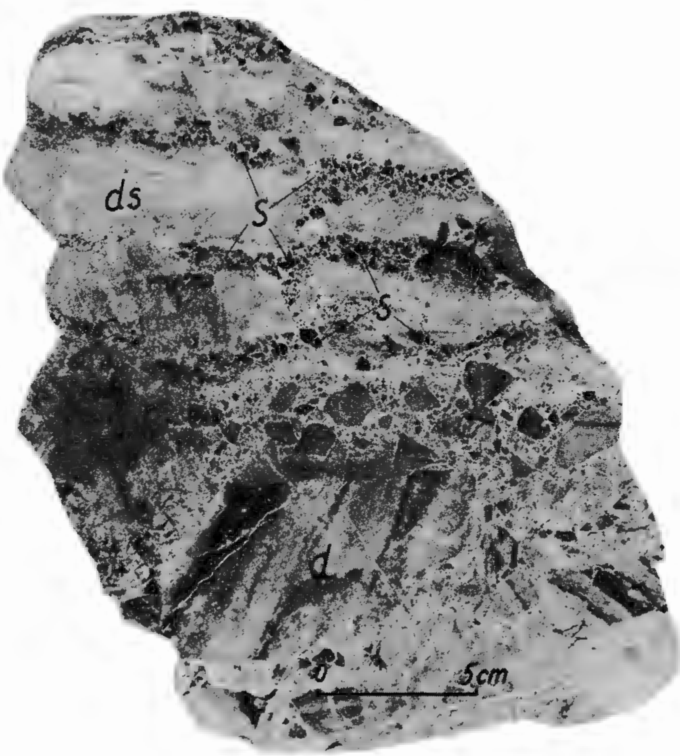
Phot. 1: Detail of collapse breccia. — d: ore-bearing dolomite. — s: sulfide ores.

Phot. 2: Detail of collapse breccia. — d: fragments of ore-bearing dolomite. — ds: "sanded" dolomite. — s: fragments of brocken sulfide veins.



Geological Position and Mineralogy of the Polymetallic Deposits in the Western Balkan Mountains confined to Triassic Sediments

By J. MINČEVA-STEFANOVA*)

Summary

For the purposes of a broader interpretation of the genesis of those specific deposits of base-metals which are found confined to predominantly calcareous sediments of varying stratigraphic position in the earth's crust, it is necessary, at the present stage of research, to re-examine the correlation of their specific features. Such a correlation should be carried out step by step, comparing at first deposits belonging to the individual regions of the earth's crust.

In connection with a forthcoming correlation of the specific features in the geological position, mineralogy and mineral-forming processes of the base-metal deposits embedded in Permian-Triassic sediments in the regions of the Eastern Alps, the adjacent platforms and the Mediterranean, this paper presents a new generalization on the deposits of this type occurring on the territory of Bulgaria and more precisely in the western Balkan Mountains. Some of the considerations and formulations are reported for the first time here.

Geological Position of the Deposits

The base-metal deposits in the western Balkan Mountains (western Stara Planina Range) confined to Triassic sediments occur on a comparatively small territory, namely the Iskar Gorge area.

Geotectonically, they form part of the Stara-Planina zone of the Balkanide system (BONČEV, 1965) which is the direct continuation of the Carpathian system of the northern branch of the Alpine-Himalayan orogen. They belong to the East-Mediterranean ore province distinguished by PETRASCHECK (1963) in connection with his interpretations of the manifestations of the Alpine-Mediterranean metallogenesis.

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With respect to the Stara-Planina structural zone, the territory occupied by the deposits forms part of the Berkovitsa block-anticlinorium which is bounded on the north and on the south by longliving deep-fault zones (BONČEV, 1961). The northern fault zone is called Stara-Planina Frontal Line and the southern one, Trans-Balkan Deep Fault (BONČEV, 1961). The axis of the synclinorium structur has a WNW2ESE direction, passing into an east—west direction to the east of the area under consideration. Over the southern limb of the Berkovitsa block-anticlinorium there lies the northern limb of the Svogé anticlinorium, occurring in the south, which in some places is upturned and overthrust, and the so-called Izremets synclinorium is squeezed between those two structures.

The limbs of the Berkovitsa anticlinorium are complicated by plicated folds of various order. Many of them are determined by the development of numerous longitudinal faults in the areas of each of the two deep-fault zones.

*) Dr. J. MINČEVA-STEFANOVA, Geological Institute B. A. W., Sofia 2 1113, Str. 'Akad. G. Bonce', Bl. II.

A typical feature of the area is the presence of faults oriented obliquely or transversely to the faults of the main set. They are part of three large fault zones (Bončev, 1965) one of which, the so-called Yablanitsa fault zone, encloses almost the entire territory of the ore deposits under consideration. The old age of the oblique fault zones as well as the controlling role of the sites of intersection of the two sets of fault zones is evidenced, according to the investigations of Haidoutov (1969), by the location of the Paleozoic igneous bodies in the western Balkan Mountains.

The Berkovitsa block-anticlinorium is built up of a Paleozoic core (with Old-Paleozoic and Young-Hercynian structural stages) and a Mesozoic mantle (with Old-Cimmerian, Jurassic Lower-Cretaceous and Upper-Cretaceous structural stages).

The Paleozoic rocks in the area of the ore deposits (Fig. 1) are Silurian ?, Upper Carboniferous and Permian. The Silurian ? rocks are represented by the so-called diabase-phyllitoid formation, comprising clay shales, greywacke, arkoses, diabases and diabase tuffs transformed into phyllites, chlorite schists and other rocks. They are crosscut by granodiorite rocks formed before the Carboniferous.

