes in the degree of crystallinity of the coal-organic substance from amorphous in unmetamorphosed rocks to crystalline graphite in rocks close to contact with a gabbro intrusion. On the basis of the position and width of the pick 002 on diffractograms, he separated four crystallinity degrees for the organic substance: (1) amorphous organic substance, (2) asphaltic coal substance with very wide d_{002}=3.50 Å, (3) graphite d with diffusive d_{002}=3.43 Å, and (4) graphite with ordered structure with a sharp d_{002}=3.36 Å.

LANDIS (1971) studied the coal-graphite substance in some rocks from New Zealand which were affected by progressive regional metamorphism. He came to a similar conclusion as illustrated by his graphite classification presented in Table 1. The Landis classification is mostly used for the determination of graphite types and it will be also used for the classification of the Slavonian graphites.

Similar results have been obtained by FIRSOVA et al. (1986) who studied metamorphic rocks from the eastern part of the Baltic Shield, and PESQUERA & VALESCO (1988) who studied Devonian-Carboniferous rocks from the Cinco Vilas Massif in Spain which were affected by regional metamorphism.

Our samples of graphite ores and graphite-bearing schists examined by X-ray and thermal analyses were collected from the Brusnik, Vodostaj and Brezovo Polje Mines in Mt. Psunj. One sample of the graphite ore was taken from the Brezovo Polje and Brusnik deposits and the samples of graphite-bearing schists from the Brezovo Polje and Vodostaj Mines. A pebble of the graphite ore found in the southwestern parts of Mt. Papuk, north of Brusnik, was also analyzed. A Carboniferous anthracite from Pittstone, Pennsylvania was also analysed for the purpose of correlation (Table 2).

