GEOLOGY OF THE ÇAYELİ-MADENKÖY COPPER-ZINC DEPOSIT AND THE PROBLEMS RELATED TO MINERALIZATION

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ABSTRACT. — The Çayeli-Madenköy copper-zinc and pyrite deposit has been known for a long time. Detailed study of the area, initiated by the Mineral Research and Exploration Institute (M.T.A.) in 1967, has now reached its final stage and detailed studies are concentrated on the Implementation of the feasibility studies of the area, for the purpose of which hydrogeological surveys are being conducted in the field, and ore-beneficiation tests carried out in the laboratories.

Resulting from the studies thus far carried out, the geological structure as well as the ore potential of the area were determined.

The sequence of the units observed in the area covered by the present paper is, from bottom to top, as follows:

Upper Cretaceous	**Upper basic series**	**13 - Marl-tuff-conglomerate-limestone-sandstone**
		12 - Basalt (β_4)
		11 - Red-colored limestone
		10 - Andesitic breccia
		9 - Olivine basalt (β_3)
		8 - Purple tuff III
		7 - Augite basalt (β_2)
		6 - Purple tuff II
		5 - Basalt (β_1)
		4 - Purple tuff I
	Lower dacitic series	**3 - Dacitic tuff breccia**
		2 - Sandy dacitic tuff
		1 - Dacitic tuff

The upper basic series and the lower dacitic series are separated by the andesitic intrusives.

The origin of the stockwork-type ore, occurring at the base of the deposit, is hydrothermal metasomatic, and the overlying massive ore is volcanogenic. Mineralization took place during the Upper Cretaceous, in the interval between the final phase of the acidic volcanism and the initial phase of the basic volcanism, and is confined to a well-defined stratigraphical level.

INTRODUCTION

The deposit is located in Madenköy, Çayeli County, Rize Province. The distance between Madenköy and Çayeli, situated on the Black-Sea coast, is 8 km. The sharp relief of the area is due to the mountain ranges occupying the southern part of the region. Here, the Kaçkar Mountains trend in a SW-NE direction. The mine site is in the center of a densely populated area, which is covered almost entirely by tea plantations.

The Çayeli-Madenköy copper-zinc and pyrite deposit is one of the most important sulphidic copper and zinc sources of Turkey.

In 1967, when detailed studies on the area described here were started by the M.T.A. Institute, available information and data on the deposit were very scarce.

Turhan (1969), who visited this area, reports the presence of horsts and grabens which developed as a result of the NE and NW-striking faults. According to this author, mineralization observed in the area under study is of impregnation and replacement type, due to hydrothermal processes which followed the formation of the Tertiary Tatos batholith of acidic character (see 1:500,000-scale Geologic Map of Turkey).

The geophysical studies conducted in this region (Turgay, 1969) revealed that the anomaly curves discovered by the I.P. method are closed towards northeast, in the vicinity of Büyük Dere, while they cover more extensive areas in the northwestern part of the region.

Ovalıoğlu (1971) reports that the purple tuffs occurring in this area overlie the massive ore lenses; he notes that the basalts, observed locally, are sills, and further states that the area may contain other lenses, although unexposed, since the horsts and grabens are likely to mask these lenses. Drilling conducted in the area gave promising results, thus increasing the importance of the deposit.

In order to determine the factors controlling the distribution and extension of mineralization, the author of the present paper has prepared a I :l,000-scale geological map (Fig. I) of a small portion (0.2 km^2) of the region, which revealed that this mineralization is closely related to the structure of the area and occurs in well-defined sequences (Altun, 1972). Based on the results obtained by the author, a total of thirteen drill holes were opened in the area by the end of 1974.

Mado (1973), who also carried out a geological survey of the area on a 1:10,000 scale, reports that the purple tuffs which constitute the hanging wall of the deposit are interbedded with basalt sills and andesitic breccia. He classified this ore as follows: I - Massive pyrite ore (yellow ore), 2 - Cu, Pb, Zn ores (black ore). Further, the black ore is divided into: (a) massive ore, (b) impregnated ore, and (c) aggregated veinlets. According to Mado, the black ore was formed in the uppermost levels, at relatively higher temperatures as compared to the yellow ore.

Nebioğlu (1975), who prepared a I :l,000-scale geological map of the same area, reports, however, that the classification of the Upper Cretaceous volcanic series as lower basic, lower dacitic, upper basic and upper dacitic series—as proposed by the earlier investigators —is not sufficient and should not be accepted, since such a classification does not solve the problem. He notes, further, that the units previously described as purple tuffs are, in fact, pumice tuff and the basalts occurring locally are of intrusive origin. Nebioğlu describes this ore as massive, disseminated stockwork and pyritic ore.

Results obtained from various studies and investigations conducted in the area by the end of I974supported the author's opinion and very important copper, zinc and pyrite reserves were established. Furthermore, some basic principles regarding this type of deposits found in the area described were determined.

The purpose of the present paper is to describe the relationship between the mineralization and structural features observed in the area.

GEOLOGY

The Madenköy copper-zinc-pyrite deposit is situated in the eastern part of the Black-Sea region (The Pontids), which was strongly affected by the Alpine orogeny (Ketin & Erentöz, 1962). Rocks developed as a result of submarine volcanic activities (Upper Cretaceous-Tertiary) are widespread in the area. These rocks (from old to young) are as follows:

5 - Young volcanic series,
4 - Upper dacitic series,
3 - Upper basic series,
2 - Lower dacitic series,
I - Lower basic series.

Sawa and Hamamcıoğlu (1970) describe the basic series, occurring in the eastern Black-Sea region and separated by the acidic series, as the lower basic and the upper basic series.

Although the exact age of the lower basic series, located outside the area under investigation, could not be determined, it is likely that the said series was formed during the lower stages of the Upper Cretaceous.

Based on the microfossils identified within the mudstone-limestone intercalations, the age of the lower dacitic, upper basic and upper dacitic series was established to be Senonian.

The young volcanic series of the area are overlain by the Miocene sandstones (Can, 1974).

Intrusive rocks (granite-granodiorite-diorite) occurring in the area are of Miocene age (Baykal, 1949; Wijkerslooth, 1946). Çoğulu (1970) established the radiometric age of the Rize-Tatos acidic intrusives as 30 M.Y. The series described here are intersected by the basaltic and andesitic intrusives. It should be noted that the same features prevail throughout the eastern Black-Sea region.

The lower dacitic series and the upper basic series are characterized by an unconformity (Altun, 1972). Here, acidic series, as compared to the basic series, show poorer development. The purple tuff-basalt alternations, observed in the basal part of the upper series, is a characteristic feature of the Çayeli-Madenköy area (Altun, 1972).

Lower dacitic series

The lower dacitic series starts with the dacitic lava and ends up with the dacitic tuff-breccia. Between these two units, dacitic volcanic conglomerates, dacitic tuff and sandy dacitic tuff units occur. Lower dacitic series is overlain by the upper basic series in the western and northern parts of the area. The upper levels of this series can be seen in the area under investigation.

Major rock units forming the lower dacitic series and their properties may be described as follows:

Dacitic tuffs.— Dacitic tuffs—generally fine-grained and bedded—show better development as compared to the other units of the lower dacitic series. They occur as a cement consisting of quartz, alkali feldspar and plagioclase. Within this cement phenocrysts of plagioclase, alkali feldspar and corroded quartz are present. These rocks are strongly kaolinized, sericitized, silicified and calcitized; chloritization, however, is poor. The unit described here can be seen in the eastern part of the area, where it extends in a NE-SW direction (Fig. I).

Dacitic sandy tuffs. — This series consists of tuffaceous sandstones and shows sorting. It is believed that—following the formation of dacitic tuffs—the depression areas, which developed as a result of the uplifting and subsidence processes, were subsequently filled with the materials transported to these areas and formed the dacitic sandy tuffs. Dacitic sandy tuffs consist of quartz phenocrysts, calcitized plagioclase and some alkali feldspar fragments contained in a kaolinized, slightly calcitized and silicified cements. They can be seen in a small area to the east and in the central part of the region (Fig. I).