The Upper Carboniferous sediments are represented by sandstones, argillites containing coal interbeds, and the Permian ones by red breccias, conglomerates, sandstones and argillites. In some places they are accompanied by Young-Paleozoic volcanics and igneous rocks.

The Mesozoic sediments in the area under consideration are of Triassic and Jurassic age.

The Lower Triassic series is developed in a continental facies with manifestations of gradually established marine conditions at the end of the period (Tronkov, 1960). Buntsandstein is represented by variegated conglomerates, breccias, sandstones and clay aleurolites, the coarser materials predominating at the bottom, and the clay constitutent in the top section of the profile. The sandstone cement is argillaceous-sericitic, and less frequently siliceous and calcareous. Upwards, the argillaceous aleurolites gradually pass into the marine sediments of the Röth stage, represented by variegated argillaceous marls grading into light calcareous sandstones, arenaceous limestones, marls and red argillaceous aleurolites and dolomites.

The Middle Triassic series is developed in a calcareous marine facies. The Anisian stage consists of grey dolomite-limestone thinto medium-layered beds, in which limestones predominate. Three horizons are distinguished in it (Tronkov, 1960, 1965) their total thickness ranging from 220 m to 290 m. The dolomite layers are more abundant in the lower sections of the Anisian profile. Although less frequent, there are also marls ranging through limestones, dolomites and marls. Between the separate layers or within them, very fine (parts of a millimeter) clay-marl interlayers are to be found in rare cases.

The Ladinian stage is characterized by uniformly developed thicklayered large- to coarse-grained dolomites their total thickness being 80 m.

The Upper Triassic series is represented mostly by dense dolomites which in the Carnian stage grade into argillaceous aleurolites, and in the Röth stage are preceeded by calcareous-marlaceous breccia-conglomerates and marls.

Of the profile of the Jurassic system, the Lower Jurassic sediments comprise continental-carboniferous deposits, quartzites, calcareous sandstones and arenaceous limestones; the Middle Jurassic ones consist of aleurolitic-argillaceous rocks, arenaceous limestones, in some places conglomerates and breccias; and the Upper Jurassic sediments are limestones.

