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Metallogeny of Murgul and Surroundings (Artvin, Hopa, Maradit) Northeastern Turkey

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With devotion and love I dedicate this book
to my brother Mišo, sister Seka
and to my lovely granddaughter Sofija
who filled my live with happiness.

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ABSTRACT

METALLOGENY OF THE MURGUL AND SURROUNDINGS (ARTVIN, HOPA, MARADIT) NE TURKEY

by

Radule Popović

This Presentation of metallogeny of Murgul and adjacent areas is mainly based on my own studies. For the deposits or occurrences which I haven't reasurched on the field, to complete the review of metallogenesis, I used literature data and archive materials. But all available data were presented as one concept, resulting from my fundamental studies, conserning either the age of formations and deposits as well as in relation to geological or geotectonic position, genesis and distribution of deposits.

In the introduction, or general part I presented data on geographic location, climate, vegetation, population etc. In addition, in the first chapter I presented the development of exploratory and exploitation works. It is well known, the exploitation in this area dates back several millenniums.

In the second or geological part were stratigraphic position of the biggest petrological units (complexes) are defined. That means genesis of volcanogenic, volcanogenic-sedimentary and sedimentary formations whose creation started most probably during Lower part of Upper Jurassic and which development extended to Malm. This is when the volcanites of andezite and keratophyre compositions were formed. Further acidization was continued passing gradually into acid volcanites of rhyolitic or rhyodacitic composition. Development of these volcanites ended during the Lower Cretaceous (Neocomian). The second stage of acidic volcanism was much stronger and greater by size of the volcanogeous material. In association with both types of volcanism a very significant mineralizations of copper and zinc occurred. During that time interval, lasting about 30 millions years, the biggest deposits of copper in the Black Sea region were formed. Malm – Neocomian time, , could be regarded as the most accurate age of the intermediate as well as the acidic volcanites. After that period

appeared a considerable sedimentation break lasting 40 – 50 millions years, and then begun a new, very strong magmatism of either intrusive or extrusive type. During that period, lasting about 40 millions years, complete volcanism was developed (in chemical sense), beginning from the basic (basalts, spilite), then intermediate (andezite) to acid (dacite, rhyolite). In the course of evolution of the Upper Cretaceous – Paleogene volcanism, in association with the volcanites, alternating clastic and carbonate formations appeared. In these sediments a rich palaeontological material was found, enabling accurate age determination of these sedimentary formations. The age of magmatic rocks was determined through the isotope analyses.

All magmatic stages are accomapanied by respective ore occurrences, from manganese- related to spillitic volcanites, followed by copper, lead, zinc, with gold and silver content in association with andezite, and finally occurerences of skarn (mainly magnetite) mineralizations, appearing on the contact of granitic rocks with surrounding rocks.

In regard to geotectonic setting where the above mentioned formations were formed, at present the generally accepted point of view, is that the island arc is the major feature, with prevailing tholeiitic type of magmatic rocks, and that the development of ore deposits could be compared with the ones formed in the contemporary Japanese island arc.

If we speak about extrusive magmatic rocks, it is essential to point out that the key role has the Tiryal Dağ – Tatos Dağları granodioritic batholite. Its formation commenced as early as in Permian, and its evolution lasted all the way through to the end of Paleogene. But its erosional level is comparatively shallow, so that in the vicinity of Murgul, or more precisely in the upper course of Murgul dere the oldest magmatic rocks are located-belonging to Upper Jurassic, and in Çoruh river valley the oldest parts of the mentioned batholith occur.

Regarding the local tectonic fabric of the region described in this monography, the essential characteristic represents the still undefined, fracture structure, along which numerous deposits occur and occurrences of copper ores are found. That structure by author of monography, was followed from Kuvasrhan across Murgul, right to the Black sea shore between Çayeli and Rize. Besides, existance of other structures of the same genetic type, as well as folds especially in vicinity of Murgul are found. All above said is complicating the general geological picture of Murgul and adjacent areas.

As the stratigraphic and petrogenetic classification of petrogene complexes for defining major petrogenetic units was used, in the same way the classification of ore deposits and occurrences was performed.

The oldest copper ore were registered in the upper course of Murgul dere in the village Iskalka Köprüsü. These are in association with volcanic-sedimentary complex incorporating volcanites of andesitic and keratophyre composition. Explorations of these mineralizations indicated that they occur in form of impregnations (syngenetic with parent rocks) or epigenetic (vein) formed after formation of this complex. Impregnations (disseminations) are characterized mainly by pyrite with minor concentration of chalcopyrite. The veins type, characterized by pyrite and chalcopyrite, where copper content varies to 2.5 %, occure in outcrops up to 0.5 m thick. The firstly given negative evaluations of the ecconomic potential of these occurrences in the monography is revised. Namely, as it was noted, the thickness of sulphidic veins increases with the depth, so my opinion is that the negative evaluation could not be confirmed without additional explorations. These mineralisation should be further researched by exploration drilling to the depth of 100 m. at least.

Other ore occurrences and deposits of Upper Jurassic – Lower Cretaceous age, i. e. of Malm – Neocomian age, are related to rhyolitic volcanic and volcanic-sedimentary formations. That includes an enormously great number of deposits appearances all around the whole region of Artvin Province. Amongst these are the two largest deposits in the whole Black sea region:Anayatak and Çakmakkaya. Both deposits are not exploited at the moment, but earlier production from them was over 30 millions tons of copper ore with copper content over 1 %. To that complex are related also the deposits of Aduca dere, Bognari, Orta Istasyon, Çarkbaşı, Gölbaşı, Kara Tepe, Kilise Tepe, Kuvarshan, Beşagül, Sinkot Maden, Umasen, Seyitli, Peronit, Sivrikaya and a whole line of insufficiently explored occurrences, so we can conclude that there may exist a great potential of copper minerals in this petrogenetic complex. Majority of investigators is of opinion that within the area, could be expected additional reserves of at least 50 millions tones of ore with commercial copper content. For example, it was mentioned that explorations outside major the deposits: Anayatak and Çakmakkaya indicated reserves greater than 50 million tones with copper content around 1 %. Besides, on Kilise Tepe, only one type of mineralization (proven were two, possibly three types) related to silicified rhyolitic breccias, with estimated quantity of poor ore (content over 0.15 %) is present in more than 10 million tones. It is important to stress that within the area there are stratiform and vein types of copper with content of over 1 %, also in the

same locality were registered mineralized quartzdiorite containing zinc from 1 – 10 % and copper 0.5 – 1 %.

All these show that there are extremely important factors present, (indications) indicating great potentiality of copper in Artvin Province.

It should be added, that in relation with this complex, occurs also molybdenum mineralization with concentrations up to 1000 ppm.

Finally it should not be omitted to mention a presence of two precious metals: gold and silver. Even tough the amounts of only 0.25 ppm are present (in Anayatak deposit), but in regard to potential ore reserves, this amount represents an exceptionally great potential because it indicates an expectance of 10 tons of gold, while the expectance of silver is even greater while the content of silver is high, varying from several ppm to over 100 ppm in greater quantities.

The following petrogenetic complex was formed during the Upper Cretaceous – Paleogene and it consists of volcanic-sedimentary formations of widespread development in association with numerous polymetallic occurrences and deposits (copper, zinc, lead) accompanied with comparatively high Au and Ag content. To this type of deposits belong the Irsa Maden, Hohur Sırtı, Akarşen, Başköy, Çayeli, Kutonit, and also the occurrences in the surroundings of Maradit and numerous others.

Within this group of deposits we could differentiate several types. The first type consists of Hohur Sırtı, Akarşen, Irsa Maden, Çayelı, Kutonit, Çavuşlu, (near Maradit) where the lead content varies up to 3%, zinc up to more than 10%, and copper to 1%. The reserves in these deposits are varying between 1 to10 million tones.

The second group of deposits includes the occurrence of Pehlivan Köy near Maradit. It is classified as the epithermal type where copper varies up to more than 1 %, while zinc and lead are practically missing, but the gold content is 0.7 ppm. For the presence of adularisation as the main characteristic of epithermal alteration type, is proven, it represents a significant indication of andezitic volcanities potential regarding copper and gold.

The third type consists of morphogenetic vein type deposits occurring in fold cracks. This type of deposit is registered near village of Başköy (vicinity of Murgul) on the southern slopes of Balıklı yayla. They

are characterized with a comparatively high content of copper (over 1.5 %) and in paragenesis high content of fluorspar, which was not recorded in any other deposit in the Artvin Province. Also in paragenesis there are occurs of pyrite-as the leading mineral according to its content, followed by a small content of sphalerite, while other sulphides such as galena were registered only in traces.

Based on all collected data, it can be concluded that this Upper Cretaceous – Paleogene petrogenetic complex has a very high potential, but unfortunately it is very poorly explored.

A special place is reserved for the intrusive complex represented with quartzdioritic rocks, in places strongly mineralized by sphalerite, pyrite and chalcopyrite. In some cases, for example on Kilise Tepe (Murgul) some of quartzdiorite bodies are intensely mineralized by sphalerite causing high zinc content varying from 1 to 10 %, and copper from 0.5 to 1 %. Such situation logically suggests the hypothesis that it is possible to expect the existence of porphyry type of copper deposits. But this problem is only recently open and requires further systematic explorations.

In relation to the granitic skarns a considerable number of these skarn type of mineralization were found in the vicinity of the Murgul, Hopa and Arhavi areas, but these occurrences have no economic significance.

Concerning the metallogeny it is unavoidable to mention the basic (lower) part of the Upper Cretaceous – Paleogene complex. Among a large number of manganese mineralization occurrences in relation with spilite, some of them arouse a lot of interest such as in the vicinity of Hopa and Arhavi areas, where they were earlier exploited. Despite all of these this type of occurrences also were not sufficiently researched, meaning that future explorations should dedicate much more attention to these deposits.

Finally, this monography is showing a lateral zonal distribution of ore deposits around the Tiryal Dağ – Tatos Dağları batholith.

Based on all relevant data the resulting evaluation is that further systematic research and exploration of all Upper Cretaceous – Paleogene formations should be undertaken, because there are essential indications for the possibility of discovering new large copper deposits with commercially significant content of this metal.

PREFACE

The region of eastern Pontids (or eastern part of Black sea region) was a subject of intensive geological investigations by groups of explorers from many parts of the world. Besides Turkish geologists, there were experts from Japan, ex West Germany, U.S.A, United Nations teams, and from 1967 Geoinstitut geologists of Belgrade. It was an opportunity for this author to explore in detail some base metal occurrences and deposits in Murgul district, and also to make many field trips to ore bodies in Hopa, Çayeli, Artvin, and Maradit areas. As a result, numerous materials were collected on many occurrences and deposits that were incompletely or little explored, or for which even the basic information were lacking. There were two large deposits in Murgul: **Anayatak** and **Çakmakkaya**, and minor ones – **Bognarı**, **Aduca Dere**, **Çarkbaşı**, etc.; some other bodies were intermittently exploited (**Akarşen**, **Başköy**) and there also were a number of deposits of the estimated reserves exceeding a million tons of ore with 1% or more copper content. Although the exploitation of Anayatak and Çakmakkaya was terminated, this field, because of very high potentiality, should be explored for finding new reserves **of** quality copper, zinc and lead ores which are sometimes followed with higher or lower concentrations of gold and silver.

Some deposits (especially Anayatak, Akarşen, Kuvarshan) are relatively much written about by many explorers, but there are many more deposits and occurrences that have not been described, of which only insufficient data is available in the MTA documentation fund (Ankara), in Etibank (also Ankara), or some other institutions either in Turkey or abroad. With these facts in mind, this monograph offers information that might be useful for future explorers. Also, it is to remember the extremely fruitful cooperation of the Geoinstitut of Belgrade and MTA of Ankara, and the friendly collaboration of experts of both institutes. Seven years of joint work have resulted in many memorable friendships on which any future cooperation of Belgrade and Ankara geologists can be firmly founded. In this light, this book is intended as a remembrances on time of enthusiastic research, when all hardship was overcome through understanding, close collaboration, professional reasoning, that were indeed necessary for the extremely strenuous work in the Pontids. The topography (from the Black Sea level to the heights of nearly 4000 m) and harsh climate (rains, fogs, steep or impassable land) required exertion of everyone. On top of it, the mental strain was high for the separation from our families and with (the only) infrequent communication with them by letters that traveled fifteen days or more. But the MTA

leaderships and the MTA colleagues had done their utmost to mitigate the hardships and to provide a normal activity under all this circumstances. Our Ankara Embassy encouraged friendliness and close cooperation in particular. Mr. M u h i d i n B e g i ć, as long as he served as the Ambassador in Ankara personally visited the field teams every year, even in Murgul, some 1500 km from Ankara of which 50 km very poor macadam road from Hopa on the Black Sea coast to Murgul. The Geoinstitut director (Mr. M i l o r a d N i k o l i ć, mining engineer) and the highest administrators of MTA Institute of Ankara (R. O v a l i o ğ l u, M. A s l a n e r, T u n c a y, and others) also yearly visited the teams. All these were expressions of good or better say, close relations that contributed to the exploration results. Over seven years of the exploration, the Geoinstitut experts, according to P e j a t o v i ć (1973), wrote thirty-seven reports on more than fifty copper, zinc and lead ore deposits. Also a number of deposits were found of the estimated ore reserve exceeding a hundred million tons. Geologists of Geoinstitut published (and continue to publish) more than twenty scientific papers and a doctoral thesis were defended (P e j a t o v i ć, 1975, Belgrade). These results were certainly encouraged by the interest expressed by Dr. S a d r e t·i n A l p a n, the MTA general director, then Dr. M u s t a f a A s l a n e r, the ore deposits sector director, and the field staff and geological experts: Mr. R ü ş t ü O v a l i o ğ l u, Mr. R e c a i K u t l u, Mr. A l a t i n H a m a m c i o ğ l u, Mr. S a v c i O z b a y o ğ l u, Mr. M e h m e t (M e t e-bey) T e ş r e k l i, Mr. M e s u t-bey, and others. My appreciation and gratitude are due to all the named and to the experts of the Geoinstitut.



Fig. 1 The team members from Germany and Yugoslavia
who were involved in the 1970-1972 geological explorations in Mugul.
Left to right: E n o N i c k e l, H e i k e N i c k e l, J a n e z Š t e r n, B o ž o Đ u k i ć,
S v e t i s l a v P e j a t o v i ć (heading Yugoslav team),
R a d u l e P o p o v i ć, D r a g a n P e š i ć.

Key words: Metallogeny, Artvin, Murgul, Hopa, Maradit, copper, molybdenum, lead, zinc, precious metals, manganese, Jurassic, Malm, Neocomian, Upper Cretaceous, Tertiary, volcanism, evolution.

I. INTRODUCTION

The extreme northeast of Turkey, that includes Maradit on the Çoruh River and the Republic of Turkey and Georgia state border, then Hopa on the Black Sea coast, Murgul area and Artvin area on the Çoruh river (Fig.2), forms the Artvin Province, or the Artvin Vilayet. The Province has been a mining region since ancient times. Through shorter or longer periods of time, more than ten copper, lead, zinc, and manganese mines have existed. There are an extremely large number of partly or slightly explored copper ore occurrences. This segment of the eastern Pontids represents great economical potential which mineral resources are far from being exhausted, because they are generally little explored. For example; the province has not been explored specifically for precious metals in spite of many small or large occurrences and deposits of copper, lead, zinc and proved relatively large concentrations of gold and silver, e.g. Akarşen and Hohur Sırtı near Murgul, Kuvarshan near Artvin and Maradit (P o p o v i ć, 2003).

It should be mentioned at this point, that water used in Damarköy hammam has the properties of a therapeutic mineral water, e.g. after only a few treatments, skin warts disappeared, or after few months of regular bathing in the hammam some black-pigmented birth marks vanished. This balneological aspect has not been even considered.

Furthermore, waste rocks, which are numerous in eastern Pontides to mention the areas of Hopa, Murgul, Kuvarshan, and flotation wast rocks in Murgul, are believed to represent technogenous raw materials. This is all the more so that obsolete flotation plants and smelteries of Murgul had high losses of chalcopyrite and with it other minerals bearing copper, zinc, gold and silver. This problem is yet to be solved.

Besides Anayatak and Çakmakkaya copper deposits, there are other ore bodies in Murgul region that had been exploited (Akarşen, Başköy). Also, near Artvin (Kuvarshan, Irsa Maden) and Hopa (Peronit, Sivrikaya) copper ore was excavated, and once also manganese was produced at Hopa and Arhavi. All this suggests mining activities and large mineral resources of Artvin Province.

II. GENERAL PART

GEOGRAPHIC POSITION

Murgul and adjoining regions are situated in the extreme northeast of Turkey. The regions are a part of the Artvin Province (Vilayet*) 7000 km^2 in surface area. The distance across from Murgul to the Black Sea is about 30 km or about 50 km by the road to Hopa. Generally scrutinized, the region occupies northwestern slopes of Tiryal Dağ enclosing the spring area of the Murgul dere that infusions into the Çoruh River at Borçka. All ore deposits are located in northwestern parts of the Artvin Province bounded on that side by the Black Sea coast, and on the north and northeast by the state border between the Republic of Turkey and Georgia, on the east by the Çoruh River generaly, and

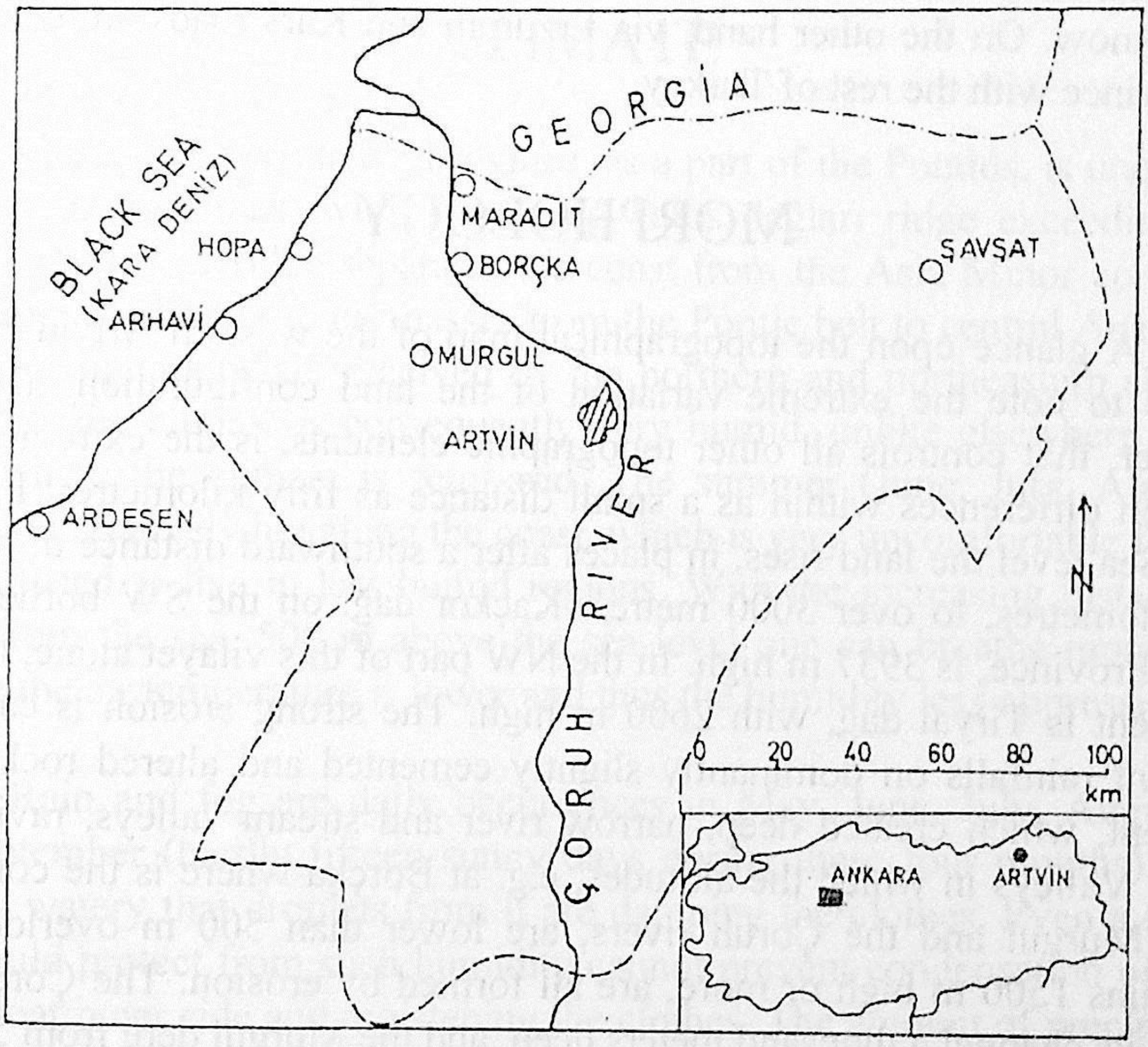


Fig.2. Geographic position of Artvin Province.

on southwest by Tiryal dağ exceeding 2600 m in height. The region is situated between latitudes 41°15' and 41°30' north and longitudes 41°16' and 41°48' east. The eastern magnetic declination is 2°.

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* Province – Vilayet (administrative subdivision)

LINES OF TRANSPORTATION

Generally, the Artvin Vilayet (Province) is traversed by four roads which are branching in the Borçka village, to Hopa on the Black Sea, and to Maradit in the Çoruh valley leading to Georgia, but this road branch from Maradit to Georgia is disused, then to Murgul and Artvin. From Artvin macadam roads lead to Şavşat and further to Ardanuç, then to Ardahan and to Kars. Finally, there is a road that runs up the Çoruh valley from Borçka by Artvin toward Erzurum.

Another type of transportation is sea shipping between Artvin province and other Black sea and Mediterranean ports. There is also a good, asphalted road along the coast from Hopa to the network of roads across Turkey. The Hopa port was expected to receive vessels for chalcopyrite concentrate transportation to Samsun smeltery, but whether it was accomplished or not, we do not know. On the other hand, via Erzurum and Kars roads are connecting the Province with the rest of Turkey.

MORPHOLOGY

A glance upon the topographical map of the western Artvin Province suffices to note the extreme variation of the land configuration. The basic character, that controls all other topographic elements, is the extremely great elevation differences within as a small distance as fifty kilometres. From the Black Sea level the land rises, in places after a southward distance of less than fifty kilometres, to over 3000 metres. Kaçkor dağ, on the SW border of the Artvin Province, is 3937 m high. In the NW part of this vilayet alone, the most prominent is Tiryal dağ, with 2600 m high. The strong erosion is caused by abundant rainfalls on dominantly slightly cemented and altered rocks in the basement, which created deep, narrow river and stream valleys, ravines and gullies. Valleys in which the altitudes, e.g. at Borçka where is the confluence of the Murgul and the Çoruh rivers, are lower than 500 m overlooked by mountains 1500 m high or more, are all formed by erosion. The Çoruh River has cut its channel a thousand meters deep, and the Murgul dere from 500 m to 1000 m.

Narrow mountain ridges separate deep, narrow river valleys where twopersons cannot pass each other on the ridge top (Kilise Tepe-Kopuk ridge near Murgul). Exposed to heavy erosion, solid rocks break off into blocks of almost a thousand cubic meters or larger (NW slopes of Kilise Tepe-Kopuk ridge), and large amounts of Delluvial debris slides down the slopes, which is conspicuous in Murgul area

HYDROGRAPHY

All rivers of Murgul and adjoining regions are draining into the Black Sea, either directly or indirectly as tributaries of the Çoruh, which flows into the Black Sea at Batumi in Georgia. The two drainage systems are locally divided by Balıklı Yayla watershed which passes SW into Şavval Tepe. One of them includes Hopa dere, Musazade dere, Abvica dere, Piskala dere, Dutha and some other rivers, which are short (less than 30 km) abounding in torrential flows over the year. The second flow is characterized by the Çoruh River, one of the longest Turkish rivers (more than 300 km) that receives the Murgul dere, the Berta suyu, etc. also abundant in water but with canyon-like valleys and torrential flows. There are also a number of glacial lakes, mostly south of Murgul.

CLIMATE

The climate of Artvin Province, as a part of the Pontids, is unque. The region is mountainous, with Tiryal dağ-Tatos dağları ridge exceeding 3000 meters height. The ridge separates the coast from the Asia Minor continental part acting as a barrier to air masses from the Pontic belt to central Anatolia, so that all precipitations are received by the northern and northeastern slopes of the ridge. The climate is consequently very humid, unlike elsewhere in Asia Minor where the climate is semi-arid. The summer (June, July, August) is humid and relatively hot along the coast, which is very uncomfortable for those who are used to live in less humid regions. With the increasing distance and height from the sea, 500 m above the sea level one can breathe more easily, because the air temperature is lower and thus the humidity less oppressive.

Rain and fog are daily occurrences in May, June, July, August, and into September (hardly fifteen sunny days during these four months). Fog is often so watery that droplets from it are damping the clothes. Even a raincoat that should protect from such humidity cannot prevent condensation of vapors on the coat inner side and moistening the clothes. The amount of precipitations is very high during summer months. Fogs are dense, sometimes opaque, even restricting visibility to 2 m.

In late summer, in September, when the first snow falls on the mountains 1500 m high, the climatic conditions abruptly change. Days are sunny and warm, suitable for fieldwork and any kind of tourism. The nice weather persists from September through October and into November. Holidays in seaside resorts are then very pleasant. Excluding the seacoast,

snowfalls and heavy snowdrifts are characteristic of the region during the winter. Inhabitants of Murgul and Borçka narrated that snowdrifts on the road to Hopa sometimes were almost 5 m high and had to be tunneled.

Abundant snowfalls in the winter and rainfalls in the summer, and the high porosity of volcanic rocks, particularly pyroclastics in the geologic basement, provide the great quantity of groundwater and the abundance of water in surface flows of eastern Pontides.

VEGETATION

Climate, as described above, is the principal factor not only of landforms and watercourses, but also of vegetation. Abundant precipitations (rain, snow) provide for luxuriant vegetation. Starting from the sea to Artvin is covered by dense vegetation. As to the variety of plant species, it is relatively poor. The dominant species, rhododendron, has expanded over most of the land (in places as much as 50%, Fig.3). Conifers and shrubs (particularly blueberry) are less widespread. What have remained of conifers are straight, tall pine, fir and spruce trees. Rhododendrons have densely covered the land, tangled and forming an impenetrable jungle. The trees may be half a meter thick and more than 3 m high (perhaps it is better to say long) with a profusion of large flowers, dominantly violet in colour.