Docitic *tuff breccia.* — This unit consists of quartz phenocrysts, plagioclase fragments and dacitic pebbles contained in a kaolinized, silicified and slightly chloritized cement. Dacitic tuff breccia can be seen in the east occupying a small area, where it overlies the dacitic sandy tuffs (Fig. I).

Andesites. — Andesite sills and dykes are encountered in the area under investigation; these consist of a groundmass containing plagioclase phenocrysts, plagioclase and dark-colored minerals. On the surface, andesitescan be found in a restricted stratigraphic level between the lower dacitic series and the purple tuff I (Fig. I).

Upper basic series

The upper basic series consist mainly of basalt, andesite, spilitic lava and their pyroclasts, sandstones and limestone intercalations. They overlie unconformably the lower dacitic series. It should, however, be noted that the surface of the unconformity does not show any sharp undulations. In the area under study, the basal part of the upper basic series consists of purple tuff and basalts, andesitic breccia, red-colored limestones, basalts and marl-tuff breccia-limestone-sandstone units (Fig. I).

Purple tuffs. — This unit consists mainly of sandstones and tuff breccia, and occurs as alternations within the basalts. The term assigned to this unit by Ovalıoğlu (1971) is based on the color observed in the field. Nebioğlu (1975), on the other hand, describes the same unit as pumice tuff.

' Mainly three purple tuff units, bordered by the basalts, were distinguished in this area (Altun, 1972); these units show close similarities regarding their external appearance. They generally consist of dacite, andesite, rare basalt pebbles, and quartz phenocrysts (Pl. V, fig. I), as well as of plagioclase, alkali feldspar and dark mineral fragments contained in a kaolinized, sericitized, hematitized and carbonitized cement.

The proportion of pebbles and mineral fragments contained in the purple tuff units varies considerably and is closely related to the order of formation of these units. Going from old to younger formations, the amount of acidic materials decreases. Sorting is common. Schistosity is also observed, and basaltic flows, although local, are present.

Basalts. — Mainly three basalt units, alternating with the purple tuff units, were distinguished in the studied area (Altun, 1972). These, in the order of formation, are basalts, augite basalts and olivine basalts.

Ovalıoğlu (1971), Mado (1973) and Nebioğlu (1975) describe the basalts, depending on their structural position, as sills and dykes. Turhan-(I969), however, identified these as basaltic flows. As a result of spheroidal weathering, jointing produced during cooling cannot be seen throughout the area. In the upper layers gas pockets filled with calcite and chlorite are very common. Near the lower and upper boundaries interbedded limestones, tuffites, and sandstones, representing a well-defined stratigraphical level, can be observed, Basalts sometimes contain tuffaceous sandstones, locally attaining considerable thickness. At the boundary with the bedded rocks no contact effects could be seen (Pl. III, fig. I, 2). Based on the above observations, the author of the present paper identified the basalts as lava (Altun, 1972). Plagioclase (labradorite) phenocrysts are the major constituents. Moreover, augite basalts contain phenocrysts of augite, whereas olivine basalts include phenocrysts of augite and olivine. Groundmass consists essentially of plagioclase with lesser amounts of augite and olivine. Basalts and augite basalts do not extend along the NW dip, whereas augite basalts pinch out towards the south.

Andesitic breccia. — Andesitic breccia consists of tuffs and tuff breccia and is more fine-grained in its lower levels. Andesites include rare basalts as well as small amounts of plagioclase and fragments of dark-colored minerals. Cementing material is represented by clay and chlorite. These rocks extend from north to south, pinching out towards the vicinity of Mezarlık Tepe (Fig. I).

Red-colored limestones. — These rocks are fine-grained and contain feldspar and quartz fragments; sandstone intercalations are also observed. The following Upper Senonian fossils were identified in this unit:

Globotruncana calcarata Cushman
Gl. cf. *fornicata* Plummer
Gl. cf. *Hnneiana* (Dlore)
Gl. cf. *concavata* (Brotzen)
GL lapp. tricarinata (Quereau)
G. *lapp. coronata* Bolli
Gl. cf. *area* Cushman
Gl. lapp. lapparenti (Brotzen)
Gumbelina sp.
Globlgerina sp.
Radiolaria

Limestone described above can be observed in the northern part of the area overlying the andesitic breccia; in Narollar they are encountered above the olivine basalts; and to the south of Narollar they overlie the purple tuff III (Fig. I).

Basalts (b_4). — Basalts occur as pillow lavas; the interstices between them are filled with light-brown-colored mudstones. These basalts consist of agroundmass composed of plagioclase (labradorite) phenocrysts, augite grains, calcite and chlorite. Gas pockets contain calcite and chlorite. The basalts occur in the northwestern part of the area studied (Fig. I).

Marl-tuff breccia-sandstone-limestone. — This unit mainly consists of rather fine-grained sandstones which contain marls and limestones in the lower levels with tuff breccia intercalations. Cementing material is represented by basalt and plagioclase pebbles, chlorite and carbonate. The unit extends from SW to NE along the western margin of the area (Fig. I).

STRUCTURAL GEOLOGY

Rocks occurring in the area covered by the present paper extend generally from NE to SW along the Black-Sea coastline. Local structural variations observed in the area are represented by NW-SE-trending folds.

Although NE-SW- and NW-SE-trending folds are not uncommon in the Madenköy (Çayeli) area, anticlines are more pronounced. Based on the facies changes observed in the dacitic sandy tuffs, it was concluded that the NE-SW-trending folds were older and that they were developed following the formation of dacitic tuffs. The NW-SE-trending folds, however, were developed after the formation of dacitic sandy tuffs. They attained structural significance with the formation of the lower dacitic series, followed by the intrusion of the basic rocks.

Both of these folding systems were penecontemporaneous to the formation of the upper basic series, and this activity continued also in the later periods. As a result, some of the units of this series (andesitic breccia does not extend to the south of Mezarlık Tepe) are confined only to a certain area, attaining their present structure.

Although several investigators—i.e. Geoffrey (I960), Turhan (1969) and Ovalıoğlu (1971)—report that block faulting is the most pronounced structural feature of the area under consideration, field observations (Fig. I) and data obtained on the subsurface geology of the area (Fig. 2,3) do not support this viewpoint, thus leading to the conclusion that folding is the predominant structural feature of the formation.

Fracturing can be seen usually in the basal part of the upper basic series and in the lower dacitic series of this area. The fractures developed within the upper basic series are small and essentially local in character.

MINERALIZATION AND RELATED HYDROTHERMAL ALTERATION

Hydrothermal alteration is represented in our area of study by chloritization, silicification, kaolinization, sericitization, pyritization and carbonatization. The types of alteration products vary in relation to the type of mineralization.

Chloritization. — Chloritization is observed along the marginal zones of the mineralized sections of the lower dacitic series; in purple tuffs; and especially in the parts of the purple tuffs encountered in the syncline in the south of the area; in basalts and in andesitic breccia. Chloritization observed in the sandstones is assumed to be related to a later phase of hydrothermal alteration.

SHicification. — Dacitic series and mineralized parts of the purple tuffs show silicification; sericitization, on the other hand, increases towards the margins.

Sericitization. — This type of alteration can be seen in the dacitic series, in purple tuffs and, locally, in the andesitic breccia; it took place in the interval between the last stage of chloritization and the initial stage of silicification.

Pyritization. — Pyrites, encountered in this area, are observed as disseminations of smaller medium-sized hexahedral, octahedral and pentagonal-dodecahedral crystals.

Fine-grained pyrite in the form of hexahedral crystals is found in the lower dacitic series, near the central parts of mineralization and is disseminated as fillings in the cracks and fissures of the same unit; very rarely it can be also observed in the purple tuffs overlying the massive ore lenses. The medium-grained pyrite (0.5-3 mm), on the other hand, is encountered as hexahedral, octahedral and pentagonal-dodecahedral cuystals, occurring in the syncline, mainly as disseminations in the purple tuffs, which overlie and underlie the massive ore bands. Disseminations of pyrite crystals, hexahedral in form and 0.5 to I mm in size, are encountered in the lower layers of the andesitic breccia.