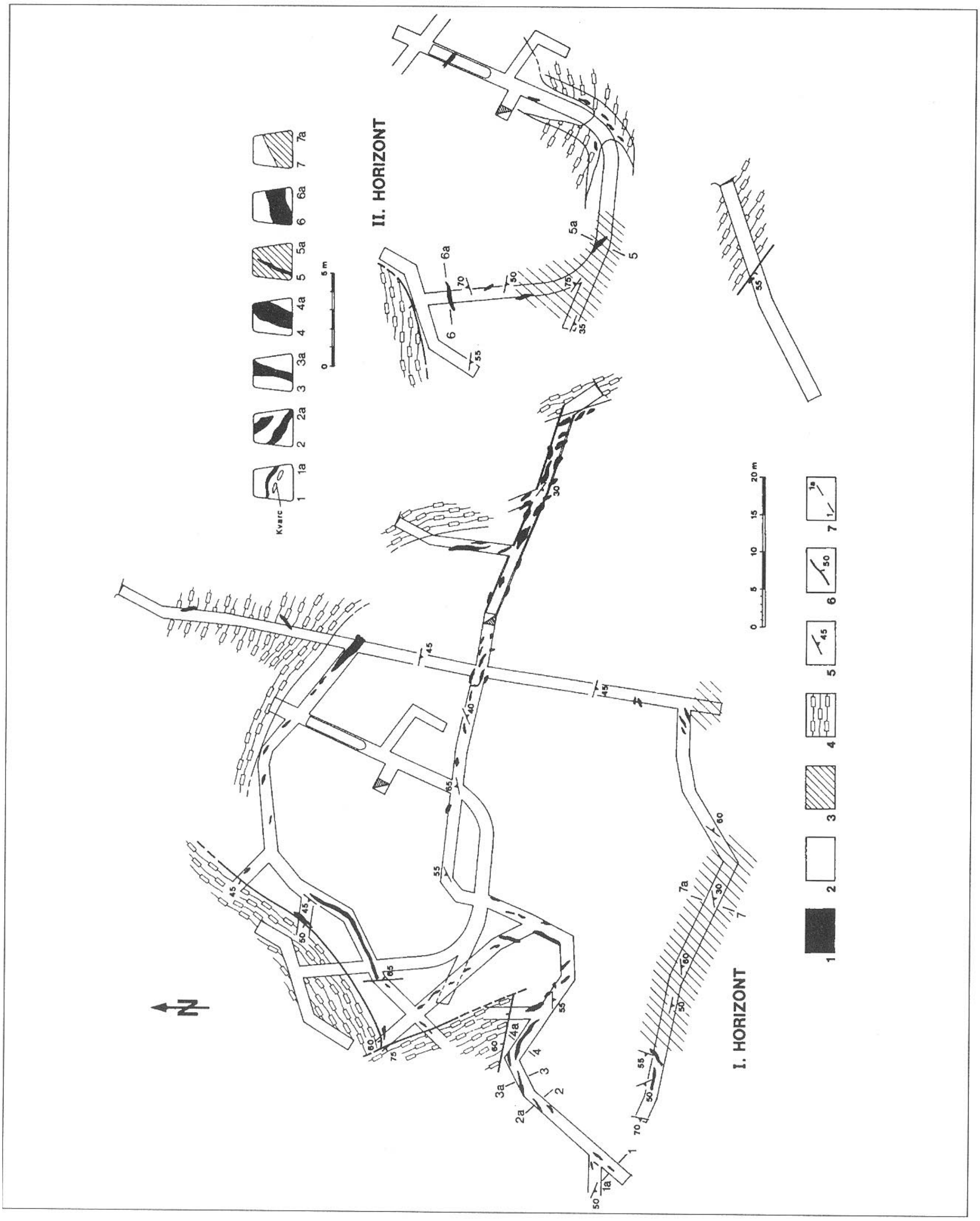

Fig. 4. Underground geological map of the Sivornica mine and cross-sections of the graphite deposit. 1 - Graphite; 2 - Predominantly graphite-bearing schists with subordinate graphite-bearing sandstones; 3 - Predominant graphite-bearing sandstones with subordinate graphite-bearing schists; 4 - Greenschists; 5 - Foliation; 6 - Fault; 7 - Cross-section.

In order to increase the concentration of graphite and remove the accompanying minerals, the samples were treated after crushing by heated HF and HCl. In the sample 25B from Vodostaj which contained only 2% C, mineral constituents were only partially separated and for that reason the X-ray analysis did not give quite as good results.

Data from Table 2 illustrate that the Brezovo Polje graphite has a higher degree of crystallinity than the Brusnik graphite. According to LANDIS (1971), both

Sample	C%	d_{002}Å	I/H(in 1/2 l)	Exothermic efects°C		
				Start	Maximum	End
Brezovo Polje, 22A	57.40	3.466	3.15	440	530	580
Brusnik	60	3.520	2.300	420	520	600
Anthracite	3.523	2.35	120	420 (530)		
Vodostaj, 25B	2.00			460	540	620
Brezovo Polje, 22B	9.50			540	630	720
Southwestern Papuk	50			480	620	

Table 2. X-ray and thermic features of graphite.

samples belong to graphite d_2, but the Brezovo Polje graphite is close to graphite d_{1A} and the Brusnik graphite close to graphite d_3 and the analysed anthracite, respectively (Fig. 5).

Experiments with coal-graphite substances from metamorphic rocks of different grades show that the ignition temmperature of organic matter increases with the increasing degree of metamorphism (ALEKSEEV & KRASAVINA, 1968; BLJUMAN et al., 1970, 1974). According to BLJUMAN et al. (1970) the exothermic effects of coal-graphite substance start at 360°C in epigenetic rocks, at 440°C in aspiditic schists, at 550°C in muscovite-chlorite subfacies rocks, at 650°C in muscovite-biotite subfacies rocks and at 740°C in amphibolite facies rocks. According to FIRSOVA et al. (1986) the exothermic effects of coal-graphite substance starts at 420°C in greenschist facies rocks, at 470-520°C in biotite-chlorite subfacies rocks and at 570-640°C in amphibolite facies rocks. Graphite diffractograms for the rocks of different metamorphic facies are also presented by FIRSOVA et al. (1986). X-ray characteristics do not change in retrograded rocks but the start of ignition of coal-graphite substance decreases, and this makes it possible to distinguish between progressively metamorphosed and retrograded sequences.