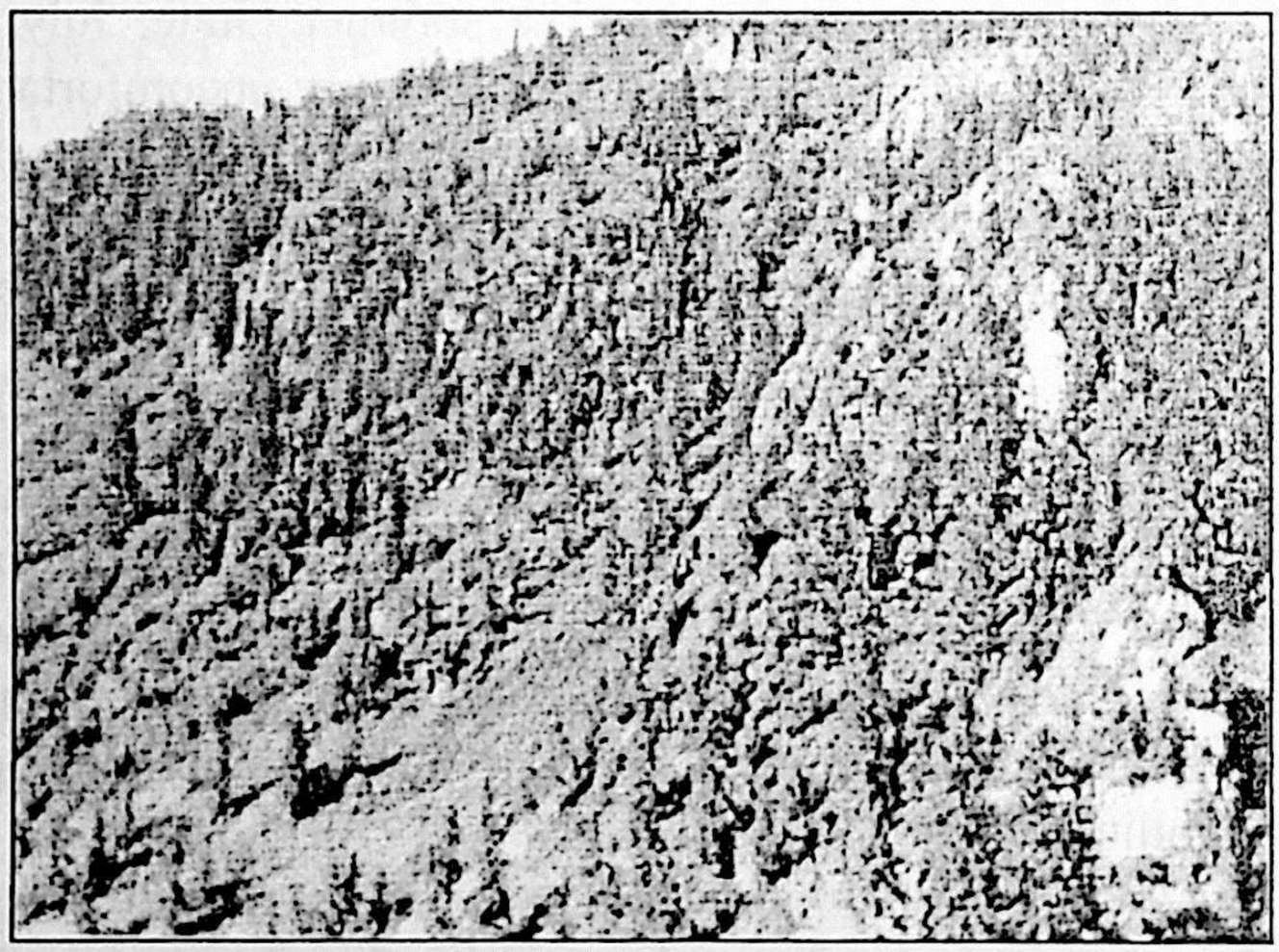


Fig.3. Land overgrows by rhododendrons and sparse conifers.

Very dense bilberry shrubs grow over the altitude of 1000 m. The shrubs are 2 m high, and their fruits, berries, are of a small marble size, as many as half a kilogram per a branch.

There are few small clearings with meadow.

In those conditions of vegetation, big game is uncommon, with the exception of Caucasian bear that may have a weight of 500 kg. Considering other animal species, only a black snake, 1.5 m long, was spotted over the two years spent in the region.

The rivers are poor in fish species but the Black sea is characterized by fish abundance.

Arable land is found only in major river valleys and along the coast, used to cultivate tea and hazelnut. Locally are also corn, potatoes, and some other agricultural product, but on a very small scale. Local population is employed in mines, mineral processing plants, commerce, then in catering services, transport, local administration, health institutions, etc. The unemployment rate is high and therefore the migration of local population is high as well.

POPULATION

There are few urban communities in Artvin Province – the towns of Artvin, Murgul, Hopa, and minor ones Borçka and Maradit, then Ardanuç, Şavşat, Kemal Paşe, Arhavı, etc. Rural communities are more numerous, the major ones being Damarköy, Basköy, Petek köy near Murgul; Kuarshan, Sinkot, Umasen, Kürdaze or Melo and other villages near Artvin; Pehlivan köy, Çavaşlu near Maradit, and villages on along the Black Sea coast.

The Artvin Province has an area of about 7000 km^2, but its population is scarce, because the climate and farming conditions are unfavourable and industry undeveloped. Artvin population is more than twenty thousand (oral information from some people in Artvin and Murgul, 1972) .

The principal sources of income are the cultivation of tea and hazelnut, commerce and services. The main occupation of the Murgul area population was in the past the copper mining, flotation, smelting and forestry.

In general, the population density is relatively small, a consequence of the living conditions in the Province.

EXPLORATION AND MINING HISTORY

The oldest copper ore extraction in the eastern Pontids, according to published information, is dated from the Ancient period, but the time of its beginning has not been fixed. If it consider the oldest copper exploitation of Europe, at Rudna Glava near Donji Milanovac, eastern Serbia, from about 4000 to 5000 years ago, and the archeological data (B o r i s l a v J o v a n o v i ć, 1985), it may be assumed that the copper excavation "moved" from Rudna Glava to other places of Balkan peninsula, more specifically across central Bulgaria, Thrace into Asia Minor to the Pontids. In this correlation, presumably the earliest copper extraction in the Pontids began not less than before 3000 to 4000 years, or even before 5000 to 6000 years, according to K a p t a n (1990). This dating problem remains unsolved. What matters for this consideration is that copper was extracted in the Pontides much Before Christ. The large number of slag spoils suggests an old and primitive copper processing, but this should not be associated with the earliest mining. Slag dumps have been found on Kilise Tepe, at Iskalka Köprüsü, in Akarşen ore field, on Hohur Sırtı, near Başköy Mine, and probably existed in the areas of Anayatak and Çakmakkaya large ore deposits. Slag samples, chemically analyzed on metal composition, indicated the smelted copper ore remains. The primitive processing left high copper contents in the slag, in places more than 4%, whereas other metals were much lower, except at Akarşen. The number and size of the old slag spoils suggest their younger age, probably medieval, which was a second period of exploitation.

The third period is more likely associated with the late 19th and early 20th centuries when some mine workings were excavated such as old adits (large adits, commonly 1.7 m high, were recognized by more modern mining technique that could not had been used in the medieval time or before it). In this period, foreign companies were involved in exploration and exploitation. Also, in the earlier half of the 20th century, a copper ore flotation and smelting work was built in Murgul. Unfortunately, this smeltery caused an ecological catastrophe that killed nearly entire vegetation and animal life between the Murgul town and Damarköy exposing land to heavy erosion.

Old mine workings (adits, shafts) from this period (end of 19th and beginning of 20th centuries) are found in Başköy, on Hohur Sirti, Akarşen, several places in Kuarshan mine field at Artvin, then at Maradit, and near Hopa. Consistent mining works and geological explorations were carried out in the late 19th and through the 20th centuries, but in spite of the economic importance, the long duration of mining activities and geological explorations, there are few published information.

The earliest published works are written by K o s m a t (1910), O s s w a l d (1912), then Z i m m e r (1937,1938), K o v e n k o (1941,1942), E g e r a n (1946), W i j k e r s l o o t h (1946), S c h n e i d e r h ö h n (1955), P e t r a s c h e k (1954/1955), Z a n k l (1959), G a t t i n g e r (1962), K l ä y (1959, in: K r a ë f f, 1963), K r a ë f f (1963), B u s e r (1970), S a w a, T e ş r e k l i (1970), A s l a n e r (1971), B u s e r, C v e t i ć (1973), P a j a t o v i ć (1973,1975/1979), K o p r i v i c a et al. (1971), V u j a n o v i ć (1976), K o p r i v i c a (1977,1979), P o p o v i ć (1972,1976,1979,2000,2002a, 2002b), N o v o v i ć (1978,1979), A k i n c i (1980), H e n d e n (1980-1981), Y ı l d ı z (1982-1983), Ö z g ü r, P a l a c i o s (1990), G e d i k o ğ l u, Ö z g ü r (1992), G ö k c e (2001), P o p o v i ć, V u k a n j a c (2002). Of all published works, the most exhaustive contributions are those of K r a ë f f (1963), B u s e r, C v e t i ć (1973), P e j a t o v i ć (1975,1979), P o p o v i ć (1976, 1978, 2000, 2001, 2002a, 2002b), K o p r i v i c a (1977,1979), N o v o v i ć (1978, 1979/1980), Ö z g ü r, P a l a c i o s (1990), and G ö k ç e (2001).

Systematic mining has began when the region belonged to the tsarist Russia and when the flotation and smelting works were constructed in Murgul. The C a u c a s u s C o p p e r C o m p a n y, formed in 1900, began the exploitation at Kuvarshane, on Anayatak, Akarşen, and the G e r m a n S i e m e n s C o m p a n y carried out exploration drilling in 1912/13. Both exploration and extraction were discontinued during the First World War and resumed in 1923 when the region became a part of the Turkish Republic territory. The Turkish governmental institution E t i b a n k (1938) recommenced the copper ore exploration and excavation. The work was intensified after the Second World War, and the exploration completed in the late sixties on Çakmakkaya where an ore body was found of about eight million tons with the copper content of about 1%. The works were managed or carried out by M T A and E t i b a n k individually or jointly, depending on the nature and the volume of works. The explorations of the 20th century proved a high potential value of Murgul region.

After the First World War, all geological explorations, ore exploitation, flotation, and metallurgy in Murgul area began during the Atatürk epoch and continued through the 20th century with unabated intensity. Two large deposits were worked; Anayatak and Çakmakkaya, producing over thirty million tons of ore with at least 1% of copper, and at the same time exploitation in other smaller copper ore deposits were done.

As to the exploration of the entire region, which is the subject of this monograph, it was prospected and explored by many geologists from all over the world, which obviously supports the existence of potential mineral resources of Murgul and the adjoining regions.

In respect of the economic, and great scientific importance, and the collected and compiled information, it is felt that a monograph about the Artvin Province may be fully justified. Moreover, it is also meant to give all the explorers gratitude for their efforts, enthusiasm and knowledge in evaluating the Murgul area and the entire Province as a very important copper-bearing region.

III. SPECIAL PART

Because copper (excluding iron) is the principal metal in sulphide ore deposits of Murgul and adjacent regions, it should be remembered that it is the first metal man learned to use and associate with more than five millenium (thousand) ago. That epoch of human history is named "Copper Age".

All relevant information suggests that copper, economically, has been the principal metal in the Pontids. An essential characteristic of this metallogenic province are primarily volcanogenic and volcanogenic-sedimentary formations with which copper ore deposits are genetically and spatially directly associated.

PRINCIPAL GEOLOGIC FEATURES

Principal petrologic members in Murgul and adjacent regions are represented by magmatic and sedimentary formations in the following order of proportion: volcanogenic, volcanogenic-sedimentary, sedimentary and intrusive rocks divided into complexes as the largest petrogenic units.

Classified by chronology on the available data, the oldest rocks are found in the Jurassic (not finally determined stratigraphic position, probably lower part of Malm (Oxfordian-Kimmeridgian) volcanogenic-sedimentary complex, which continues into Upper Jurassic (Upper Malm, Tithonian) to Lower Cretaceous volcanogenic and volcanogenic-sedimentary complex. Upward follows an unconformity – a hiatus between the Lower and the Upper Cretaceous. A new magmatic activity (volcanism) in the Upper Cretaceous produced volcanic, volcanogenic-sedimentary and sedimentary formations which all together formed the Upper Cretaceous-Tertiary petrogenic complex. Finally, the youngest lithologic complex is represented by intrusive rocks that belong to the extensive (about 12 km^3) Tiryal dağ-Tatos dağları batholith, which formed lateral intrusions in the form of sills, dikes, or minor bodies irregular in shape, all over Artvin Province (Popović, 1976).

Chronostratigraphic Position of Petrogenic Complexes and Lithology

The most detailed stratigraphic descriptions are given for Hopa-Murgul-Kuarshane tract by K r a ë f f (1963) and for Murgul area by B u s e r (1970) and B u s e r, C v e t i ć (1973). All investigators of the region have the same opinion about the stratigraphic succesion. There are variations in the interpretation of individual larger or smaller petrogenic units, formations or subformations. It has been realized after detailed investigation that the definition of each petrogenic complex and its component formations, and the chronostratigraphic classified them in time and space, give a comprehensive and clear classification of well defined chronostratigraphic relationships. This helped lithological classification into complexes – the largest petrogenic units, and formations – smaller lithological units, related with the geologic time. Classification of ore deposits followed the same model.

The principal petrogenic characteristic of Murgul and surrounding areas is magmatism. The fundamental build up of the area is directly associated with strong volcanism which is than directly associated with the Tiryal dağ-Tatos dağları granitoid batholith.

Strong volcanic processes operated with shorter or longer interruptions in the area between the Black Sea and the Çoruh River over a period of about eighty million years from the Jurassic through into the Eocene (Gattinger, 1962). During this period one interruption happened in volcanic activity (This activity discontinued) for an unknown period between the Lower Cretaceous and the Senonian (Upper Cretaceous). According to B u s e r and C v e t i c (1973) it can be supposed that the hiatus began in the late Lower Cretaceous and lasted to the Maastrichtian, or for about twenty million years. On the other hand, the absolute age determined by M o o r e, M c K e e and A k i n c i (1980) prove that the strongest magmatism in eastern Pontids lasted from about eighty-five to sixty million years before, and continued through the Oligocene (i.e. to about twenty-five million years ago). Mentioned authors suggested that the date of the formation of magmatic rocks in Murgul and adjacent regions was in the period between 60 and 35 million years ago. If so, volcanic rocks of the second magmatic cycle formed in Artvin Province during the Paleocene and the Eocene (excluding volcanic rocks formed by magmatism of the first cycle from the lower Jurassic to the Neocomian). Faunal evidence, however, cited by B u s e r (1970), Š t e r n (1971), and B u s e r, C v e t i ć (1973) indicated formation of sedimentary deposits through shorter or longer intervals of quiescence between volcanic activities in the Upper Cretaceous (Senonian-Maastrichtian). Other volcanic and volcanogenic-sedimentary formations are

only indirectly dated. In any case, volcanic (magmatic) activities of short or long duration produced characteristic volcanic, volcanogenic-sedimentary and sedimentary formations. Generally, these formations can be divided into four petrogenic complexes, in the following sequence:

1. Jurassic volcanogenic-sedimentary complex (undifferentiated stratigraphy, presumed lower Malm, or Oxfordian-Kimmeridgian);
2. Upper Jurassic-Lower Cretaceous (likely upper Malm, Tithonian) volcanic and volcanogenic-sedimentary complex;
3. Upper Cretaceous-Eocene (probably even Oligocene) volcanic, volcanogenic-sedimentary, and sedimentary complex; and
4. Intrusive complex of granitoid rocks intruded, according to G a t i n g e r (1962), during the Eocene and later, and younger basalt intrusions that vertically penetrate all formations to the Quaternary.

Review of Lithologic Units

The Jurassic (Lower part of Malm – Oxfordian-Kimmeridgian) according to available data volcanic-sedimentary complex is the oldest. It consists of extrusive rocks dominantly andesites. K r a ë f f (1963) identifies it as **Spilitic series I**, and B u s e r (1970) and B u s e r, C v e t i ć (1973) as **spilite-keratophyre-porphyry formation** that passes into the next, rhyolitic and rhyodacitic volcanogenic and volcanic-sedimentary complex.

This complex is also defined as **the Lower Basic Series** (A k i n c i, 1980), the term used by majority of investigators in their reports or oral communications. However, a detailed lithological study identified the complex as volcanic-sedimentary composed dominantly of andesite, subdivided into several formations: sandstone, tuffogene sandstone, agglomerates, and andesite flows. Sandstones are true sedimentary rocks, formed during the volcanic quiescence, that alternate with tuffogene sandstones. Unlike sandstone, tuffogene sandstone deposited with the appreciable supply of tuffogene materials. The deposition was interrupted by periods of volcanism, which produced andesite flows, tuffs and agglomerates. The pyroclastic material is a clear evidence of the explosive nature of andesite volcanism. Generally, all the mentioned formations are alternating, thus indicating periods of volcanic activity and his quiescence. The thickness of andesite suggests a short period of the andesite lava flow, while the explosive character lasted longer. This is best illustrated by thin (less than 5 m) andesite flows. According to our examinations, most of andesite flows are only 2 m thick. Sedimentation products, also relatively thin, lie in places between the flows. Thus all the

alternating rocks can be identified by detailed investigation. More difficult is the distinction between sandstone and tuffogene sandstone and between the latter and tuff. Generally scrutinized, it is not clear why the complex was classified into **the lower basic series** (or in K r a ë f f, 1963, **the Spilitic Series I**), because spilite, basalt or diabase have not been found in this complex. It has been known, however, that spilite, basalt or diabase were submarine lava-flow products, which assimilated some sodium from seawater and were albitized or spilitized. Because andesite of this complex was extruded into the marine environment, it suggests keratophyre rather than spilite. B u s e r (1970) and B u s e r, C v e t i ć (1973) identified keratophyre, but as quartz-keratophyre – a formation that occurs above the andesite formation – and assign both to one unit under the name of the spilite-keratophyre-porphyry formation.

The formations are presumably identified as basic for the associated alteration – epidotization, chloritization, prehnitization, albitization, etc. Considering the matrix, altered by mentioned alterations, it is andesite, not basalt or diabase. Consequently, volcanic rocks of these formations should be classified into medium acidic, not basic rocks. It should be emphasized that the complex includes minor parts of andesite basalt, but much more subordinately than andesite, therefore it is identified as volcanogenic-sedimentary with volcanic rocks dominantly of andesite composition (Fig.4). Moreover, it is highly pyritized, and pyrite is mostly syngenetic with the rock.

The age of the complex has not been determined for the lack of reliable data on its origin. The proved Upper Cretaceous sedimentary formations in the Arkaşen dated on faunal evidence, and the underlying rhyolite and rhyodacite formations of the presumed Upper Jurassic age, separated from the former by a tectonic discordance, lead to the conclusion that this (andesite) complex, at the base of all petrogenic formations in Mugul and adjacent region, was formed in the Jurassic not yet defined (lower Malm, probably Oxfordian - Kimmeridgian).

The thickness of the oldest petrogenic complex is more than 500 m, which can be assessed in the outcrops near Iskalka Köprüsü in the Murgul Dera valley.

Upper Jurassic - Lower Cretaceous (Malm - Neocomian) volcanogenic and volcanogenic-sedimentary complex is one of the most extensive petrogenic complexes in the region of Murgul ore deposits (Anayatak, Çakmakkaya, etc). It normally succeeds volcanogenic formations formed in the preceding time.

It is assumed that the volcanism which was of intermediate acidity changed with the time into dominantly acidic rhyolite and subordinately rhyodacite in composition.

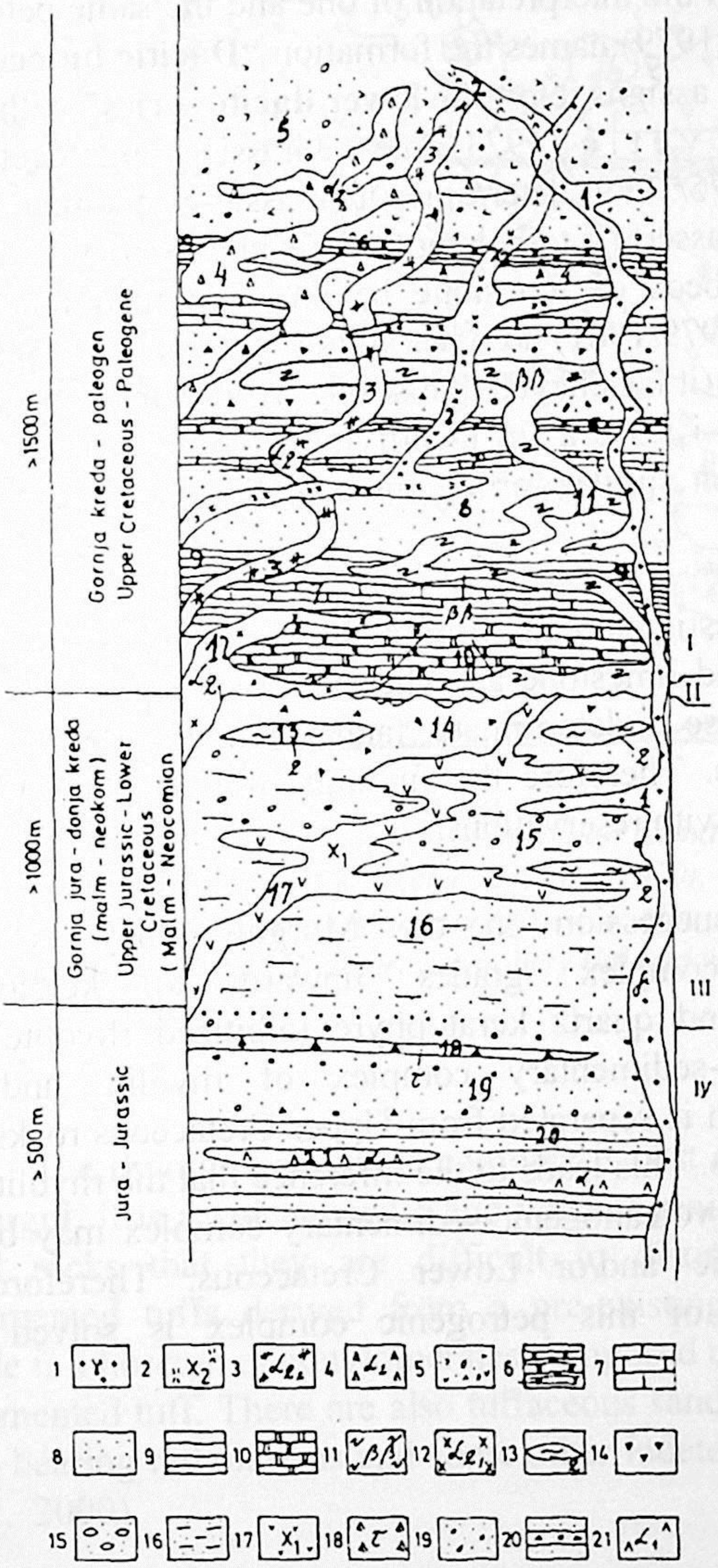


Fig. 4. Geologic column for Murgul area.

1.Granitoid (γ); 2. Rhyolite 2 (χ_2);
3. Dacite 2 (αq_2); ***I*** *= Volcanogenic, volcanogenic-sedimentary and sedimentary complex;* ***A****. Subcomplex: 4. Andesite 2; 5. Pyroclastic; 6. Thick-bedded limestone; 7. Limestone; 8. Sandstone; 9. Marlstone;* ***B****. Subcomplex: 10. Inoceramic limestone; 11. Diabase, basalt, spilite, chert bearing Mn and hematite (ββ); 12. Dacite 1(αq_1);* ***II*** *= Tectonic discordance;* ***III*** *= Rhyolite volcanogenic and volcanogenic-sedimentary complex; 13. Quartzite and cher (q)t; 14. Rhyolite breccia; 15. Conglomerate; 16. Rhyolitic tuff; 17. Rhyolite 1(χ_1), subordinately rhyodacite and dacite;* ***IV*** *= Volcanogenic-sedimentary complex; 18. Keratophyre and quartz keratophyre (τ); 19. Agglomerate; 20. Sandstone and tuffaceous sandstone; 21. Andesite (α_1).*

This petrogenic complex, determined by B u s e r and C v e t i ć (1973) as **"keratophyre, quartz keratophyre and their pyroclastics"**, and K r a ë f f (1963) as **"Albite dacites I"**, is developed in a relatively large space between Artvin and Murgul. Correlated data of K r a ë f f (1963) and K o p r i v i c a (1977,1979) differ in the interpretation of one and the same petrogenic unit. K o p r i v i c a (1977,1979) names the formation **"Dacitic breccias and tuffs"** and K r a ë f f (1963) assigns it to **"the lower dacite series"** without the defined age. B u s e r and C v e t i ć (1973) date it Jurassic-Lower Cretaceous (Fig.5), P e j a t o v i ć (1975/1979) determines it Jurassic-Neocomian, and K o p r i v i c a (1979,1981) asserts it to belong to the Upper Senonian because the complex contains interbeds of limestone bearing Senonian fauna. But except for K o p r i v i c a (1979/1981) no other author mentioned the presence of limestone in this complex (it is believed that strong hydrothermal alterations could have mislead K o p r i v i c a in identifying rhyolite and rhyodacite complex, all the more so that similar formations actually exist in the Upper Cretaceous).

During detailed investigation in Murgul area, particularly on Kilise Tepe, this author did not find limestone anywhere; there were deposits with chert (radiolarite) and sparse indeterminate faunal remains, but only in redeposited rhyodacite rocks. Therefore the findings of K o p r i v i c a (1979,1981) should be taken with reservations.

The stratigraphic succession in the Murgul valley is clear: volcanogenic-sedimentary complex grades upward to keratophyre (metamorphozed trachyte) and quartz keratophyre (albitized rhyolite) into volcanic and volcanogenic-sedimentary complex of rhyolite and less rhyodacite composition which is separated from Upper Cretaceous rocks by a tectonic-erosional discordance. This leads to the inference that the rhyolite and rhyodacite volcanogenic and volcanogenic-sedimentary complex may belong only to the Upper Jurassic and/or Lower Cretaceous. Therefore the chronostratigraphic position of this petrogenic complex is solved with reasonable certainty.