Carbonatization. — This type of alteration is represented by siderites ($FeCO_3$) and rhodochrosites ($MnCO_3$). Siderite was formed in the intervals between mineralization phases of sulphide. It occurs mostly as disseminations within the purple tuffs overlying the massive ore lenses and in the basal and marginal zones of the mineralized units, and to a lesser degree as veinlets. There is a clear relationship between siderite and hematite contained in the purple tuffs. It is evident that hematite observed in our area of study must be an alteration product of siderite formed during the metamorphism of the purple tuffs.

Rhodochrosite, however, mainly occurs as veinlets and dots within the purple tuff III unit and is generally accompanied by Mn-oxides.

MADENKÖY COPPER-ZINC ORE DEPOSIT

At the surface of the deposit—subsequent to mineralization—very fine-grained pyrites in the form of hexahedral crystals occur as filling in the cracks and fissures developed within the dacitic pyroclasts; silicified parts of the deposit, however, contain veins and veinlets consisting of gray-colored quartz-pyrite-chalcopyrite and small quantities of sphalerite. Massive ore bands are found within the purple tuffs occurring to the south of the area and along the boundary between the purple tuffs and the dacitic pyroclasts; while in the central part of the area, again at the boundary between the purple tuffs and dacitic pyroclasts, pyrite masses containing kaolinized tuff fragments were observed.

However, in general, ore masses do not crop out in this area. Stockwork-type of ore occurs mainly in the upper levels of the dacitic pyroclasts and, locally, in the purple tuffs; the massive-type ore, however, mostly occurs along the boundary between the dacitic pyroclasts and upper basic series and in the lower parts of the upper basic series as well. Detailed surveys conducted in the area—in order to investigate the extension of the stockwork and massive ore—gave very satisfactory results.

Stockwork ore, although irregularly distributed throughout the area, is well developed under the massive ore lenses; average thickness of this ore is about 20 m. Metallic minerals, occurring as veins and veinlets and local disseminations, show a gradual decrease from top to bottom (Fig. 2, 3).

Massive ore, on the other hand, occurs as lenses and bands in the basal part and in the lower levels of the upper basic series. In the upper part, these massive ore lenses and bands are bounded by the purple tuff unit, and—in the order of formation—the second group of lenses shows a relatively better development.

The massive ore lenses described above plunge 20°-25°NE(Fig. 3), dipping 60°-85°NW (Fig. 2). The average thickness measured in the central part of mineralization is approximately 20-25 m. Their extension along the NW dip—in the order of formation—is 200 m, 300-350 m, and 250-300 m, respectively, whereas along the NE dip these lenses extend as much as 450 m.

The massive ore bands occur within the purple tuff units and are represented by several levels. Their extension is limited, and their thickness varies from 0.5 m to 2 m.

Dacitic tuffs and tuff breccia occur as country rock in the stockwork-type of ore, while in the massive ore-type they represent the footwall of the formation. The purple tuffs, on the other hand, are encountered as hanging wall or more often as footwall of the massive ore. Basalts and augite basalts observed on the surface in this area in the purple tuffs dip in a NW direction and gradually pinch out beneath the massive ore lenses (Fig. 2).

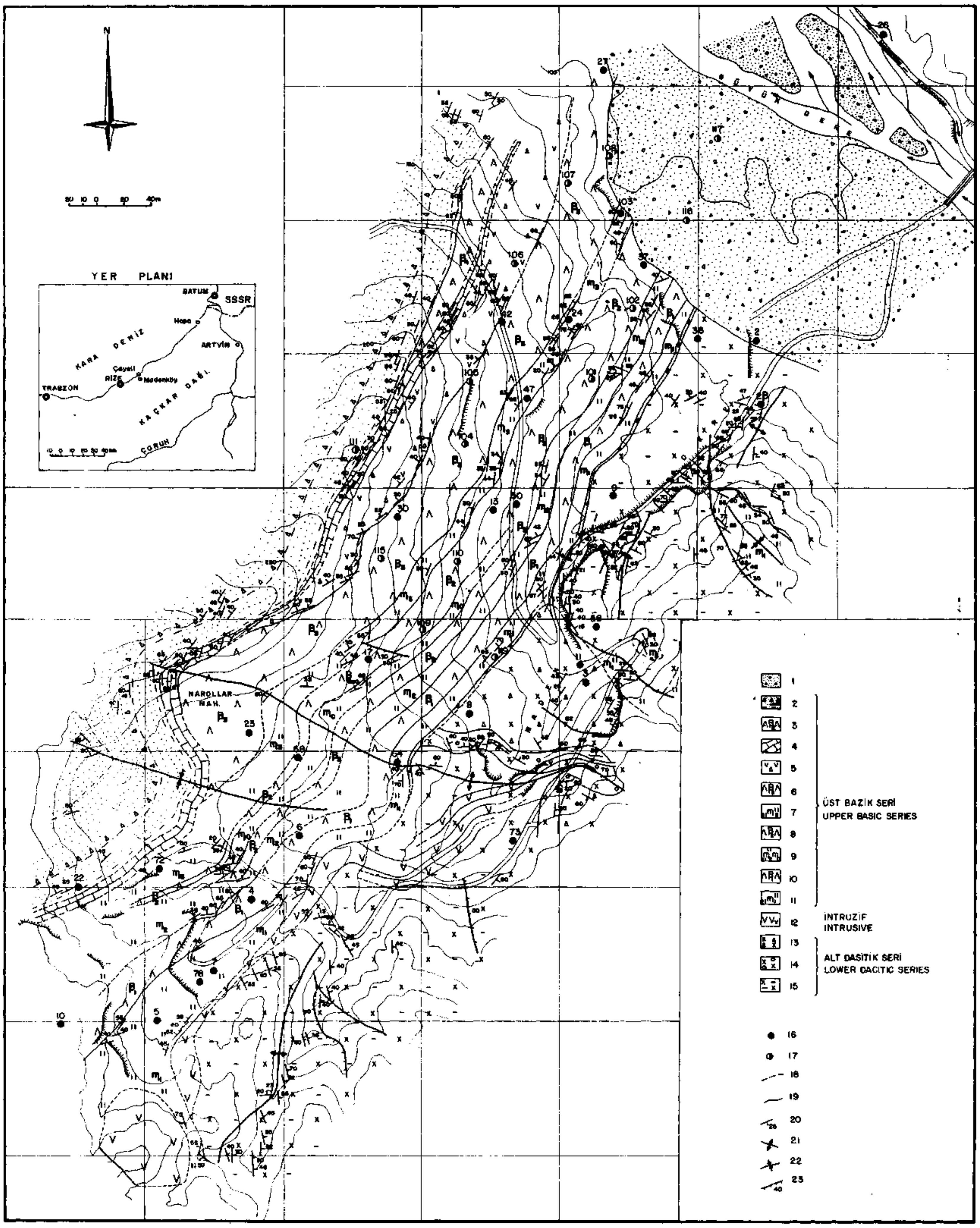

Fig. 1 - Geologic map of the Çayeli ore deposit.

1 - Alluvium; 2 - Marl-tuff breccia-limestone-sandstone; 3 - Basalt; 4 - Red-colored limestone; 5 - Andesitic breccia; 6 - Olivine basalt; 7 - Purple tuff III; 8 - Augite basalt; 9 - Purple tuff II; 10 - Basalt; 11 - Purple tuff I; 12 - Andesite; 13 - Dacitic tuff breccia; 14 - Dacitic sandy tuff; 15 - Dacitic tuff; 16 - Drilling conducted by M.T.A. in 1967-1972; 17 - Drilling conducted by M.T.A. in 1972-1975; 18 - Probable formation boundaries; 19 - Formation boundaries; 20 - Strike and dip; 21 - Anticline axis; 22 - Syncline axis; 23 - Fault.