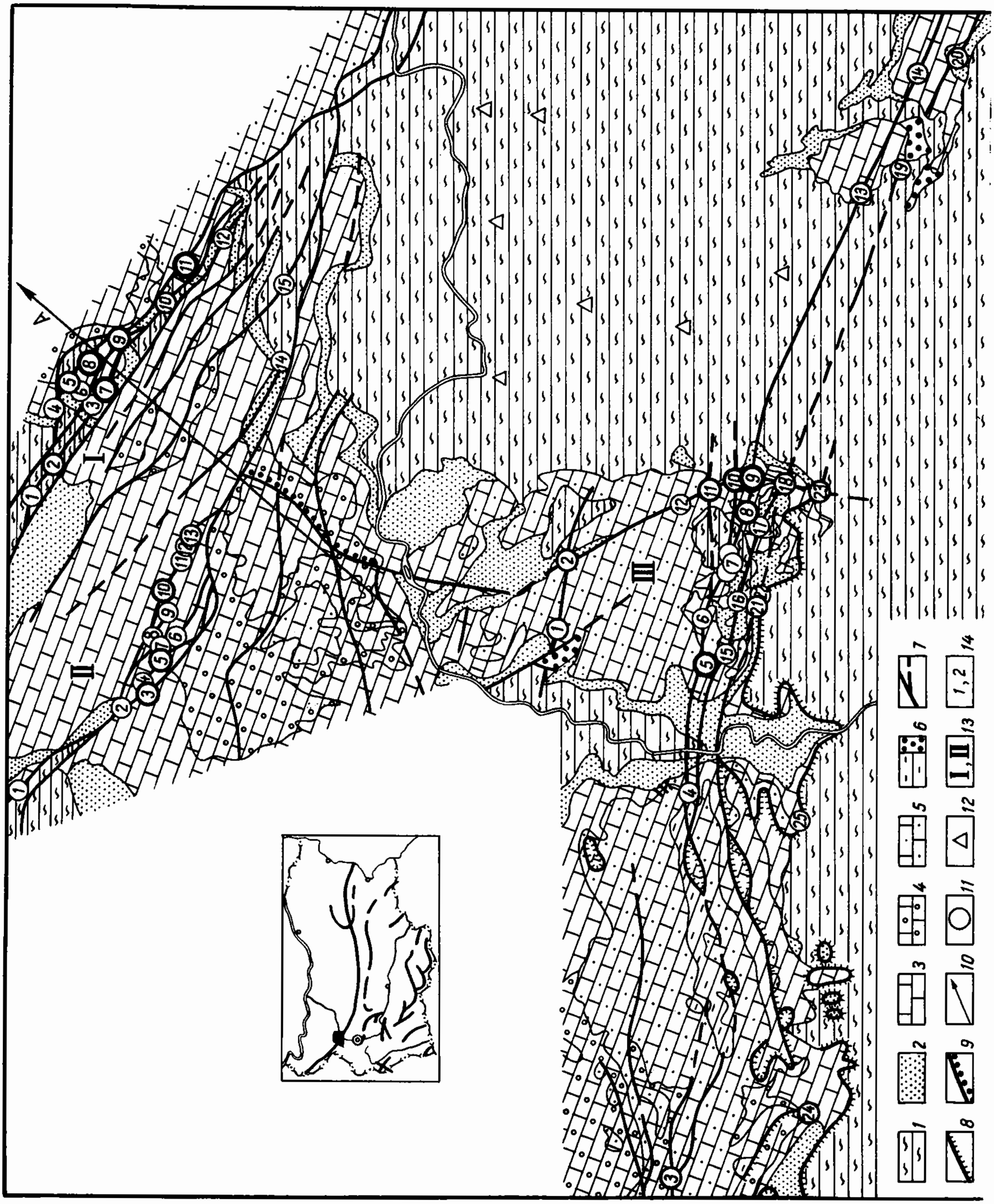

Fig. 1 : Geological map of the district of the deposits
1 — Paleozoic rocks; 2, 3 and 4 — Lower, Middle and Upper Triassic sediments; 5 — Jurassic sediments; 6 — Cretaceous sediments and Quaternary deposits; 7 — faults; 8 — line of overthrust; 9 — flexures; 10 — profile line (see fig. 2); 11 — ore deposits; 12 — barite vein deposits; 13 — mineralized zones; 14 — name of the ore deposits: I, Vratsa zone — Sedmochislenitsi, old mine (7), Sedmochislenitsi, new mine (8), Plakalnitsa (11); II, Sokolets zone — Măzho (3), Balichin preslap (5); III, Izremets zone — Zapachitsa (10), Rakov dol (11), Bakăra (8), Izremets, old mine (9).

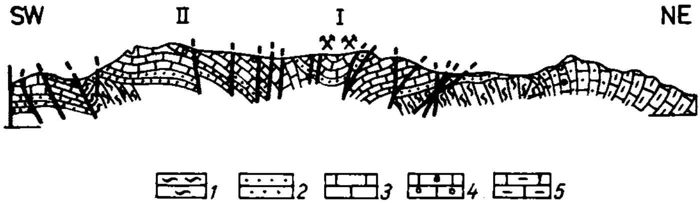

Fig. 2: Geological cross-section according to D. TRONKOV (1965) across the Vratsa (I) and the Sokolets (II) mineralized zones (the profile line is given on fig. 1, its northeastern end extending out of the map) 1 — Paleozoic rocks; 2, 3 and 4 — Lower, Middle and Upper Triassic sediments; 5 — Jurassic sediments.

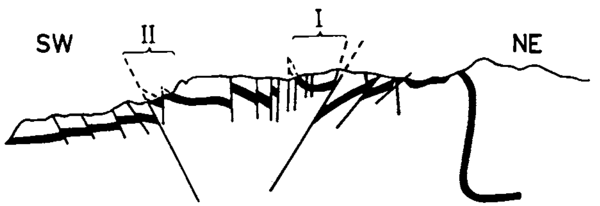

Fig. 3: The complex wedge-like uplift between the Plakalnitsa and the Sokolets disolocations according to TRONKOV (1965). The Vratsa (I) and the Sokolets (II) mineralized zones are shown. Heavy black — Lower Triassic

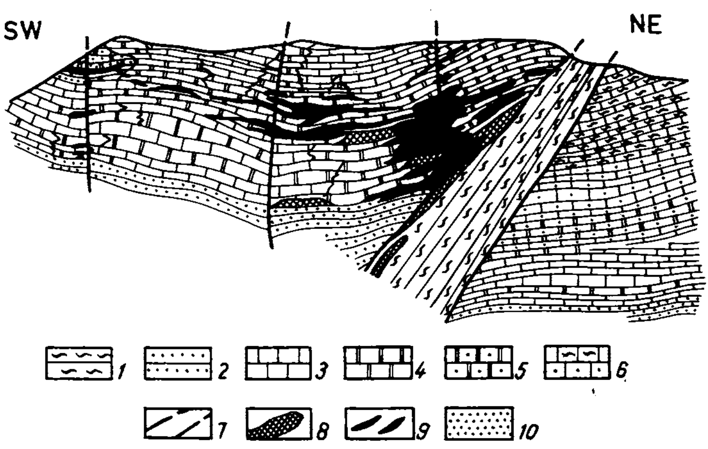

Fig. 4: A profile across the Sedmochislenitsi synkline
1 — Carboniferous sediments; 2 — Lower Triassic sediments; 3 — Anisic sediments — limestones; 4 — Anisic sediments — dolomites; 5 — Ladinian sediments; 6 — Upper Triassic sediments; 7 — faults; 8 — mylonites; 9 — ore bodies; 10 — the areal of the Sedmochislenitsi deposit — the old mine.

Regularities in the Spatial Distribution of the Deposit

There is a distinct tectonic, structural, lithological and stratigraphic control in the spatial distribution of the ore deposits.

First of all they occur in the area of the Stara Planina Frontal Line and of the Trans-Balkan Deep Fault (Fig. 1). In the first deepfault zone, the mineralizations follow a pair of conjugated fault sets, between which the respective part of the northern limb of the anticlinorium has been uplifted. As a result of this confinement to tectonic areas, three mineralized zones occur, designated as Vratsa (Fig. 2), Sokolets (Fig. 3) and Izremets (Fig. 4) zones, the latter falling in the area of the Trans-Balkan Deep Fault. In view of the facts described above, the former two zones can be considered also as two subzones of a single zone.