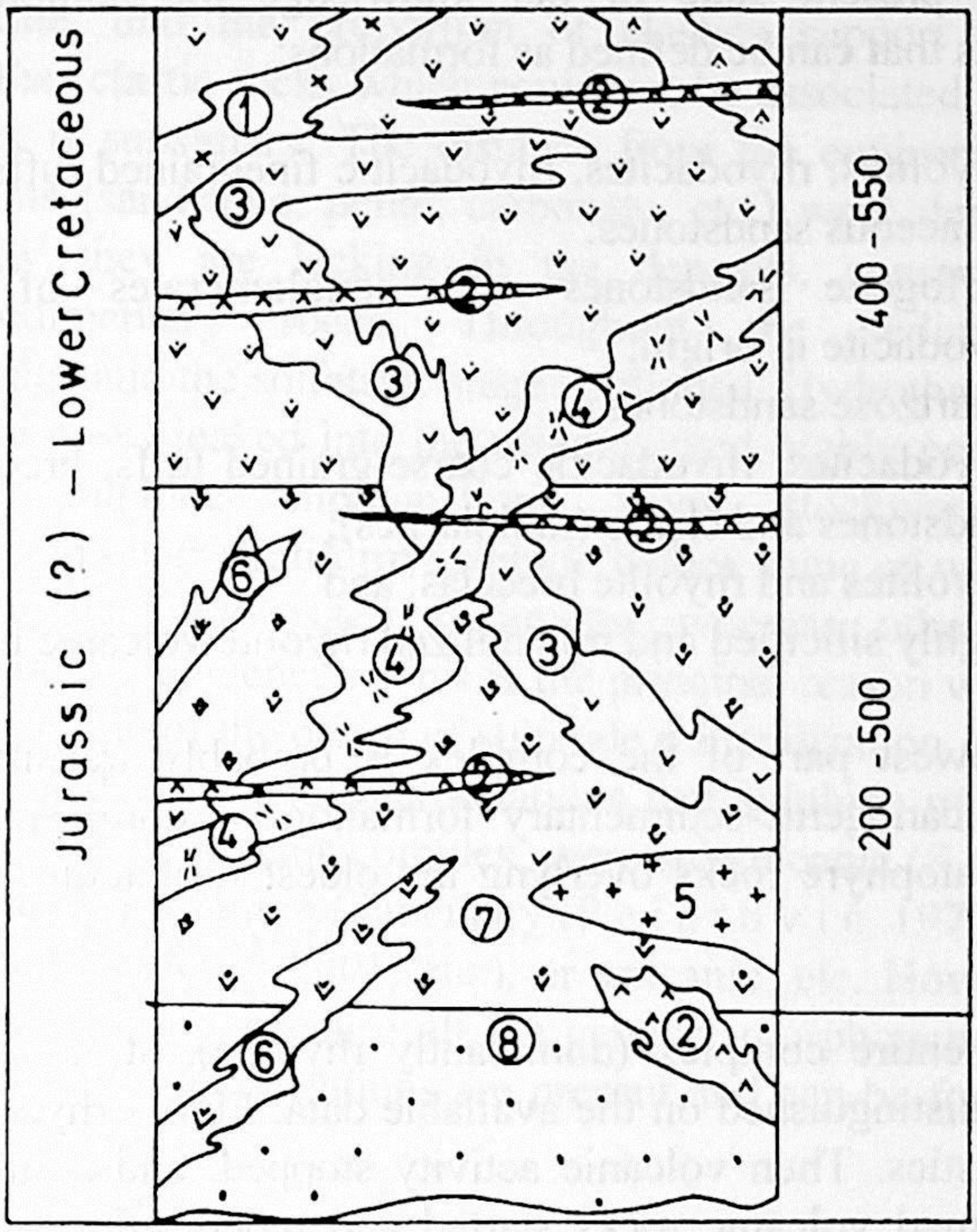


Fig. 5. Stratigraphic position of the oldest formations in the Murgul area (after B u s e r, 1970).
1. Dacite, 2. Augit-basalt, 3. Quartzporphyry, 4. Albit-rhyolite, 5. Microgranodiorite, 6. Quartzkeratophyry, 7. Quartzkeratohyry tuff and volcanic breccia, 8. Spilite tuff.

The rhyolite petrogenic complex is best studied on Kilise Tepe, south of Murgul. It is a volcanogenic and volcanogenic-sedimentary complex of so mixed rocks that they are difficult to distinguish in places, especially resedimented tuffs derived from a pre-existing volcanic rock. Particularly notable is a horizon of conglomerates composed of rhyolite pebbles and locally resedimented tuff. There are also tuffaceous sandstones, quartzose sandstones, cherts bearing radiolarians and some other indeterminate fossil remains (P o p o v i ć, 2000).

The most widespread rocks are rhyolites, then rhyodacites and dacites, and subordinately and locally in lower levels of andesite flows. Volcanism was mostly submarine including in places subaerial explosions.

In the present state of our knowledge the complex consists of petrogenic units that can be defined as formations:

1. Rhyolites, rhyodacites, rhyodacitic finegrained tuffs, breccias, and tuffaceous sandstones;
2. Tuffogene sandstones and conglomerates of rhyolite and rhyodacite in origin;
3. Quartzose sandstones;
4. Rhyodacites, rhyodacitic coarse-grained tuffs, breccias, tuffogene sandstones and cherts (radiolarites);
5. Rhyolites and rhyolite breccias; and
6. Highly silicified and mineralized rhyolite volcanic breccias.

The lowest part of the complex is probably transitional from the preexisting volcanogenic-sedimentary formation of dominantly keratophyre and quartz keratophyre rocks overlyng the oldest formation so far known in Murgul region.

In the entire complex (dominantly rhyolite), at least three volcanic events can be distinguished on the available data: First – rhyolite followed by abated pyroclastics. Then volcanic activity stopped, and a strong destroying process of formed volcanic rocks started and redeposition of them into the marine environment. In the aftermath a new volcanic phase begun (its character explosive) producing volcanic breccia.

Rhyolite and rhyodacite volcanic rocks in Kilise Tepe area give the impression that strong volcanism, both submarine and sub aerial, was followed by a shorter or longer discontinuation of volcanic activity, after which the formed volcanic rocks were easily destroyed by waves and other exogenic factors and transported into the adjacent sea basin. This redeposition of volcanic rocks led to the formation of tuffaceous sediments and conglomerates composed of rhyolitic and rhyodacitic volcanites, well stratified and sporadically accompanied by cherts with radiolarians. Most of volcanic rocks resulted from explosive volcanic activity and were broken by sea waves, ash from them was carried away to smaller or greater distances from the centre of volcanism, and entered into a sediment composed of tuffs and volcanic rock fragments. It is believed, however, that the resedimented volcanites on Kilise Tepe were deposited near the centre of volcanism, which explains the lack of varied sediments (clastics and carbonates). The formed deposits included volcanite fragments and were followed by a smaller amount of quartzite and chert bearing radiolarians. It is believed that the depositional environment was shallow and the material transportation short. The lack of sediments such as

carbonates, pelite, and the proportion of clastics support this inference. Existence of other clastic rocks which could not be associated with the Kilise Tepe volcanites is subsidiary. The distance from the environment in which marine sediments (sandstone, pelite, carbonate, etc.) were deposited showes the reason why they are lacking in the deposits, consequently in the volcanogenic-sedimentary rocks. Throughout the sedimentation, the hydrothermal stage and the solfataric stage continued. Hydrothermal water rich in sulphides and gases leaked into the resedimented highly porous volcanites which formed sulphide impregnations, veins, stockwork-impregnation mineralizations and other stratiform sulphide bodies some of which only were syngenetic with the redeposited sediments, whereas others were post-sedimentary, therefore epigenetic. This is the principal reason why there is not a unified interpretation of the origin of sulphide mineralization in the complex. One-sided views led to limited interpretations that sulphide mineralization in the region, and in the petrogenic complex, were subvolcanic (S c h n e i d e r h ö h n, 1955), or volcanogenic-sedimentary (P e j a t o v i ć, 1975/1979; V u j a n o v i ć, 1976; G ö k ç e, 2001; etc.), or volcanic, etc. However, all these interpretations are correct, because all the genetic, morphogenetic, and other types of deposits and mineralizations are present and can be found in Murgul region.

But between the volcanogenic-sedimentary complex of andesite composition, at the base of all complexes in Murgul region, and the rhyolite volcanogenic and volcanogenic-sedimentary complex (Jurassic/Neocomian in age) there is a transitional unit, determined as keratophyre and quartz keratophyre. Many authors of the reference literature have not noted the difference between keratophyre and quartz keratophyre, on one hand, and the rhyolite complex, on the other. As a certainty keratophyre and quartz keratophyre belong to different type of volcanism and were formed before the rhyolite complex. Keratophyre and quartz keratophyre sharply differ in its chemistry from rhyolite rocks. In this respect, particularly characteristic are Na_2O and K_2O contents in either rock. B u s e r and C v e t i ć (1973) report the Na_2O and K_2O contents in keratophyre and quartz keratophyre of Murgul area:

Na_2O	K_2O
From 3.78% to 5.24%	from 0.39% to 0.99%

These compounds in the rhyolite complex on Kilise Tepe are Na_2O - 0.125% and K_2O - 2.09%. The proportions are represented on a diagram of their contents (Fig.6).

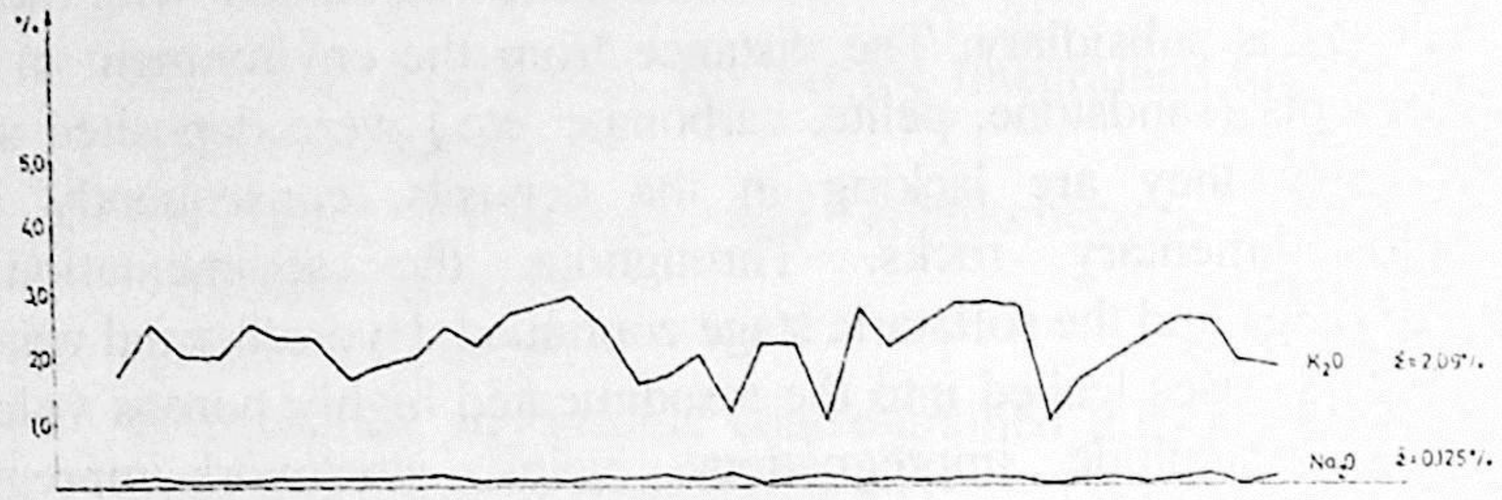


Fig. 6. Diagram of Na_2O and K_2O contents in rhyolite and rhyodacite rocks on Kilise Tepe.

In the former (keratophyre and quartz keratophyre), as shown in the above diagram, Na_2O is much higher that K_2O. In the latter (rhyolite volcanites), Na_2O varies from the lowest 0.10% to the highest 0.20%, whereas K_2O content in the same number of samples (20) varied from the lowest 1.05% to the highest 2.93%, which obviously suggests that these rocks are not rich in K_2O though it is contained by as much as almost 3%, but only in one sample. This information proves a sharp difference in chemical composition between keratophyre and quartz keratophyre (generally Na_2O-enriched) in relation to rhyolite volcanites, which is low in Na_2O and much higher in K_2O than keratophyres.

The diagram (Fig.6) shows that average K_2O (2.09%) in rhyolite and rhyodacitic volcanites of Kilise Tepe is much higher than Na_2O (0.125%), therefore these rocks can by no means belong to keratophyres. This is all the more so that keratophyres contain sodium-bearing feldspar (albite) manifested in primary and secondary (sea water) albitization.

The presence of highly silicified and mineralized volcanic breccia on the SW margin of Kilise Tepe peak (1917 m) may suggest a nearby paleovolcanic centre. Unfortunately, remote sensing by H e n d e n (1980-1981) and Y ı l d ı z (1982-1983) did not detect any structures in the region that could indicate paleovolcanic centres. Some features on the imageries indicate minor circular structures, but they are nearer to the Black Sea coast than to Murgul. However, there is an intrusion in the Murgul Dere, near the townlet of Murgul, which could be assumed to be a remnant of dacite neck (Fig.8). If so, it could be some kind of indication of a paleovolcanic centre, but could not be related to Kilise Tepe, because this dacite is younger than rhyolite.

A mass of rhyolitic rocks is identified within the Jurassic (Malm)-Neocomian complex over a large area. The rocks locally show fluidal structure

and vitrophyric texture that clearly suggest extrusion, and there is also volcanic glass. But it should be remembered that at present, under rhyolite flows, lies pyroclastic material mixed with redeposited volcanites and radiolarites, which indicates a somewhat earlier volcanic activity and redeposition of its products.

A particular characteristic of these formations in Murgul and adjacent regions is hydrothermal alterations that include mineralization of individual sulphides, as a specific kind of hydrothermal alteration of volcanites.

The commonest hydrothermal alterations are silicification, argillization, kaolinization, pyritization, chloritization, sericitization, in places more or less advanced carbonatization (calcitization), bleaching, then also supergene changes such as oxidation and forming small iron hats. Intensive water erosion leached and removed soluble minerals from the oxidized zone leaving the less soluble ones such as quartz, chalcedony, opal, etc., that developed interstices, or pores and honeycomb habit of these volcanites. Also particular landforms developed – pyramidal stacks 3 m high or more (Fig. 7).

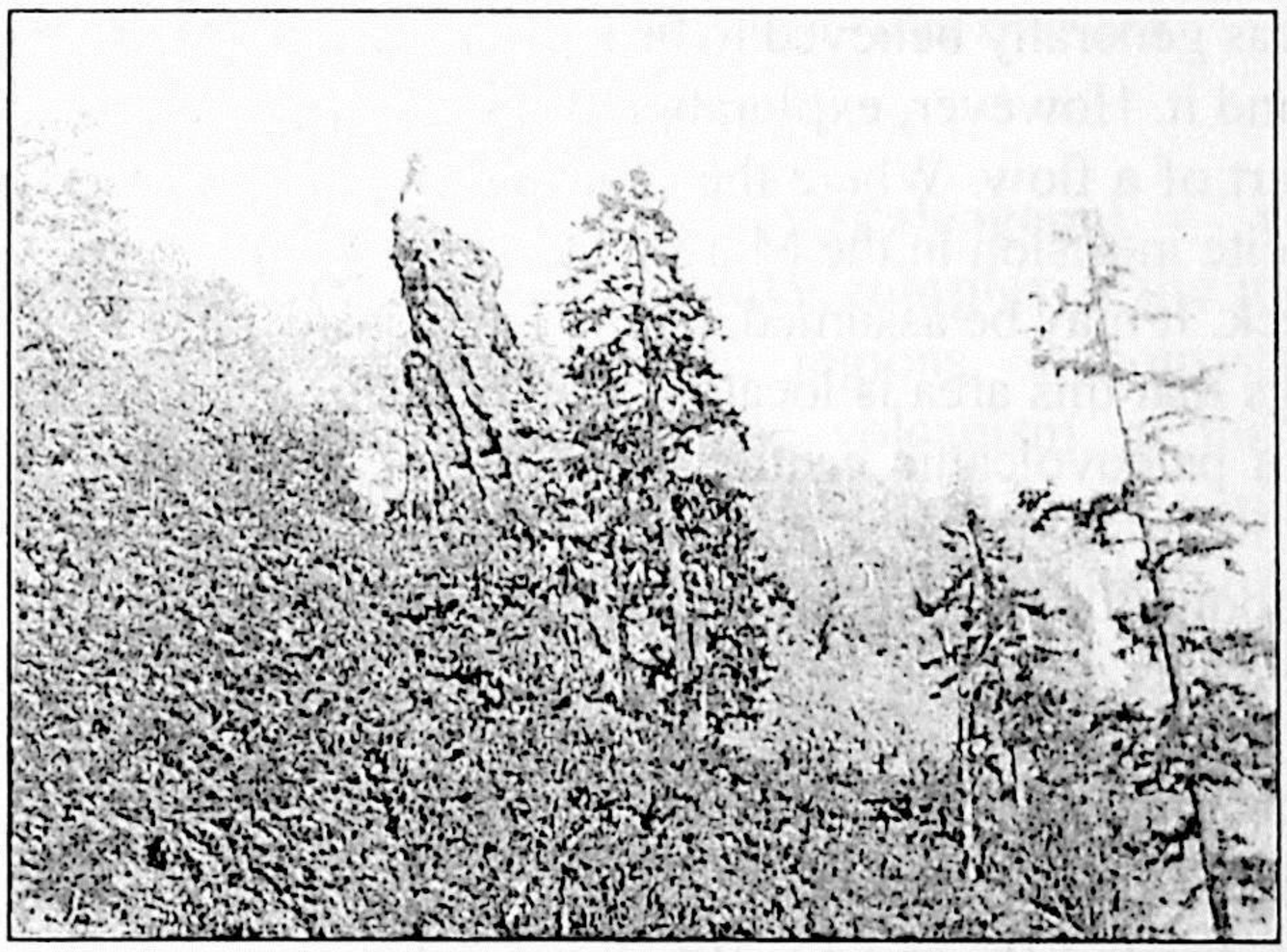


Fig .7. Aerosional pyramid stack in the Kopitvan dere (Kilise Tepe area, after P o p o v i ć, 2000).

In places of quartzdiorite intrusion, adjacent rocks have been more or less metamorphosed at the contact producing corneitization and epidotization.

The mentioned hydrothermal alterations of rhyolite rocks on Kilise Tepe is identical as that of adjacent rocks in the deposits of Anayatak, Çakmakkaya, the Aduca Dere, Çarkbaşı, and in the Lebiskur Dere valley, then near Hopa and east of Murgul, in Artvin area or in the Kuarshan ore field and in the Çoruh valley near Artvin.

Rocks of this petrogenic complex, like those near the Anayatak and Çakmakkaya deposits, and on Kilise Tepe, are locally schistose near the fault zones. This is an obvious proof, besides the presence of tectonic breccias, especially on Kilise Tepe, and elsewhere within the complex, that the rocks were affected by subsequent tectonic events.

Generally, one can say that the extrusion of rocks of dominantly rhyolite composition lasted a long time. However, not only during short breaks, but also during the volcanic activity, volcanites were fragmented, either in marine or subaerial environment, and redeposited near or at some distance from the effusion. This is what gives the impression that volcanites were older; rhyolite flows are older and, being more resistant, have been preserved in prominent places, whereas the resedimented flows and tuffs were deposited in low points of the relief; hence the impression of an inverse stratigraphic position.

In reference to this complex and the rocks overlying it, one should mention dacite of Kara Tepe rising above the Anayatak and Çakmakkaya deposits. It was generally believed to be a paleovolcanic centre with copper ore deposits around it. However, exploration drilling gave evidence that Kara Tepe dacite was part of a flow. Where the centre of its effusion was, is hard to say. There is a dacite intrusion in the Murgul Dere (Fig.8) that looks very much like a volcanic neck. It may be assumed, taking into consideration Y ı l d ı z (1982-1983) findings that this area is located on margins of a large circular structure, that there is a paleovolcanic centre. The fact is that the given dacite flow is more than 150 m thick on Kara Tepe, which suggests the likely original thickness of about 400 m. This all the more so that a part of the flow is of about 50 m thickness has remained on Orta Istasyon. It means that the base level of erosion is relatively deep and that the neck (?) in the Murgul Dere is in its deeper part. Though the time of the dacite formation is not reliably determined (some assign it to the Senonian), some relationships are clear. This dacite, determined as **dacite I** (K r a ë f f, 1963), is a columnar jointing extension over the ore-bearing rhyolite and rhyodacite volcanogenic and volcanogenic-sedimentary complex. But dacite, in the Murgul dere, is also overlain by Upper Cretaceous basalt and spilite violet in colour. This is well represented by B u s e r (1970) on his geological map. Dacite is not uniformly distributed horizontally; spilite-basaltic formation locally lies over Kara Tepe dacite or over the rhyolite complex or a fault structure. Researchers overlooked these relationships, and this resulted in many confused interpretations of the regional stratigraphy. In another place, K o p r i v i c a (1981) presumes that Sivri Tepe, near Hopa, is a volcanic neck, which is more likely, because also H e n d e n (1980-1981) and Y ı l d ı z (1982-1983) in the interpretation of satellite

photographs, indicate in the same area the existence of a circular structure that could be a paleovolcanic centre. Like in the Murgul channel, this could be taken provisionally for a dacite volcanic neck (Fig.15).

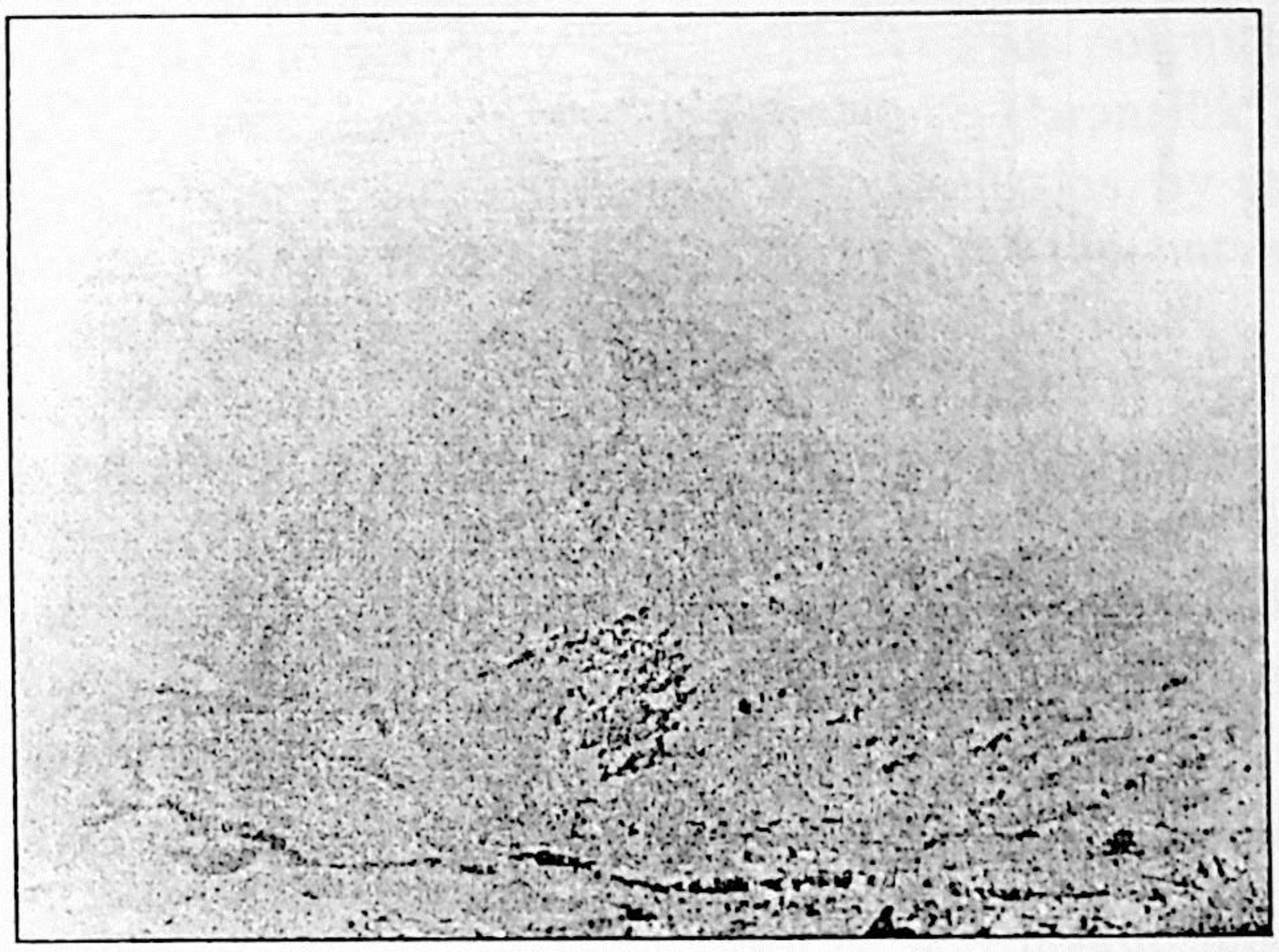


Fig. 8. Dacite neck(?) in the Murgul dere river bed.

Upper Cretaceous-Tertiary (Paleogene) volcanogenic, volcanogenic-sedimentary and sedimentary complex is the most extensive petrogenic unit in Murgel and adjacent regions. It consists of various formations of a great total thickness. The volcanism of this period was intensive and completely developed, from the most basic varieties (basalts, spilites) to the most acidic rocks (dacite and rhyolite). Throughout the period of no less than 25 million years, volcanic and sedimentary rocks alternated in the complex extraordinarily abundant in heterogeneous formations. It could be said that the complex consists of about twenty formations, each different from another in origin, petrologic composition, and stratigraphy or the geologic time of origin.

Before proceeding to detailed description, it should be emphasized that a distinct tectonic discordance separates the preceding rhyolite and rhyolite dacite (Jurassic-Neocomian) complex and this unit. The discordance is a structure mentioned by K r a ë f f (1963), B u s e r and C v e t i ć (1973), unconformity without describing its character. There is obviously a discontinuity between the rhyolite volcanogenic and volcanogenic-sedimentary complex and the younger Upper Cretaceous-Tertiary unit, in the form of a tectonic or tectonic-erosional boundary that does not allow mixing of the complexes.

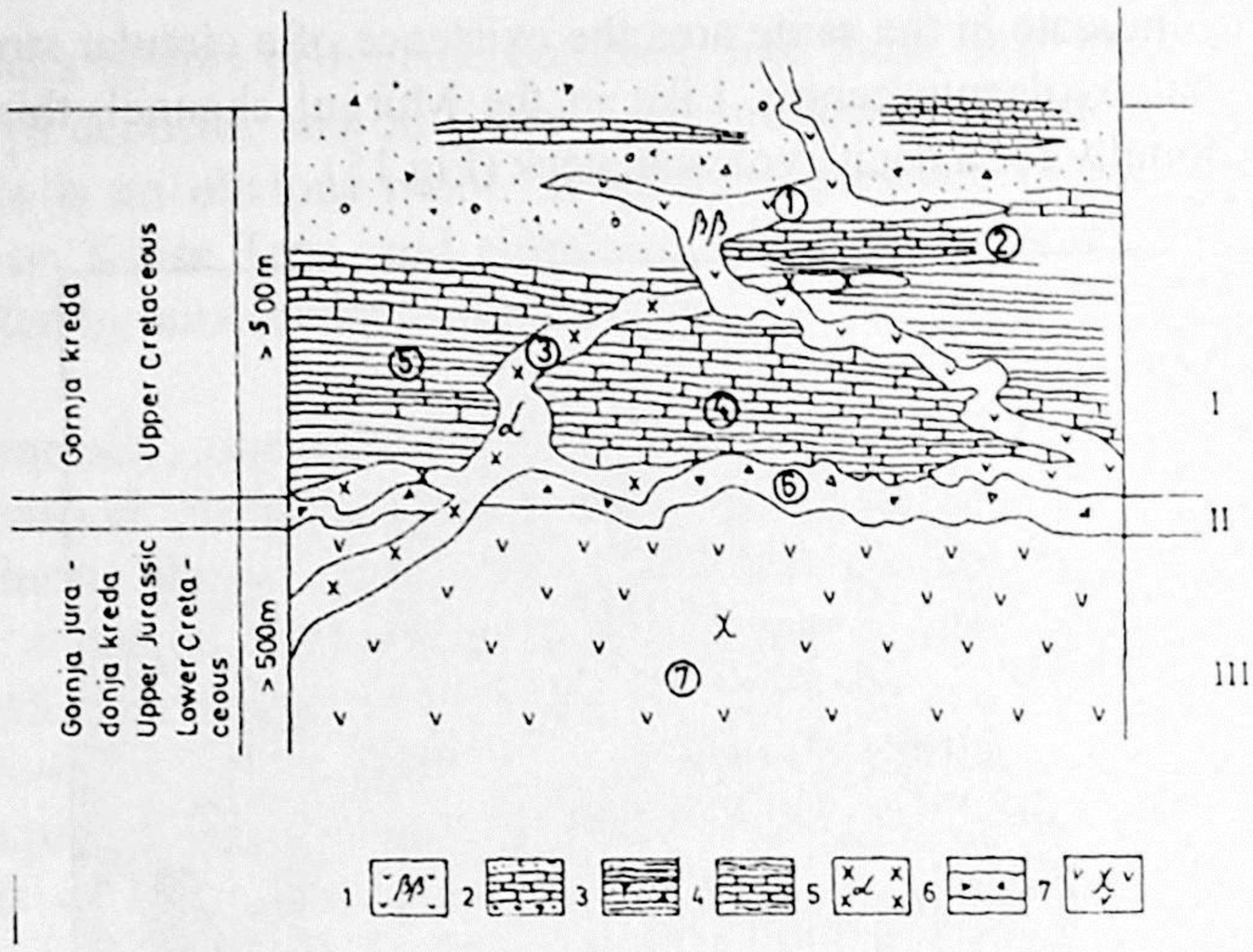


Fig. 9. Stratigraphic relationship between Malm-Neocomian and Upper Cretaceous (Maastrichtian) petrogenic complexes.