Thermal data obtained for the Psunj graphite ores and graphite-bearing schists (Table 2) show that the exothermic effects start at the temperatures of 420-480°C. The only exception is the Brezovo Polje sample 22B with its exothermic effect at 540°C. The samples 22B and Southwestern Papuk were not sufficiently cleaned and properly prepared, and therefore their thermograms indicate the presence of the accompanying minerals (340°C muscovite?) - see Fig. 6.

The presented thermal data for the analysed graphite ores and graphite-bearing schists show that the organic matter was metamorphosed under P-T conditions of greenschist facies. Correlation of X-ray and thermal data indicates that the rocks from Mt. Psunj (including the graphite deposits), belong to a progressively metamorphosed greenschist facies succession which is in accord with the other geological data.

Graphites and graphite-bearing schists were studied under normal and reflected light (Plate I). Graphite ore is commonly microbrecciated in structure and angular graphite fragments predominate over the non-graphitic matrix. The fragments are of different sizes, from very tiny to 6 mm long. Many grains display alternating strips of porous and compact graphites which probably reflect the original structure of the organic coal matter. The strips have the parallel orientation in neighbouring graphite grains which indicates that the graphite (or organic matter) was tectonically crushed in situ.

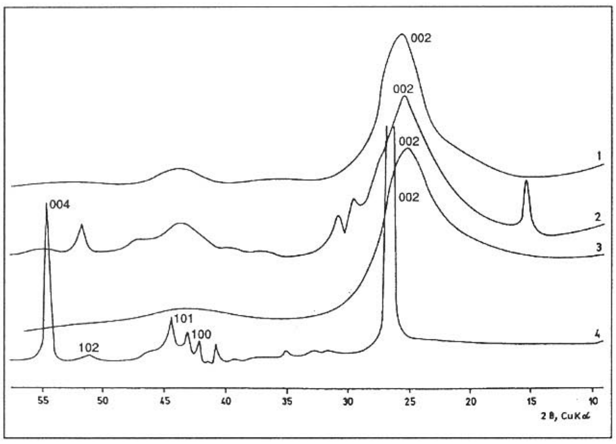

Fig. 5. X-ray diffraction powder patterns of graphite. 1 - Brezovo polje, 22A; 2 - Brusnik; 3 - Anthracite; 4 - Fully ordered graphite (TRUBELJA, 1981).

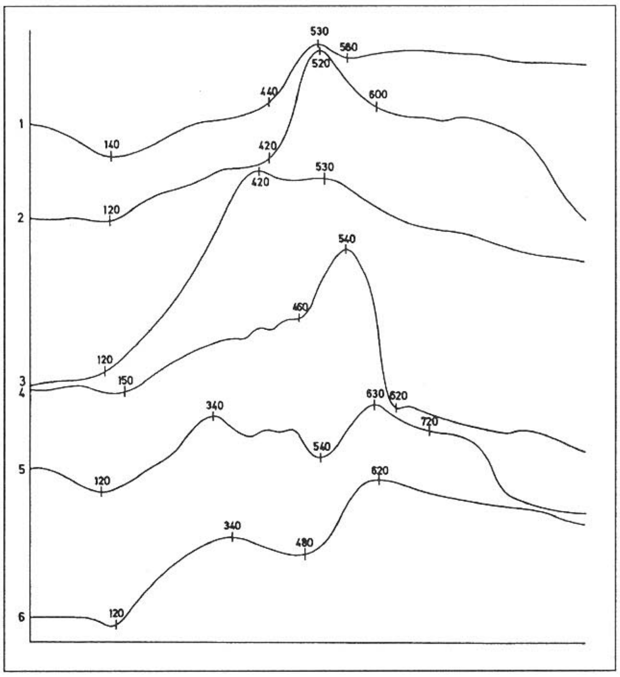

Fig. 6. DT curves of graphite 1 - Brezovo polje, 22A; 2 - Brusnik; 3 - Anthracite; 4 - Vodostaj, 25B; 5 - Brezovo polje, 22B; 6 - SW Papuk.