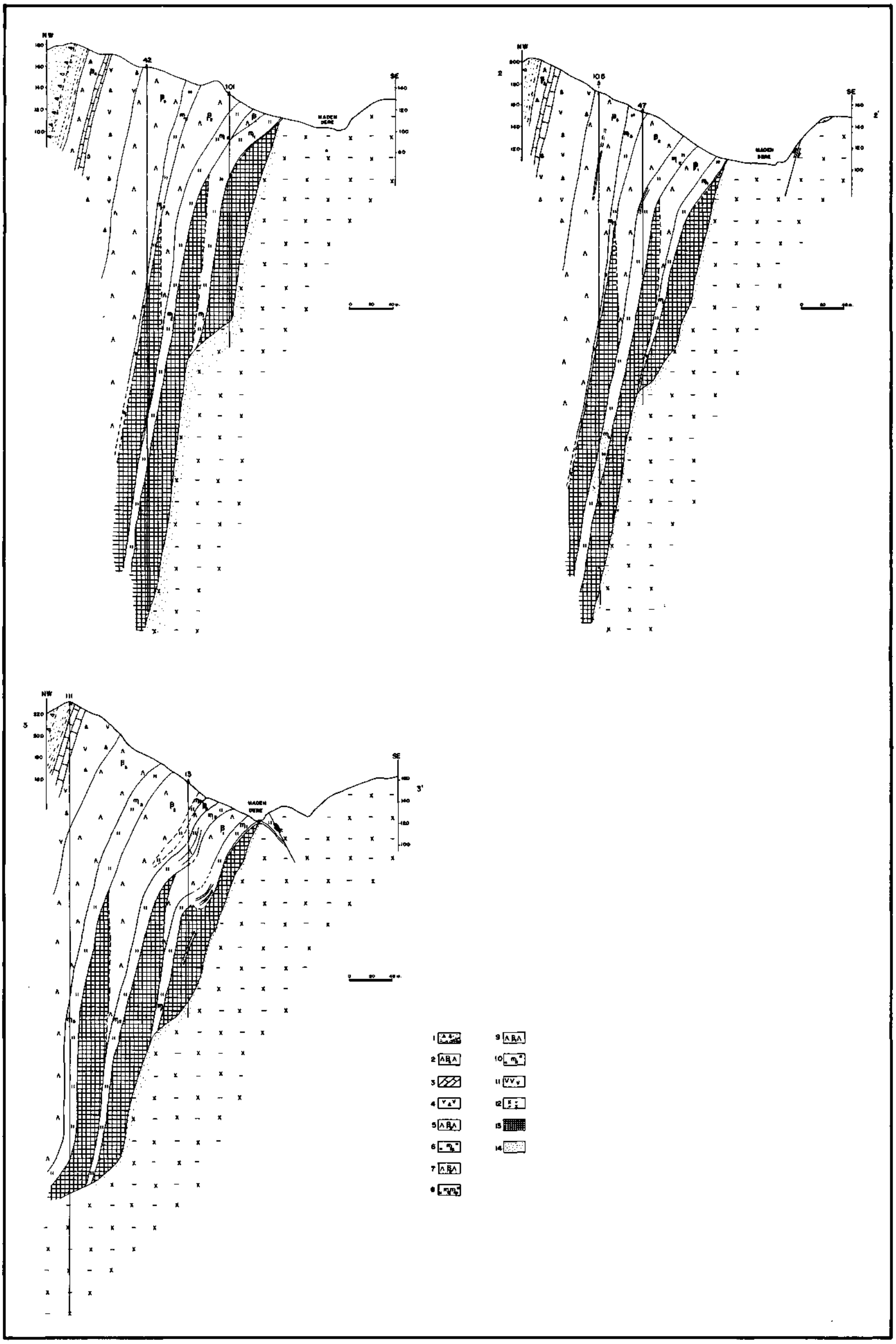

Fig. 2 - Geological cross sections of the Çayeli ore deposit.

1 - Marl-tuff breccia-limestone-sandstone; 2 - Basalt; 3 - Red-colored limestone; 4 - Andesitic breccia; 5 - Olivine basalt; 6 - Purple tuff III; 7 - Augite basalt; 8 - Purple tuff II; 9 - Basalt; 10 - Purple tuff I; 11 - Andesite; 12 - Dacitic tuff; 13 - Massive ore; 14 - Stockwork ore.

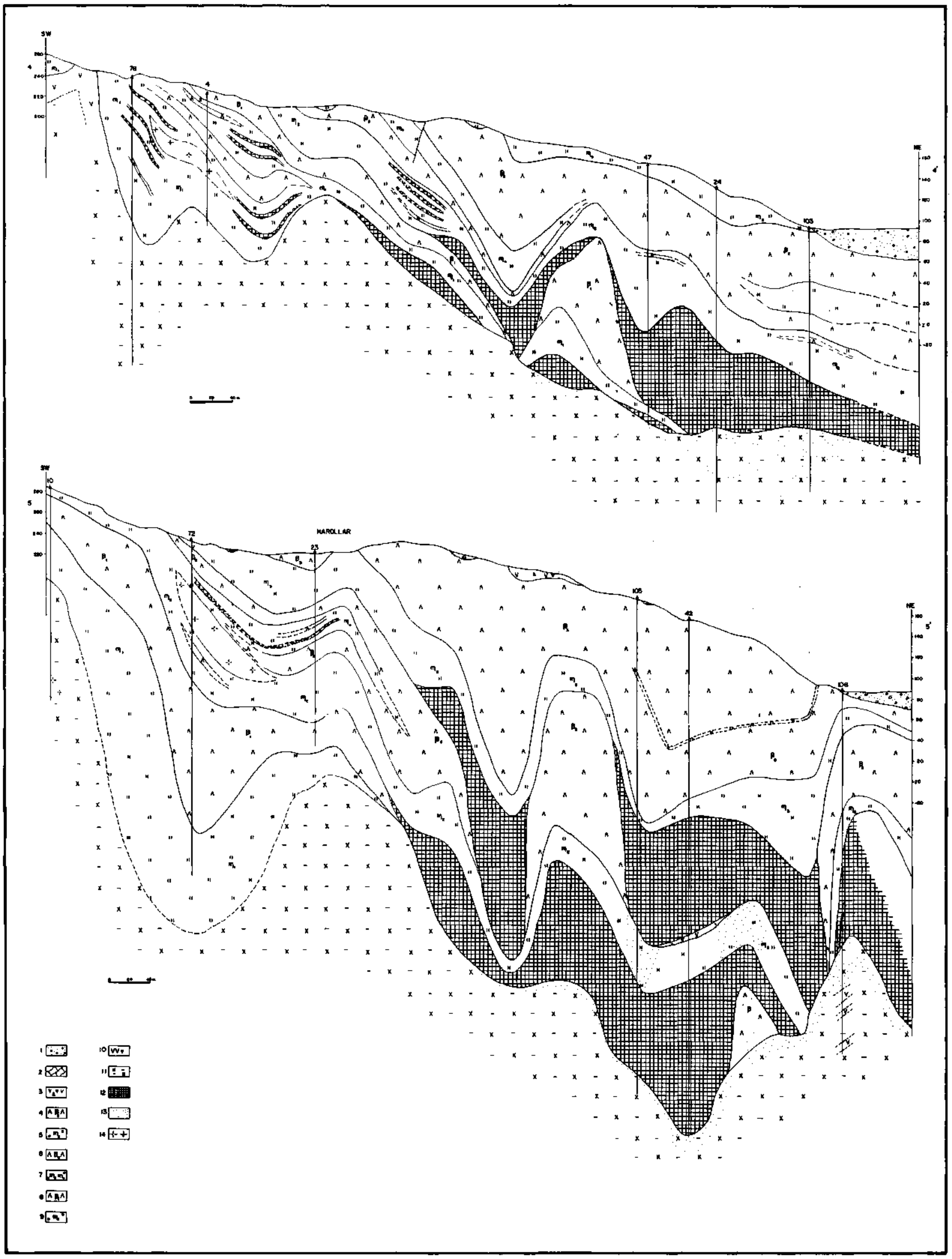

Fig. 3 - Geological cross-sections of the Çayeli ore deposit.
1 - Alluvium; 2 - Red-colored limestone; 3 - Andesitic breccia; 4 - Olivine basalt; 5 - Purple tuff III; 6 - Augite basalt; 7 - Purple tuff II; 8 - Basalt; 9 - Purple tuff I; 10 - Andesite; 11 - Dacitic tuff;- 12 - Massive ore; 13 - Stockwork ore; 14 - Gypsum.