***I.** Upper Cretaceous volcanogenic, volcanogenic-sedimentary, sedimentary subcomplex (lower): 1. Basalt, diabase, spilite, chert; 2. Marlstone and thin bedded limestone; 3. Dacite 1, 4. Thin bedded limestone bearing inocerams; 5. Pelite, tuffogene sandstone and sandstone; **II.** Tectonic-erosional discordance: 6. Mylonite; **III.** Rhyolite volcanogenic and volcanogenic-sedimentary complex: 7. Rhyolitic and rhyodacitic volcanites.*

The structure, or the tectonic-erosional discontinuity (better say tectonic zone), was traced from near Kuvarshane, along the Çoruh river, to Artvin, Murgul, foremostly Anayatak and Çakmakkaya ore-bodies, Aduca dere, Kilise Tepe, Akarşen, to Madenköy and further SW to Black Sea (Fig. 4, 9, 14). The zone is well marked by tectonic breccia and schistosity. One other rupture separated from the main structure runs between Hohur Sırtı and Barnalük Tepe to SW. It may be assumed that the major fault zone was the main channel through which magma arrived, and that there were many volcanic centres along this zone in a length of about 150 km (or more) where volcanic activity endured during twenty to twenty-five million years.

The Upper Cretaceous-Eocene volcanic, volcanogenic-sedimentary and sedimentary complex consists of formations of determined ages. The oldest rocks, dated on the abundant faunal data, are Maastrichtian sediments bearing *inocerams* and *globotruncanae*. The information was used in dating the basic volcanism as Upper Cretaceous, the products of which are distributed over the large Murgul and adjacent regions. K r a ë f f (1963) referred to the volcanism as the **Spilite series II**. B u s e r (1970) terms it **"obere basische Serie"** (upper basic series). The two terms are commonly used in many references. In any event, these rocks are submarine basalts strongly spilitized

and should be identified as **diabase-basalt-spilite subcomplex** composed of diabase, basalt, spilite, chert, and thin-bedded limestones with inocerams. The unit, as mentioned before, discordantly lies over rhyolite volcanic and volcanogenic-sedimentary formations. The thickness of this, spilitic, formation is not uniform. It varies from 0,00 m south of the Akarşen polymetallic Cu-Pb-Zn deposit, of the Murgul valley to 400 m or more on Baranalük Tepe. Spilite effusion on the sea floor was accompanied, in distal basins, by sedimentation of thin-bedded *inoceramic* limestone. The formations are notably violet in colour. Like the basalt-spilitoid formation, the thin-bedded inoceramic limestones are not uniformly spread laterally and vertically (Figs. 4, 9). All the formations are synchronous. In the Akarşen area (near Murgul), a thin-bedded unit of limestones lies over the Jurassic-Neocomian rhyolite complex, and more northward in Petek Köy area the Jurassic-Neocomian formation is overlain by spilite (Figs. 4, 9). This is an evidence of a rapid and relatively shortlived creation of the spilite-basalt formation.

Spilites are characterized by the amygdaloidal structure; amygdules are filled with calcite, albite, less frequently zeolite, and locally occur as pillow lava, characteristic for this formation and also albitization as a specific characteristic.

Spilite-basaltic rocks are found in all grades between diabase, basalt and spilite, so that it may be named the diabase-basalt-spilite-chert formation by analogy to the diabase-chert formation of Balkan Peninsula. The formation is also characterized by the relatively large distribution. It contains locally interlayered red chert with which manganese mineral are associated and paste by hematite, which directly relates it with the space and origin of basic volcanic flows.

The diabase-basalt-spilite subcomplex is definitely of Upper Cretaceous age but its uneven horizontal position (where missing, carbonate or clastic sediments occur) mislead many researchers in dating its individual units. Sedimentary rocks, synchronous with the extrusion of diabase-basalt-spilite volcanites, are thin-bedded red limestones bearing Upper Cretaceous (Maastrichtian) fauna. Synchronous with carbonate deposits are tuffite and breccia also deriving from basic volcanism. Stratigraphically, however, these rocks gradually pass upward into intermediate volcanic or volcanogenic-sedimentary rocks of andesite, or less frequently trachyandesite composition, which together form the upper subcomplex. Volcanites are composed by tuffs, agglomerates, subordinately andesite flows, and other intermediate or acidic volcanic rocks. These rocks were formed under submarine and subaerial conditions. Their contact with seawater either while an explosive pyroclastic or

flow material, caused chemical reactions that resulted in albitization. The same processes produced albite-trachyte facies. The volcanism was paralleled, laterally and further from volcanic centres, with sedimentation that formed thick limestones and a large mass of marlstone.

Subsequently, in the early Tertiary, volcanism continued in somewhat changed composition: andesite containing augite and hornblende. The volcanism was explosive and led to the development of large masses of agglomerate and tuff. Short intervals between reduced or abated volcanic activities are marked by sedimentation in marine environment and formations of pelites, sandstones, tuffogene sandstones, and redeposited tuffs, then sedimentation of limestones with a tuffogene component. Individual thickness is small, mostly between one and ten metres in most areas, but on the whole, the sedimentary interbeds in volcanites are thin. Upper parts of these volcanogenic and volcanogenic-sedimentary formations are represented by acidic varieties, dominantly dacites. The total thickness of the subcomplex is exceeding thousand metres. Its sedimentary part alone has an estimated thickness of three hundred metres. Admittedly, local folding could have increased the apparent thickness, which should be remembered when estimating the thickness of the formations, to avoid omission of some authors who estimated the thickness to more than 2000 metres.

Volcanites of the whole complex evolved from the basic to the acidic rocks with all grades in between. Sedimentation products are equally varied, from chemical deposits (carbonate, chert) to mixed chemical and clastic varieties, particularly notable in marly and pelitic deposits, which frequently laterally and vertically gradual passing one into the other, ending with true carbonate and clastic rocks.

Intrusive complex. The described volcanic activities by no means were isolated, but in direct genetic, temporal and spatial association with the intrusive complex. This refers primarily to the Tiryal dağ-Tatos dağları granodiorite pluton (batholith), which takes the central part in magmatism of the Pontids. Only the peripheral parts of the plutonics are found in Murgul and adjacent regions, represented by minor masses in the form of sills, dikes, or smaller or larger intrusive bodies irregular in shape.

The petrogenic complex consists of granitoid rocks (quartzdiorite) that were intruded during the Eocene. All these intrusions provoked metamorphism at the contact with adjacent volcanogenic-sedimentary rocks forming hornfels or skarns.

Wherever found, it seems the temperature of the intrusive rocks had not been very high, as indicated by the grade of contact-metamorphism, which is represented by thinner or thicker hornfels and skarn, or barely noticeable. An essential characteristic of the intrusions is local enrichment, even mineralization, in some metals, especially zinc, copper, and occasionally molybdenum. The intrusive rocks vary over a wide range from diorite to microquartzdiorite, quartzdiorite, and granodiorite, to granite. M o o r e et al. (1970) suggested that the development of the Tiryal dağ-Tatos dağları batholith lasted from before 257 (Permian-Triassic) to about 30 million years. Their data is based on the absolute age determination by K/Ar method. Hence, magmatism of the Pontids began in the Permian, continued with shorter or longer breaks to the Oligocene. Consequently, each volcanic cycle and each volcanic-phases were directly associated to the mentioned batholith. But in Murgul and surrounding areas, granitoid intrusions developed in the Paleogene, and partly the Neogene.

The largest masses of quartzdiorite occur in the Başköy dere valley south of Kilise Tepe (Murgul) and in the Çoruh valley. Minor extrusions are noted in other localities, to mention Hopa, Arhavı, etc.

Intrusion of these rocks probably led to local folding of the volcanogenic and volcanogenic-sedimentary formations, particularly notable in Balıklı Yayla and Başköy Maden (Başköy Mine), and resulted in the development of the deposit and to the somewhat peculiar occurrence of quartzdiorite in the valleys of the Başköy dere and its tributaries. The quartzdiorite finger-like occurrence may explain the formation of overfolds with quartzdiorite intruded in the apex. Because the base level of erosion is deepest in the mentioned small rivers, the largest masses of this rock occur in them.

Besides the mentioned granitoid batholith, a number of rhyolite, dacite, diabase, basalt, and similar rocks intruded during the late stages of the Cretaceous/Tertiary magmatic activity could be assigned to the intrusive complex of rocks. But magmatism did not end with these intrusions. There are young volcanites in eastern Turkey, beyond the limits of Artvin Province, which, geologically, can be taken for recent. Traces of volcanism have been known to exist in this large area, left by volcanic events during the last million years. As early as in 1906, F e l i x O s w a l d was showed volcanic centres of the Caucasus on the **Tectonic Map of Armenia** including a part of Turkey. It may be assumed that magmatism, in the Artvin Province, has not ended.

IV. GEOTECTONIC EVOLUTION

If the absolute age of the Tiryal Dağ-Tatos dağları granitoid batholith was Permian, as stated by M o o r e et al (1980), then this period was the beginning of all geodynamic processes that operated in Murgul and adjacent regions, or the Pontids in general. The given region cannot be considered isolated from the unified geotectonic realm, on which many references were written from different aspects and with different interpretations of the geotectonic history of the Pontids. The modern geotectonic model is based on the movement of Earth's crust plates (continental and oceanic type), their rifting or collision, which controlled the geodynamic processes. The best presentation of tectonic events is given by P e j a t o v i ć in his doctoral thesis (1975/1979). Many publications followed: A k i n c i (1980), Ö z g ü r (1992), G ö k ç e (2001), and many others, with similar or identical interpretation of the geotectonic events in the Pontids.

A principal point of the modern interpretation of the geotectonic setting of magmatic formations in eastern Pontids is the subduction of northern Anatolia ophiolites and the development of the island arc. Ophiolites of northern Anatolia are remnants of the oceanic crust that, pushed by the Arabian-Anatolian continental plate, compressed the north Anatolian oceanic plate (ocean) forming as a result an island arc similar to the modern Japanese arc.

It should be added to this general outline of the regional geotectonic events that led to the development of the Pontian island arc as the principal component of the geotectonic setting for the development of the magmatic rocks, that the Pontids are part of a larger, global geotectonic belt extending from Balkan Peninsula across Asia Minor (Pontids) to Iran into the Himalayas. The two basic characteristics control the entire geotectonic setting of the Pontids. In view of the duration of the geotectonic events, the local tectonics could not be simple, as expressed by magmatic, or volcanic activity, and consequently the local tectonic pattern.

For geotectonic explanation of the Pontian volcanism, it is significant to point out its chemical and mineralogical composition.

There are interpretations (A k i n c i, 1980, referring to K i l i n ç , 1971; E g i n, 1978, etc.) that the so-called upper basic series was calc-alkalic, and the lower tholeiitic, but we prefer the determination by P e j a t o v i ć (1975/1979) of the tholeiitic type of volcanites in eastern Pontids. The latter author established his determination on a large number of chemical analyses of samples from the Pontids and from Caucasus Minor (for the latter he used Soviet published sources and compared them with his own findings). He inferred the tholeiitic character of Pontic volcanites from M i y a s h i r o (1973) and K u n o (1968) diagrams. We also made some chemical analyses while working near Murgul. These chemical results we interpreted by using AFM discriminant three-component (Fig.10) and P e a r c e' s (1975) two-component (Fig.11) diagrams. The AFM diagram (Fig.10) shows that Malm-Neocomian (Upper Jurassic-Lower Cretaceous) volcanic formations fall only in the tholeiite field, and the same goes for volcanites of the Upper Cretaceous-Tertiary volcanogenic and volcanogenic-sedimentary complex.

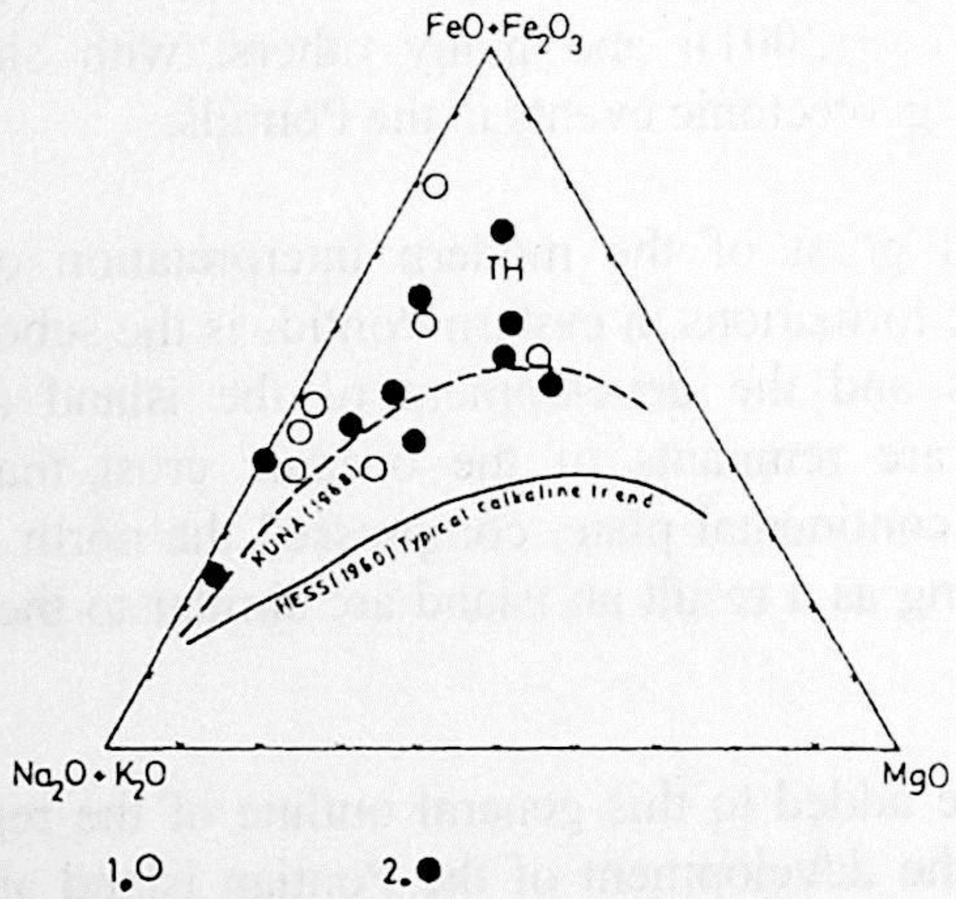


Fig. 10. Three-component AFM diagram.
1, Malm-Neocomian volcanites; 2. Upper Cretaceous-Paleogene volcanites.

On the other hand, using P e a r c e' s (1975) diagram (Fig.11) of the chromium to titanium relationship it was suggested that the same rocks fell into the area of island arc. Even with the small number of available samples the agreement of the results with those of P e j a t o v i ć (1975/1979) fully justify the opinion that volcanites from Murgul area formed in the island arc and that their character is tholeiitic.

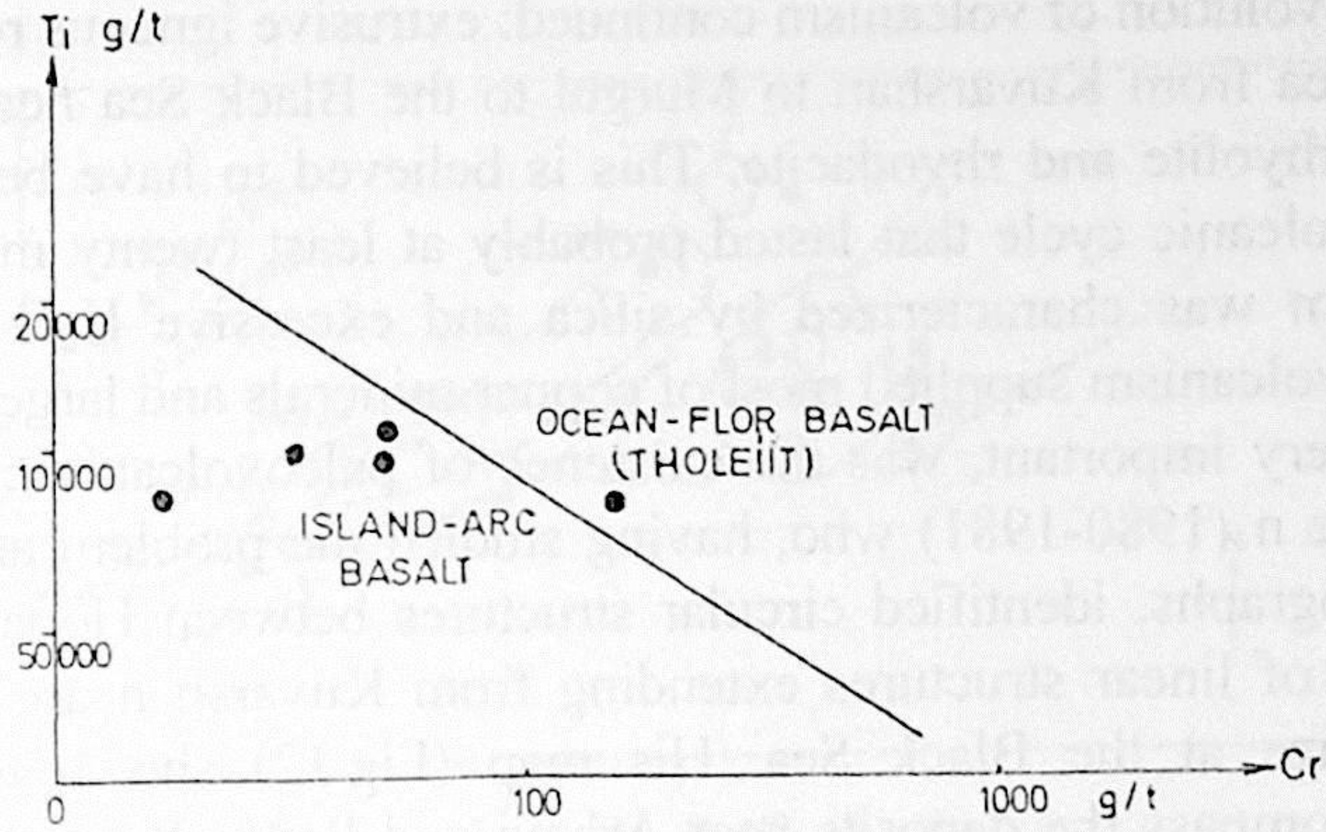


Fig. 11. P e a r c e' s diagram (1975) of Cr-Ti relationship in magmatic rocks (andesite, quartzdiorite; Cretaceous-Paleogene) of the Murgul area.

Thus defined geotectonic setting, within which volcanic-intrusive complexes of Murgul and adjacent regions were formed, and on which the Metallogeny is based, leads to description of other processes through the geotectonic evolution.

TECTONIC, VOLCANOGENIC CYCLES AND PHASES

In the part of this text concerning chronostratigraphic and lithologic features, volcanic activities were mentioned and four main volcanic periods identified in time. Products of the oldest volcanism are volcanite volcanogenic, volcanogenic-sedimentary formations exposed in the upper flow of the Murgul dere. The age of this volcanism is not finally dated, but being the oldest it is attributed to the undefined Jurassic period (possibly lower Malm, Oxfordian-Kimmeridgian). It was a submarine volcanism that formed volcanogenic-sedimentary rocks including andesite flows. The activity could have partly evolved under the subaerial conditions, when pyroclastic material (tuff, agglomerate) was expulsed and included into the complex either as an extrusive or subsequently redeposited material. Few data are available about this volcanism and its products. It is obvious, however, that through its development, the rocks became increasingly acidic: from andesite to keratophyres, also under submarine conditions, and with abundant supply of SiO_2 to quartz keratophyre.

The evolution of volcanism continued: extrusive igneous rocks formed in a broad area from Kuvarshan to Murgul to the Black Sea near Hopa and Çayeli were rhyolite and rhyodacite. This is believed to have been the final period of a volcanic cycle that lasted probably at least twenty million years. The volcanism was characterized by silica and excessive K_2O over Na_2O (Fig.6). This volcanism supplied most of copper minerals and large amounts of pyrite. But, very important, was the existence of paleovolcanic centres. First was H e n d e n (1980-1981) who, having studied the problem and analyzed satellite photographs, identified circular structures between Hopa and Pazar, and a system of linear structures extending from Kuvarshan area across the Murgul to Rize at the Black Sea. His map (Fig.12) shows that circular structures encompass the deposits near Arhavi and Pazar, but not the copper deposit at Murgul. This interpretation of satellite photographs was soon followed by another, given by Y ı l d ı z (1982-1983). Y ı l d ı z clearly identified circular structures, also between Hopa and Pazar, then near Kemal Paşa (NE from Hopa – Black Sea coast) and an extensive circular structure between Artvin and the Murgul dere, and within the latter, a large and a small elliptic structure that included Anayatak, Çakmakkaya and other copper deposits near Murgul. Finally, same author clearly identified three linear, but different, structures. One is extending from Murgul, from the margin of the elliptic structures, southwestward to Of. Another is parallel with the former (Figs. 12. and 13) also extending from Murgul and ending at Rize on the Black Sea coast. The third extends from Ardeşen and converges with the former at Rize. This explains the direct interrelation of the paleovolcanic centres and the major linear structures.

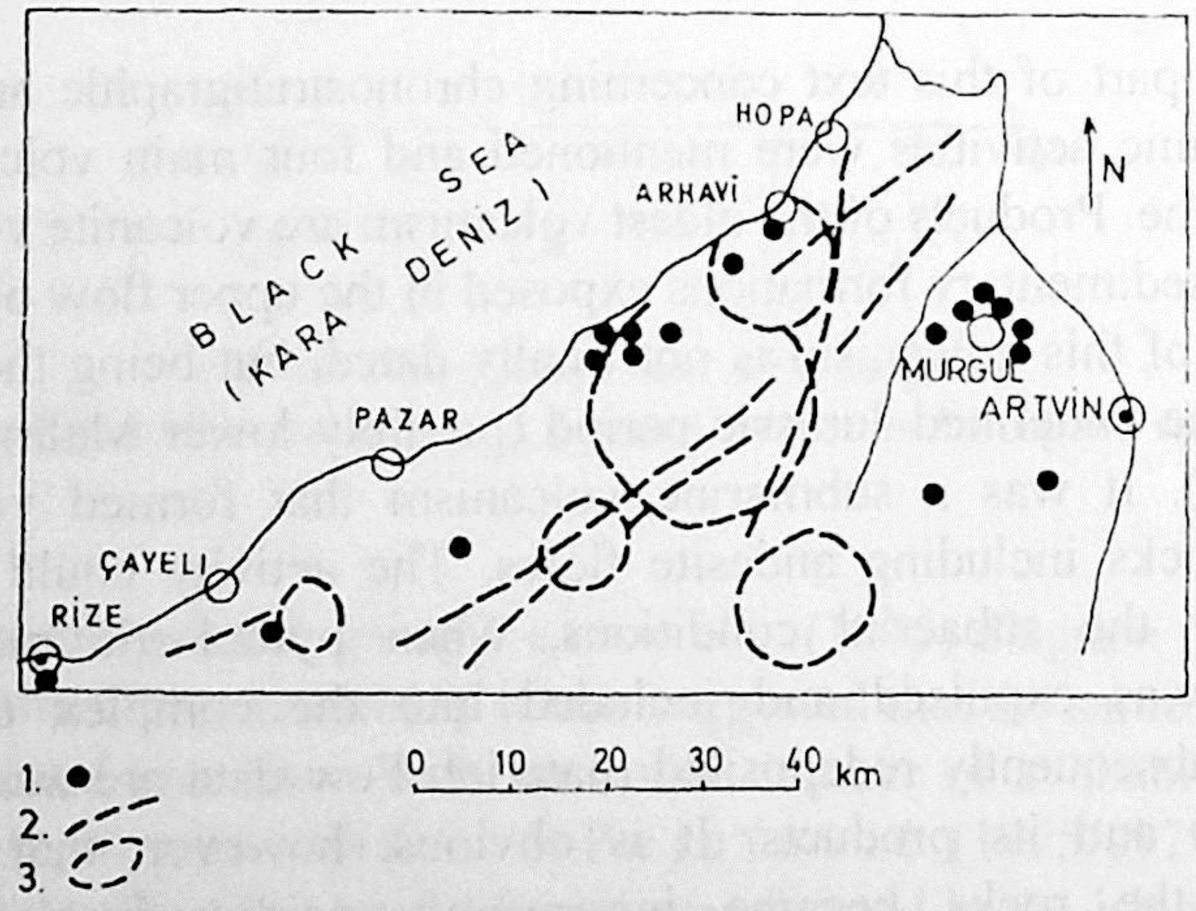


Fig. 12. Tectonic sketch map based on remote sensing (H e n d e n, 1980-1981). 1, Ore deposit, 2. Fracture structure, 3 .Cirkular structure.

