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SOME OF THE STRUCTURAL AND GENETIC CHARACTERISTICS AND THE ZONAL DISTRIBUTION OF NONFERROUS METALS DEPOSITS IN EASTERN PONTIDES

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INTRODUCTION

The writer has been engaged in certain studies on the structural and economic geology in the eastern Pontides. These studies, including the field work of the author (observations, research, mapping) gave numerous new data on the structural, geochemical, geological, genetic and paragenetic features of the suphide deposits (Cu, Pb, Zn) located in this region.

This paper is related to the part of the Black Sea region, situated between the town of Rize and the Turkish-USSR border, and between the Black Sea coast in the north and the Çoruh River in the south (Enel. I).

This is the typical mountainous area with highly developed relief, and dense rhododendron vegetation. The elevations range from sea level to over 3,000 m.

The hydrographic network is well developed, the rivers and streams are rich in water but their flows are short.

The outcrops are relatively rare, and the field work has been faced with numerous difficulties.

The area is very interesting both from the economic and theoretical importance, due to the fact that numerous sulphide occurrences and a number of sulphide deposits have been discovered here. On the other hand, the investigations have demonstrated that this area belongs to a very large zone, i.l. to the copper-bearing metallogenic belt which extends throughout Iran, Caucasus, Northeastern Turkey, Bulgaria, Eastern Yugoslavia and Romania.

The Black Sea region has been of continuous economic importance since ancient civilization. This conclusion is based on the numerous traces of the ancient mining. From the beginning of this Century the importance of this region is rapidly growing. The investigations were conducted by numerous geologists, starting from the amateur geologists to the most famous names in modern geology.

The author's desire is to give a modest contribution to the common efforts with intention to solve some of the geologic problems related to the described area.

GEOLOGICAL FEATURES OF EAST PONTIDES AREA

The geological investigations, completed in 1970 and 1971 in the Murgul (Artvin) area, as well as the visits to the numerous copper, lead and zinc mineral deposits and occurrences inside the area between Rize, USSR border, Black Sea and the Çoruh River, have helped the author of this paper to obtain the detailed ideas on the geological and structural relations, as well as on the spatial distribution of copper, lead and zinc deposits and relations to structural features and magmatic activities.

The available data, collected by numerous investigators, point out that this area consists of:

1. Upper Jurassic - Lower Cretaceous rhyolite-dacite volcanic-sedimentary complex

The investigators do not agree on its exact age, although most of them point out to the Upper Jurassic or Lower Cretaceous as the most probable. Such conclusion is the most probable, when the litho-stratigraphic and structural features of this area are compared with those in similar areas in Iran, USSR, Bulgaria and Yugoslavia.

2. The Upper Cretaceous volcanic-sedimentary complex

It consists of the complete volcanic evolutionary cycle, from the basic to the acidic rocks.[1] The oldest extrusions are the most basic, transferring, gradually, into the more acidic, and the basalts, melaphyres, diabases and their pyroclastites (agglomerates, tuffs and breccias), with subsequent andesites, trachyandesites, trachytes, dacites, rhyolite-dacites and rhyolite extrusive products have developed.

The lower part of this sequence is of a violet color and contains numerous limestone intercalations with abundant macro and microfauna. The Inoceramus and sea urchins are the most frequent macrofossils with globotruncanae, globigerinae and rotaliae as the most frequent microfaunal forms.

The middle or trachy-andesitic level is mostly of dark-gray color; the upper, or dacitic and rhyolitic, level is usually of grayish-green color.

The lowermost part of this sequence has been dated as of the Upper Cretaceous age; the Maestrichtian has been identified by the rich fossil findings.

Due to their relations with the flysch-type sediments, as well as with the lowermost part of this sequence, the trachyandesites and zones with dacitic and rhyolitic products may be considered as the uppermost part of the Upper Cretaceous, and, probably, partially transferring into the Tertiary, when this phase of volcanic activity has ceased.

3. Flysch-type sediments

After the cessation of the Upper Cretaceous volcanic activity, due to the marine environment, the sedimentation continued by flysch-type sediments, composed of marls, marly limestones, marls and tuffaceous sandstones, sandy marl and bituminous limestone beds. The collected fauna points out to the Paleocene and Eocene age.

4. Intrusive rocks

The intrusive rocks in this area consist of differentiates of granodiorite magma. The largest single pluton is the Tiryal Dağ-Tatos Dağları, although the related larger or smaller intrusives are present all over this area. The diorites, quartzdiorites, granites and gabbrodiorites have been identified. It is believed that the gabbrodiorite has been formed by the assimilation of the extrusive basic rocks by granodiorites during their emplacement.

These intrusives are of Neogene age, due to the fact that they have produced contact metamorphic phenomena both in the oldest rocks in this area, as well as in the Paleogene flysch; this metamorphism consists of silicification, and formation of hornfels and skarns. The contact-metamorphic phenomena are accompanied by pyrite and chalcopyrite, and, in a lesser degree, sphalerite, magnetite and hematite mineralizations.

5. Basalts and diabases

The basalts and diabases are the youngest rocks in this area (apart from the Quaternary and recent sediments), which intersect not only the volcanic rocks, but also the intrusives and the flysch. The basalt and diabase dikes and sills are particularly conspicuous in the flysch near Başköy and Murgul; numerous dikes are visible in the granodiorites along the Çoruh River and along the Artvin-Yusufeli road. These diabases along the Çoruh River are intensively chloritized where the minor displacements along their intrusive plains may also be observed.

STRUCTURAL FEATURES

It is already well known that Pontides represent a labile zone—particularly during the paroxysm of Alpine Orogen—subject to strong pressures produced by the Russian Platform. At the same time, the indirect pressures, produced by the Arabian Shield and the resistance by the Anatolian Massif, have been also active. The magmatic movements, in addition to these pressures, were also active in the East Pontides, and, due to the influence of all these factors, the resulting structural features are rather complex. The two main regional structures are an anticlinorium, its core being formed by a granodiorite pluton, and a synclinorium, with its central parts below the present sea level.

The anticlinorium has been recognized by USSR geologists and included in the Tectonic map of Euroasia (1966, Fig. 1); the synclinorium has been reported by Buser (1969) in the Murgul area. This synclinorium has been included in the «International Structural Map of Europe» (I. Ketin, 1964), but, it is our opinion that the position of this large structure, in this map, is not correctly located, when compared with the recent Structural Map of Euroasia.

Inside these large structures, the second-order structures have been formed as well, and they are of particular importance in respect to mineralizations. They include folds, imbricate and fault-type structures.

The fold-type structures vary in size from «cm», to «km» (Photo 1, 2, 3 and 4). Nearer to apical parts of anticlinorium, only the «cm» folds are developed, becoming progressively larger farther away in the direction of Black Sea and are transformed from overturned to kink fold type. All the folds extend in NE-SW and E-W direction, i.e., concordant with the general extension of large structures. The axial planes of these folds dip, at various angles, toward N and NW.

Due to the fact that different rock types, of different plasticity, grain-size and lithological composition are present in this area, the study of fold-type structures is relatively complicated. In the pelitic sediments, sandstones and marls (Photo 1, 2, 3, 4), these structures are easily observed, but in the pyroclastics, due to their heterogeneity in lithology and grain-size, such observations are particularly impossible.