The role of the sites of intersection of the faults of the main (Balkanide) set with those of the oblique or transverse set for localization of the mineralization is manifested both on a regional and a local scale. It is pointed out for the first time here, that the formation of the deposits embedded in calcareous Triassic sediments in the Iskar Gorge area is controlled by the Yablanitsa fault zone mentioned above. Within it fall the places of densest concentration of deposits in the Vratsa and Sokolets zones (Fig. 1). The direction of an imaginary strip connecting these two groups of deposits coincides with the direction of the Yablanitsa zone. The concentration of deposits in the Izremets zone (Fig. 1), viz. the deposits of Rakov Dol, Zapachitsa, Bakura, Izremets and others, is also associated with oblique and transverse faults, probably subordinate with respect to the Yablanitsa zone.

The role of the sites of intersection of faults in localization of the mineralization in the individual deposits is clearly manifested in many ore bodies, particularly in the smaller ones.

Another manifestation of the tectonic factor are the interface faults subparallel to the bed interfaces which are marked by distinct slickensides, frequently forming the upper boundary of the ore bodies. They are found in all deposits embedded in calcareous rocks. Such subparallel faults occur also along the interformational boundaries between the Paleozoic and the Lower Triassic, and Lower Triassic and Lower Jurassic in the Izremets zone, and they have favoured the ore deposition, for instance, in the Rakov Dol deposit (Minčeva-Stefanova, 1965, 1967).

Besides all these specific features, there is also a direct-proportional relationship between the magnitude of faulting in the main set and the intensity of mineralization.

The structural factor is reflected in the mineralizations being confined to plicate structures, usually small, flat synclines (Fig. 4), formed as a result of the evolution of faulting. Part of them is interpreted as being the result of sedimentation in depressions in the Hercynian relief (Kalaidjiev, 1975, for the Rakov Dol deposit).

The lithological factor is manifested in the mineralizations being confined to calcareous sediments and partly to calcareous sandstones, while the stratigraphic factor is expressed in the sediments belonging to the Triassic and partly to the Jurassic system. The calcareous sediments are mostly of Anisian age, partly of Röth, and very infrequently Toarcian age, while the calcareous sandstone belongs to the Bundsandstein and partly to the Pliensbachian.

Whithin the Anisian calcareous complex, the ore mineralizations are not found to adhere to any definite stratigraphic horizon.

Specific Features of the Embedding Rocks

It is typical of the calcareous embedding rocks that the dolomite areas in them increase abruptly in direct relationship to the intensity of mineralization. For instance, in the northeastern limb of the so-called Sedmochislenitsi syncline (Fig. 4), where the mineralization occurs through almost the entire Anisian profile, the latter consists entirely of dolomites. Towards the axial sections and the southwestern limb of the syncline, where the mineralization is localized in the middle and upper sections of the Anisian complex, the dolomitic areas are limited around the respective ore bodies. The dolomitic areas follow in shape the ore bodies, being however larger than the latter. The position of the dolomitic beds in the Anisian complex is not dependent on any changes in the position of the ore mineralizations.

With exception of its final manifestations, sulphide formation is accompanied by a formation of dolomite metacrystals. Sulphides themselves occupy more or less the space in between, corroding them also in varying extent. These relationships reveal the development of a secondary dolomitization, synchronous with the mineralization, together with infrequent manifestations of a pre-ore dolomitization as well (near the large faults only). The secondary dolomitization extends over the limestones and dolomitic limestones, partly over the calcareous dolomites as well. In the dolomite beds, sulphide deposition is restricted to tectonic fissures and cavities only, while around them slight recrystallization and impregnation in the dolomite is to be found.

Morphology of the Ore Bodies

The ore bodies form mostly lenses, veins being the least frequent bodies. Bed-like ore bodies are also to be found (Fig. 5). Some of the ore lenses, being of much greater length and width than thickness, pass into bed-like bodies.

In some of the deposits (Fig. 4), the ore lenses are arranged closely one above the other and form ore columns or small ore stockworks.

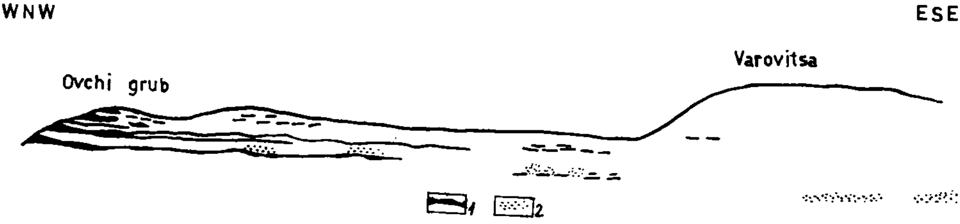

Fig. 5: Longitudinal profile cacross the Sedmochislenitsi deposit, old mine
1 — lead-zinc ore bodies; 2 — lead-copper ore bodies and manifestations.

Mineral Composition, Kinds of Ore Mineralizations and Sequence of Mineral Deposition

Compared to all other base-metal deposits in the earth's crust embedded in calcareous sediments, the deposits from the western Balkan Mountains are unique in the complexity of their mineral composition and the sequence of mineral formation. This complexity is determined by the ores being formed by two kinds of sulphide mineralizations (Fig. 6), designated as lead-zinc and lead-copper-arsenic-silver