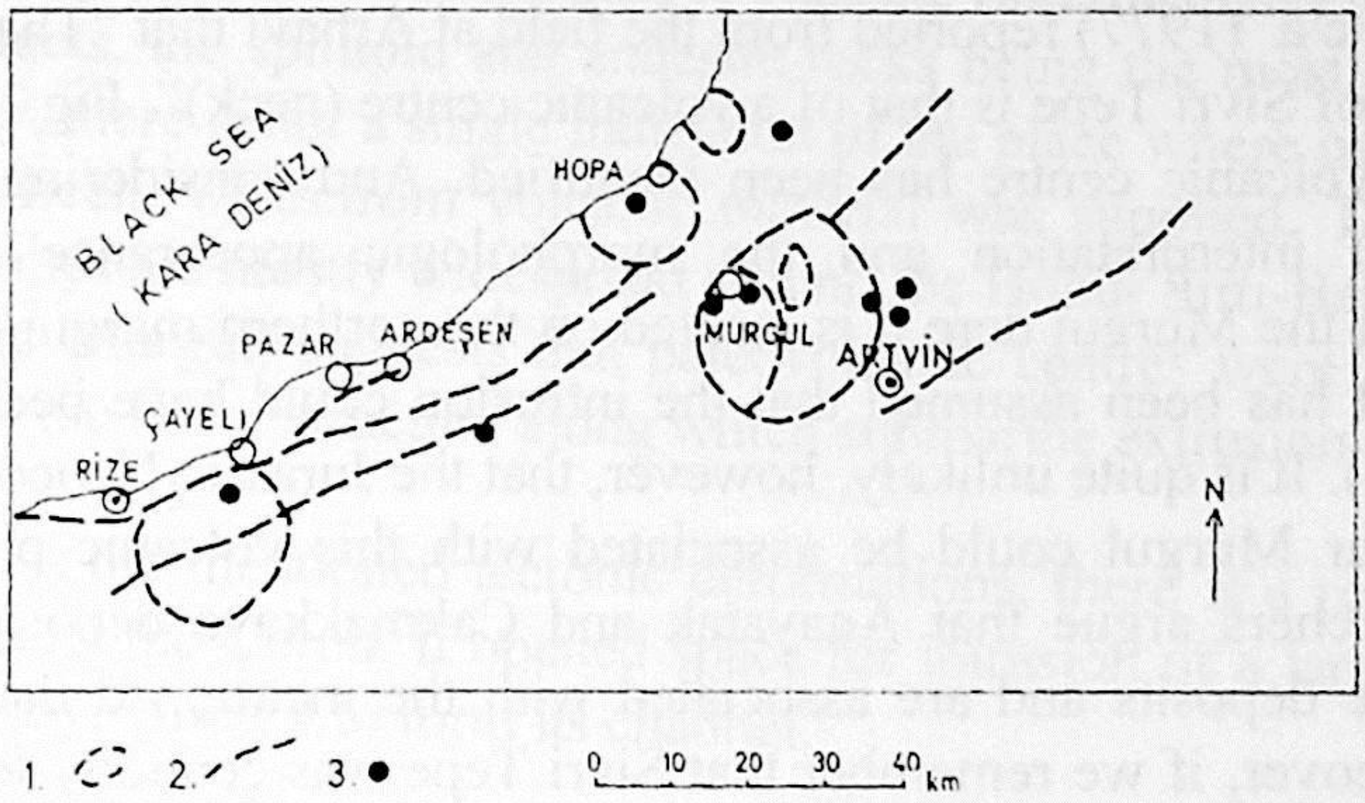


Fig. 13. Structural map based on remote sensing (Y ı l d ı z, 1982-1983).
1. Circular structure, imbricate structure, 3.Ore deposits.

The linear structures on the mentioned map are almost identical with the fracture structures identified by P o p o v i ć in 1976 (Fig.14).

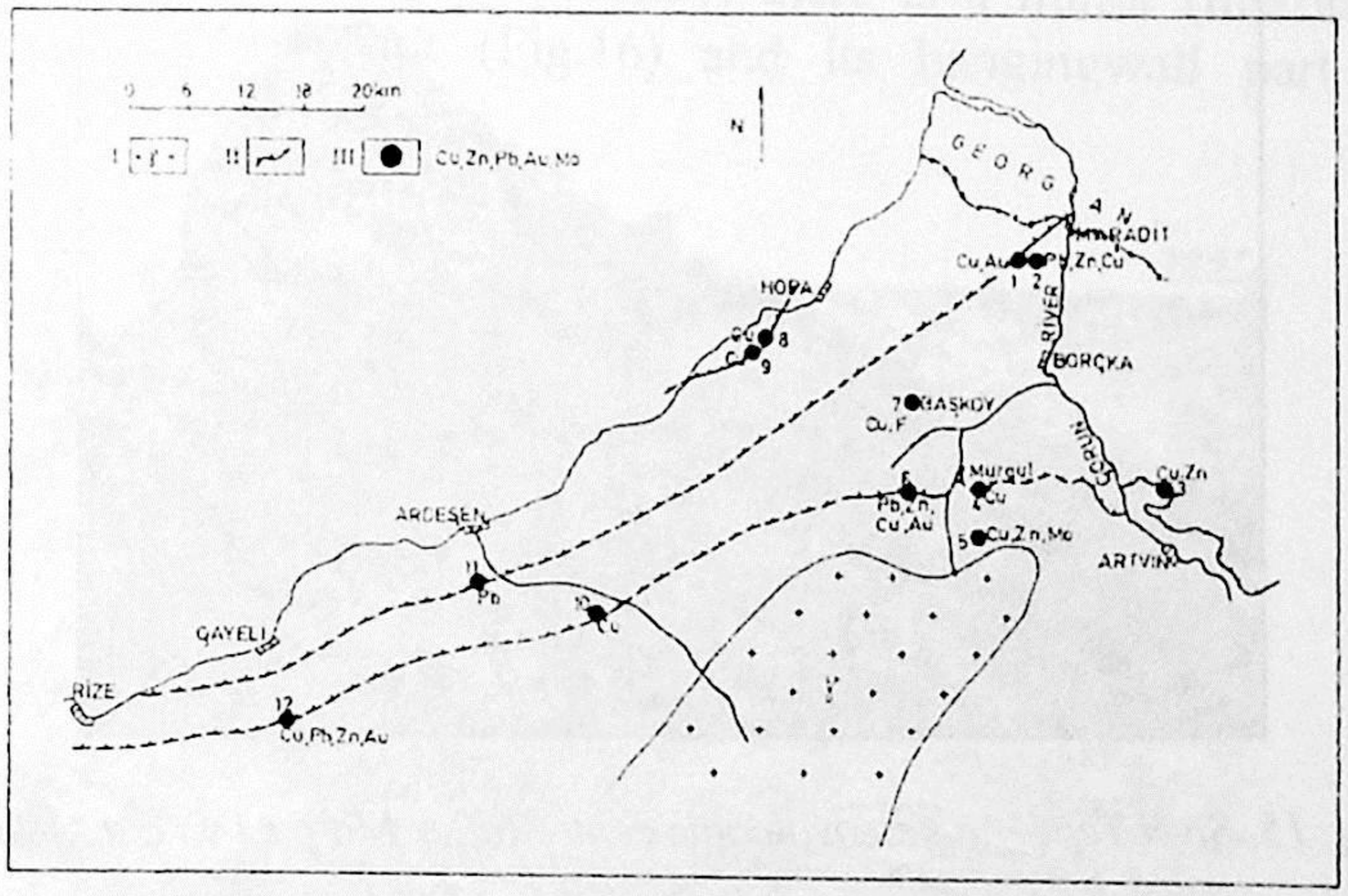


Fig. 14. Geotectonic sketch map of Artvin Province (Popović, 1976).
I.Granitoid; II. Imbricate structure; III Ore deposits.

Copper deposits in the areas of Murgul, Kuarshane, Tunca, Cayelı, Arhavı, according to this author, are directly associated with the linear structures imbricate in character. Y ı l d ı z (1982-1983) interpreted eight circular or elliptic structures distinctly recognized between Kuvarshane and Rize. This information leads to the assumption that the mentioned fracture

structure preceded the extrusion of rhyolite and rhyodacite. On the other side, K o p r i v i c a (1977) reported from the field at Arhavı that "The present-day appearance of Sivri Tepe is that of a volcanic centre (neck)", Fig.15. So far, no other paleovolcanic centre has been identified. And considering Y ı l d ı z (1982-1983) interpretation and the morphologic appearance of a dacite intrusion (in the Murgul dere it is located on the northern margin of an elliptic structure), it has been assumed that the intrusion could have been a volcanic neck (Fig. 8). It is quite unlikely, however, that the Jurassic/Neocomian copper deposits near Murgul could be associated with this volcanic phase, though some researchers argue that Anayatak and Çakmakkaya deposits belong to Kuroko-type deposits and are associated with the mentioned dacite neck, or dome. Moreover, if we remember that Sivri Tepe was centrally located in the circular structure identified by Y ı l d ı z (1982-1983), then K o p r i vi c a (1981) was right for identifying Sivri Tepe as an old volcanic neck. Therefore, two paleovolcanic centres in Murgul and adjacent regions have been identified, and so some of ore occurrences can be genetically directly associated with them.

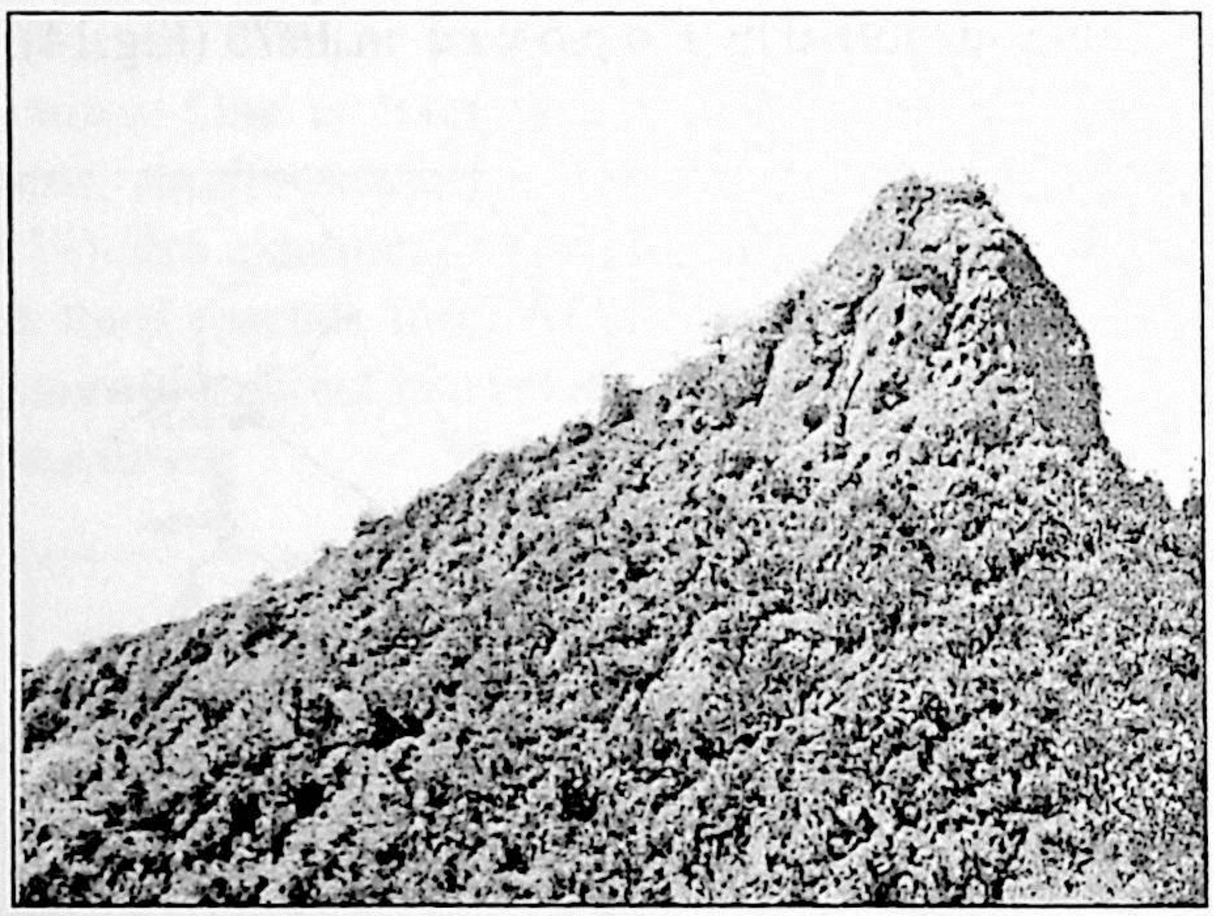


Fig. 15. Sivri Tepe – a paleovolcanic centre (after K o p r i v i c a, 1981).

Still considering Murgul area, it may be argued that Kara Tepe dacite lies over the linear structure and Malm-Neocomian volcanic rocks that include ore deposits of the Anayatak-Çakmakkaya ore field and, where dacite is lacking, the ore-bearing formations are overlain by products of a new volcanic phase, or better say cycle, which are products of the Upper Cretaceous, basic, intermediate or subordinately acidic volcanism. The new volcanic cycle began about 30 to 60 million years after the preceding one had ceased. All the investigation data indicate the presence of volcanic products in the rock complex, which represent the full evolution of volcanism: from basic

(basaltoid and spilitoid) volcanic rocks, to andesite (intermediate) to dacite and rhyolite products, the spilitoid and andesite rocks being the most widespread. Unfortunately, there is not a single indication of the place where paleovolcanic centres have been, wherefrom volcanic material was supplied. The fact that spilitic volcanites are mostly widespread around the Hohur Sırtı-Barnalük Tepe structure (near Murgul) suggests that paleovolcanic centres were in this fault zone or it was the linear structure along which submarine extrusion occurred.

Besides the mentioned tectonic deformations, there is a regional fault that strikes along the Çoruh. It opened space for intrusion of a large granitoid body, and the river used it to form its channel.

As to other tectonic deformations besides linear structures, local folds characterize the Murgul area. Folding is distinctive between Blıklı Yayla and Hohur Sırtı, and on Kilise Tepe. Folds in Blıklı Yayla are metric to hectometric. Folds are well visible in Başköy copper deposit where a recumbent fold is dekametric in size (Fig.63), or further southwest, about 1 km from the Mine, a metric fold has been intersected by a fault and thrust over.

Also, near the village of Başköy, there is a minor (metric) flexure ruptured by a reverse fault (Fig.16) and its hangingwall part plunged southwards.

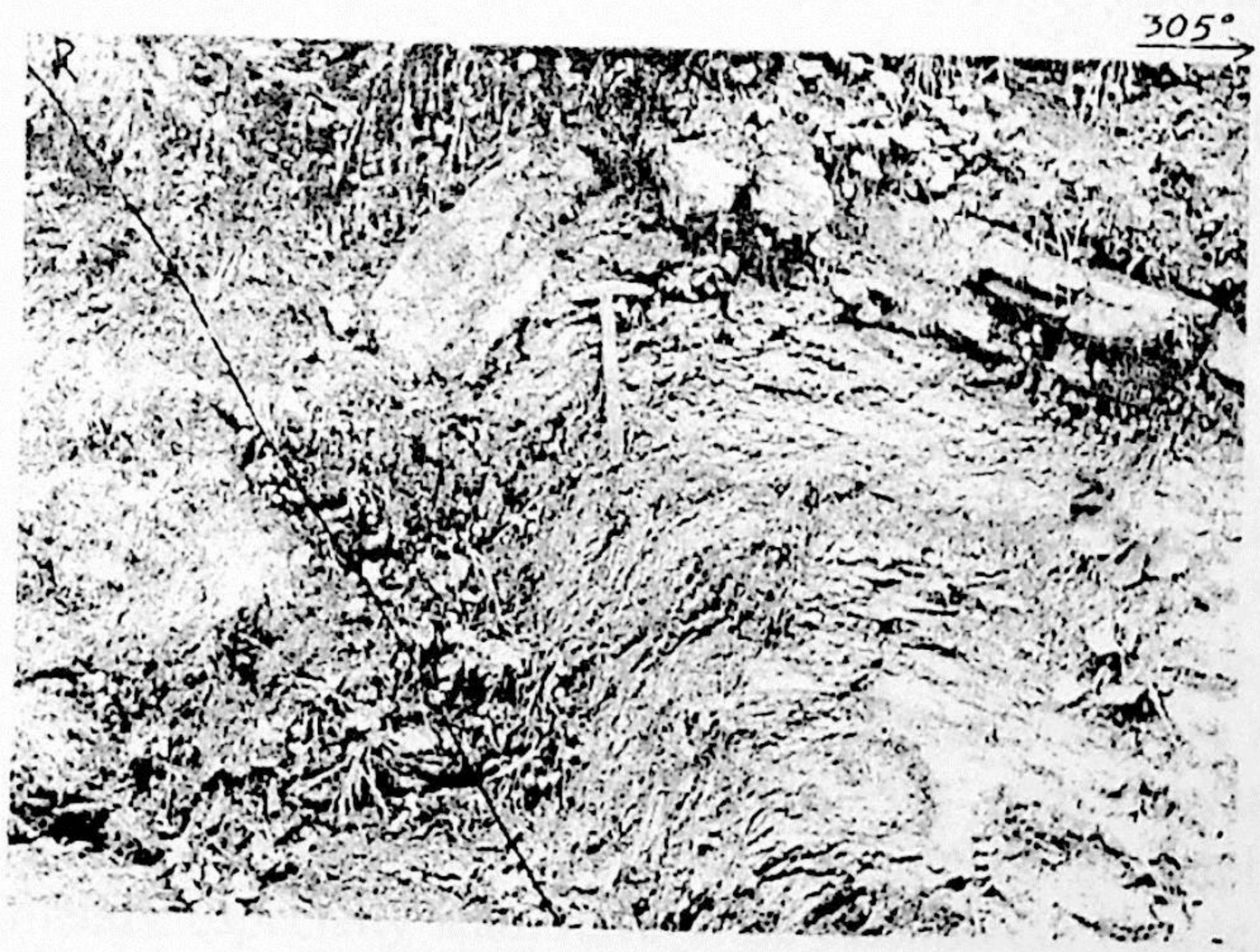


Fig. 16. Fold intersected by fault (P o p o v i ć, 2002c).

Another reverse structure has been identified on Kilise Tepe. It crushed rhyolitic volcanites (Malm-Neocomian volcanism) in a zone about 25 m thick. Its displacement also caused folding, but like the one between Balıklı Yayla

and Hohur Sırtı, the folds are small, local, and nevertheless important for copper mineral exploration.

In addition to the mentioned tectonic deformations, Murgul and adjacent areas were affected by strong local faulting, which induced many researchers to believe that this was the only kind of structural deformation, and explained the entire region as having the block tectonic style.

The source of all the mentioned structural deformations is associated with the subduction and development of the island arc, or the development of Tiryal Dağ-Tatos Dağları pluton. Consequently, the geotectonic setting of magmatic rocks, volcanic activity, regional and local tectonic deformations, and the origin of associated sulphide ore deposits are interrelated.

Finally, speaking of tectonics and magmatism, it is certain that minor faults also had important role in the development of various morphogenetical types of mineralized numerous formations with different mineralization. Faults were either smaller or larger supply conduits with ore-fluids enabling development of, primarily, pyrite veins of variable thickness, or quartz-pyrite-chalcopyrite veins, and pyrite-chalcopyrite-fluorite veins, etc.

V. METALLOGENIC IMPORTANCE OF PETROGENIC COMPLEXES AND ORE DEPOSITS

ORE-BEARING VOLCANOGENIC-SEDIMENTARY COMPLEX OF JURASSIC (LIKELY OXFORDIAN-KIMMERIDGIAN) AGE

Ore deposits in Murgul and adjacent regions are all related to certain formations that were formed in various geologic periods.

The oldest sulphide minerals occur associated with sandstones, tuffogene sandstones and andesite flows, found at Iskalka Köprüsü hamlet in the Murgul Dere valley. Syngenetic impregnated pyrite occurs in sedimentary rocks, and other (lead, less copper and zinc) sulphides in small amounts occur in andesite flows. However, Cu and Zn principal mineralizations (vein type), in this complex, are epigenetic and subsequently formed, and these two types differ in the time of their origin.

Geochemical prospecting of the sedimentary part of the complex (sandstones, tuffogene sandstones) at Iskalka Köprüsü gave us a general insight into its metallogenic character. These sedimentary rocks are characterized by stronger or weaker syngenetic pyrite mineralization. Unfortunately, the small number of geochemical samples (Table 1) does not allow a serious estimation, but the copper contents from 40 ppm to 500 ppm are not to be rejected before a systematic geochemical exploration has been made. Zinc concentrations are similarly variable, from 30 ppm to 220 ppm, and lead is contained by less than 50 ppm. Where this petrogenic complex is concerned, attention must be given to andesite flows, which are a component of the complex. As mentioned before, sediments and andesite flows are alternating within the complex, therefore enrichment in sulphides of the mentioned metals, especially lead, have to be considered. Beside sedimentary and volcanogenic-sedimentary sulphide mineralizations, this complex is characterized also by another type – epigenetic mineralization. The latter is a subsequent copper and zinc sulphide mineralization in the form of thin or thick veins that are filling various ruptures, which should not be rejected without additionally explored.

Table 1. Geochemical test results from Iskalka Köprüsü

Cu (ppm)	Zn (ppm)	Pb (ppm)
50	220	50
1000	48	<50 (vein)
260	56	900 (andesite flow)
40	30	< 50
500	136	< 50
48	30	< 50

This complex, estimated on few earlier explorations of syngenetic mineralizations in tuffogene sandstones and sandstones, is less significant for ore-bearing, but the concentrations of lead (to 900 ppm) and copper (about 260 ppm) in andesite flows could be of some significance, because it is believed that they have been formed under volcanogenic-sedimentary conditions. A more accurate estimate is not possible, because the observable distribution of the formation is small. The situation with the volcanogenic formations composed of keratophyre and quartz keratophyre is similar. These rocks also bear the presumably syngenetic pyrite mineralizations but because of very limited prospecting it is not possible to confirm this presumption. Rocks of this complex are located in the Murgul dere, from Iskalka Köprüsü to the south towards the spring of the river.

COPPER

MURGUL AREA

1. Iskalka Köprüsü. Sulphide mineralisations in this, above described, petrogenic complex are known only in the Murgul valley, at Iskalka Köprüsü. The ore body, in this or some nearby location, have been exploited in the past. Evidence is the slag dump remains found on the Murgul west bank.

Copper minerals are located on the southern outskirts of Iskalka Köprüsü hamlet, on the east bank of the Murgul dere some 8 km south of Murgul town (Fig. 29).

Some of the occurrences were first noted by B u s e r et al. (1970) and explored by author of this paper. K r a ë f f mapped geologically in 1963 the entire Murgul region, including this locality, but did not mention copper mineralization at Iskalka Köprüsü.

B a s i c G e o l o g i c a l C h a r a c t e r i s t i c s

All the available information indicates that rocks of Iskalka Köprüsü are the oldest in Murgul region. Earlier explorers defined the entire petrogenic complex as **"lower basic series"** or **"Spilitic series"** (K r a ë f f, 1963). Detailed explorations later disproved the definition **"basic"** or **"spilitic"** series simply because, excluding the young (Quaternary) basalt dikes, all other formations are tuffogene sediments, volcanic rocks of andesite and keratophyre composition or granitoide intrusions.

Generally, two petrogenic complexes, volcanogenic-sedimentary and intrusive, have been identified.

The volcanogenic-sedimentary complex consists of sandstones, tuffogene sandstones, tuffs, and agglomerates of andesite composition, covered by keratophyre and quartz keratophyre rocks.

In both cases constituent formations of this complex were formed in the Upper Jurassic (lower Malm; possibly Oxfordian-Kimmeridgian).

The other petrogenic complex, though much younger, is presently mentioned because it also represents geological characteristics of the area. It is represented by granitoid, intruded during the Eocene – mainly small quartz diorite masses. The central mass is larger than the others; although not too big itself it is less than 200 m long and less than 30 m thick. The intrusion provoked contact metamorphism on volcanogenic-sedimentary rocks manifested by forming hornfels.

Basalt dikes (Quaternary, Fig. 17) are also noted in the area, but are not presently considered.

Notable tectonic deformation of rocks was noticed through detailed exploration even in the small area (0.25 km^2).Only a few number of faults, fissures and joints, were mineralized, these are pre-mineralized ruptures and remain as the only determined form of tectonic deformation. Major faults have NNW-SSE strike, and some of the fissures and ruptures have the same direction, but others spread WNW-ESE.

Rupturing deformations are particularly important for the area, because they had the major part in forming of sulphide mineral veins. Pre-mineralized structures served as a space for ore veins deposits. But only a small number of faults are mineralized, in contrast low grade ruptures as a fractures and fissures which most of them are mineralized. This suggests a genetic relation between the two types of tectonic deformations.



Fig. 17. Basalt dike (ββ) at Iskalka Köprüsü (after P o p o v i ć, 2003).

Ore Occurrences

In an area of about 0.25 km^2, seven pyrite-chalcopyrite outcrops are found more or less notable, unlike pyrite impregnations in sediments. Copper is mineralized mainly along fissures, fractures, and some faults. This mode of sulphide occurrence suggests dominantly syngenetic and pre-mineralized pyrite impregnation in sediments. Mineralization, however, associated only with faults is younger and occurs as a thinner or thicker ore veins. There are few examples of mineralization parallel with stratification, where pyrite formed lenticels of 10 cm in length and less than 0.5 cm thickness.

All the mentioned sulphides are affected by stronger or weaker oxidation. This the pyrite-chalcopyrite occurrence **No.4** oxidized to the degree of a minor gossans formation.

Where pyrite is most abundant, its total concentration does not exceed 10% of all rock constituents. In the present state of our knowledge, the contents of copper mineral or of other metallic minerals is even lower.

A higher proportion of magmatic rocks (andesite, tuff, agglomerate, quartz diorite, and basalt) in the area, and the distribution of sulphide minerals, indicate an important rock alteration due to hydrothermal solutions. Thus, in addition to hornfels formed by metamorphism on quartzdiorite contact with adjacent rocks, tuffogene sandstones are affected by silicification, epidotization (Fig.18), kaolinization, argillization, chloritization, albitization, calcitization, prehnitization, zeolitization, sericitization, and locally hematitization. Pyritization should be included as one of the most important hydrothermal alterations. The pyritization, which is not associated with copper, zinc and lead sulphides, clearly indicates two pyrite generations: syngenetic or older, which occurs impregnated in tuffogene sandstones, and the younger, epigenetic, which associates with copper, zinc and lead minerals in veins. As to the vein occurrences and pyrite within them, the principal gangue constituent is quartz. The veins intersect tuffogene sediments. In either generation, pyrite occurs in irregular or crystalline grains. Where in crystal form, cubes and octahedrons as dominant crystals; they are small, rarely as large as 1 cm^3.