The case is slightly simpler in the areas of Kilise Tepe (Fig. 5) and Murgul mine, where the folding inside the rhyolite-dacite sequence is visible; the pyroclastics here are redeposited, with a number of characteristic layers (such as conglomerates), where the fold-type structures may be traced. These structures have been described elsewhere (Popovic, 1972).

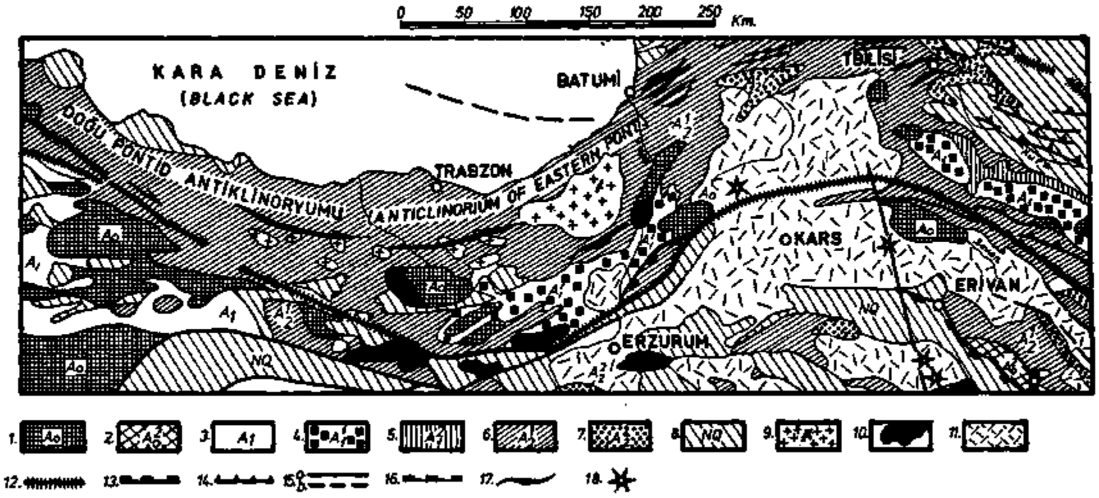

Fig. 1 - Structural map of Eastern Pont and Minor Caucasus (Geological Institute of Academy of Sciences of USSR, 1966: Tectonic map of Euroasia).

Regions of Alpine (Mediterranean) folding: 1 - Built by Precambrian and Paleozoic rocks; 2 - Built by Paleozoic rocks. Lower structural stage: 3 - Lower and upper sub-stage, undivided (T-Cr_1) in Himalaya and Zagros (Pz_3-Cr_1); 4 - Lower sub-stage (T-J_2); 5 - Upper sub-stage (Js-Cr1). Upper structural stage: 6 - Lower sub-stage (Cr_2-Pq_2); 7 - Upper sub-stage (Pqs-N^1_1). Orogenic structural stage: 8 - Interior basins (N-Q). Granitoids: 9 - Synorogenic granitoids (in Himalaya, in part pre-Mesozoic). Igneous rocks: 10 - Ultra-basites and locally basic rocks; 11 - Lava sheets of Mesozoic and Cenozoic effusive rocks of complex composition. 12 - Main deep faults; 13 - Overthrusts (nappes); 14 - Thrusts; 15 - Undifferentiated faults: (a) traced, (b) hypothetical; 16 - Normal faults; 17 - Axes of linear anticlines; 18 - Volcanoes extinct.

The above-mentioned pressures, and particularly the one produced by the Russian Platform, have deformed the fold-type structures. The folds were broken down, and the overlying blocks from N and NE were overthrusted towards S and SW, and the thrust fault structures have been formed.

The thrust fault structures are featured by the relatively broad mylonite and schistose zones, where the minor granodiorite bodies have been intruded. Such zones also represent the traps for deposition of mineral materials, and a number of copper, zinc and lead mineral occurrences and deposits are located inside these zones.

Inside each of these individual structures the mineral occurrences and deposits are paragenetically, genetically and spatially related; at a number of places, the direct relations between the mineralizations and the granodiorite intrusives may be traced.

The numerous fault-type structures, of different orientation, may be included as the third-order structures.

According to the available data, collected by us and the other investigators, the three larger and two secondary thrust fault structures may be identified in the Black Sea area. Due to their importance, each of these structures will be described separately.

Arranged from the Black Sea coast towards S and SW, the following structures have been identified:

Main structures:

- — Arhavi - Sivrikaya - Peronit thrust fault;
- — Rize - Pilargivat - Kutonit - Pehlivan Köy - Maradit thrust fault;
- — Maden Koy - Tunca - Akarsen - Murgul Maden - Ormanlı Köy - Kuvarshan thrust fault.

Secondary structures:

- — Başköy - Borçka - Camili thrust fault;
- — Barnalük Tepe - Hohur Sırt thrust fault (Encl. no. I).

INDIVIDUAL DESCRIPTION OF IMBRICATE STRUCTURES

Arhavi - Sivrikaya - Peronit thrust fault

This thrust fault has been observed in a relatively limited area near Arhavi and Peronit, where it dips towards the sea. Mylonitized zone, composed of rhyodacitic, diabase basaltic and pelitic material, is over 25 m thick.

Going from the seashore to the land, appears the following sequence of the rock units: First one is the basic series composed of diabase, basalts, their tuffs and agglomerates, remarkably hematitized, including calcite and zeolite amygdales. Smaller occurrences of manganese mineralizations are frequent. At Sivri Tepe this series is intruded by dacite. The next described unit is the zone of intensively cataclased and mylonitized rhyodacitic tuffs, forming the core of an overthrusted anticline. This zone is older than basic series, not only in respect to the superpositional order of units at this place but also stratigraphically. In the lower parts of basic series the redeposited fragments of rhyodacitic rocks Upper Jurassic - Lower Cretaceous have been found. This feature is evident on the road cut in the Peronit Dere valley. Further, the identical rhyodacitic series appears in the Murgul area, which is reported to be Upper Jurassic or Lower Cretaceous in age. Going further across this section we meet the brecciated zone composed of pelitic material.

The described mylonite zone is hydrothermaly altered. The most remarkable types of alteration are kaolinitization, silicification and pyritization. Many copper ore occurrences near Peronit and Sivrikaya coincide with the zone.

Coming next toward south is again the basic series, with identical composition as the first one in the coastal area. In both locations in the basic series the Upper Cretaceous fauna has been found. These two localities, separated from one another by a zone of rhyodacitic rocks, were considered by preceding investigators (A. Kraeff 1963; D. Koprivica 1971) as a normal superpositional succession. It is consequently, very hard to support the concept of two basic series of identical age, separated by a horizon of rhyodacitic rocks. We have questioned the interpretation of preceding authors considering this superpositional sequence and explain it as a consequence of tectonical disturbance. There is only one horizon of basic series overlying the rhyodacitic series.