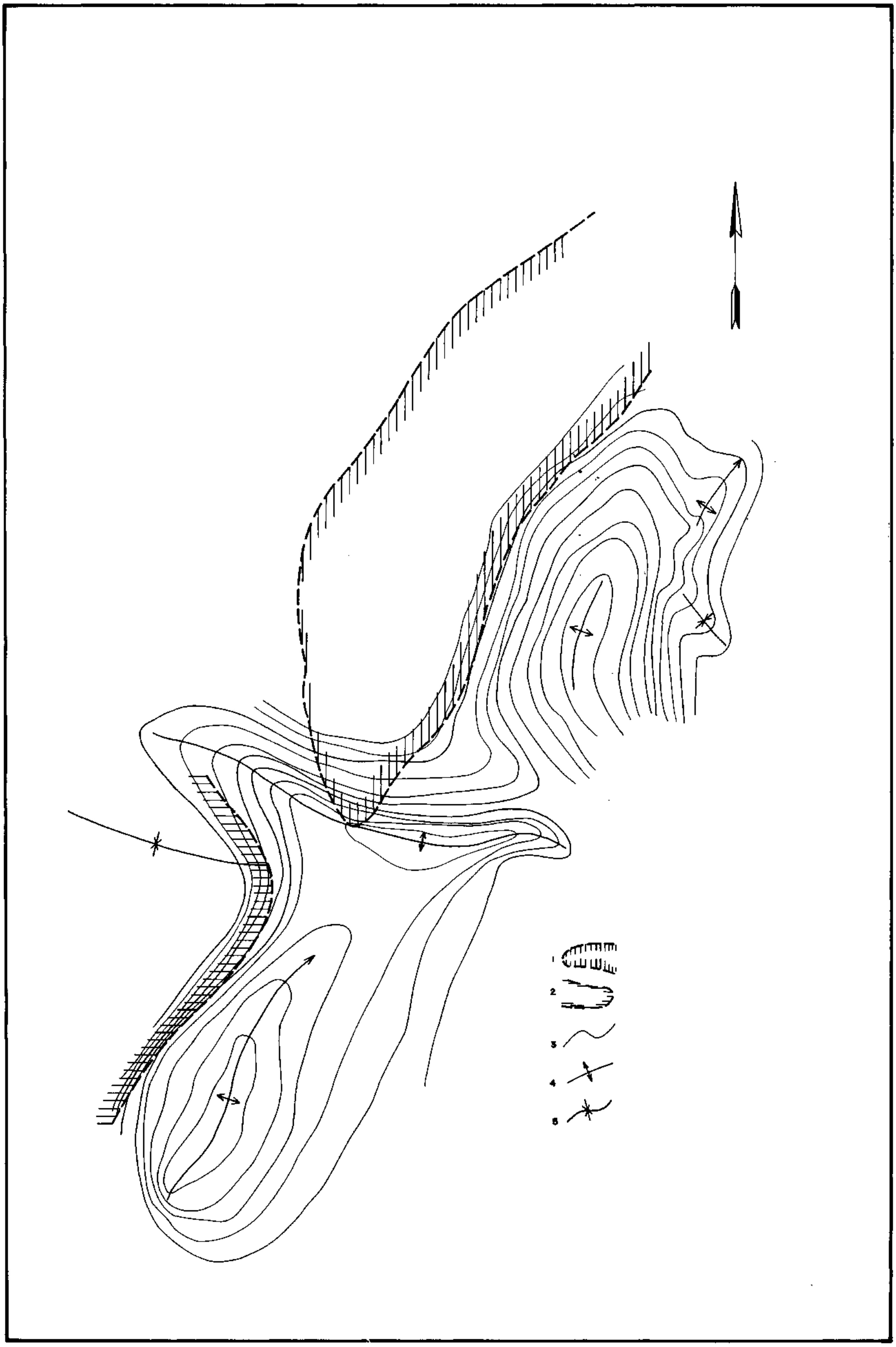

Fig. 4 - Schematic map showing the stratabound ore (based on the geological map).

1 - Massive ore lenses; 2 - Massive ore bands; 3 - Structural contour; 4 - Anticline axis; 5 - Syncline axis.

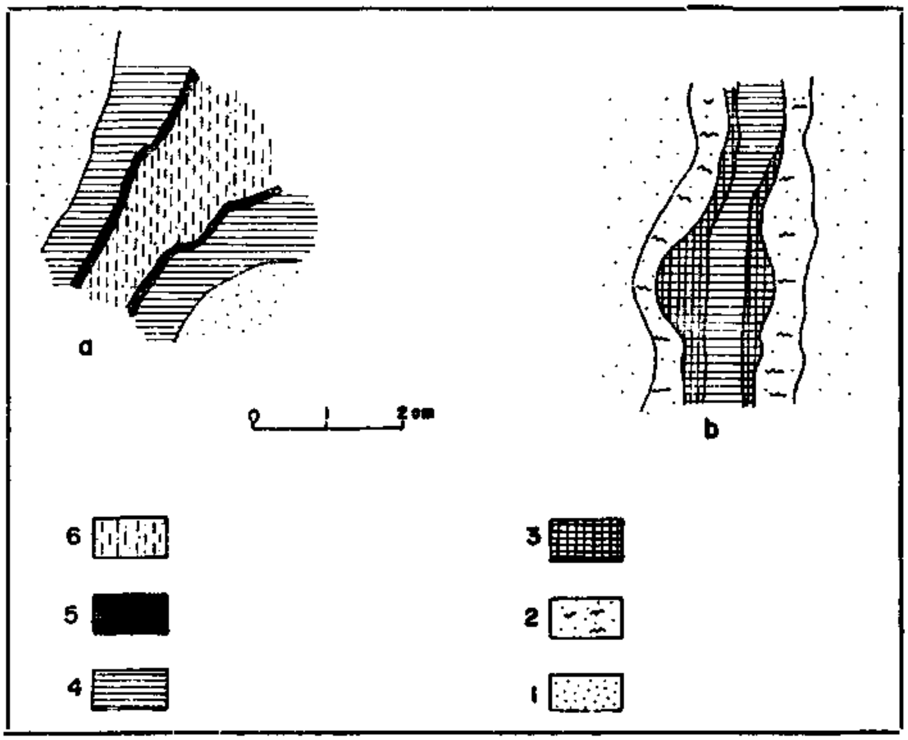

Fig. 5 — 1 - Dacitic tuff (contains disseminated silicified pyrite); 2 - Gray-colored quartz-pyrite; 3 - Pyrite; 4 - Chalcopyrite; 5 - Sphalerite; 6 - Pyrite-barite.

The stockwork-type ore is composed of veinlets and disseminations; it is developed in the dacitic pyroclasts and also, locally, in the silicified parts of the purple tuffs, and underlies the massive ore lenses.

The ore essentially consists of chalcopyrite, pyrite and small amounts of sphalerite. Quartz and barite occur as gangue minerals.

Stockwork-type veins are generally composed of gray-colored quartz-pyrite and chalcopyrite in the outer part, with sphalerite in the middle, and barite-pyrite in the innermost part. Some veins, however, are composed of chalcopyrite on the outside, of sphalerite in the middle and of barite in the central part; in some cases, only pyrite-chalcopyrite or on the outside chalcopyrite, and in the central part sphalerite are observed (Fig. 5a-b). Moreover pyrite, chalcopyrite and sphalerite frequently occur as loose disseminated grains and veinlets. It is generally presumed that mineralization observed in the area took place as a result of hydrothermal metasomatic processes. In the upper parts of the deposit, the amount of the ore minerals increases, whereas the country rock decreases. Here, ore minerals are accompanied by the gray-colored quartz and kaolinized rock fragments. This type of ore represents the transition from stockwork-type ores to massive ore.

Massive ore occurs mainly as bands and lenticular bodies in the area studied. The hanging wall of this ore shows a sharp boundary as this ore is developed conformably with the purple tuff units (Fig. 2).