Sample	1	2	3	4	5	6	7	8	9
I	5.13	5.46	4.25	7.30	2.65	6.35	2.65	3.70	100
II	4.37	5.33	3.30	8.67	0.71	7.07	0.96	6.11	43
III	3.57	5.24	1.89	5.42	1.66	5.29	1.69	3.60	5
IV	4.45	6.18	2.62	8.39	1.35	8.39	1.76	6.63	11
V	3.95	4.63	3.26	5.17	2.81	4.90	2.81	2.09	5

Table 3. Reflection degrees (R%) of graphite both in ores and graphite-bearing schists. I = Brusnik (ore), II = Brusnik (graphite-bearing schist), III = Sivornica (ore), IV = Brezovo Polje (graphite-bearing schist), V = Pebble from south-west Papuk (ore). 1 - Average value of reflection degree; 2 - Average value of higher reflection degree; 3 - Average value of lower reflection degree; 4 - Maximum measured values of reflection degree in sample; 5 - Minimum measured values of reflection degree in sample; 6 - Higher value of reflection degree in the grain with the highest bireflection; 7 - Lower value of reflection degree in the grain with the highest bireflection; 8 - Difference 6-7; 9 - Number of the measured grains.

Optically, each grain behaves mostly as a single grain. Very fine-aggregated (2-5 μm) fragments, which can be easily identified due to the high anisotropic effects of graphite, are rare. Graphite has characteristic optical features. Bireflectance is very strong so that the quantity of the reflected light changes from the moderate to weak one. Anisotropic effects are also obvious and are shown by a yellow brownish colour with purple shade in the diagonal position. In the grains with traces of the original plant structure it can be noticed that the indicatrix orientation is parallel to "layering". In sticky and flaky graphite grains, the optical axis with the higher degree of reflection is oriented parallel to the grain elongation. Optical features indicate that the Psunj graphite falls between anthracite and graphite with ordered structure. Minute pyrite grains are included in graphite.

The matrix of graphite ores is composed mostly of quartz with subordinate muscovite, hydromica, chlorite which is partly limonitized, and epidote. The quartz crystallised after the crushing of graphite; graphite grains are characterized by a "shadow" structure. Veinlets of secondary quartz are also present.

Graphite-bearing schists represent dark grayish to black schistose rocks which contain a few per cent of graphite (rarely up to 10%). The rocks consist of detrital grains of quartz, feldspar, muscovite and rock fragments and metamorphogenetic minerals typical for greenschist facies rocks: quartz, chloritoid, hydromica and epidote. Graphite is mostly cryptocrystalline, either evenly distributed or concentrated in very thin beds. Graphite occurs partly in fine, isometric, flaky and elongated grains which are commonly of detrital origin. Optical characteristics of these grains are similar to the graphite from graphite ores.

	KWIECINSKA R%	STACH et al. R%
Graphite	9	10 - 18
Semigraphite	6.5 - 9	
Meta-anthracite	3.0 -6.5	6 - 10
Anthracite	3	2.8 - 6

Table 4. The reflection degree of organic matter and graphite.

The reflectance of graphite (R%) was measured both in graphite ores and graphite-bearing schists. The measurement was carried out in oil and obtained data are presented in Table 3 (we thank T. TROSKOT-ČORBIĆ and D. ŠPANIĆ from "INA - Naftaplin" who carried out the measurement in the Laboratory of Rock Geochemistry). Each grain was measured in two mutually perpendicular positions. In samples I, II and V random sections of the grains were measured whereas in samples III and IV, the elongated and flaky grains were measured. In the latter, both the highest and the lowest noticed degrees of reflection (parallel to the grain orientation) were measured and thus the values obtained are close to the maximum and minimum values of the reflection degree of a measured grain. For that reason the differences of the average values of higher and lower reflection degrees are larger in these than in other samples.