In the cross section (Fig. 2) are shown the genuine relations, partly interpreted according to the exploratory drilling, undertaken in 1971 by both M.T.A. Institute, Ankara, and «Otto Gold» from Koln. The drill holes penetrated the rhyodacitic series and finished in basic rocks. Following the succession this is an overturned anticline, later affected by thrust faulting.

According to our observations the movements are not of a great magnitude. Horizontal displacement of the upper plate of thrust ranges between several hundreds to one thousand meters. The very incomplete exposures preclude a more detailed study of geology of the zone.

The tectonic zone trends northeasterly, and the thrust dips northwest at 30° - 40°. The overthrusted rhyodacitic series consists of finer-grained pyroclastic rocks, which have undergone penetrative deformations, producing parallel structures. This slightly expressed schistosity has been considered by some authors as bedding.

The folded structure of the zone was accompanied by two fault systems which were reported in 1971 by D. Koprivica *et al.* From the geological map one system of faults parallel to the axis of the fold is easily recognized. Other faults are perpendicular to the first one.

This tectonic zone is marked by some smaller intrusions of granite and granodiorite, accompanied by aureoles of contact-metamorphosed rocks. They also were the channels used by the hydrothermal solutions producing some Cu, Zn, Pb ore occurrences. They occur as minor veins and lenses, as well as some sporadic impregnations, followed by processes of hydrotermal alterations. Pyrite is the most abundant ore mineral, occurring as impregnations. Chalcopyrite is subordinate, sphalerite and galena are sporadic.

One has the impression that the exploratory drilling was programmed upon the premise that in this part of the Black Sea region the exhalative sedimentary type of sulfide ore is prevailing. This hypothesis has never been fully approved. All former investigations, especially those led by E. Zimmer (1937), as well as the actual drill holes, suggest vein type and Idnticular ore bodies in the tectonic zone, followed by impregnations of ore minerals. For this reason further explorations, including a new drilling program, should be oriented in respect to this last concept.

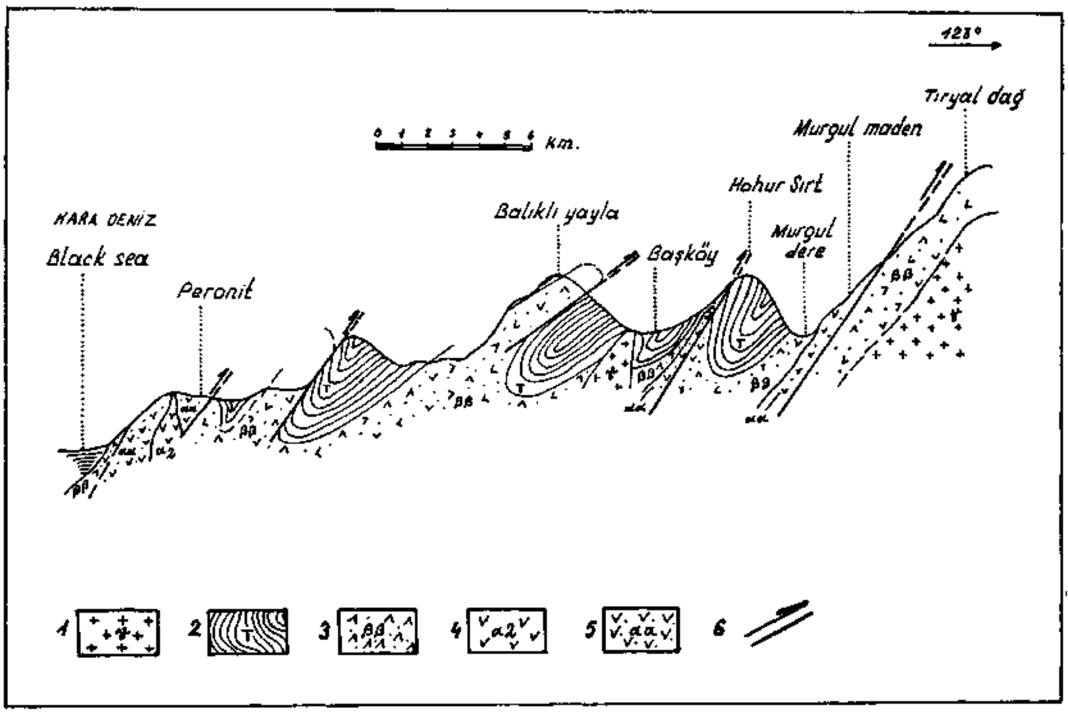

Fig. 2 - General section: Black Sea - Tiryal Dağ.
1 - Granodiorite; 2 - Flysch sediments—Tertiary; 3 - Upper Cretaceous volcanic sedimentary series; 4 - Dacite; 5 - Rhyodacite (Upper Jurassic-Lower Cretaceous?) volcanic sedimentary series; 6 - Thrust fault.

All this leads us to suppose that the upper plate of the thrust represents the screen which has caused the precipitation of ore minerals. Those are the planar surfaces of schistosity in rhyodacitic series.

The footwall parts of the structure are highly brecciated and mylonitized. In Sivrikaya and Peronit localities, this bottom part of the structure is rich in impregnations of fine-grained pyrite. Copper contents gradually increase going to the upper parts of the structure.

Rize - Pilargivat - Kutonit - Pehlivan Köy - Maradit thrust fault

This structure has been only partially traced in the area Pehlivan Koy - Maradit. In the rest of the terrain the reconstruction was done on the basis of recent geological mapping (D. Koprivica *et al.,* 1971) and other available information.

Lithostratigraphical relations inside of this structure are comparable with the previously described zone. This structure has been recognized by the large sheared zone of silicified and pyritized rocks near Kutonit. Here we have again two parts of basic series, Maestrichtian in age, separated by tectonically intervening rhyodacitic series. This structure is marked by presence of lead and zinc veins near Maradit, then by veins with pyrite and chalcopyrite near Kutonit (explored by E. Zimmer, 1937), as well as Pb - Zn veins near Pilargivat and Çayeli. Two systems of faults, one parallel to the thrust fault and the other perpendicular to it, are present as well. They suggest faults created during folding and overthrusting.

Abnormal relations of basic and marly pelitic horizon are well remarkable in the road cut between Hopa and Borçka. At this section the following features of tectonic movements have been expressed: dip angle of the sediments grades from subhorizontal to subvertical, inverse position of lithological units, existence of both folded and faulted structures. However, at this section the rhyodacitic series does not crop out, but the basic series (diabase-basalt) alternates with flysch sediments which are younger than basic series. The same relations are shown in the geologic map made by A. Kraeff (1963), who interpreted the relations in a different way.

The above-mentioned thrust fault forms typical imbricate structure. It sinks under the sea in the vicinity of Rize, and in the NE direction passes into the territory of USSR. This structure has been also shown on the Tectonic map of Euroasian continent by USSR geologists (Fig. 1). It should be stressed that this structure is not identical with the one presented by I.G. Magakhyan (1970) in the area of Minor Caucasus (Sevan Lake). This is a structure of first order which also occurs more southwards. Our structure of second order, is running most probably from the Tbilisi and Kura River area. We emphasize the problem of correlation of structural features in Turkey and USSR, which are of different type.