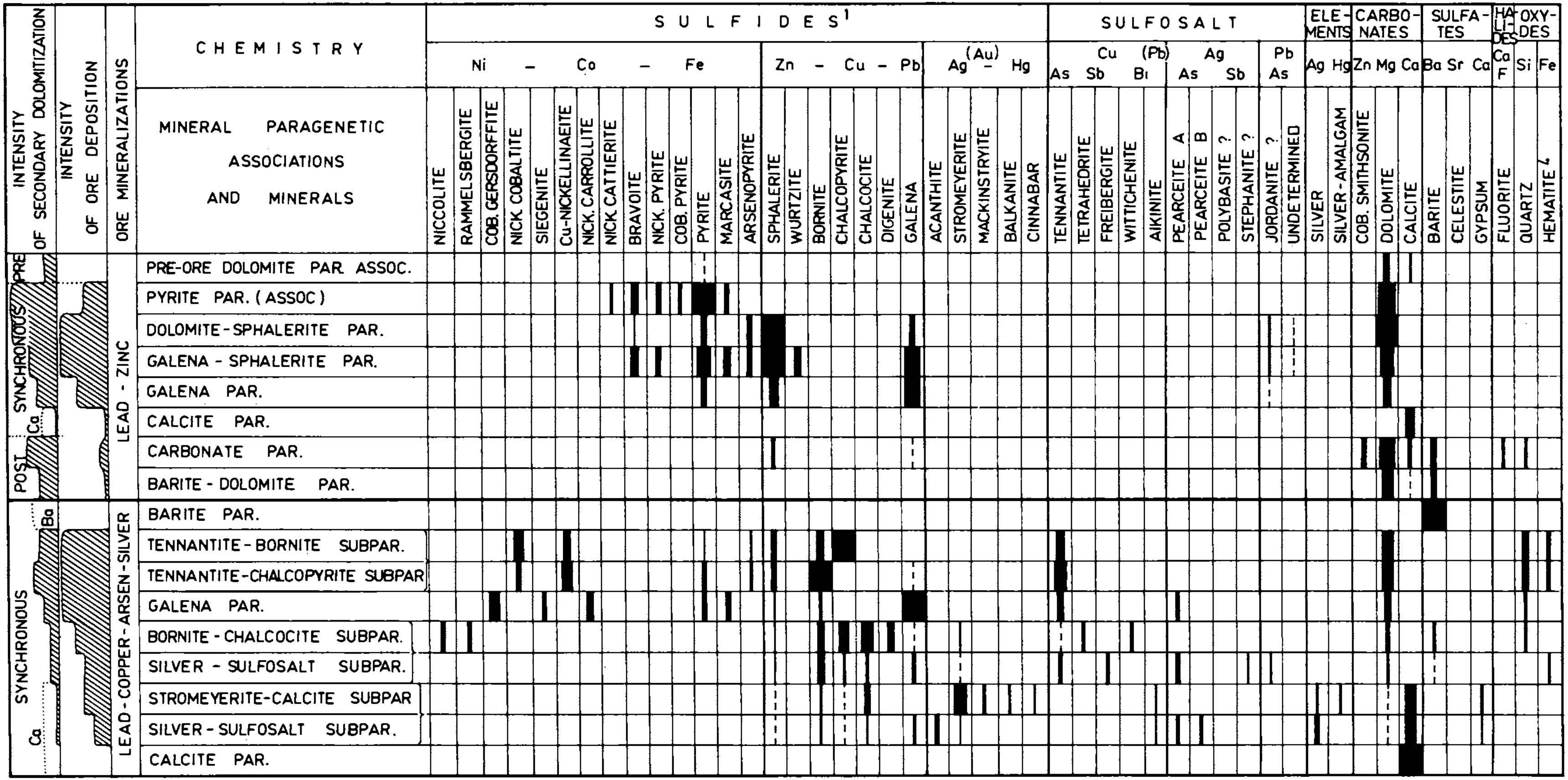

Fig. 6: Diagram of the paragenetic mineral associations

1 geomechanical triads according to KOSTOV (1954, 1968). Ni-Co-Fe association on the diagram includes arsenides, sulfoarsenides and sulfides. The minerals mackinstryite, balkanite, cinnabar, freibergite, wittichenite, aikinite and Ag-Sb ?-sulfosalts are found by V. A. ATANASSOV.

mineralizations according to the most abundant metals in them. Arsenic is found in appreciable amounts in the first mineralization, too, while in the second one, there are also bismuth, antimony and mercury. Cobalt and nickel participate in both mineralizations having the significance of typochemical elements.

The mineral composition, together with the distinct mineral parageneses, called recently paragenetic associations, are shown on Fig. 6. Diagram of such a type has been constructed for the first time here. In order to achieve an explicit representation both of the sequence of deposition and of the geochemical evolution of the mineral-forming processes, an attempt was made to use the mineralogical classification set up by I. Kostov (1968) on a geochemical-crystallochemical principle as a basis of the diagram of the mineral paragenetic associations. We allowed ourselves a certain freedom in the general arrangement of the minerals in it putting the native elements after the sulphosalts in order to express the gradually diminishing participation of sulphur. Since the minerals of the nickel-cobalt-iron association are found in the deposits discussed her in the form of sulphides, sulphoarsenides and arsenides, they are designated as "sulphides" in the diagram for the sake of conciseness, but it should be kept in mind that arsenic also forms part of their composition.

The general trend of mineral formation during the lead-zinc mineralization is characterized by the successive deposition of the major quantities of pyrite, sphalerite and galena. At first, mineral deposition proceeded metasomatically (Fig. 7), mostly in the beds of pure limestones and dolomitic limestones (Minčeva-Stefanova, 1961, 1972). The initial "imbibition" of mineralizing solutions into the chemically most active rocks was favoured by the not very high supersaturation of these solutions and by the preserved original chemical composition of the embedding rocks. Later, as a result of the high supersaturation of the solutions during the formation of sphalerite mineralization, sulphide deposition was confined mostly to the cracks and cavities where the typical colloform sulphide aggregates, Schalenblende type (Figs. 8, 9, and 10), were formed. (Minčeva-Stefanova, 1961.) The still later mineral deposition has takén place in mineralized areas which predetermine again its veinlet nature although metasomatic processes have also taken place besides the filling of cracks and cavities.