Reflection degree increases with the increasing graphitisation of organic matter and the maximum measured reflection degree (No. 4, Table 3) is the controlling factor for the determination of graphite type.

KWIECINSKA (in FIRSOVA et al. 1986) and STACH et al. (1982) give data on the reflection degree of organic matter and graphite which are presented in Table 4.

On the basis of the correlation of reflection degree data presented in Tables 3 and 4, it can be concluded that the examined graphites from Mt. Psunj belong to semigraphite and meta-anthracite (Kwiecinska) and meta-anthracite (Stach et al.), respectively.

In the coal matter-graphite classifications proposed by different authors, a general agreement in terminology and criteria does not exist and therefore the term for the Psunj graphites cannot be precisely determined. On the basis of the data presented above, we are of the opinion that the most convinient term would be graphite d_2 and metaanthracite, respectively. The term graphite d_2 defines its position in the continuous succession: amorphous coal - well ordered graphite, whereas the term metaanthracite, with its genetic meaning points out that these deposits originated by metamorphism of coal.

5. CONCLUSION

The mode of occurrence of the graphite ore bodies and the presented analytical documentation undoubtedly indicate that the Slavonian graphite deposits originated from a coal substance by regional metamorphism.

Sediments were deposited in a sedimentary basin during the Palaeozoic. Sedimentation took place in a shallow-water environment with a tendency to shallowing, and in some places, lagoonal and continental conditions were maintained. Small coal deposits might have been generated under these continental environments. In this sedimentary sequence, in which clayey sediments predominate over sandy sediments, small metabasic dykes were intruded. However, those did not influence the graphitisation of the coal matter.

These rocks were regionally metamorphosed with the different intensities during the Variscan orogeny. The rocks with coal deposits were metamorphosed under P-T conditions of greenschist facies, and thus the coal was metamorphosed into meta-anthracite and graphite-type d_2, respectively. The metamorphism was accompanied by a strong deformation and coal beds and lenses are commonly broken into larger and smaller blocks, and coal itself changed by cataclasis into a microbreccia.

Post-Variscan tectonic movements brought different parts of the graphite-bearing formations to different altitudes and gave rise to their additional tectonization. Graphite ores from all locations have similar average carbon contents (50 to 55%), and the graphites show a similar degree of crystallinity. Slight differences in the degree of crystallinity from samples from different locations are probably brought about by slightly different (related) P-T conditions which controlled the metamorphic processes.

Data presented above suggest that all Psunj graphite-bearing deposits may be penecontemporaneous and originated during the Variscan orogeny. Compared with other metamorphic deposits of "amorphous" graphite in the world, the Slavonian graphites show differences in age and also in origin. For example, the Austrian and Czech graphite deposits originated by regional metamorphism from Proterozoic bituminous clayey and sandy sedimentary rocks. The bitumen was generated by anaerobic activity from plankton and nekton (HOLZER, 1964; KUŽVART, 1985). Meta-anthracite deposits from Iron River (Michigan) and North Minnesota are Precambrian in age and originated by metamorphism of coal (MANCUSO & SEAVOY, 1981).

The Slavonian graphite occurrences and deposits, despite their smaller size, are of economic interest. On the basis of the explored but unmined graphite reserves, it can be estimated that about 52,500 tons of graphite remain in the abandoned graphite mines of Mt. Psunj. It must also be stressed that the depth of occurrence in parts of all three graphite-bearing zones were not explored.

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PLATE I

1 Microbrecciated structure of graphite ore. Graphite fragments (white) are included in the matrix consisting of silicate minerals. Reflected light, Brusnik.