Continual tracing of this structure was prevented by the vegetation cover. The trend of tectonic zone is northeasterly and the thrust dips northwest more than 50° in the vicinity of Pehlivan Koy, but they may dip very gently south of Pazar, according to the actual geologic map (D. Koprivica *et al.,* 1971). The thickness of the sheared zone varies too, depending on the intensity of the stress, length of transport, mechanical properties of underlying and overlying masses, and the thickness of overthrusted mass. This tectonic zone has been characterized—except the mylonite and ore occurrences—also by smaller granodioritic intrusions, observed by all investigators of the region. The contact metamorphic aureoles were reported as well.

All ore occurrences and mineralizations are hydrothermal in origin, according to our observations and other informations. Most of them are veins, then lenses, and some impregnations. Among the ore minerals pyrite is prevalent, galena, sphalerite and chalcopyrite are subordinate.

With regard to the fact that this very long zone escaped the observations, a new exploratory program has to be undertaken, which should lead to a better reconnaissance of economic value of the zone.

Maden Köy-Tunca-Akarsen-Murgul-Kuvarshan thrust fault

This is the most important overthrust zone, according to its magnitude and the number of copper ore deposits and occurrences. It has been investigated in the area of Maden Köy, Akarşen, Murgul mine, and the right bank of the Çoruh River near Artvin.

The zone of mylonitized rocks is more than 25 m thick near Maden Köy and Murgul mine, and lesser thickness near Akarşen mine.

According to the published and unpublished informations (E. Zimmer, 1937; J. de Geoffroy, 1960; D. Milutinovic *et al.,* 1972), the zone of mylonitized rocks has been identified near Tunca and Büyük Köy. Identical structural feature can be reinterpreted on the geological maps of A. Kraeff (1963) and S. Buser (1970) as well, which cover the Murgul area. Correlation of lithostratigraphical units, systems of faults, and schistosity of rhyodacitic series suggest the existence of the structure of higher order in that area. In the Murgul mine (ore deposits Çakmakkaya and Anayatak) as well as in other localities (Maden Köy, Çoruh River) are evident various manifestations of this structure, such as schistosity, tectonic breccia, and minor folds.

The «cm» and «dm» size folds were observed at Maden Köy, Anayatak, Çakmakkaya and «m» size folds in the Çoruh River valley, where the Kuvarshan and Ormanlı Köy are located.

In the considered structure the identical lithostratigraphical section has been observed. This is an expected appearance because the whole region from the Black Sea coast up to the anticlinorium of Tiryal Dağ-Tatos Dağları consists chiefly of both rhyodacitic and basic series, then of flysch sediments and intrusions. It should be focussed on the following features: (1) determination of Senonian age for the lowermost parts of Upper Cretaceous volcanogenic-sedimentary series (diabases and basalts); (2) near Murgul Maestrichtian has been reported (S. Buser, 1970); (3) the uppermost parts of the Upper Cretaceous volcanogenic-sedimentary series are passing into flysch sediments Paleocene and Eocene in age, indicating that volcanic activity occurred in Paleogene as well; (4) pebbles of rhyodacitic rocks occur in lowermost parts of basic series indicating unconformity between them. This means it is evident that rhyodacitic volcanic-sedimentary series cannot be neither younger from Upper Cretaceous volcanogenic-sedimentary series (D. Koprivica, 1971), nor synchronous with the same series (D. Milutinovic *et* al., 1972).

Several cross sections exemplify a composite tectonic feature in this region. In the Murgul Dere valley, particularly on the left bank of the stream, are present minor folds (Fig. 3).On the section of Murgul Dere-Hohur Sırt could be reconstructed folded structures according to the position of lithological units (Fig. 4). They alternate in both normal and reverse sequences, indicating imbricate structures. Along the section (Fig. 2) Murgul-Tiryal Dağ an identical feature has been observed. Here we have volcanogenic-sedimentary basic series (Upper Cretaceous) outcropping at the beginning and at the end of the section. Intervening masses of rhyodacitic series (Upper Jurassic-Lower Cretaceous) partly schistose and brecciated are present also. Thirty years ago V. Kovenko (1942) reported Eocene sediments overthrusted by Upper Cretaceous sediments (Kuvarshan) based on the faunal evidence.

All formations in this tectonic zone show a northeasterly trend, and dip nortwest at 25°-60°. In the zone occur many small granodioritic intrusions with well expressed contact metamorphic changes. All observed rock units are more or less pyritized, kaolinized and silicified. In this struc-

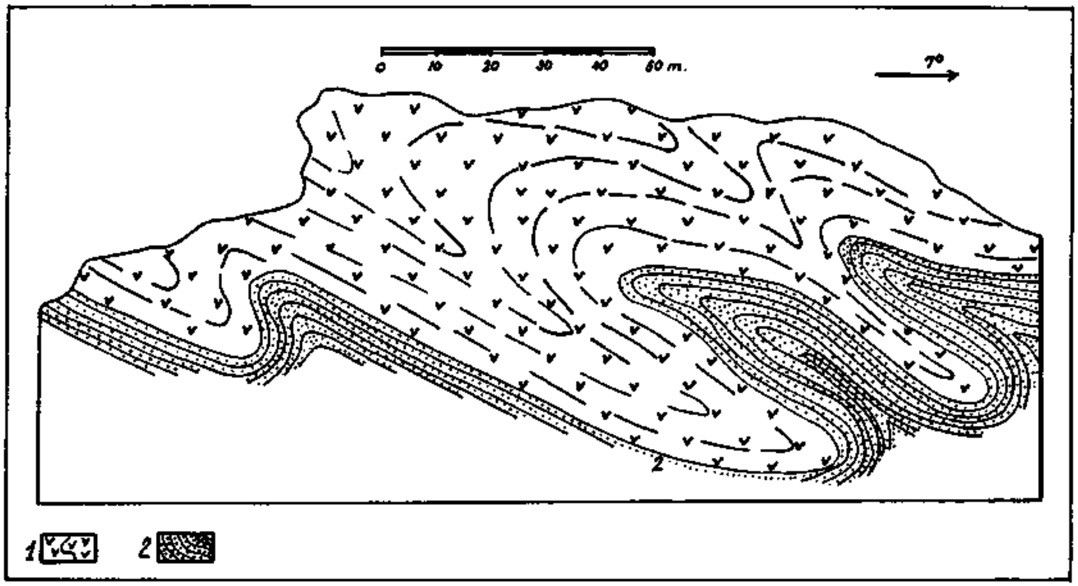

Fig. 3 - Murgul Dere left bank, north of Murvani Evi—Local section.

1 - Rhyodacite volcanic sedimentary series (Upper Jurassic - Lower Cretaceous); 2 - Tuffaceous sandstone, well stratified (age not identified).