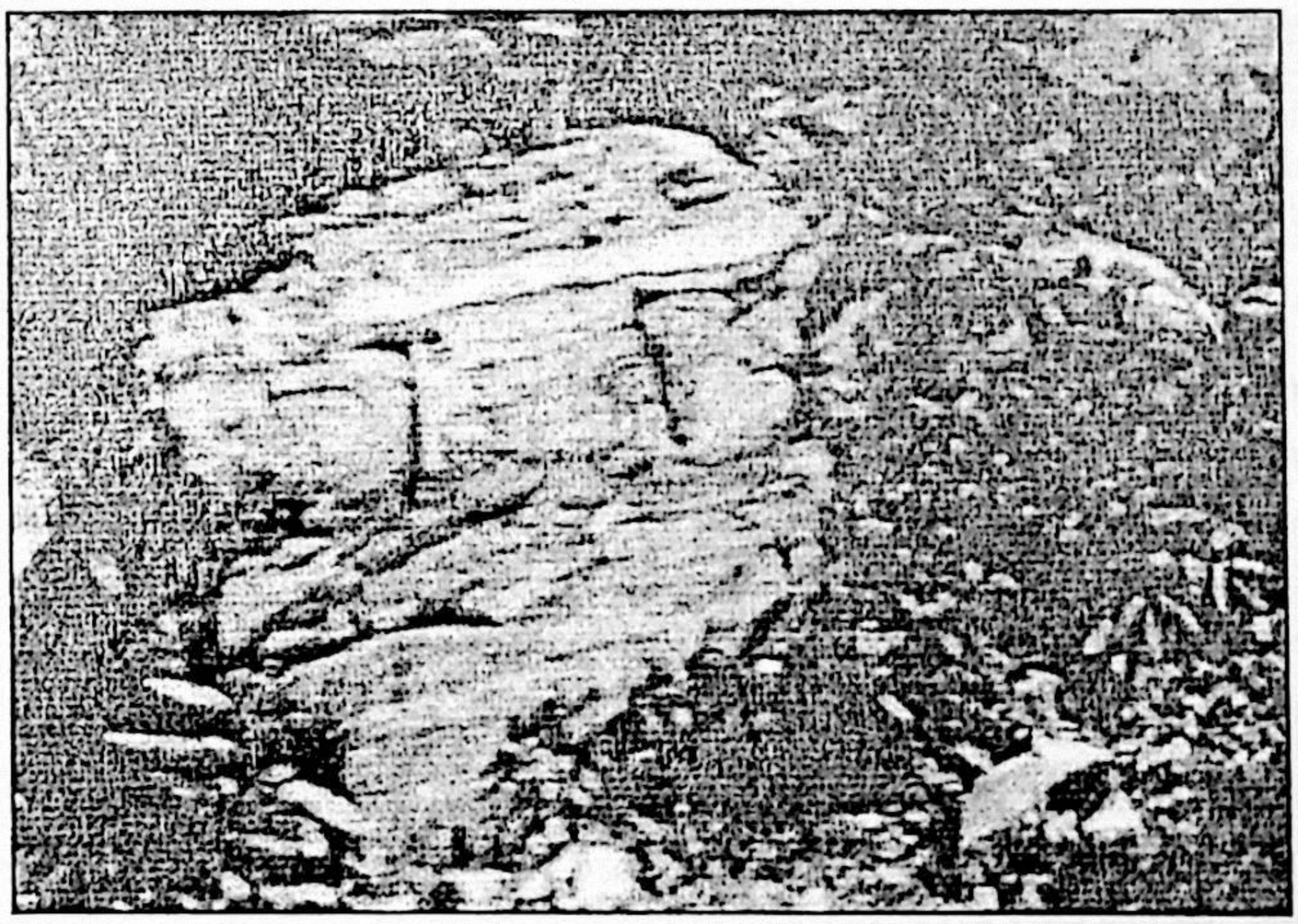


Fig. 18. Tuffogene sandstone highly epidotized (after P o p o v i ć, 2003) .

As has been mentioned, Cu-occurrences are relatively numerous in a small area (about 0.25 km^2). Of the noted seven occurrences, three are on the eastern bank of the Murgul dere, and four in the central area (Fig.19).

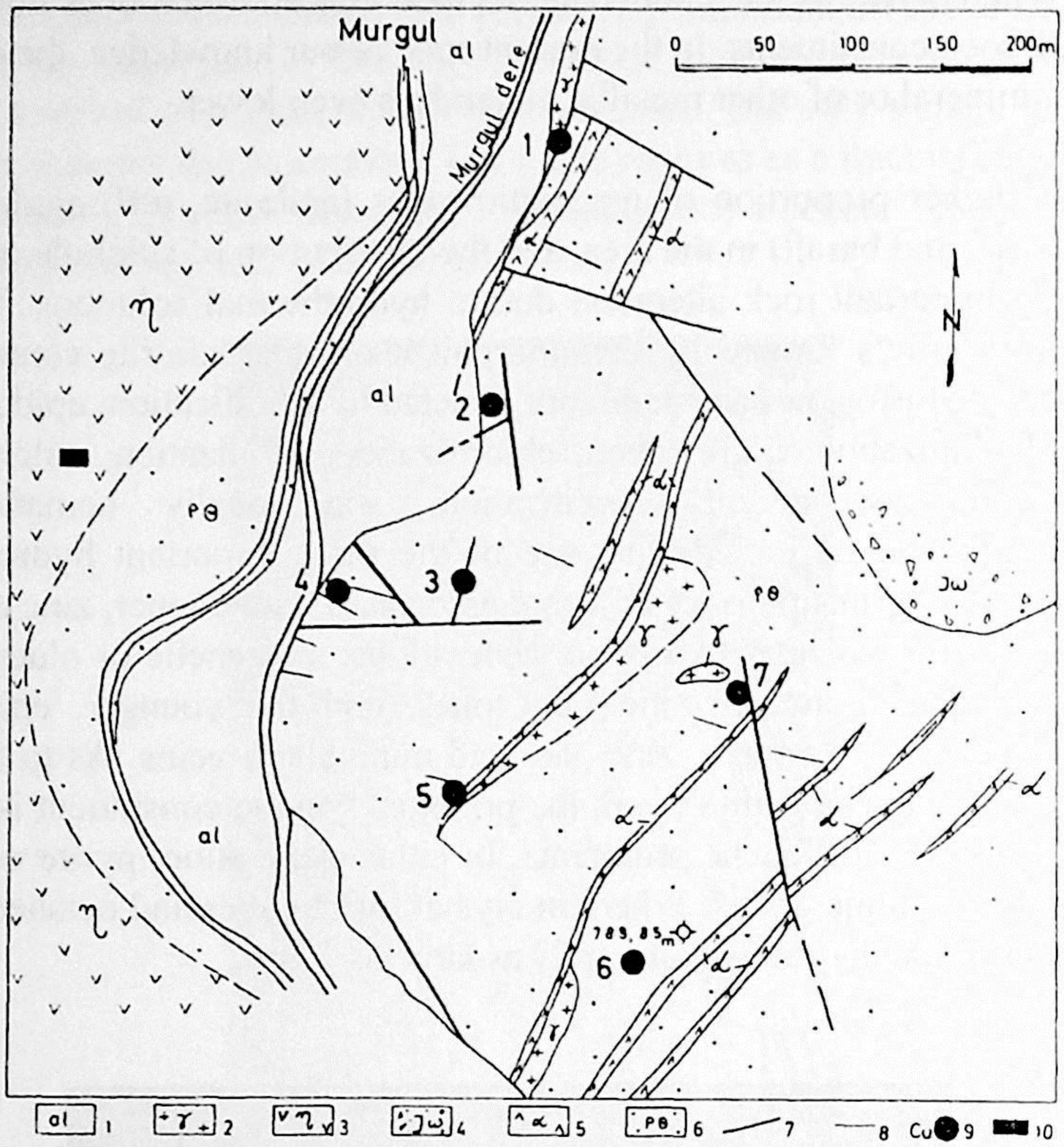


Fig. 19. Geologic map of Iskalka Köprüsü with Cu-mineralizations (after P o p o v i ć, 2003).

1. Alluvium,2. Quartzdiorite, 3. Keratophyre and quartz keratophyre volcanic rocks, 4. Andesite agglomerate, 5.Andesite flow, 6. Sandstone and tuffogene sandstone,7. Fault, 8. Joint, 9. Cu-mineralization, 10. Slag dump.

Occurrence 1 in the north part of the map (Fig.19) is associated with the fault zone along which quartzdiorite was intruded and mineralized. Quartzdiorite and the fault in which it was formed, were observed in a length of about 100 m. The mineralization in the fault and on quartzdiorite is explained by the presumed hydrothermal alteration along the same fault zone after the intrusion of the mentioned magmatic rocks.

This is the type of poorer Cu-mineralization. Ore minerals were deposited along the fault zone in which the fractured rocks were much hydrothermally altered, particularly by silicification, epidotization, pyritization,

and descendant limonitization. The fault, and at the same time mineralization, zone is about 1 m thick. The minerals identified in the zone are pyrite as the most abundant primary mineral, lesser chalcopyrite, and secondary limonite. The chalcopyrite constituent is small, as indicated by copper amount of only 300 ppm. The zone strikes approximately in NNE-SSW direction at a dip of 60° to SE.

Occurrence 2. Cu-mineralization, numbered **2** on the Geological Map (Fig.19), is the most important of the seven identified occurrences in the area. It is located about 150 m SW of the **occurrence 1** in the east bank of the Murgul dere, and consists of several mineral veins deposited in fault zones, fissures and joints. Over a length of about 32 m, three joints and two faults contain sulphide ores. Rocks between the faults are well impregnated with pyrite, and are silicificated and epidotized. The SW block (Fig.20) is pyritized, and pyrite grains are affected by advanced limonitization. The NE block (extreme NE of the section, Fig.20) is much more fractured and some ruptures are filled with quartz pyrite veins, locally associated with chalcopyrite.

This mineral occurrence consists of three systems of fractures, one of which strikes roughly in N-S direction, almost parallel with the main fault to which **occurrence 1** is associated and along which quartz diorite was intruded. Another system of fractures that strikes NE-SW is also characterized by sulphide minerals. Fractures of this system contain quartz-sulphide veins of variable thickness, from 2 mm to 10 cm, or commonly from 3 mm to 5 mm. Two of these joints are shown in the cross section Fig.20, characterized by a small number of chalcopyrite grains and even fewer sphalerite grains present in the quartz-pyrite vein. In the middle between the two faults in the central part of the cross section a notable fracture was located, filled with quartz pyrite vein, from 2 mm to 10 cm thick, but without chalcopyrite.

Faults are another type of ruptures. Two have been identified in the cross section (Fig.20) along 32 m of the area. One, in SW, is marked by fault breccia and poor pyrite mineralization, and the other, fault in the central part of cross section, is characterized by the main Cu-mineralization vein of the entire Iskalka Köprüsü area. Both faults are steep, with the dip angles from 60° to 67°. A quartz-pyrite-chalcopyrite vein is filling the latter fault zone. The vein was observed in a length of about 5 m and a depth of 8 m. One of its characteristics is the increasing thickness with the depth. The upper end of the vein is 2mm to 3 mm thick, and the lower 0.50 m. Sampling length was adjusted to the vein thickness: upper sample of 0.10 m and the lower sample of 0.30 m. Metal contents in the samples are given in Table 2.

Table 2. Ore vein (occurrence 2) sampling results (%)

Sample No	Sample length (m)	Cu	Pb	Zn	Fe	S
1	0.10	0.54	x	0.035	X	x
2	0.30	2.50	-	0.100	12.60	10.90

x – not analyzed

This vein may be considered prospective for the copper percentage, mode of occurrence, variation of thickness with depth, and also taking into consideration hydrothermal alterations (silicification, epidotization, pyritization) adjacent to the vein. The vein is poor in ore minerals. So far only pyrite was identified most abundant, then chalcopyrite and rarely sphalerite. Primary minerals in the occurrence outside the ore vein are magnetite and hematite, and secondary minerals are covellite and limonite.

Unlike other minerals, which form fine irregular grains, pyrite occurs either in irregular grains or in crystals that vary in size. Irregular pyrite is commonly fine-grained, and crystalline pyrite occurs in cubes or octahedrons of less than 3 mm.

As to the local descendent alterations in this ore occurrence, limonitization has advanced to forming a minor iron oxide cap (iron hat), whereas other alterations are insignificant, except the presence of covellite.

All veins with variable concentrations of sulphide minerals in several mineralized ruptures through the cross section length of 32 m should be considered as a unified ore occurrence (Fig. 20).

Occurrence 3. An occurrence of Cu and Zn minerals is located in a gully some 100 m southward from **occurrence 2**. Like the former, it consists of a system of fractures filled with quartz-pyrite-chalcopyrite veins, in thickness of about 1 m. The primary alteration in the occurrence is silicification, so advanced that the rock can be considered quartzified. The supergene alteration is limonitization. The ore paragenesis includes pyrite, chalcopyrite, and few sphalerite grains. Some talus rock fragments show malachite, in addition to secondary limonite.

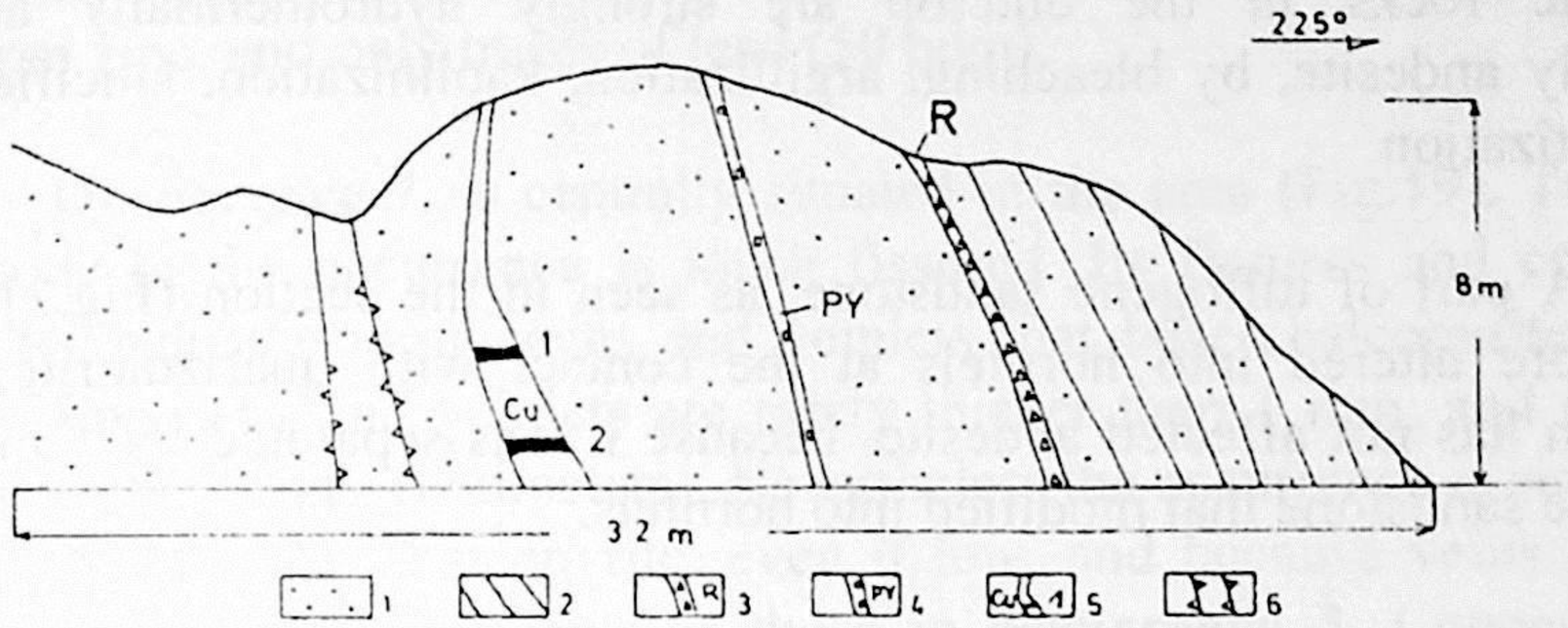


Fig. 20. Geological cross section of Cu-mineralization ***occurrence*** *(after P o p o v i ć, 2003).*

1.Tuffaceous sandstone intensively pyritized, epidotized and limonitized; 2. Fissures frequently filled with quartz-pyrite veinlets (about 1 mm thick); 3. Brecciated and slightly pyritized fault zone (R); 4. Larger fissure filled with pyrite (py); 5. Fault mineralized by pyrite and chalcopyrite and sampling sites (samples 1 and 2); 6. Fissures filled with thin quartz-pyrite-chalcopyrite veins (less than 5 mm thick).

One sample of 0.80 m contained 0.18% of copper and only 0.03% of zinc. General direction of the ore zone is north-south, the same direction as that of fissures that contain ore veins.

Occurrence 4 is found about 80 m to west from **occurrence 3** (Fig.19). Unlike the preceding occurrence, the system of mineralized fissures has the general direction WNW-ESE. Dip angles of the fractures vary between 70° and 80°. The fractures are filled with thin quartz-pyrite veins and some with chalcopyrite as well. One sample gave 0.10% of copper, but zinc and lead were extremely low (zinc 48 ppm, lead 50 ppm).

The area including **occurrences 1** through **4** represents a heavily fractured tectonic block that gives the impression, by the distribution of fracture deformations and the related pyrite-chalcopyrite mineralizations, of a single zone of ore-bearing.

Occurrence 5 is located about 130 m SE of **occurrence 3**. It is exposed on a village path, in an area of 2x5 m, where also developed limonitization is noted. The area of the occurrence is made of tuffogene sandstone, andesite flow, and a quartzdiorite mass. Quartzdiorite was traced over 20 m alonge, and andesite was traceable over more than 200 m. The andesite flow is 2 m thick. At its contact quartzdiorite with adjacent rocks, irregularly developed hornfels as a product of contactmetamorphism. Both

magmatic rocks in the outcrop are strongly hydrothermally altered, especially andesite, by bleaching, argillization, kaolinization, silicification, and pyritization.

A part of tuffogene sandstone, as seen in the section (Fig.21), has been more altered into hornfels at the contact with quartzdiorite. This alteration has not affected andesite, because it was separated by 1 m thick tuffogene sandstone that modified into hornfels.

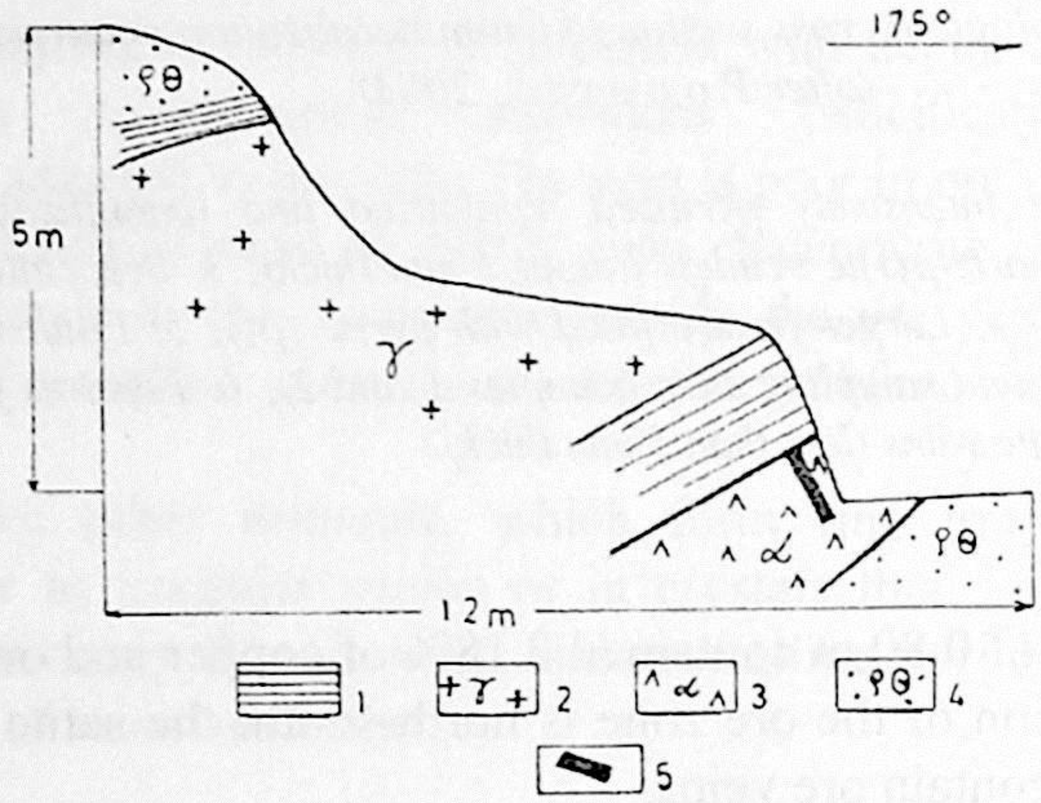


Fig. 21. Geological cross section of ***occurrence 5*** *(after P o p o v i ć, 2003).*
1.Hornfels, 2. Quartzdiorite, 3. Andesite hydrothermally much altered and mineralized, 4. Tuffogene sandstone, 5. Sampling site.

The most abundant mineral in the ore paragenesis is pyrite, highly limonitized, followed by far scarcer chalcopyrite and lead. A half a metre long sample contained only 260 ppm copper, 900 ppm lead, and only traces of (56 ppm) zinc. Note that hornfels was slightly mineralized, unlike andesite, which was highly pyritized and enriched in galena and chalcopyrite. This was the reason for sampling andesite. Sulphide mineralization in andesite occurs in impregnations, which calls for a different approach in future explorations.

Occurrence 6. This sulphide mineralization is noted some 40 m SW of the elevation point 789.95 m in the southeastern part of the area (Fig.19). It is characterized by highly limonitized tuffogenous sandstone that contains the scarce pyrite remains. The advanced limonitization, in an outcrop of only few tens of square meters, has the character of an iron hat. It is considered as

a separate occurrence, because a sample point contained 500 ppm copper, 136 ppm zinc, and only traces of lead (50 ppm).

Occurrence 7. is centrally situated in the area (Fig.19). Tuffogene sandstone in the occurrence is much fissured. Its fissures and cracks are filled with quartz-pyrite veins and veinlets that bear chalcopyrite only in traces. The veins and veinlets are rarely thicker than 1 mm, and are short visible (barely thirty centimeters). Nevertheless the occurrence is significant, because it contains chalcopyrite, even if low, and because veins have the same strike and dip elements as those in **occurrence 3**. Connecting the characteristics of these two occurrences suggests the likely presence of another ore-bearing zone perpendicular to the zone of the first four occurrences. Moreover, a minor quartz diorite mass noted in the area, may be important, because some of the described occurrences are associated genetically with quartz diorite. The elevation difference between the occurrences on the Murgul dere right (east) bank and this occurrence suggests that this orebearing zone was emplaced at a shallower erosion level than the mineral occurrences at the Murgul bank. If so, the altitude difference is between 20 m and 30 m, which by no means is a small difference and which raises the mineral potentiality of the Iakalka Köprüsü to a higher degree.

According to all given data this small area of only 0.25 km^2 possesses a great deal of Cu-mineralizations and as such is worth for further mettalogenic exploration and for economic potential estimation of the Murgul region in general.

It must be said that lead and zinc concentrations are mostly low, zinc less than 0.10% and lead less than 0.09%. In contrast to these two minerals, chalcopyrite was found in all seven occurrences in concentrations varying from 260 ppm to 2.5% copper. There are probably other occurrences in the area, but they have not been found yet due to outsized covering rocks.

The largest ore occurrences are located at the river-bed of Murgul Dere. Going eastward, the depth of the erosion level decreases with the rising altitude, and consequently the number of mineral occurrences, concentration of ore minerals, and mineral vein thickness are decreasing. This leads to the conclusion that the earlier estimates of economic insignificance should be corrected. A final assessment cannot be made without additional explorations of both lateral and vertical distributions of mineralization, this even more so that sulphide mineralization occurs in veins and impregnations. Impregnated types are older and syngenetically

associated with sediments and andesite volcanic rocks, veins are younger, so probably partly represents regenerated older minerals. In any event, these facts support the assumed larger resource of Cu-mineralization in the locality.

Separately observed occurrences in outcrops may be estimated at present as not very prospective. If the increasing thickness of veins with the depth were proved by additional exploration, it would confirm the presence of stockwerk-impregnation type of mineralization at a greater depth. In that case, the described occurrences should deserve serious attention of researchers, this all the more so that an ore zone along the Murgul Dere about 500 m long and about 100 m wide was clearly indicated. In this zone the highest concentrations of chalcopyritr and markedly hydrothermal alterations have been located.

2. B u d i y e t K ö p r ü s ü. This area, as mentioned earlier, consits of volcanic rocks of keratophyre composition. Most of the rocks are highly affected by hydrothermal alterations, commonly by pyritization, argillization, kaolinization, albitization, and silicification. Copper mineralization was not noted in keratophyres and quartz keratophyres, but only as epigenetic occurrences along the fault. This Cu-mineralization is found in veins with principal pyrite and subordinate chalcopyrite minerals. The occurrence was found on the Murgul dere left (western) bank, and contained 0.8% copper.

In accordance to the above, the metallogenic of the volcanic and volcanogenic-sedimentary petrogenic complex of the Lower Malm (Oxfordian-Kimmeridgian) has been least studied in Artvin Province. Nevertheless, its estimation is favorable, though the geochemical analyses was inadequate (few samples analyzed) for establishing the economic significance of Cu-mineralizations without additional explorations even if some of mineralization were syngenetic with sedimentation. There were samples that contained 200 ppm or 500 ppm of copper, but even these contents are low and the information insufficient for a serious estimation of the potentiality. But, mineral veins with increased Cu and Zn, or the andesite flow with relatively high lead are sufficiently strong reasons for considering the complex of interest for a future prospecting.

ORE – BEARING OF VOLCANOGENIC AND VOLCANOGENIC-SEDIMENTARY COMPLEX MALM (TITHONIAN) – NEOCOMIAN AGE

The following petrogenic complex in the stratigraphic column is represented by Malm (Tithonian) - Neocomian rhyolite formations. The complex is very important for its extensive pyritization and for large copper ore deposits such as Anayatak, Çakmakkaya, Kilise Tepe, Kuvarshan, Peronit, Sivrikaya, etc. Geochemical examinations of the complex were detailed in several places (Kilise Tepe, Sileh Kale, Kuvarshan, Kürdaze, etc.) and indicated wide distribution of copper and less of associated zinc. For instance, copper in rhyolite and rhyolitic volcanic rocks from Kürdaze-Melo (Artvin) varied from a few grams per ton to mineral ore concentrations. Average content of copper, however, was 58 ppm. From about 60 samples, ten contained copper 100 ppm, and four contained the so-called ore concentrations from 0.1% to 1% (S i m o n o v i ć, 1972, unpublished). The same author argues that the mentioned concentrations characterize the formations that contain them by a high coefficient of anomaly, and a large dispersion of copper.

The amounts of zinc vary from 10 ppm to 1.5%. Anomalous contents of this element are correlated with those of copper. Only lead concentrations in rhyolite and rhyolitedacite formations vary from 10 ppm to 0.6%, but high lead is scarce and cannot be taken for an indication of lead-bearing rocks, unlike copper or zinc.

Geochemical examinations in Kuvarshan area also indicated high copper distribution, from 5 ppm to ore concentrations (1% or more) near the deposit. These rocks also indicated a high anomaly coefficient by which they were classified as formations of high grade of ore potentiality.

Zinc has similar geochemical characteristics at this and other localities, Sinkot, Beşagül, Seyitli, and Umasen. In other words, copper and zinc, and largely lead, have a similar geochemical character in this rhyolitic ore-bearing zone. The three metals differ in distribution. Copper is always a guiding element followed by much lower zinc and subordinate lead.

Geochemical examinations of rhyolitic volcanic rocks in Beşagül indicated increased copper and zinc, but not much increased as the anomalous amounts varied from the lowest 70 ppm to a concentration of

2.09% associated with Cu-mineralization outcrops. The situation with zinc was similar, which varied from 500 ppm to 0.41%. The ratio of copper to zinc was the characteristically (5:1) for rhyolitic volcanic rocks. Lead concentration in some point of anomalies varied between 300 ppm and 350 ppm.

Increased (anomalous) copper content in Sinkot varied from 100 ppm to 300 ppm. In the hangingwall of the Upper Cretaceous-Tertiary volcanic rocks, anomalous concentrations of lead were from 150 ppm to 250 ppm.