Gümüş (1970) attributes the exhalative character of the mineralization, observed in the area, to the fact that tectonic activities took place immediately before the formation of the tuffs, and to the fact that the solutions accumulating along the boundary penetrated at the contact

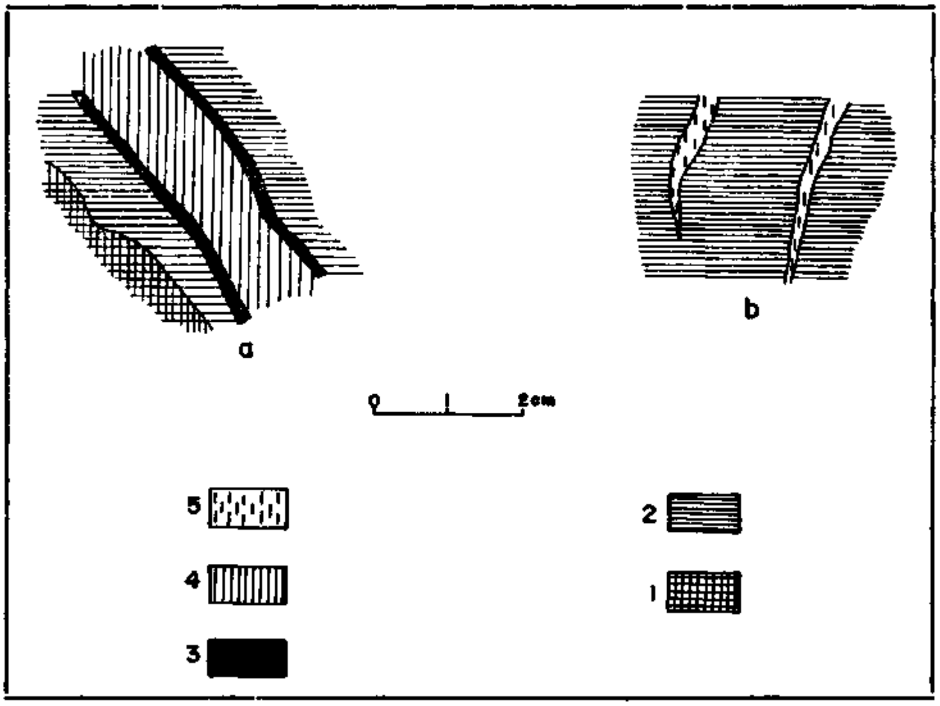

Fig. 6 — 1 - Pyrite; 2 - Chalcopyrite; 3 - Sphalerite; 4 - Pyrite; 5 - Barite.

zones. Turhan (1969) suggests, however, that the ore that might be found under the impermeable volcanic sedimentary series (basic series) was formed by the replacement processes. Vujanovic (1974), on the other hand, Considers this deposit as being of a volcanic sedimentary origin.

The brownish-purple color of the deposit—attributed to the presence of iron oxides and hydroxides—is a characteristic feature of the hanging wall ore in the area. The uppermost part of this deposit strongly suggests that this bed is of a marine sedimentary origin.

Massive ore bands consist mainly of sphalerite, chalcopyrite and small amounts of pyrite and galenite. It should, however, be noted that sphalerite and chalcopyrite occur generally in separate stratigraphic levels. Thus, it was concluded that one of these minerals occurs in the form of exsolutions in the other.

In the massive ore lenses the content of ore minerals varies considerably. In the first and especially in the second lens sphalerite is dominant, whereas in the third lens chalcopyrite is more abundant. The ore minerals of an earlier origin are intersected by the younger ones, which fill in the cracks and fissures of the deposit (Fig. 6a-b), and in the hanging wall they are covered by these minerals. Thus each lens consists of layers rich in zinc in its upper part and of copper-rich layers in the middle. The amount of pyrite increases in the basal part.

This ore consists mainly of pyrite, marcasite, chalcopyrite, sphalerite, galenite and, in lesser amounts, of bornite and tetrahedrite. Barite, chlorite and calcite occur as gangue minerals.

Ore minerals

Pyrite is found as round and amorphous grains, partly contained in chalcopyrite and sphalerite, or as gel composed of sphalerite, chalcopyrite, bornite and tetrahedrite (Pl. I, fig. 2), some fissures are filled with chalcopyrite.

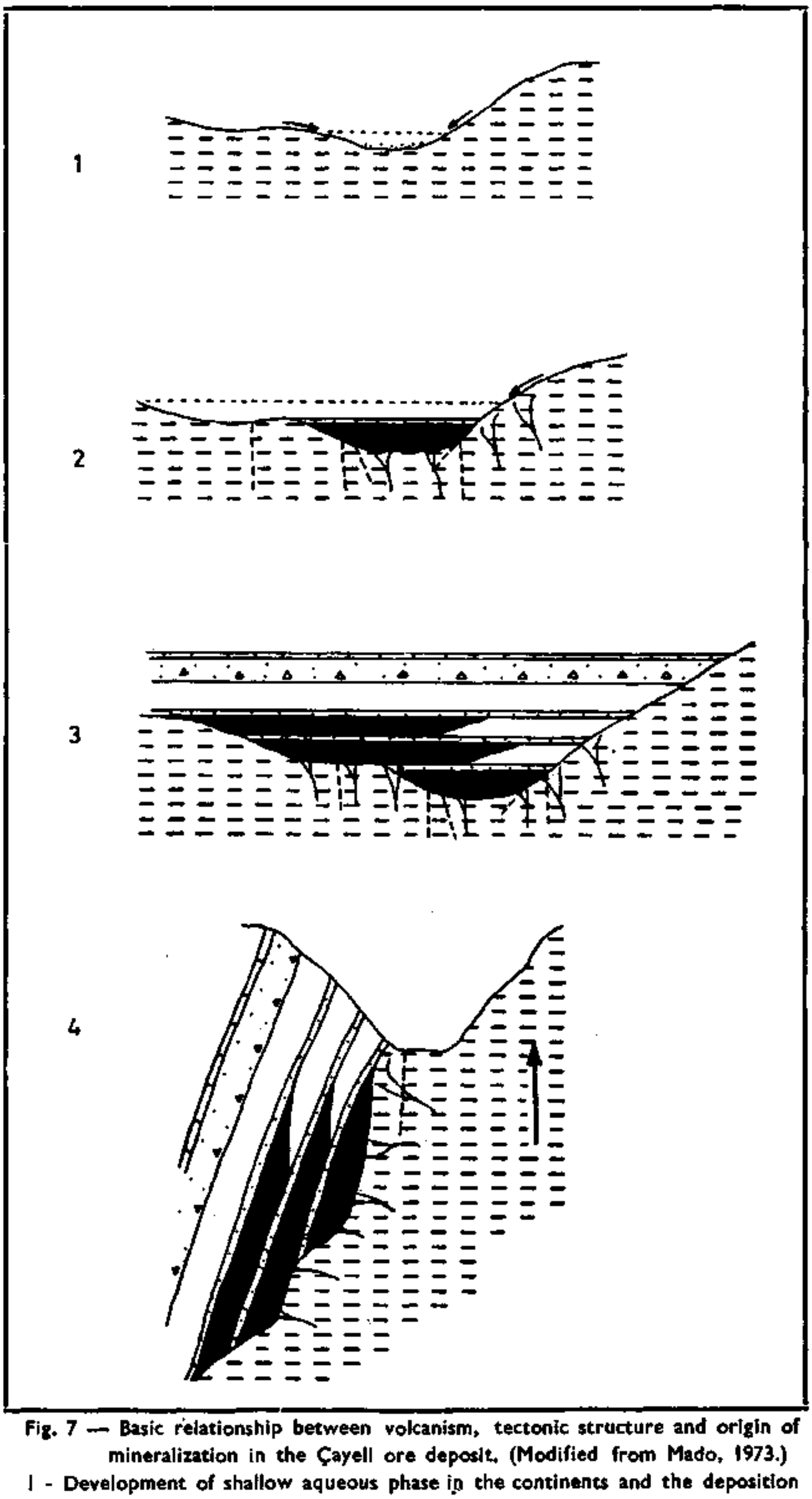

Fig. 7 — Basic relationship between volcanism, tectonic structure and origin of mineralization in the Çayeli ore deposit. (Modified from Mado, 1973.)

1 - Development of shallow aqueous phase in the continents and the deposition of fragments transported from the lower dacitic series; 2 - Initial stage of the deposition of stockwork and massive ore, and the formation of purple tuff I; 3 - Formation of massive ore, purple tuff and basalts (upper basic series) in the marine environment; 4 - Present condition of the deposit due to the effects of later folding.