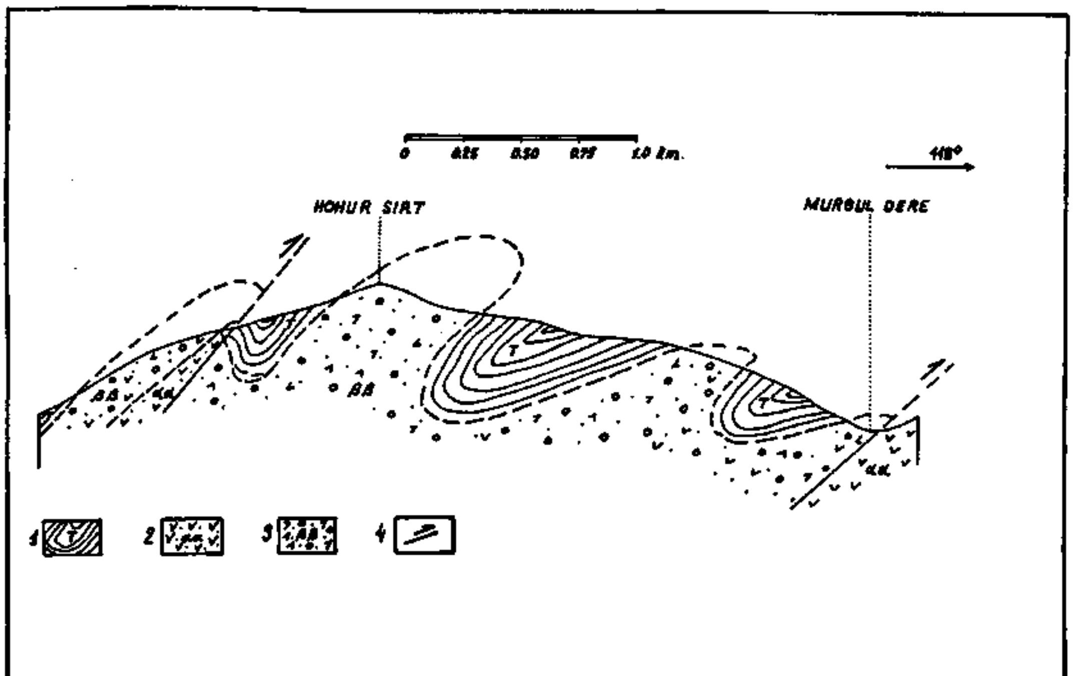

Fig. 4 - Section: Murgul Dere - Hohurt Sırt.

1 - Flysch sediments—Tertiary; 2 - Rhyodacite (Upper Jurassic - Lower Cretaceous ?) volcanic sedimentary series; 3 - Upper Cretaceous volcanic sedimentary series; 4 - Thrust fault.

ture appear the most important ore deposits and occurrences, for example Maden Köy, Yukarı Zigam, Tunca, Akarşen, Ormanlı Köy, Murgul and Kuvarshan. The ore occurrences Karaağaç and Büyükköy should be mentioned as well. It is supposed that the ore occurrences near Of and Sürmene are confined to the same structure.

All ore deposits are characterized by identical mineral composition, mode of occurrence and genesis. The most abundant is pyrite, chalcopyrite, sphalerite, galena, but others are subordina and sporadic.

The ore bodies are lenses variable in size, partly accompanied by impregnations of ore minerals. Ore veins are subordinate and they are not of economic value. This type of ore bodies has been reported by Kovenko (1942) near Kuvarshan, then by Geoffroy (1960) and Zimmer (1937) near Tunca, Zigam and Maden Köy. Ore deposits Anayatak and Çakmakkaya as well as Akerşen mine exemplify lens-shaped ore bodies.

It is our opinion too, as it has been of many predecessors, that these ore deposits are hydrothermal in origin, confined to granodioritic magma of Tiryal Dağ-Tatos Dağları pluton.

Başköy-Borçka-Camili thrust fault

This structure was observed in the Başköy mine area. North of the Borçka mine it is rather covered, so that traceable structures are rare. In northeastern direction the structure has been recognized by sporadic observations. The structure was also traceable by mineralization near Camili. The southwestern extension of the zone was not traceable.

This structure is an overturned fold locally passing into a recumbent fold (Photo 6), faulted thrusted over younger flysch sediments. For, contrary to other structures, here the latest members of the Upper Cretaceous volcanic activity are developed. These are volcanogenic-sedimentary products mostly of andesitic and trachyandesitic composition. Locally occur interbeds of sandstone and marl marking the structure themselves. Later modification of the structure was caused by quartzdiorite intrusion, outcropping near the Başköy mine. This and other examples suggest that folding is a consequence of granodioritic intrusion.

This major structural feature has been followed by small-scale structures, such as drag folds and reverse faults (see Photos 1 and 2), as well as by systems of fractures (see Fig. 5).This also exemplifies our concern about thrust folding tectonics, and leads us to wonder whether concepts about fault block tectonics are acceptable.

Başköy ore deposit is a typical example of an anticline vein type mineralization (Photo 6 and Fig. 5), where the deposition of the ore was in the fissures perpendicular to the axis of the fold. This is a regular pattern of fissures from 1 mm to 3 cm in thickness, spaced from few cm to 50 cm. A little chalcopyrite occurs as impregnation in the sandstone. The most abudant mineral is pyrite. Chalcopyrite is less abundant, sphalerite is subordinate, galena is sporadic. As gangue minerals occur fluorite, calcite, quartz and barite.

Barnalük Tepe - Hohur Sırt thrust fault

This thrust has been traced for 10 km. It is parallel to the other structures and the thrust plane dips 45°-70°. In the Barnaluk Tepe and Hohur Sırt area a large zone of mylonitization follows the thrust fault. In the other parts this structure has been recognized only by overturned position of sediments, which is evidenced by faunal determination (I.J. Stern, 1971). In this structure the following lithostratigraphical units have been observed: Upper Cretaceous volcanogenic-

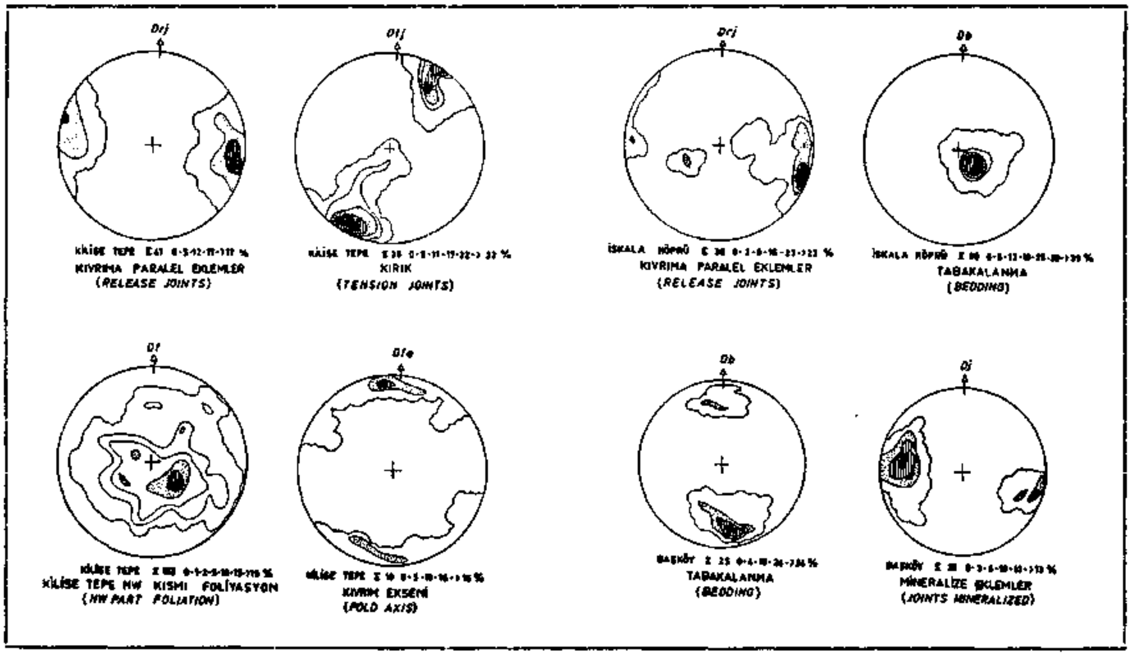

Fig. 5 - Structural diagram.