This mineralization is accompanied by the synchronous secondary dolomitization mentioned already (Fig. 6). Its formation finishes with an abundant deposition of white or light-grey crystalline or grainy dolomite in numerous veinlets and nests. They can be defined as a manifestation of a post-ore dolomitization with respect to the lead-zinc mineralization.

As a result of the varied conditions of mineral deposition, which has taken place at very low temperatures and near the surface, and in connection with the specific features of the chemical composition and the structures of the embedding sedimentary rocks, the lead-zinc mineralization is characterized by various structures: massive structure grading into banded one (Fig. 7), banded and brecciated (Fig. 8 and 9), cocarde (Fig. 10), veinlet, nested and impregnation structures.

The banded structure is determined by various causes: a) by the wave-like advance of the front of metasomatosis in the massive sphalerite mineralization (Fig. 7), where either dolomite or sphalerite predominates alternately (Fig. 11); b) by the rythmic deposition of colloform sulphides of varying chemical composition in subparallel cracks (Fig. 8); by the formation of subparallel metasomatic veinlets in banded metasomatic sphalerite mineralization (Minčeva-Stefanova, 1961, 1972).

A specific type of brecciated structure has been formed by metasomatic mineralization of resedimented breccias (MINČEVA-STEFANOVA, 1965).

The lead-copper-arsenic-silver mineralization, designated briefly as lead-copper one, is superimposed on the lead-zinc mineralization and in some places is intimately mixed with it. It occurs in an already considerably dolomitized complex, because of which veinlet structure is the typical structure in it. Besides, in the richer ore bodies massive structure is also typical. Sulphide minerals frequently replace the limestones preserved between the dolomite metacrystals formed earlier (Fig. 12), corroding the latter in varying extent and being accompanied by larger redeposited dolomite crystals.

This mineralization is represented by two main paragenetic associations, copper and lead one and final silver-bearing paragenetic association (Fig. 6). In the spatial distribution of the main copper minerals, bornite, tennantite and chalcopyrite, there is a distinct facies localization where two subassociations, tennantite-bornite and tennantite-chalcopyrite, are found to occur (Fig. 6). The former occupies the bottom sections of the calcareous complex (including Röth and Anisian sediments), while the latter is confined mostly to the middle section of the complex. The next major paragenesis, the galena one, occurs mostly above and around the tennantite-chalcopyrite levels and less frequently within them. Thus, a distinct zonality is formed in the lead-copper mineralization which penetrates into or envelopes the lead-zinc ore bodies formed at various levels.

The final manifestations of sulphide formation in the deposit are marked by numerous silver-bearing veinlets (with calcite). Their paragenetic minerals are affected by the composition of the ore lenses, mostly by the tennantite-bornite and tennantite-chalcopyrite, resp. galena lenses, because of which subassociations are again to be distinguished in their paragenetic associations (Fig. 6). So, for instance, the bornite-chalcocite and stromeyerite-calcite subassociations containing some Bi and Hg are formed amid the bornite lenses rich in copper.

In some of the deposits (the Sedmochislenitsi one) the lead-copper mineralization is preceeded by an abundant metasomatic barite mineralization.

Mineralogy of cobalt and nickel varies in the lead-zinc and lead-copper mineralizations. In the former, where pyrite is the main mineral, the two elements are fixed in the form of bravoites, nickelian and cobaltian pyrite. In the lead-copper mineralization, which is characterized by minerals poor in sulphur (Fig. 6), the two elements occur in the form of cobaltite, gersdorffite, siegenite, nickellinnaeite, carrolite, niccolite and rammelsbergite (MINČEVA-STEFANOVA, 1971, 1975).

An important feature of the spatial distribution of the two kinds of sulphide mineralizations in the calcareous complex ist that the lead-zinc mineralization is usually confined to smaller faults while the lead-copper mineralization adhere to faults with considerable displacements along them. This dependence on tectonic factors is illustrated on Fig. 13 using as an example the mineralizations in the Sedmochislenitsi syncline (cf. Fig. 4 and 5).

Another feature typical of both types of ore mineralizations is the occurrence of the lead-zinc one in calcareous sediments only, lean manifestations being found in Paleozoic aleurolitic and phyllitoid rocks in places of tectonic contacts. Having the same metal composition and the same general trend of mineral deposition, the lead-copper mineralization is equally abundant both in the calcareous sediments and in the sandstones.