S i m o n o v i ć (1972) reported from Umasen and Seyitli Mahallesi the anomalous copper concentrations vary from 100 ppm to 1000 ppm, and zinc from 350 ppm to ore concentrations in sulphide mineral outcrops where old adits were (there were three adits, the extreme NW one was located in basalt-spilitic rocks that lie over rhyolitic volcanites). Unlike these two metals, lead concentration varied only from 120 ppm to 500 ppm that was the highest content of this metal in geochemical samples of rhyolitic volcanite in Seyitli and Umasen Mahallesi. Maximum concentrations were found only in copper and zinc mineralization outcrops north of Umasen Mahallesi. Note that there were eight lead anomalies from 100 ppm to 500 ppm, seven zinc anomalies from 100 ppm to 500 ppm, and only two copper anomalies, one of 100 ppm and the other of 1000 ppm.

According to the above information, the area is a geochemically anomalous zone, but also is a ore-bearing zone of copper and zinc.

In contrast to the mentioned localities of a regional geochemical exploration, Kilise Tepe near Murgul was geochemically explored in detail by using 840 samples. The content of copper varied from 5 ppm to the so-called ore concentration[1] of 1% or more. The average copper concentration of more than 100 ppm (102.55 ppm) was 3.5 times higher than the average content in acidic magmatic rocks of granodiorite composition. The given information is obviously in favour of the rhyolitic (Malm-Neocomian) complex as a very suitable petrogenetic complex for research of a copper deposit. This is also indicated by the elements associated with copper in rocks of the complex, which also on Kilise Tepe are contained in even higher average concentrations than copper (e.g. average zinc content is 105.12 ppm). But the highest anomalous concentrations were found near fault zones where copper mineralization was observed. Besides, twelve

[1] Note: all geochemical explorations were only for the primary dispersion halo.

outcrops of Cu and Zn mineralizations were found on Kilise Tepe (area about 4 km^2). Thus, ore outcrops indicate an increased ore-bearing prospect of this complex.

There were 18 samples from rhyolitic volcanites with anomalous copper concentrations of 400 ppm or more, without those from ore outcrops, or even 30 samples including those from ore outcrops on Kilise Tepe, in an area of only 4 km^2. Also 30 samples contained anomalous zinc concentrations of 300 ppm or more, and as much as 10% including ore-concentrations from outcrops. The highest zinc concentrations were found in quartz diorite, not in rhyolitic or rhyodacitic volcanic rocks. Anomalous lead concentrations of 300 ppm or more were found only in 12 samples, and the highest of 1500 ppm only at one site where zinc was 500 ppm and copper 200 ppm.

The results for Sileh Kale near Murgul should be added to the above information. In both Kilise Tepe and Sileh Kale, metal concentrations were explored in rhyolites footwall of the ore deposits of Anayatak and Çakmakkaya.

In 16 samples from rhyolites of Sileh Kale the average metal contents were: copper 66.13 ppm and zinc 128.44 ppm (Table 3). Both quantities indicate that average contents of these metals are much higher than the average concentrations for this rocks after V i n o g r a d o v (1961).

Table 3. Geochemical exploration results for Sileh Kale (in ppm)

Cu	28	80	20	72	44	320	20	10
	10	136	68	32	10	16	156	36
Zn	10	250	80	520	400	64	72	80
	16	128	44	80	50	136	>1600	125

In the hanging wall of ore-bearing zone contents of: copper is 20 ppm, zinc 10 ppm, and lead 40 ppm.

Geochemical investigations shown that the hanging wall of the Malm-Neocomian rhyolite complex on Sileh Kale and Kilise Tepe contain low copper and zinc concentrations, commonly copper about 30 ppm, zinc 60 ppm and lead 48 ppm which is lower even than average content for this

rock type. In footwall of this complex, the situation is different. Copper contents on Sileh Kale vary from 20 ppm to more than 100 ppm or to the so-called ore concentrations which is not considered in statistical processing of geochemical data. In the Kilise Tepe area, 800 samples were analyzed, 90% of which were rhyolitic rocks the resulting concentrations of Cu and Zn were relatively high.

Finally, exploring rhyolitic pyroclastics over the Çakmakkaya mineral deposit it was found that rhyolitic tuff from the fault zone, which is the contact zone between the Çakmakkaya ore deposit and Kara Tepe dacite, contained copper to 70 ppm, zinc to 500 ppm and lead only 20 ppm.

It is this geochemical, petrogenetic and geotectonic environment in which the largest copper deposits of Pontic region are located.

Rhyolite in a geochemical section through the Çakmakkaya ore body contained copper 1000 ppm, zinc 250 ppm, and lead only 20 ppm (the same lead concentration as on Sileh Kale). However, the extreme, hanging wall of the ore body, represented by rhyolitic tuff, had maximum copper 80 ppm, zinc 130 ppm, and lead only 20 ppm. Also, a sample (only 10 cm long) from the ore body at its contact with adjacent rock contained very high copper concentration (as much as 10%) and relatively modest amount of zinc (only 0.10%), which is natural for this ore body. The high copper concentration at the contact indicates that this environment was suitable for big amount of copper precipitation. Only a dozen cm off the contact, copper is lower, to fall below 100 ppm in adjacent rocks. An important characteristic of rhyolite rocks, besides mylonite, in both footwall and hangingwall of the fault zone, is their notable schistosity. The mineral ore is pyrite- and chalcopyrite-mineralized tectonic and volcanic breccias. The fault zone includes gypsum, which is a subsequent (epigenetic) product of calcium-sulphate of probably descendent origin, because it contains low amounts of copper and zinc.

The few dacite analyzes from Kara Tepe showed contents of copper less than 70 ppm, zinc less than 136 ppm, and lead less than 50 ppm. Though indicative, the data of five samples are inadequate for reliable conclusions. It still may be stated that dacite was not synchronous with mineralization, but a post-ore cover.

COPPER

ARTVIN AREA

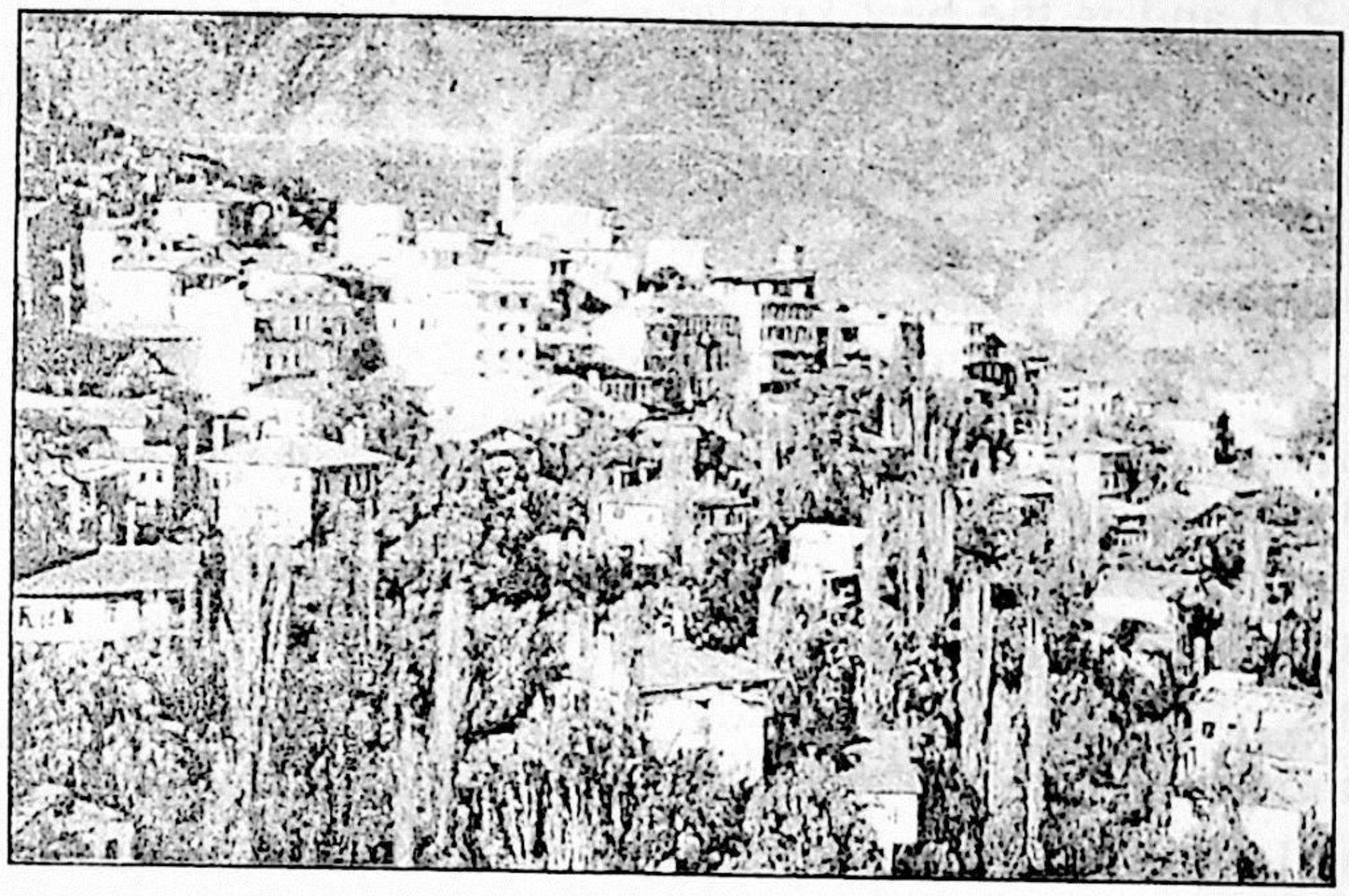


Fig. 22. Artvin, administrative centre of Artvin Province (photo, 1971).

All ore deposits and occurrences of Artvin area are predominantly located in the Kuvarshan mineral zone. So far Cu-mineralizations have been known in Kuvarshan, Beşagül, Sinkot, Seyitli, and Umasen Mahallesi. Because all the mentioned sulphide ore occurrences and deposits are of the same genetic and mineralogical types, located in the same zone, they are classified into a unified sulphide ore-bearing zone of Kuvarshan (Fig. 23).

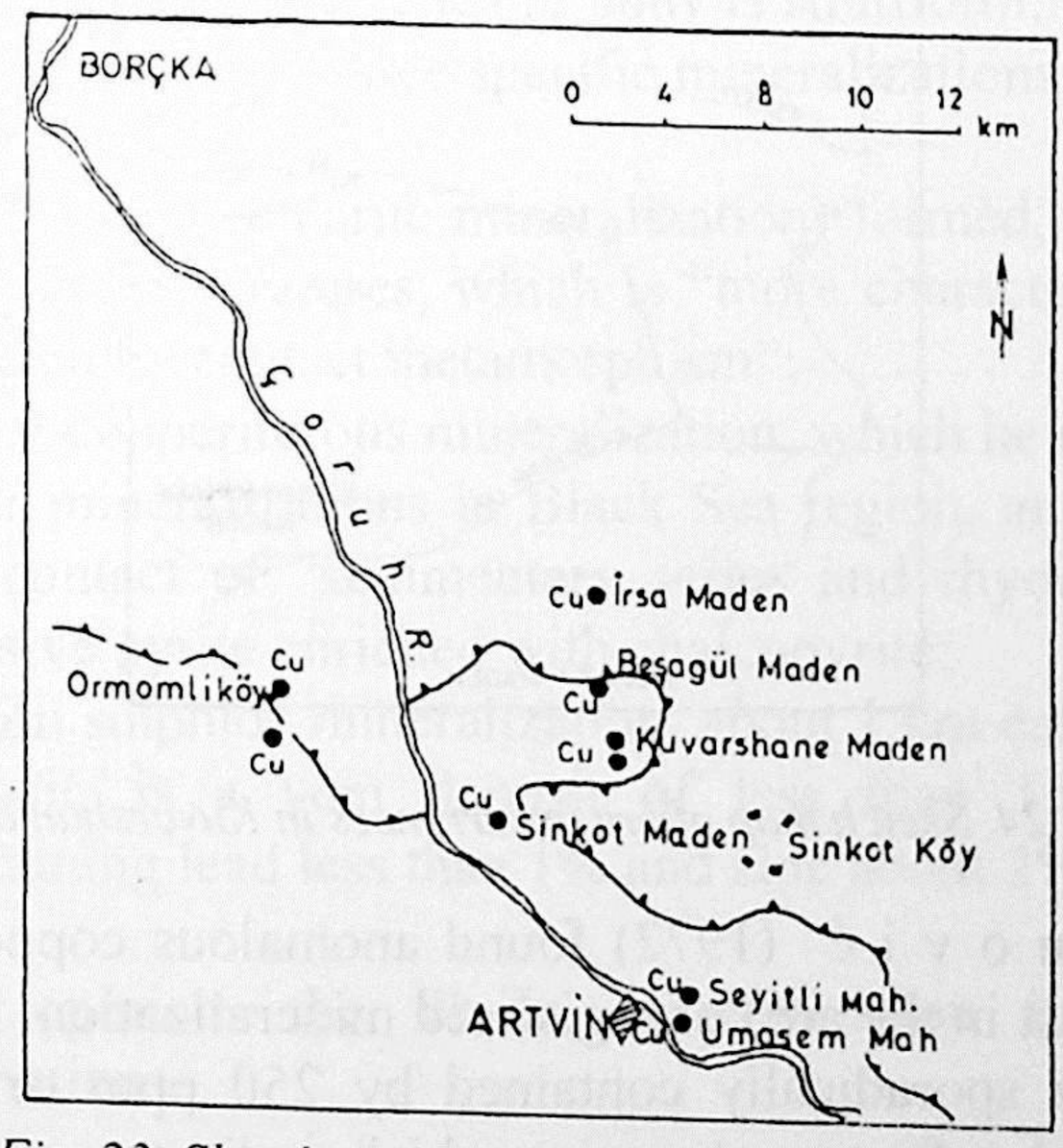


Fig. 23. Sketch map of ore deposits in Artvin area.

Ore Deposits

1. K u v a r s h a n . This deposit lies about 10 km north of Artvin(Fig.22) and is the best known in the ore-bearing zone. The deposit was explored and worked from the beginning of the 20th century. Copper ore exploitation was stoped 1929. and was continued 1937. (Novović, 1979). According to the available information, this small deposit was emplaced in Malm-Neocomian volcanic rocks of rhyolite composition, subsequently affected by folding and "situated in a overturned block zone" (Kraëff, 1963).

During the last period of ore extraction (1937-1941), almost 250 thousand tons of ore was produced in which copper was contained by 4%. The ore is pyrite-chalcopyrite found in rhyolitic rocks and based on data from waste rocks it is supposed that this ore belong to stockwork-impregnation and impregnation types. The deposit is associated with the regional fault Kuvarshan-Murgul-Rize, in which the largest copper deposits, Anayatak, Çakmakkaya, Madenköy, etc, of the Black Sea region are located. As mentioned before, Upper Cretaceous-Tertiary formations along the tectonic zone are in discordant relationship with Malm-Neocomian formations, locally inverted and lying over the younger Cretaceous-Tertiary formations.

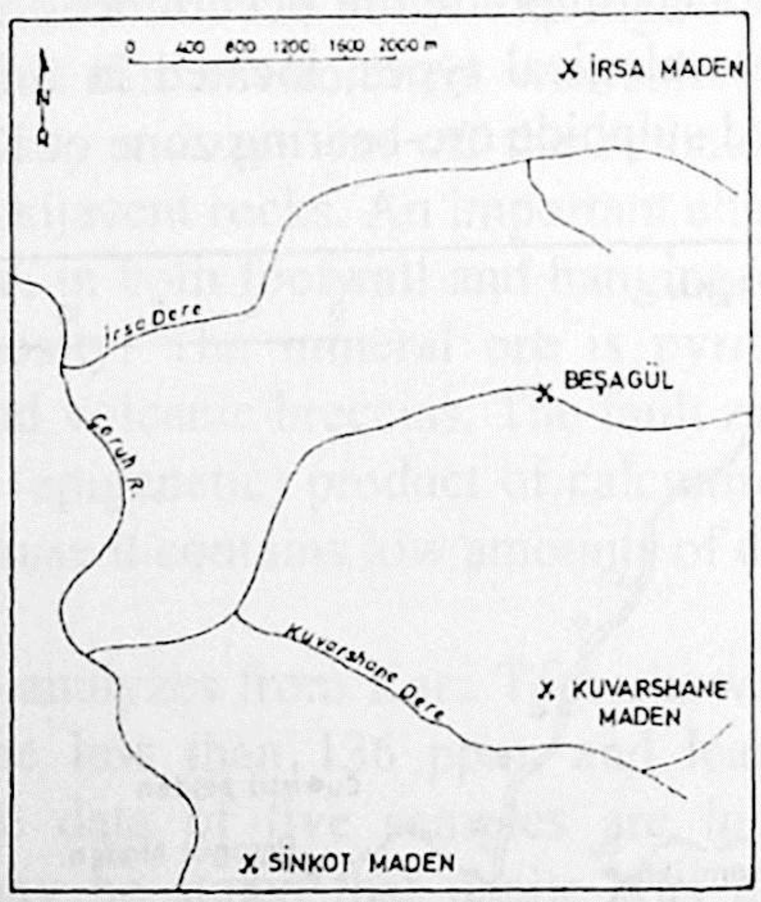


Fig. 24. Sketch map of ore occurrences in Kuvarshan area.

S i m o n o v i ć (1972) found anomalous copper, zinc and lead concentrations just in the area of registered mineralization. Beyond this area, copper was only sporadically contained by 250 ppm or more in altered rhyolitic tuff and tuffogene breccia, which indicates additional sulphide

enrichment. Zinc was similarly found only in two places with increased lead (80 ppm and 100 ppm). Zinc proportion in rhyolitic rocks was from 1% to 10% with associated copper from 0.4% to 1%. Mineralized rocks are much hydrothermally altered wherever rhyolitic formations were found.

Most abundant in the ore paragenesis are pyrite, chalcopyrite, less sphalerite. The associated minerals are tetrahedrite (probably tennantite) and scarce bornite. Chemical composition of the ore, according to S i m o n o v i ć (1972) is the following:

Table 4. Chemical composition of Kuvarshan copper ore

	%	
	Cu	Zn
1, Mineral zone	1.13	0.74
2. Falled-in adit	6.01	0.61
3. Rhyolite pyroclastics	0.01	trace
4. Rhyolite breccia	0.06	0.31

This is a massive sulphide mineral deposit (P e j a t o v i ć, 1975/1979) of about 800 thousand tons of ore – an isometric ore body of 250x250 m in size (K r a ë f f, 1963) and 8 m average thickness (maximum 25 m, N o v o v i ć, 1978). Generally, besides the mentioned minerals, it contains galena, chalcocite, covellite, and (secondary, trace) bornite. P e j a t o v i ć (1975/1979) argues that the ore body is stratiform, whereas N o v o v i ć (1978) distinguishes in it three specific mineralizations:

1. Hematite (specularite mineralization) formed, according to him, at high temperatures, which is "more characteristic of the areas affected by contact metamorphism";
2. Pyrite-copperiferous mineralization, which he distinguishes from other mineralizations in Black Sea region, and which occurs at the contact of "sedimentary series and rhyodacite", arguing a massive pyrite enriched with chalcopyrite;
3. Pb, Zn sulphide mineralization, about 1 km east of the preceding deposit, is a vein deposit of less than 15 cm thick veins containing lead less than 1% and zinc about 2%.

In our opinion, the Pb-Zn mineralization belongs to Upper Cretaceous formations.

According to W i j k e r s l o o t h (1946, in: K r a ë f f, 1963), the deposit includes two ore types, upper, pyrite ore poor in copper, called "Gelberze", and lower, much richer in copper, called "Grauerze". Copper concentrations vary from 1% to 1.5% in the first from 6% and to 7% in the second case. The ore reserve, cited by the mentioned authors, is one million tons with the average copper concentration of more than 1%.

2. B e ş a g ü l. The sulphide mineral deposit of Beşagül is located between the Kuvarshan and Irsa Maden deposits (Fig.24). It is associated with the hydrothermally much altered rhyolite pyroclastics, as is the entire mineralized zone of Kuvarshan all the way to Umasen Mahallesi. The hydrothermal alterations involved are silicification, pyritization, kaolinization, bleaching, etc. The impregnated pyrite and local chalcopyrite make a combined pyrite-chalcopyrite type of mineral occurrence.

Geochemical exploration of rhyolite volcanic rocks of Beşagül indicated increased copper and zinc concentrations from the lowest 70 ppm to 2.09% in Cu-mineralization outcrops. Zinc similarly varied from 500 ppm to 0.41% and fitted the characteristic Cu:Zn ratio of 5:1.Lead amounts in some point anomalies varied between 300 ppm and 350 ppm.

This and the preceding ore occurrences were explored by mining works at the same time in Kuvarshan and Irsa Maden. A short adit was excavated in Beşagül but the mineralization in that time was found uneconomic. S i m o n o v i ć (1972) explored the area, registered some neglected geochemical anomalies, though sampling from three outcrops gave interesting results (Table 5):

Table 5. Copper and zinc contents in some outcrops of Beşagül area (S i m o n o v i ć, 1972).

	%	
	Cu	Zn
1. Pyritized rhyolite pyroclastics	0.10	0.10
2. High pyritization zone	2.09	0.41
3. Rhyolite pyroclastics	0.03	0.05

The Table above shows mostly low copper and zinc, but in the zone of high pyritization copper is a serious constituent. Zinc amounts are also anomalous, but lead is very low, less than 350 ppm.

3. S i n k o t M a d e n. Sinkot Maden is located about 2 km west of Sinkot Köy and about 500 m east of the Çoruh river (Fig.25). Like the preceding two, this occurrence was explored by one adit excavated in highly silicified and pyritized rhyolitic volcanic rocks (pyroclastics). The adit cut through an ore body of massive pyrite and associated low chalcopyrite. The copper concentration found was 0.9% according to K r a ë f f, 1963.

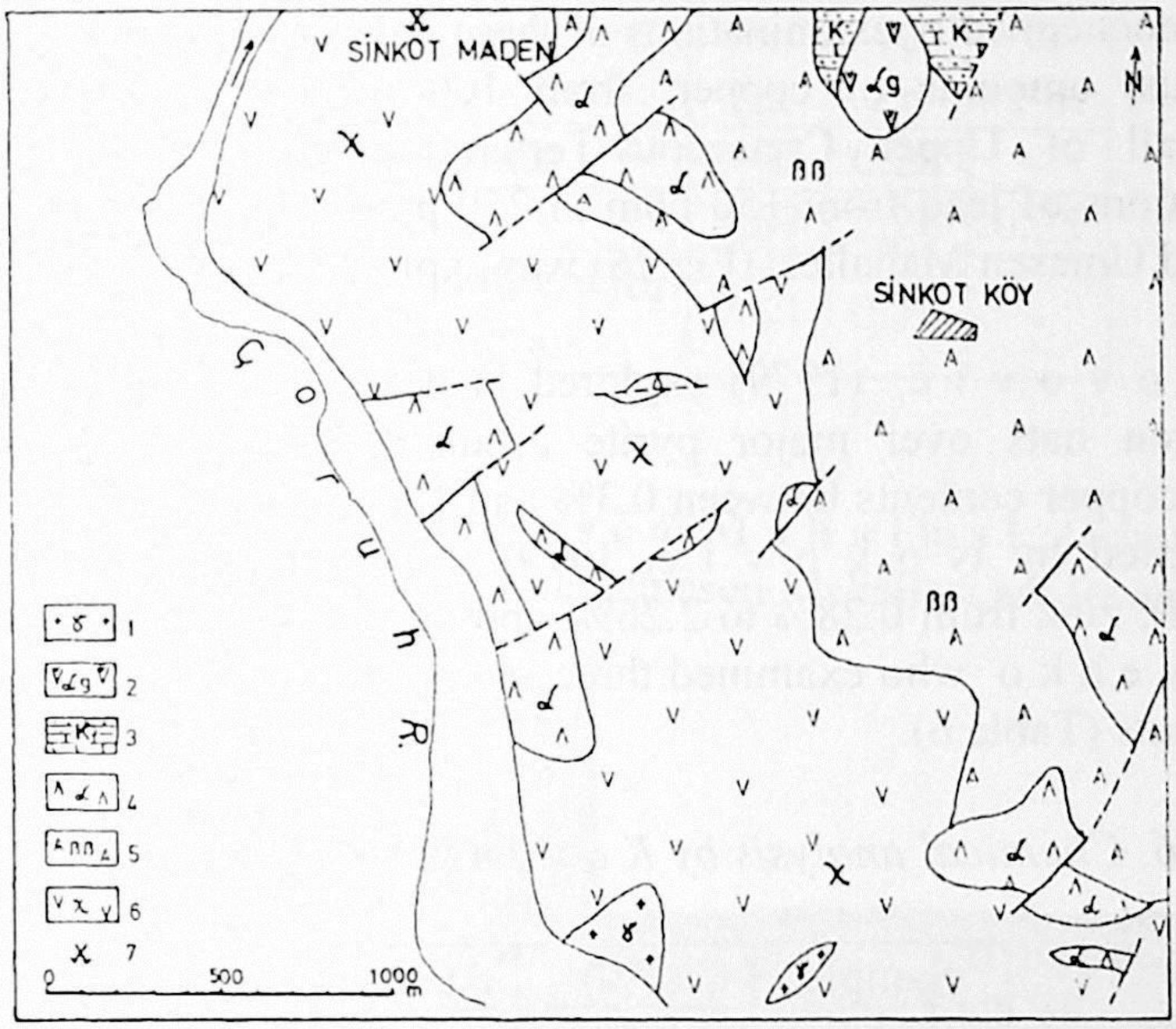


Fig. 25. Geological map of Sinkot Köy area (after S i m o n o v i ć, 1972).

1.Granitoid; 2. Dacite (Eocene); 3. Limestone, marlstone, pelite (Upper Cretaceous);
4. Andesite and andesite pyroclastics (Upper Cretaceous/Tertiary);
5. Basalt, spilite and their breccia and tuff;
6. Rhyolite, rhyodacite and their pyroclastics; 7.Closed Mine.

Sulphide mineralizations are localized in hydrothermally much altered rocks as: silicified, pyritized, kaolinized, argillized, bleached, etc. The rocks are slightly cemented, exposed to heavy erosion disintegrated into grus, not only in Sinkot but also in other areas of Kuvarshan that extend along the Çoruh east bank. Acidic volcanic rocks in the zone are sporadically enriched in pyrite and can be traced along the road from Artvin to Borçka, as illustrated by phorograph (Fig.26). In this location also traces of short adits are noted where pyrite and secondary copper minerals indicated that primary copper, especially chalcopyrite, may have been

expected. Some samples from the adits contained a next association of ore minerals: pyrite, chalcopyrite, tetrahedrite, low sphalerite, secondary copper minerals – chalcocite, covellite, and malachite.

Sulphide mineralization is mostly present as impregnated and sporadically in veins represented by pyrite veins 30 cm thick or less.

Geochemically examinations of these volcanites contained increased (anomalous) amounts of copper, from 100 ppm to 300 ppm, and in hangingwall of Upper Cretaceous-Tertiary volcanic rocks anomalous concentrations of lead from 150 ppm to 250 ppm. The area from Sinkot to Seyitli and Umasen Mahallesi (Fig.26) was explored.