sedimentary series (basic, diabase-basaltoid), Paleogene flyschoid (marly-pelitic) and partly rhyodacitic volcanogenic-sedimentary series, Upper Jurassic up to Lower Cretaceous in age. By geologic mapping (B. Djukic, R. Kovacevic, J. Stern, and R. Popovic) undertaken in 1970 it was established on the basis of faunal determination that the Eocene flyschoid sediments are overlain by Upper Cretaceous formations. In the deeper parts of the structure denuded by erosion, the rhyodacitic series also crop out.

In this zone the high level of copper content has been found in the rocks. Alteration (silicification and kaolinization) and chalcopyrite and pyrite mineralizations also took place. The most frequent mineral is, as usual, pyrite, less chalcopyrite, sphalerite and galena. Quartz and calcite veins are present too. Many of the fissures are perpendicular to the strike of the zone and were channelways used by the hydrothermal solutions. Veins are up to 20 cm in thickness. The hydrothermal activity is possibly associated with intrusions of quartzdiorite which are also present in the zone.

The structure is represented by an overturned fold, overthrusted along the axial plane of the fold. By this reason we have now the inverse position of stratigraphic units: the most commonly flysch series (Eocene) is overlain by rhyodacitic series (Upper Jurassic - Lower Cretaceous) or, in some places, by Upper Cretaceous volcanogenic-sedimentary series, its basic part.

ARTVİN-MELO-YUSUFELİ ZONE

In this zone formerly the schists of Paleozoic age were reported. According to our information, this zone near Melo appears as a corridor between two granodioritic masses: the larger one is Tiryal Dağ-Tatos Dağları mass, and the smaller is in the Çoruh River valley. The zone consists chiefly of volcanogenic-sedimentary series and flysch sediments, Tertiary in age, which were considered formerly as Paleozoic schists. Flysch sediments include marls, marly sandstones, norm.al sandstones, and pelitic sediments, partly accompanied by limestones. According to microscopical investigation there are no traces of recrystallization or any change of primary sedimentary fabric of rocks. Flysch sediments overlie the Upper Cretaceous basic series. Globotruncana has been found in the sandstones, which is likely to be the result of redeposition. Those sediments resemble very closely the flysch sediments near Murgul, which are determined, on the basis of fossils, to be Tertiary in age.

The very incomplete informations preclude a discussion about tectonical feature of the area. Here occur the same types of ore occurrences as in the previously described zones. The only difference is that in this zone the mineralizations occur not only in rhyodacitic series but in the basic series as well.

SOME OBSERVATIONS ON THE GENESIS OF COPPER DEPOSITS

The author's opinion, relating to the genesis of copper deposits in the eastern part of the Black Sea Coastal Region, has been based on the described geological and structural relations.

The question of genesis of copper ore deposits in the Black Sea Coast Region has been, during the last few years, much disputed. Formerly accepted theory on hydrothermal origin of copper, lead and zinc deposits in this region, has been recently highly criticized. Namely, the study of genesis of copper ore deposits in the Caucasus (Major and Minor) areas in USSR, done by numerous investigators, lead to the new aspect on the genesis of copper deposits of the eastern Black Sea Coast Region in Turkey.

The theory on the volcano-sedimentary genesis of the Caucasus Minor deposits has numerous followers, but it seems to have the opponents as well. Due to the fact that our knowledge of the Caucasus Minor deposits has been based on the available publications only, this discussion will be limited on the deposits covered by this paper and actually visited by the author.

The problem of the genesis of copper deposits in the eastern part of the Black Sea Coastal Region does not have the theoretical aspects only, but also the influence on the practical problems related to the approach of the methods of explorations.

It should be stated at the beginning that, when dealing with volcanic-sedimentary or sedimentary deposits, the explorations should be oriented primarily towards the determination of stratigraphic levels and of underlying and overlying formations. However, due to the fact that these deposits are of hydrothermal origin and related to particular structures, with mineralizing solutions originating from the granodiorite magma, it is also important to determine the mineralized horizons and the channels, where the solutions have circulated, and most efforts to be concentrated on these investigations.

The concept of volcanic-sedimentary type of deposits, in the eastern part of Black Sea (Coastal) Region, has numerous weak points. In the first place, no stratigraphic level has been defined, and the deposits occur in rhyodacitic, or older volcanic series, and in the younger, Upper Cretaceous basic series as well.

In rhyodacite series, the most important are: Anayatak and Çakmakkaya deposits near Murgul, Peronit and Sivrikaya near Hopa, Tunca near Ardesen, Maden Köy near Çayeli, Kuvarshan and occurrences Kürzade near Artvin, and others.

The basic series contains the deposits near Melo, Camili, Maradit, Pehlivan Köy and at Başköy (the later two are located in the upper, andesitic parts of the basic series), and the several copper, zinc and lead occurrences inside the contact metamorphic zones, but presently of no economic importance.

In the Çakmakkaya deposit, after the ore body has been opened for exploitation, it can be seen that the stratigraphic control is missing. The ore body is actually an elliptical lens, elongated in NW-SE direction, with steeper dip than the surrounding schistose and mylonitized rhyodacitic pyroclastites.

In addition, the Anayatak and Çakmakkaya deposits represent a typical sample of a tectonic breccia cemented by silica and ore material.

It is important to note that the polished sections of ore samples collected from the Akarsen mineral deposit contain oval structure, which are, according to V. Vujanovic (1972), the remnants of the «ore bacteria». Vujanovic has also identified a typical hydrothermal paragenesis, which he explains as a subsequent regeneration of the original volcanic-sedimentary deposit.

It is apparent that here a tectonic zone, with a highly developed mylonitization, is present, with mineralization in the form of lenses, as confirmed by the preserved old workings. Along the country road, near the mine, several quartzdiorite intrusions, which have produced the contact alterations in the marly limestones, were observed.

According to these data, it seems that the ore structures are not of sedimentary origin, but the gel structures of hydrothermal origin; the ore material originated from the granodioritic magma, and the mineralization was formed during the quartzdiorite intrusion, with the existing structural zone as favorable for ore deposition.

This opinion was accepted long ago by numerous investigators; it is further supported by zonal distribution of mineral deposits around the plutons, a fact discussed in more detail in the next chapter.