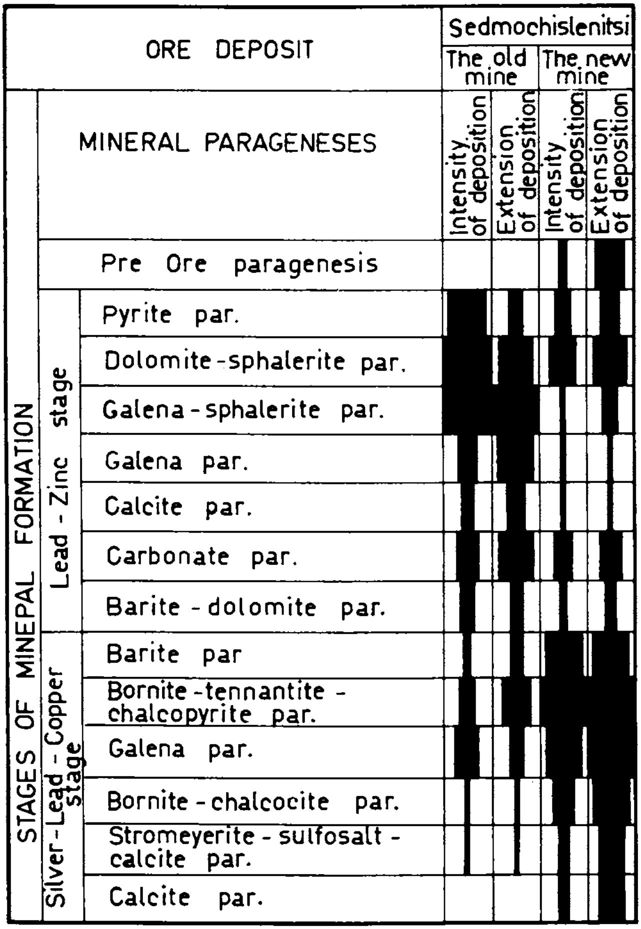

Fig. 13: Intensity and extension of the ore deposition in the old and the new section of the Sedmochislenitsi deposit.

Genetic Interpretation

The specific occurrence of copper in the type of deposits occurring in the western Stara Planina Range is a manifestation of the appreciable participation of copper in the northern branch of the Alpine orogen. W. E. Petrascheck (1955, 1963) has pointed out that the metal distribution in the two branches of the orogen is clearly related to the gross tectonics: the total copper content predominates in the northern branch, and that of zinc and lead in the southern one.

Various opinions have been expressed concerning the origin of these deposits. They have been considered as synsedimentary by Keil (1942), as hydrothermal-synsedimentary by Rentzsch (1964), as telemagmatic by Petrascheck (1955, 1963) probably sekundär-hydrothermal in the sense of Schneiderhöhn, and as hydrothermal-metasomatic by Dimitrov (1955) and Minčeva-Stefanova (1961—1972).

The well expressed structural control in the spatial distribution of the deposits in the Iskar Gorge area as well as their being formed by two sulphide mineralizations of different metal composition (each of them having a definite geochemical development), furnish grounds for interpreting their origin as an epigenetic one. The bed-like shape of some of the ore bodies and the infrequent structures imitating sedimentary structures are controlled by the bedded shape, the structures and the differences in the chemical composition of the embedding sedimentary rocks, as well as by the developed subparallel faults and fissures. The special studies of BOGACZ, DŻUŁYŃSKI and HARAŃCZYK (1973) on the Upper Silesian mineralizations also point to the ore structures reflecting the pattern of the primary sedimentary structures of the embedding rocks.

The low activity of the solutions which produced the lead-zinc mineralization has predetermined a mineral deposition under the influence of chemically very active rocks and at a favourable pH of the solutions. The latter has been made possible after certain interaction with these rocks (Minčeva-Stefanova, 1962), which, however, has not resulted in the formation of hydrothermal karst. A presence of such a karst which has later determined the occurrence of collapse structures in the calcareous complex has been found in some deposits in Upper Silesia (BOGACZ, DZUŁYŃKI and HARAŃCZYK, 1973, SASS-GUSTKIEWICZ, 1975).

The hydrothermal-metasomatic genesis of the mineralizations discussed can be logically explained in the light of the concept of generated solutions in the earth's crust during great tectonic stress and their migration in the periods of relaxation into the zones of dislocation (KOSTOV, 1968). Due to the crystallochemical differentiation of chemical elements in the earth's crust, the composition of the generated solutions will be different depending on the level of tectonic stress.

The two kinds of sulphide mineralizations can be accounted for by a supply of hydrothermal solutions of different chemical composition in connection with mobilizations at different levels. The lead-copper mineralization, undoubtedly confined to higher-order faults, is an indication of the connection of the respective hydrothermal solutions with deeper levels of the earth's crust. The individual quartz-diorite dykes crosscutting Cretaceous sediments to the east of the area where the mineralizations occur (between the towns of Botevgrad and Etropolé) can be interpreted as a manifestation of magmatic melts generated in the zones of stress.

The very rare and scarce inclusions of synsedimentary sulphides (mostly galena, less frequently chalcopyrite, and in least amounts sphalerite) found in individual beds of biodetritic arenaceous-aleurolitic limestones from the Triassic complex (ČATALOV, 1972) furnish no ground for associating the origin of the mineralizations discussed, even of the lead-zinc mineralization alone, with these lean sulphide manifestations. In them, local accumulations or signs of dissolution and redeposition processes have not been found.