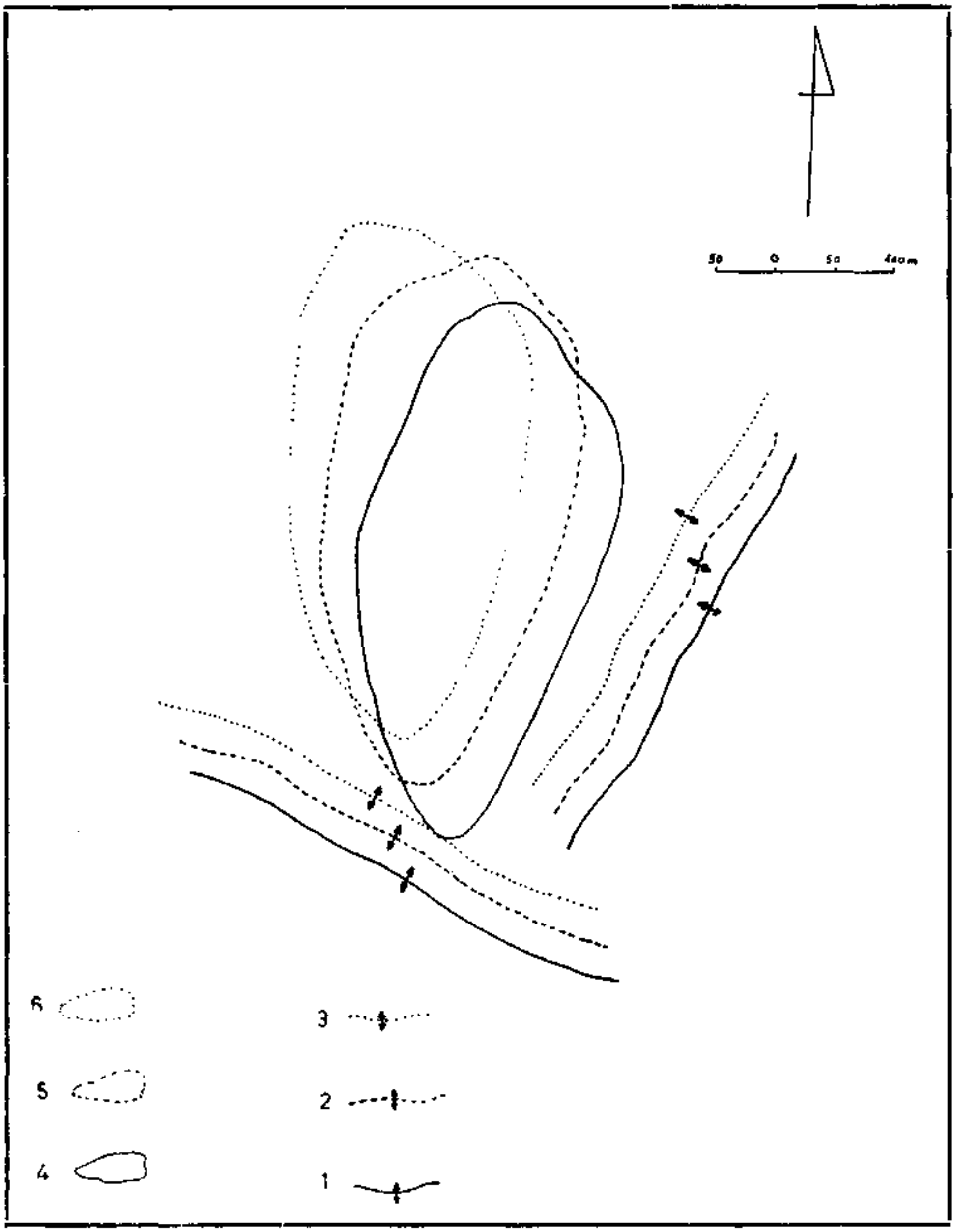

Fig. 8 — Diagram showing shifting of the axes of folds which control the mineralization and extension and boundaries of the massive ore lenses.

I - Anticlinal axes of the first ore lens at the time of its formation; 2 - Anticlinal axes of the second ore lens at the time of its formation; 3 ? Anticlinal axes of the third ore lens at the time of its formation; 4 - Extension boundary of the first ore lens; 5 - Extension boundary of the second ore lens; 6 - Extension boundary of the third ore lens.

Marcasite is found in the pyrite ores or as its alteration product.

Chalcopyrite occurs in sphalerite in the form of exsolution, as well as partly formed crystals (Pl. II,fig. I, 2); sometimes it is found together with sphalerite in the pyrite veins or in the form of hard, concentric spherules in association with pyrite in the sphalerite.

Sphalerite is amorphous, it occurs as inclusions in pyrite, chalcopyrite and gangue minerals (Pl. II, fig. I, 2) or replaces pyrite.

Bornite occurs in the outer part and the core of the concentric spherules; some tetrahedrite is also found in the outer part of these spherules.

RELATIONSHIP BETWEEN MINERALIZATION AND STRUCTURE

The Çayeli-Madenköy deposit covers an area which is bordered by NW-SE-trending anticlines in the south, and NE-SW-trending anticlines in the east, and in the south by synclines which extend from NW to SE. The mineralization of this deposit shows certain variations. After studying the type and characteristics of ores in this deposit, the boundaries of which are of structural nature, it must be assumed that these differences are closely related to the structure of this area.

Along the NW-SE syncline, in the vicinity of Narollar (Fig. 3), several layers of massive ore bands are observed within the purple tuffs. Stratigraphically these ore bands are located over the massive ore lenses and their mineralogical properties are different. In the massive ore bands the percentage of chalcopyrite and sphalerite, as compared to pyrite, is considerably higher. The grayish-brown-colored gypsum, encountered in the same area within the purple tuffs shows bedding. Mineralization of the dacitic tuffs (pyroclasts) located at the base of this unit is not of the stockwork type.

The massive ore lenses, comprizing the bulk of the stockwork-type ore and the massive-type ore, can be seen in the area bordered by the NW-SE-trending anticline in the south, and by the NE-SW-trending anticline in the east. In this area, the stockwork-type ore is well-developed within the upper parts of the dacitic tuffs (pyroclasts), particularly beneath the massive ore lenses. Going from the central part towards the margins, transition to the vein-and veinlet-type zones can be observed. Gypsum veins are encountered in the marginal zones.

The massive ore, which is situated between the anticlines described above and the low mountain ridges, running parallel to the NE-SW-trending anticline in the west (Fig. 4), is found in the form of lenticular bodies (Fig. 2, 3). These massive ore lenses were formed at relatively short intervals. Since during the formative period of each lens the axes of folds which controlled the mineralization were shifted in the northern and western directions (Fig. 8), the earliest massive ore lens that was formed is the nearest to the present axis of the anticline, while the youngest lens is the farthest from it.

The average content of copper and zinc minerals in the marginal parts of the massive ore lenses is higher in comparison to the central parts. The fact that during the ore formation process the central parts of the depression existing at that time were filled with pyrite explains a more extensive distribution of chalcopyrite and sphalerite, which were formed at a later date. Consequently, the contents of copper and zinc in the upper levels of the massive ore lens show very slight lateral changes.

The manganese formations—which can be occasionally observed within the deposit and in the adjacent areas—are mostly found in the marginal and upper zones of the mineralized units.

CONCLUSIONS

Results obtained from the present study may be summarized as follows:

In the Çayeli-Madenköy copper-zinc and pyrite deposit, the bulk of the ore masses is unexposed:

Mineralization occurred in the interval between the Upper Cretaceous acidic volcanism and the beginning of the basic volcanism, and can be traced in a well-defined stratigraphical zone.

Mineralization is controlled by folding.

The contact between the hanging wall and the overlying purple tuffs is very sharp. There is a strong evidence pointing to a hydrothermal sedimentary origin.

The stockwork-type of ore is of metasomatic hydrothermal nature; this ore is well-developed under the massive ore lenses.

The fact that chalcopyrite is found in the sphalerite in the form of fine exsolutions and disseminated grains will cause, in future, problems regarding the ore-beneficiation methods.