The author is not inclined to diminish anybody's contribution in the study of genesis of nonferrous metals in the Eastern Black Sea Coastal Region, but only to help, as much as he can, in reaching to the solution of problems of importance from both the theoretical and practical aspects.

The local presence of colloidal structures, and explanation of genesis based only on these data, do not contribute to the final solution, at least in our opinion; the colloidal structures are not necessarily the sedimentary structures, as pointed out by Betehtin *et al.* (1964), when discussing the Caucasus Minor copper deposits. The oolitic structures are normal in the sedimentary deposits, but, on the other hand, the circular structures, observed in some deposits, have not been completely proved as oolitic. In some cases they were described as the remnants of «ore bacteria», but, if this explanation is accepted, the true sedimentary oolitic structures are still missing.

Another serious drawback of volcanic-sedimentary theory has been pointed out by geochemical investigations. According to geochemical investigations in Tunca, Kuvarshan, Hohur Sırt, Çakmakkaya, Kilise Tepe and other areas, the copper concentrations in pyroclastics are at normal levels, sometimes well below these levels. If the deposits were formed in the submarine environment, in volcanic-sedimentary sequence, then the copper background should be higher at least in the vicinity of such deposits. On the other hand, the geochemistry has detected the abnormal copper concentrations in the quartzdiorite near Murgul and in granite and granodiorite near Melo and Kuvarshan. At Kilise Tepe, the copper background, in quartzdiorite, is 93 ppm, and the zinc background is 210 ppm. Between the Çoruh River and Melo, malachite, chalcopyrite and pyrite have been observed in granite, in a road cutting. Both the field observations and the geochemical data have been confirmed by polished section examinations conducted by V. Vujanovic (1972).

The mentioned data point out to the hydrothermal origin of mineralizations; the ore body, in the eastern part of Karadeniz, is located in the structural, hydrothermally altered zone; the numerous and intensive hydrothermal alterations, developed in a number of other deposits, clearly demonstrate, in addition to other data, their origin.

ZONAL DISTRIBUTION OF MINERAL DEPOSITS IN THE EASTERN PART OF THE BLACK SEA COASTAL REGION

According to published data and the author's field observations, the zonal distribution is clearly visible at a number of deposits in the eastern part of the Black Sea Coastal Region. As presented in the enclosed map (Encl. I), the molybdenum-copper and zinc zone is developed immediately around the granodiorite pluton. In the northern and northeastern parts of the granodiorite pluton southwest of Tiryal Dağ, at Kilise Tepe and in the upper course of Murgul Dere, this zone is very narrow. The presence of molybdenite was detected in 1971, when the geochemical prospecting has detected up to 1000 ppm of molybdenum in the sample rocks (R. Popovic *et al.*, 1972). The southern and southwestern parts of this zone are broader, and according to Talic (personal communication, 1971), the molybdenite occurrences are more numerous there. This zone contains also copper and zinc occurrences. Zinc occurs in quartzdiorite or together with copper, and is located in the fault zones; the same is true for copper, although it is more frequent in fault zones. Although no larger deposits are located in this zone, some minor ore bodies, with copper and zinc minerals, may be expected; although they may have the local importance only, they may be exploited profitably if located near an operating mine. Due to the reason that the mineral occurrences at Kilise Tepe are near the Murgul mine, they were recommended for additional explorations.

This inner, molybdenum-copper-zinc zone is surrounded by a copper-zinc zone, of a highest economic importance, due to the fact that the largest copper deposits, in the Black Sea Coastal Region, are concentrated here. In the area covered by this paper, the deposits near Tunca, Peronit, Sivrikaya, Kutonit, Başköy, Hohur Sırt, Çakmakkaya, Anayatak, Akarşen mine, and the deposits near Kuvarshan and in the Kürzade-Melo area, are located in this zone, in addition to numerous copper mineral occurrences.

All these deposits are featured by high copper concentrations, and relatively subordinate presence of zinc. Generally, the lead is highly subordinate and present locally only, for instance at Budiyet Köprü - Çamur Yayla mountain road.

Inside this zone, the most abundant ore mineral is pyrite, in the form of cubic, pentagon-dodecahedron and octahedron crystals; the second in abundance is chalcopyrite sporadical in the form of tetrahedron crystals, with less frequent other copper minerals, followed by sphalerite and very subordinate galena.

The copper-zinc zone is featured by numerous minor quartzdiorite intrusive bodies, where the copper and zinc background concentrations are appreciably higher than those normally found in the similar rocks.

It is the author's opinion that this zone is neither adequately studied nor investigated, and that several new mineral occurrences and deposits may be expected here, as indicated by the geological and structural relations.

One of the serious problems related to investigation of this zone represents the difficulty of access and the thick overburden; then aeromagnetometric survey may be highly helpful to locate the mineralized structures, simplifying in this way the subsequent ground explorations for copper and zinc deposits.

The next and final zone, identified so far, is the lead-zinc zone. It contains numerous lead-zinc deposits and occurrences, associated locally with copper; sometimes the copper concentrations are high enough to form a copper deposit.

This zone is developed over a small part of investigated area, mainly along the coast, and partially submerged. The most important are the Büyükköy, Karaağaç and Maden Köy (near Çayeli), Pilargivat (near Ardeşen) and Pehlivan Köy and Maradit (near Maradit) mineral deposits and occurrences. It is also possible that Köprübaşı deposit near Tirebolu belongs to this zone (Encl. I).

Here the most abundant are galena and sphalerite; chalcopyrite is generally subordinate, although it sometimes may form its own deposits (Maden Koy); pyrite is of variable abundance.

The zone is featured by high lead and zinc concentrations. The deposits are of vein type, and located inside the structural zones.

The future explorations should introduce the necessary corrections in the present concepts and ideas, particularly relating to location of structures and the spatial distribution of different zones around the granodioritic pluton.

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Photo 1 - A «m» fold (faulted) in the tuffaceous sandstone (about 2 km W of Başköy mine, Murgul).

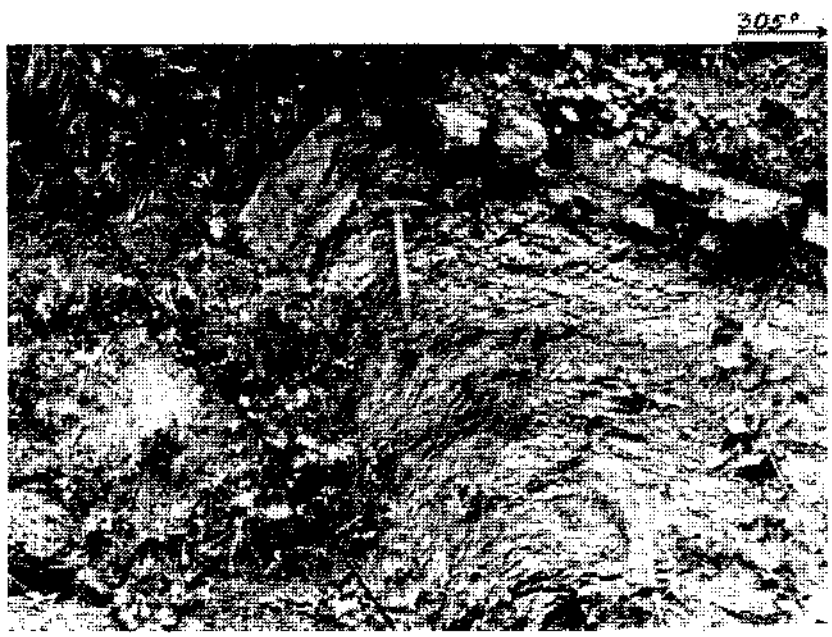


Photo 2 - A limestone bed inside the marls (folded, faulted and reversely overthrusted) about 2 km NW of Başköy mine, Murgul area.