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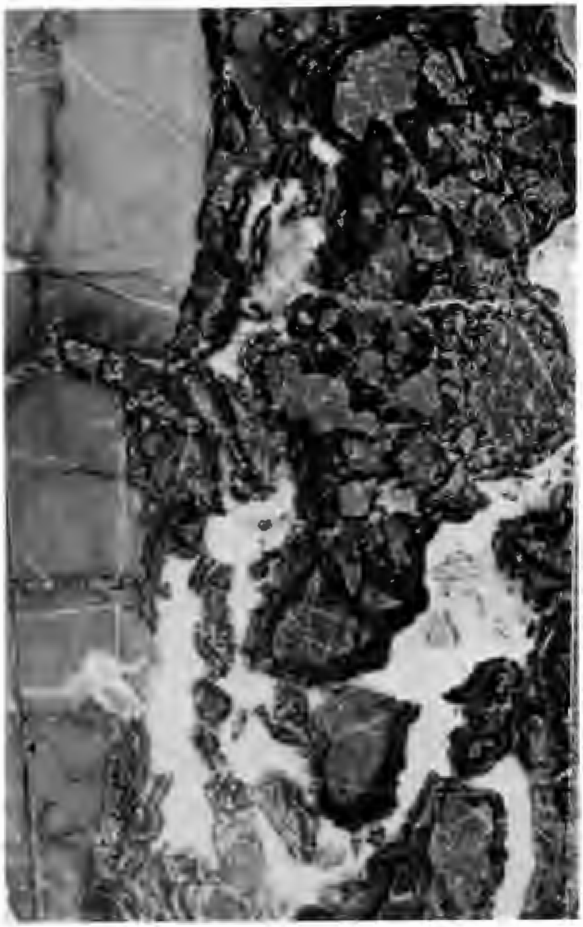

Fig. 7: Massive metasomatic fine-grained sphalerite mineralization with banded structure. Galena metacrystals and pyrite developed later. Scale 2,5:1.

Fig. 8: Banded structure grading into brecciated one in the zinc mineralization. Scale 2,25:1.

Fig. 9: Brecciated structure of the zinc mineralization in the primary dolomite. Scale 1,8:1.

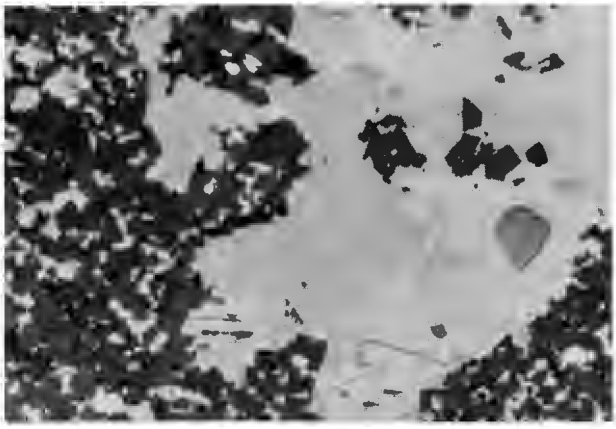

Fig. 10: Cocarde structure of the zinc mineralization. The fragments are metasomatically mineralized and are enveloped by Schallenblende. Scale 1,3:1.

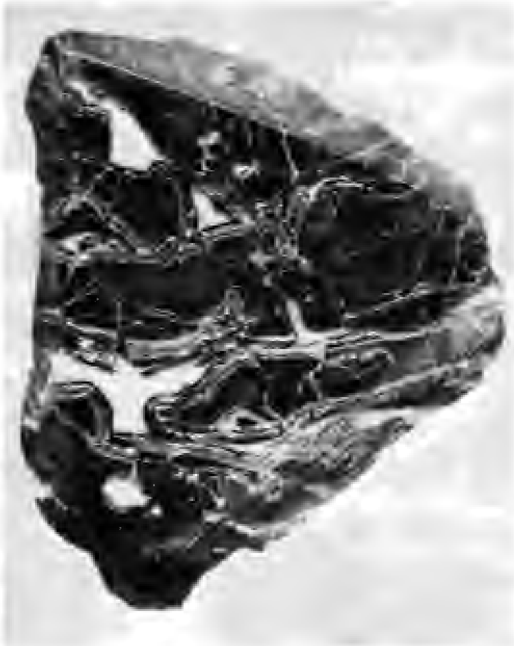

Fig. 12: Galena-chalcopyrite mineralization in the secondary dolomite. Scale 63:1.

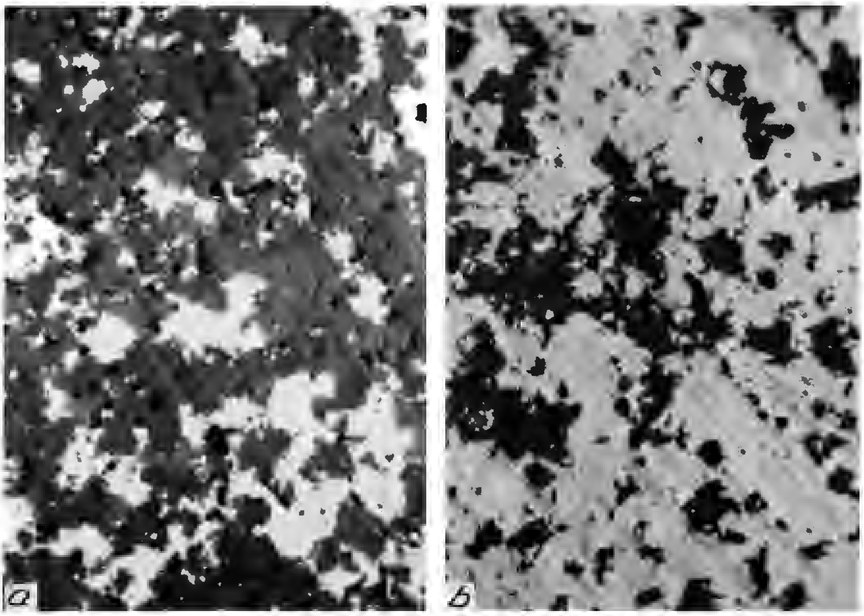

Fig. 11: A detail of fig. 7, showing two adjacent metasomatic bands. Predomination of dolomite rhombohedral crystals (a) and of fine-grained sphalerite, replacing the limestones between the dolomite crystals (b). Scale 63:1.