2 The same as in Fig. 1. Sivornica.

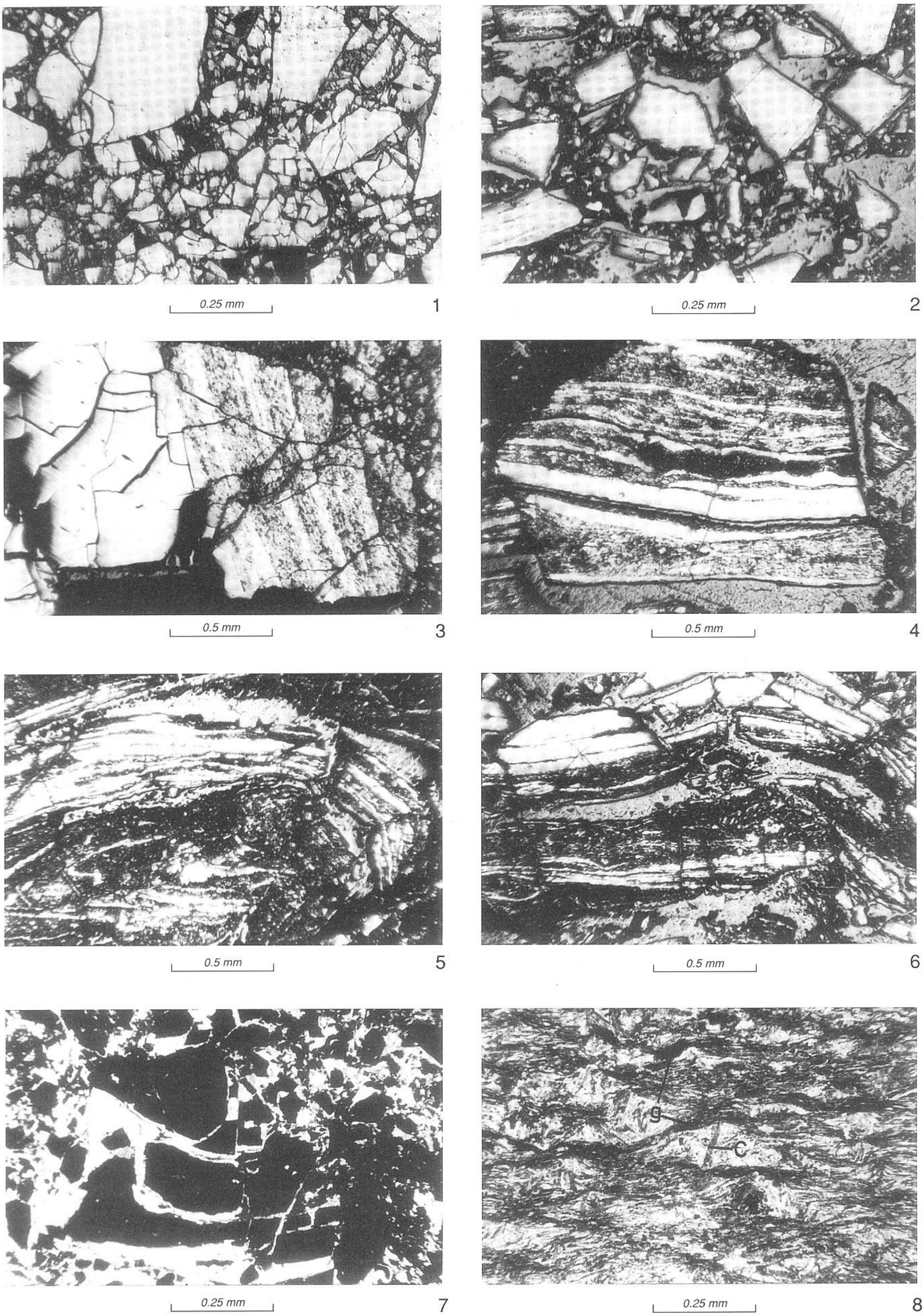
3 A graphite fragment with preserved primary coal structure. Reflected light, Brusnik.

4 The same as in Fig. 3. SW Papuk.

5 and 6 Microfolds in bedded graphite. Reflected light, Southwest Papuk.

7 Microbrecciated structure of graphite ore. The graphite (black) is embedded in the matrix made up of quartz and hydromica (white). Normal polarized light, Brezovo Polje.

8 Graphite-bearing schist. The graphite (g) is interlayered in the quartz-mica-chloritoid (c) graphite schist. Normal polarized light. Sivornica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