Structural features such as folding, bedded gypsum and manganese formations, characteristic brownish-purple color of the hanging wall, as well as the hydrothermal alteration processes observed in the country rock should be taken as a guide in the exploration programs of these unexposed deposits.

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PLATES

Fig. I - Colloidal texture (kidney-shaped, concentric spherules). Spherules contain chalcopyrite, sphalerite, galenite, pyrite and bornite. Dark sections indicate gangue minerals. Magn. 10x25 = 250.

Fig. 2 - Pyrite (white) shows cataclastic texture: the cracks are partly filled with chalcopyrite, fahlerz and galenite (gray). Dark sections indicate gangue minerals. Magn. 10x25 = 250.

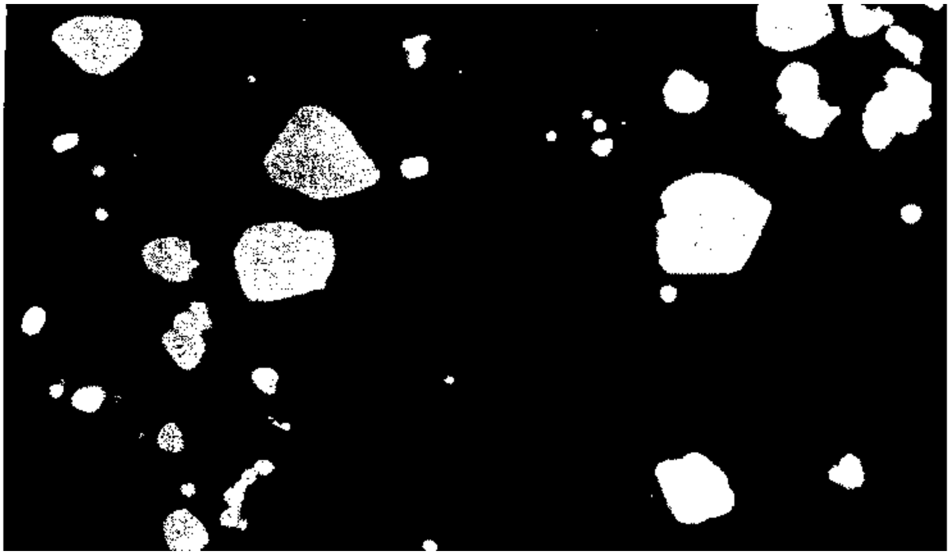

Fig. 1 - Idiomorphic and hypidiomorphic chalcopyrite (white) grains are surrounded by sphalerite. (gray). Dark sections indicate gangue minerals. Magn. 10×25 = 250.

Fig. 2 - Sphalerite (gray) contains very fine-grained chalcopyrite (white). Dark sections indicate gangue minerals. Magn. 10×25 = 250.

Fig. I - Lower boundary of the sandstone bed intercalated in the augite basalts. Magn. 2.5 x 8 x 1.25 = 25.

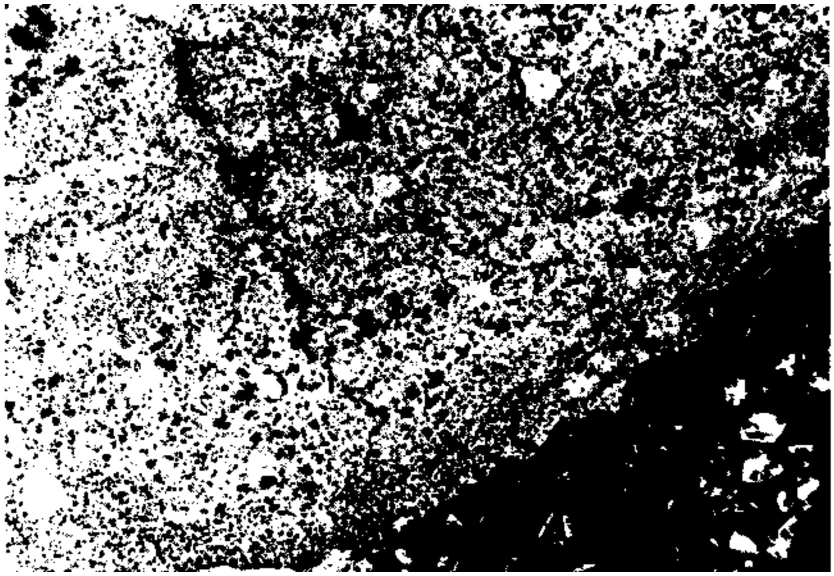

Fig. 2 - Lower boundary of the sandstone bed intercalated in the augite basalts. Magn. 2.5 x 8 x 1.25 = 25.

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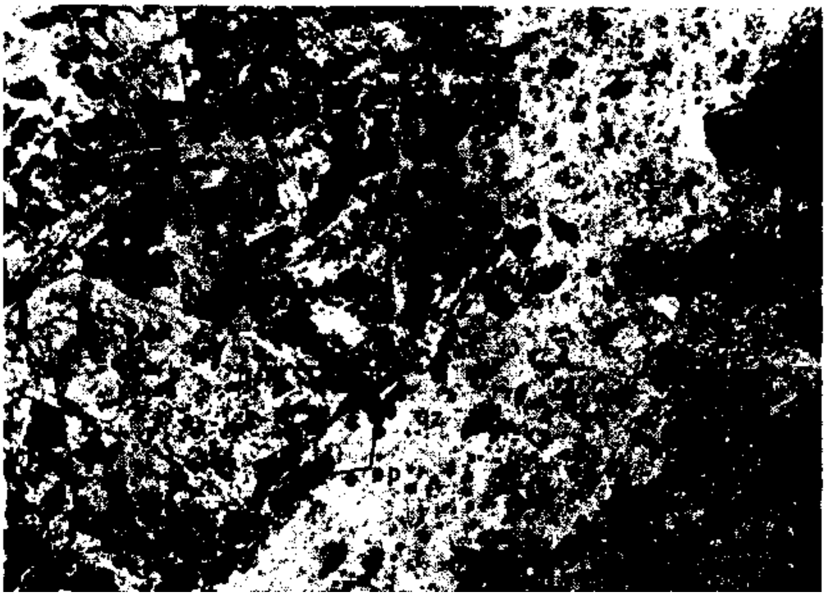

Fig. 2 - Quartz vein (qz) containing sulphide minerals (Op) (pyrite-chalcopyrite-sphalerite) occurring in the basalts. Magn. 2.5x8x1.25 = 25.

Fig. 1 - Purple tuff II. Fragments of quartz phenocrysts (qz). Magn. 2.5×8×1.25 = 25.

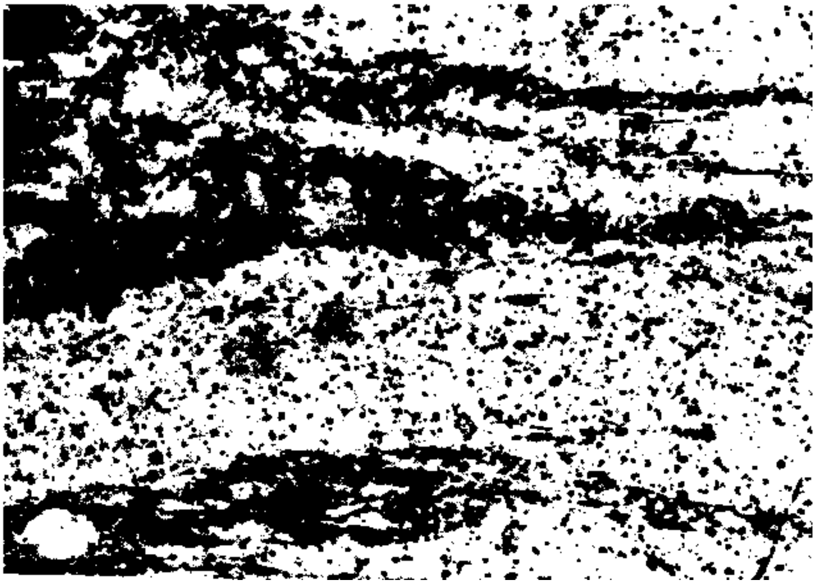

Fig. 2 - Tuff (grayish-white) and sulphide minerals (black) (contemporary formation). Magn. 2.5×8 ×1.25= 25.

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