Photo 3 - A «dm» fold in marls. Murgul - Petek Köy road.

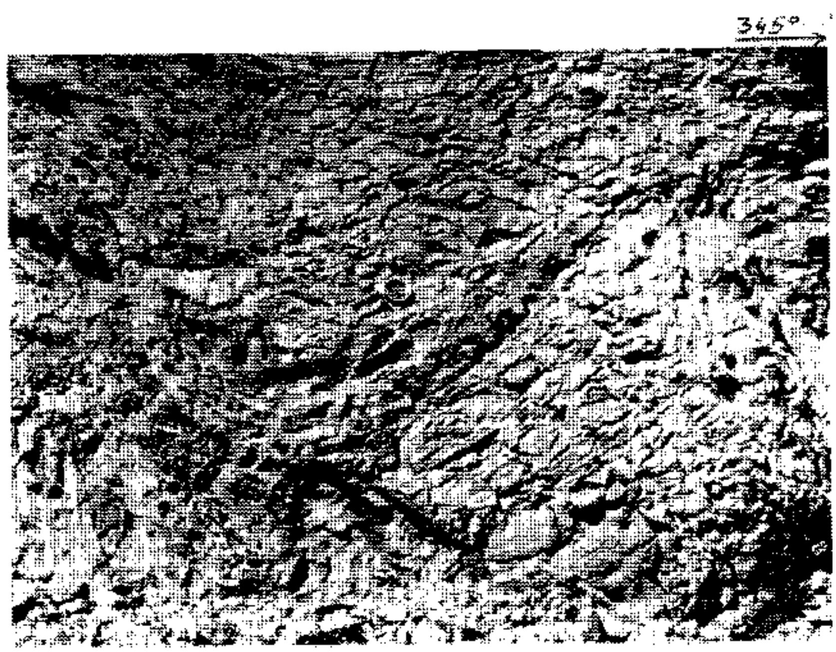
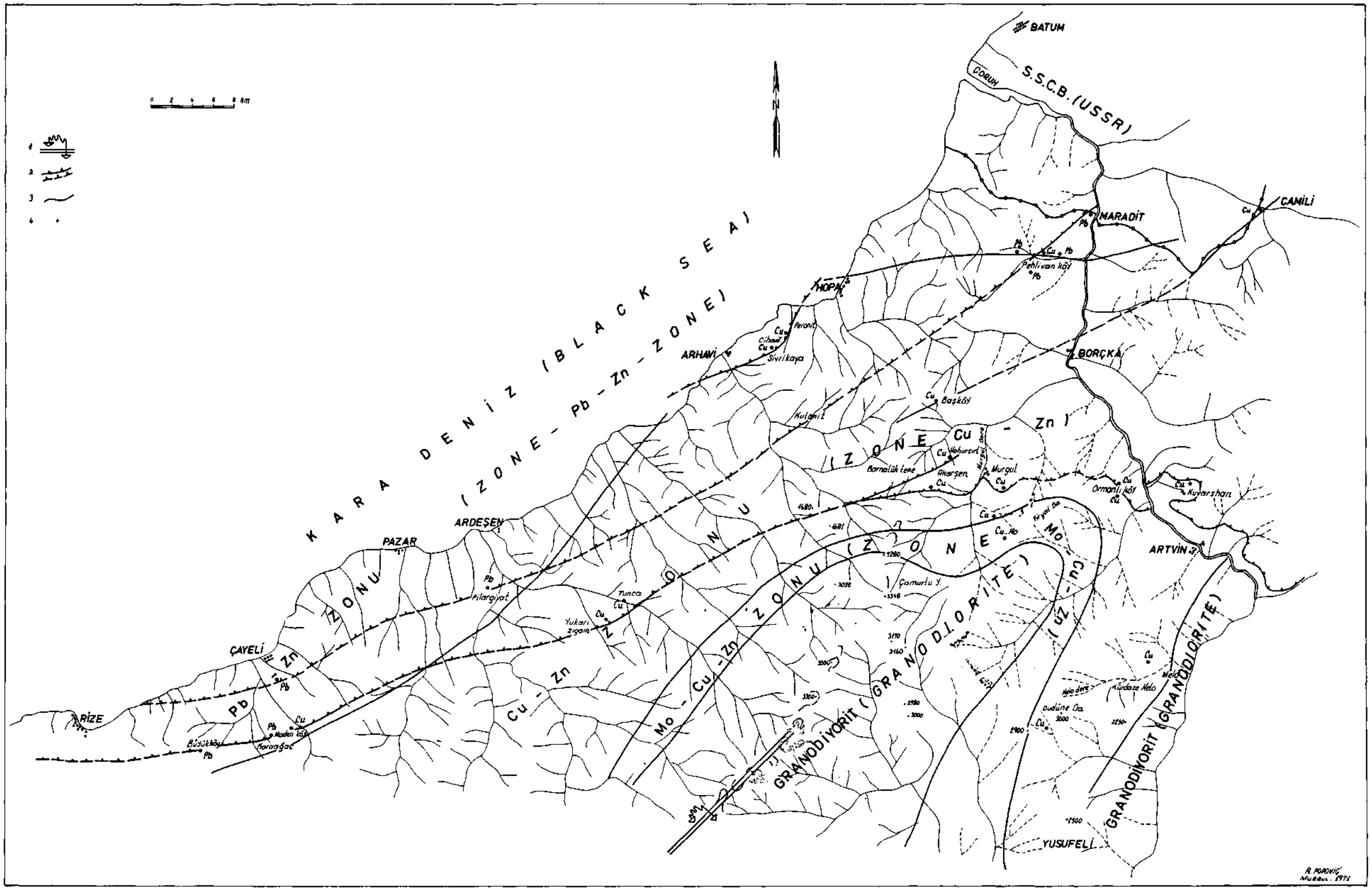


Photo 4 - A «m» fold in marls. Murgul - Petek Köy road

Photo 5 - An overturned «m» fold inside the rhyolite-dacite sequence (Upper Jurassic - Lower Cretaceous?), Kilise Tepe, Murgul.

Photo 6 - The apex of recumbent anticline (left) and mineralized fissures (right).



EASTERN PONTIDES — STRUCTURAL MAP WITH THE ZONAL DISTRIBUTION OF ORE DEPOSITS AROUND THE GRANODIORITE PLUTON

1 - Axis of anticlinorium; 2 - The visible and inferred imbricate structures; 3 - The schematic zonal boundaries between the different ore deposits; 4 - Ore deposits and occurrences.