N o v o v i ć (1979) explored in detail this location and found several iron hats over major pyrite accumulations or ore bodies. He mentions copper contents between 0.3% and 1% at Sinkot, and quotes other authors (cited by N o v o v i ć, 1979): copper from 0.01% to 7.64% (exception), zinc from 0.28% to 2.26%, and lead maximum 0.20%. He also cites K o v e n k o who examined three samples from one pyrite body with next contents (Table 6).

Table 6. Chemical analysis by K o v e n k o (in N o v o v i ć, 1979)

Sample	Cu (%)	Au (ppm)
I	0.80	0.50
II	0.07	0.25
III	0.24	0.28

The table shows that pyrite is not only copperiferous (though mostly low) but auriferous as well. Gold content from 0.25 ppm to 0.50 ppm is very indicative. Ore minerals identified in the paragenesis are: abundant pyrite, less abundant chalcopyrite, secondary chalcocite, malachite, azurite, and limonite. There were also single pyrite veins, less than 20 cm thick, bearing some chalcopyrite. N o v o v i ć (1979) mentions that K o v e n k o obtained copper concentrations of 2% to 3%. Similar mineralizations are noted along the Artvin-Borçka road, found in thin (less than 10 cm) pyrite veins with associated chalcopyrite.

Generally, the pyritization zone is extensive and approachable for observation, but not sufficiently studied and therefore not in fact estimated.

In contrast to the above data, S i m o n o v i ć (1972) collected samples from adit waste rocks and from altered rhyolite volcanic rocks. The obtained analytical data are given in Table 7.

Table 7. Base metals contents after S i m o n o v i ć (1972) in Sinkot Maden

Sample species	% Cu	% Zn	% Pb
Pyrite from wast rock	0.01	0.28	-
Silicified rhyolite	1.67	2.26	0.25
Disintegrated rhyolite with secondary Cu-minerals	7.64	0.74	-

4. S e y i t l i a n d U m a s e n M a h a l l e s i. Occurrences of sulphide mineralizations in Seyitli and Umasen Mahallesi are located in the

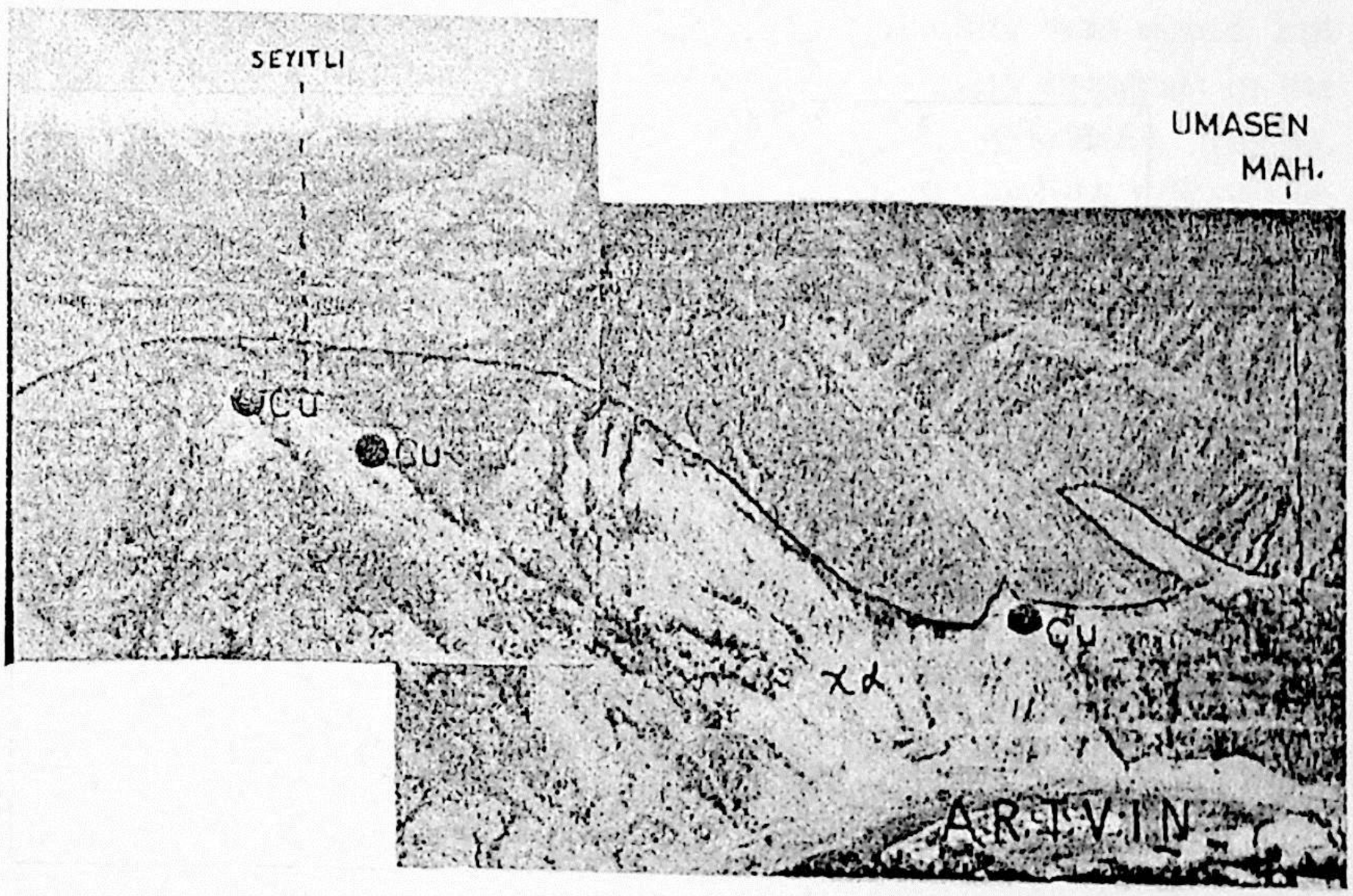


Fig. 26. Seyitli-Umasen Mahallesi hydrothermally highly altered rhyolite volcanite (χα) and copper mineralizations.

Çoruh east bank, across Artvin town, the centre of Artvin Province. There are five occurrences of Cu and Zn mineralizations extending NW-SE over 1800 m, between 100 m and 400 m wide, from the eastern Çoruh bank and Artvin-Erzurum road, or Artvin-Borçka, via Seyitli hamlet (Figs. 26 i 27).

Sulphide mineralizations occur in hydrothermally highly altered (argillized, kaolinized, silicified, and pyritized) rhyolite volcanic rocks. This ore sub-zone is a part of the Kuvarshan ore bearing zone, which is extending from Irsa Maden via Beşagül Köy, Kuvarshan Maden, and Sinkot to Seyitli-Umasen Mahallesi at the Çoruh eastern bank.

S i m o n o v i ć (1972) found by geochemical examinations that anomalous copper amounts varied from 100 ppm to 1000 ppm, and zinc from 350 ppm to ore concentrations in sulphide mineralization outcrops and places of old adits (there were three adits, the northwestern adit located in basalt-spilitoid volcanic rocks which are the rhyolite hangingwall). Lead varied only from 120 ppm to 500 ppm that was the maximum lead content in geochemical samples of rhyolite volcanites in the Seyitli and Umasen Mahallesi area. The maximum concentrations were found only in Cu and Zn mineralization outcrops north of Umasen Mahallesi. Note that the metal concentration anomalies in the area were eight for lead from 100 ppm to 500 ppm; seven for zinc from 100 ppm to 500 ppm; and only two for copper one of 100 ppm and the other of 1000 ppm.

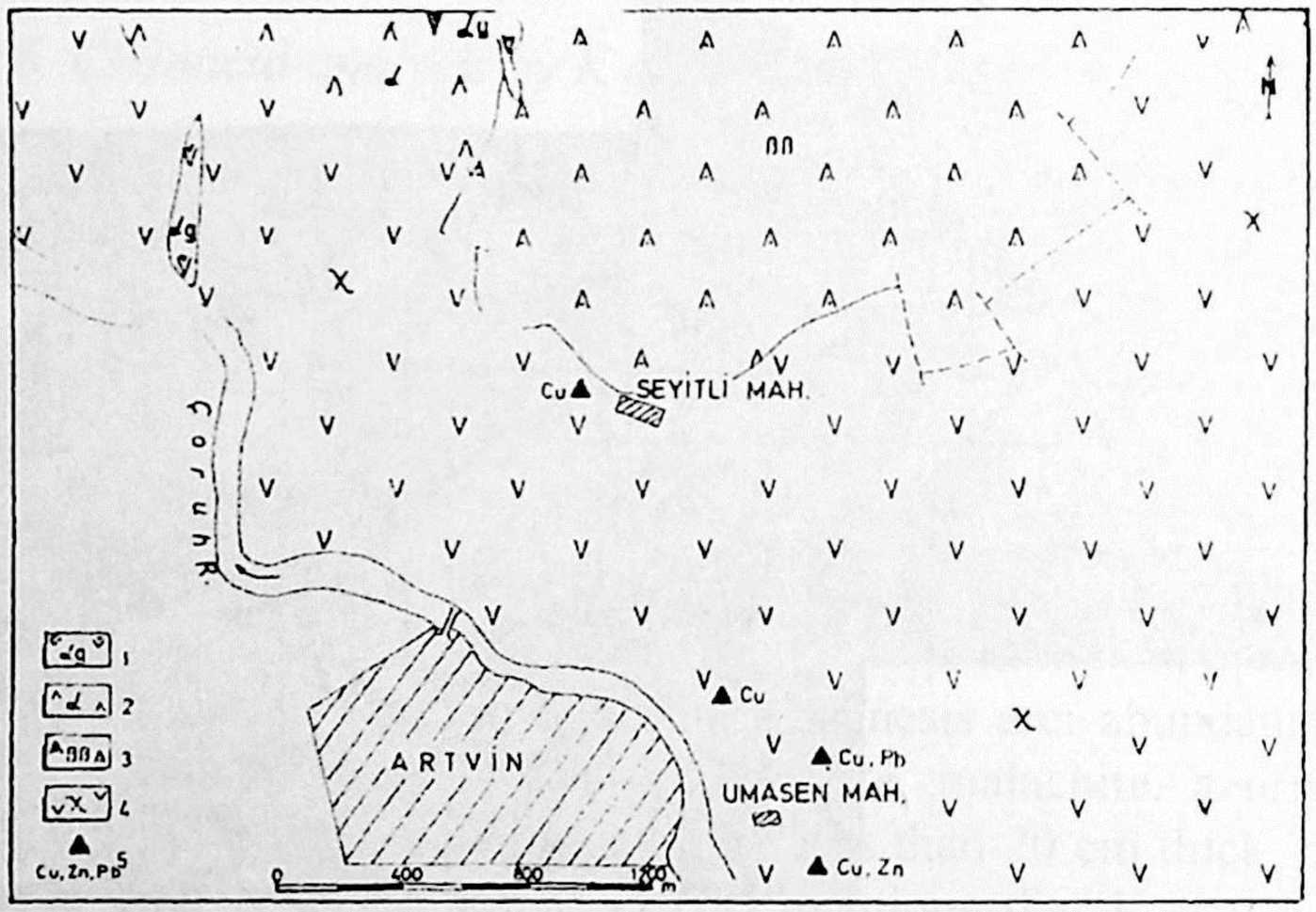


Fig. 27. Geologic map of Seyitli-Umasen Mahallesi (after S i m o n o v i ć, 1972).

1. Dacite (Eocene); 2. Andesite and andesite pyroclastic (Upper Cretaceous-Tertiary); 3. Basalt, spilite, breccia, tuff (with limestone); 4. Rhyolite volcanite; 5. Sulphide mineralization occurrence.

In places of notable pyritization, pyrite is locally massive and more or less associated with chalcopyrite forming a pyritaceous (Russian, kolchedan) type of copper mineralization.

The mentioned adits were located at different elevations, not for tracing the variation in the mineralization degree, but in search for quality mineralizations, or the highest copper concentration. The exploration, unfortunately, could not give an answer to the question how prospective were the mineral occurrences or even the ore bearing zone.

Primary mineral ores found in places of the old adits were pyrite, chalcopyrite, sphalerite, only sporadically galena and tetrahedrite, and secondary minerals, malachite, covellite, chalcocite, and limonite. This paragenesis should not be overlooked, the more so that some of them contained relatively high amounts of copper (Table 8). Also, locally were found high concentrations of zinc, even more that 5%, and copper 1%. According to V u j a n o v i ć (in: S i m o n o v i ć, 1972, unpublished), it is believed that lens-like and stockwork type accumulations of sulfide mineralizations are located near the adits. At the entrance to the lower adit (Umasen hamlet) near the Artvin-Erzurum road, malachite was noted, but analyzed for mineral composition it was found that primary minerals in the ore paragenesis were pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, tetrahedrite, marcasite, hematite, and secondary malachite, covellite, chalcocite, and limonite. Associated with the paragenesis were quartz, calcite, gangue minerals and siderite. The same authors mention two generations of the mineralizations:

1. Volcanic-sedimentary, dominantly pyrite, and
2. Hydrothermal, younger, subsequent separate reticulate pyrite and accompanied by chalcopyrite, galena, tetrahedrite, and some trace minerals.

S i m o n o v i ć (1972) collected seven samples from the adit entrance for detected contents of Cu, Zn, and Pb (Table 8).

There are more copper occurrences on the Çoruh western bank, for instance Ormanlı Köy, but the only information about them is that they are associated with Malm-Neocomian rhyolitic volcanites and that they are located about 10 km NW of Artvin.

Table 8. Chemical composition of sulphide mineralizations Seyitli-Umasen Mahallesi in two adits near a road, (S i m o n o v i ć, 1972)

Sample location	Cu	Zn	Pb
Entrance to upper adit	0.01	0.54	6.60
Footwall of the adit	0.03	0.26	-
Between upper and lower adits	0.37	0.61	0.45
Hangingwall of the adit (near entrance)	0.73	0.80	-
Front of the upper adit	1.75	8.96	0.49
One metre before entrance to upper adit	1.94	1.02	-
Entrance to lower adit	0.32	0.41	-

MURGUL AREA

The most important copper deposits in the entire Pontic region are located in Murgul area. Two main ones are Anayatak and Çakmakkaya, and there are many others that have not been explored and found prospective for new, larger reserves of copper ore. These are Aduca Dere, Bognari, Orta Istasyon, Gölbaşı, Karagöl, Çarkbaşı, Sileh Kale, Kilise Tepe, and many occurrences in the valleys of the Murgul Dere, Lebiskur Dere, and their tributaries.



Fig. 28. The small town Murgul (photo, 1970).

All Malm-Neocomian copper ore deposits and occurrences in Murgul area are classified into two ore fields: **A.** Anayatak-Çakmakkaya and **B**. Kilise Tepe.

I. Anayatak–Çakmakkaya Ore Field

Besides two main ore deposits; Anayatak and Çakmakkaya, this ore field includes others as: Bognarı, Aduca Dere, Orta Istasyon, Sileh Kale, Çarkbaşı, Kara Tepe, Gölbaşı, Karagöl, and many other occurrences.

The copper ore deposits of Anayatak and Çakmakkaya are located on the SW margin of Damarköy (Fig.29), about 4 km (across) or 12 km by a macadamia road south of Murgul. The two deposits are in one ore field, but the distance between them is about 500 m. The Anayatak ore deposit has been known from the end of the 19th century and was worked with short or long breaks almost throughout the 20th century. The Çakmakkaya is a newer deposit, found in the late fifties and worked from the early seventies. Neither of them is exploited at present, but is being explored. The Anayatak deposit is commonly referred to in literature as the Murgul copper deposit or Murgul Mine after the small town of Murgul. In the beginning of the 20th century the town was named Fabrika (factory, after the flotation and smelting plants), but changed the name after the Second World War into Göktaş. The village of Damarköy formed with the beginning of copper ore extraction at Anayatak.

The total ore reserves in Anayatak were not estimated, because the information, especially in the beginning of exploitation and copper ore smelting (under the czarist Russia), was not reliable based on vague records. After the inclusion of the area into the national territory of the Republic of Turkey and continuation of ore extraction, the records were more accurate and the ore reserves estimated at more than 30 million tons with the copper content exceeding 1.5%. For the Çakmakkaya deposit, the ore reserve calculated from the seventies was about 8 million tons with the average copper content of 0.86%.

Though near one another, the two deposits differ in the reserves, ore quality, and in other aspects. Thus, in Anayatak, also massive chalcopyrite occurs, frequently vein like, because it fills the fractures and spaces among the breccia fragments, locally several metrics in length and the thickness up to half a meter. Also chalcopyrite with pyrite occurs as the cement in the volcanic and tectonic breccias, containing as much as 23% of copper. This high percentage of copper was found when the exploitation began, and the deposit was then one of the richest in the Mediterranean metallogenic region. With the progress of production and the transition from the

underground to surface mining, the amount of copper in the extracted ore decreased but remained relatively high, more than 1.5%.

Both deposits are found in a regional fault, characterized by tectonic breccia, tectonic clay and hydrothermally altered volcanic rocks. The fracture is certainly regional, but whether it is a trust fault or an imbricate structure has not been decided.

The names of the Anayatak and Çakmakkaya copper deposits need an explanation. The oldest deposit in Murgul area is **Anayatak**. When it was worked, the ore was primary prepared in the flotation and smelting plants at Murgul, and the deposit was referred to in literature as the Murgul copper deposit until 1970. At the beginning of ore extraction in Anayatak, the village of Damarköy was formed, whose name literally meant "Ore Vein Village" or "Mine Village". The deposit name Anayatak means "main". In the late fifties of the 20th century, a new copper deposit was found near Anayatak and named Çakmakkaya. By many authors, the Murgul deposit stands for Anayatak, and in few for Damarköy instead of Anayatak. The use of different names for one and the same deposit is confusing for the reader who is in doubt whether the names refer to Anayatak or both Anayatak and Çakmakkaya. Fixing the names is necessary also because there are other deposits in Murgul area, to mention only the major ones: Aduca Dere, Kilise Tepe, Akarşen, Başköy (Fig.29) and many occurrences, so that the use of the name Murgul could be misleading to mean all the ore deposits and occurrences, which would imply the Murgul metallogenic district, not the Murgul deposit or Murgul copper deposit.

Moreover, Anayatak changed the name several times through its history. Published sources mention the names of : **Dzambul-as**, name given after its uncover by the Mining Caucasus Ltd. (M a g a k ya n, 1962); **Murgul** until the Second World War (Z i m m e r, 1938); **Murgul-Çankara-as**, when working was resumed in 1953 (S c h n e i d e r h ö h n, 1955); and **Anayatak** (mother deposit) when other massive deposits were found in the region (H a m a m c i o ğ l u and S a w a, 1971); and finally **Damarköy** (G ö k ç e, 2001).

In view of the above history, in this book the actual names are used instead of the Murgul ore deposit - the names of Anayatak copper deposit, Çakmakkaya and all other names given in subtitles.

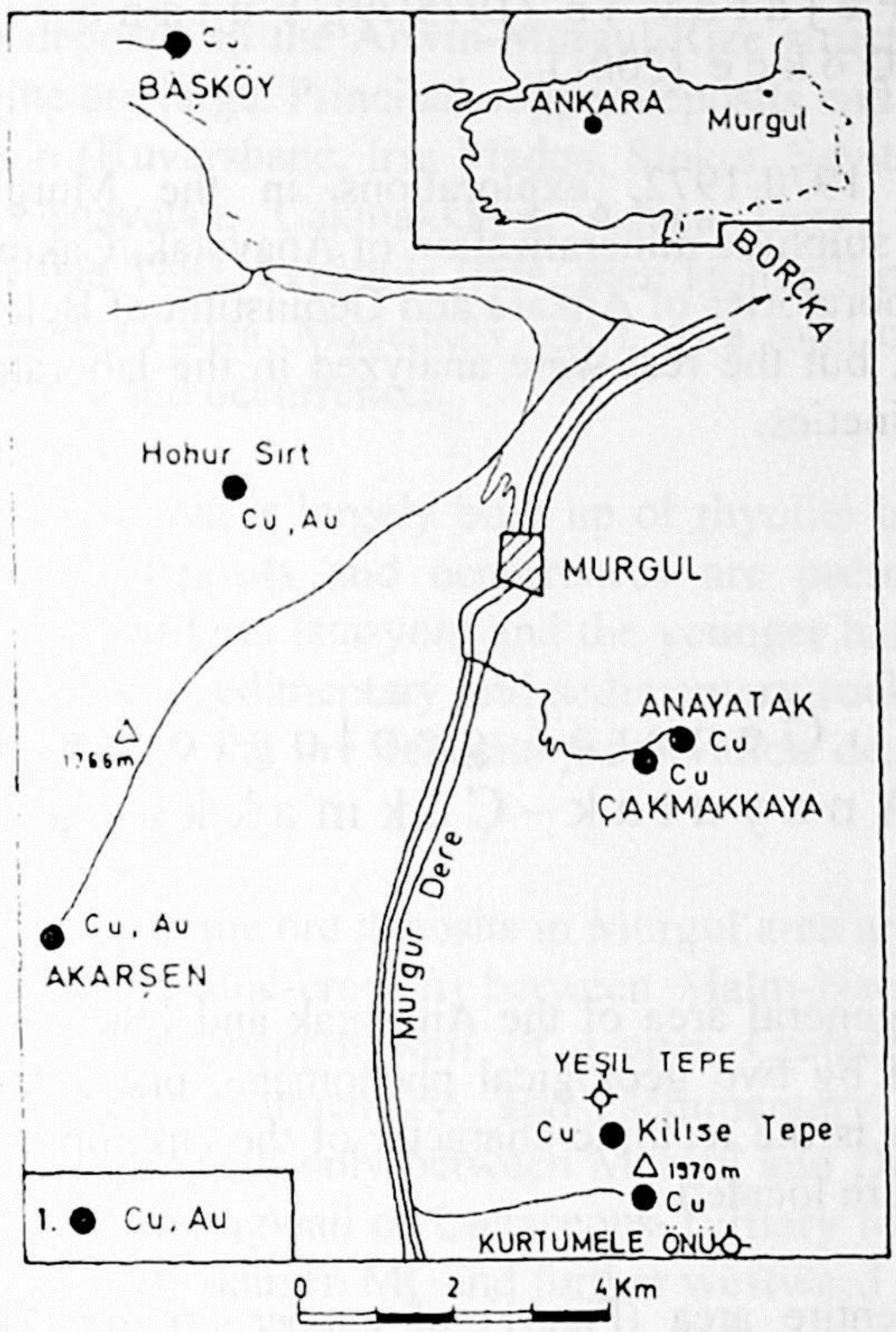


Fig. 29. Location map of ore deposits and occurrences in Murgul area.
1.Copper ore deposits and occurrences.

Many geologists explored the ore deposits of Anayatak and Çakmakkaya through the 20th century and left short or long records. Most important among the explorers were Z i m m e r (1938); K o v e n k o (1942,1944); P e t r a s c h e k (1954/1955); S c h n e i d e r h ö h n (1955); G a t t i n g e r (1962); L. K l ä y (1959, in: K r a ë f f, 1963); then B u s e r (1970); B u s e r, C v e t i ć (1973); P e j a t o v i ć (1975,1979); P o p o v i ć (1976,1979); V u j a n o v i ć (1976); E n g i n (1986); E r s e ç e n (1989); Ö z g ü r (1992); Ö z g ü r (1992); G ö k ç e (2001); P o p o v i ć, V a k a n j a c (2002), and many others. Every one of them gave his contribution to the study foremostly of Anayatak and less of Çakmakkaya. Most exhaustive information about the Murgul ore deposits is given by K r a ë f f (1963); B u s e r (1970), B u s e r, C v e t i ć (1973), P e j a t o v i ć (1973,1975/79), and about the origin of the deposit by S c h n e i d e r h ö h

n (1955), P e j a t o v i ć (1975/79), V u j a n o v i ć (1976), Ö z g ü r (1992), and G ö k ç e (2001).

The 1970-1972. explorations in the Murgul region included sampling of sulphide mineralization of Anayatak, Çakmakkaya. At that time the MTA laboratories of Ankara and Geoinstitut of Belgrade examined some the samples, but the rest were analyzed in the laboratories of Geoinstitute during the nineties.

General geologic setting of the Anayatak–Çakmakkaya ore field

The general area of the Anayatak and Çakmakkaya ore deposits is characterized by two geological phenomena: one is the lithology settings and the other is the tectonic character of the environment within which the ore deposits are located.

The entire area (Fig.31) of copper ore deposits is made up of Malm/Neocomian acidic extrusive rocks, dominantly felsitic in character. Dominant among these are pyroclastics of rhyolite composition, and less abundant are dacite flows. Rhyolitic volcanic rocks rocks are represented by tuff, tuff breccia, volcanic breccia, redeposited volcanite, and rhyolite flow. All these rocks were formed, according to available information, during the Malm and the Neocomian when presumably a strong tectonic deformation occurred and formed a tectonic structure of high order, defined as thrust fault or an imbricate structure. It is extending from Kuvarshane (wherefrom we traced it) to the deposit near Damarköy to Akarşen to Rize on the Black Sea (Fig.14). The fault occupies a wide zone marked by fault clay and fault breccia. It is believed that the rhyolitic phase preceded a strong tectonic activity which triggered activity along the Kuvarshane-Murgul-Rize tectonic zone, thereafter another volcanism and hydrothermal activity evolved that resulted in main ore bearing phase deposition. At the same time adjacent rocks affected by hydrothermal alterations were silicified, pyritized, kaolinized, bleached, etc. The final volcanic activity occurred in the post-ore period, when dacite flows formed as those of Kara Tepe.

Sulphide ore deposits in the Artvin-Murgul-Rize structure (Fig.14) are numerous and some are large. Principal copper deposits and occurrences are located near Artvin (Kuvarshane, Irsa Maden, Sinkot, Seyitli, Umasen), then near Murgul (Anayatak, Çakmakkaya, Aduca Dere, Sileh Kale, Karagöl, Çarkbaşı, Kilise Tepe, Lebiskur Dere, then Hohur Sırtı, Akarşen), and deposits near Çayelı (Tunca, Madenköy, etc.), or a total of more than thirty copper ore-deposits and occurrences.

Generally, Murgul area is largely built up of rhyolite or rhyodacite pyroclastics. Copper ore-deposits and occurrences are preserved where dacite flows (Kara Tepe and Orta Istasyon) and the younger hangingwall of (Upper Cretaceous) volcanic-sedimentary and sedimentary rocks remained. The number or the degree of the ore deposits preservation depends on the depth of erosion.

The zone, with which the ore deposits in Murgul area are associated, represented discordance (tectonic-erosion) between Malm-Neocomian ore-bearing formations and the hangingwall of Upper Cretaceous-Tertiary volcanogenic, volcanogenic-sedimentary and sedimentary formations. Dacite of Kara Tepe is developed only between Murgul and Damarköy and on Kara Tepe, while the hangingwall of Cretaceous-Tertiary formations are located between Murgul and Akarşen Mt. and further westward (Fig.30).

A cross-section of the Anayatak and Çakmakkaya ore deposits (section through the tectonic zone) shows in the footwall part: fault clay, kaolinized and argillized pyroclastics heavily impregnated with pyrite crystals. The abundant crystals are octahedrons and pentagonal dodecahedrons (pyritohedrons) varying in size to 5cm or even more (Fig. 23). Chalcopyrite is scarce in this ore deposit.

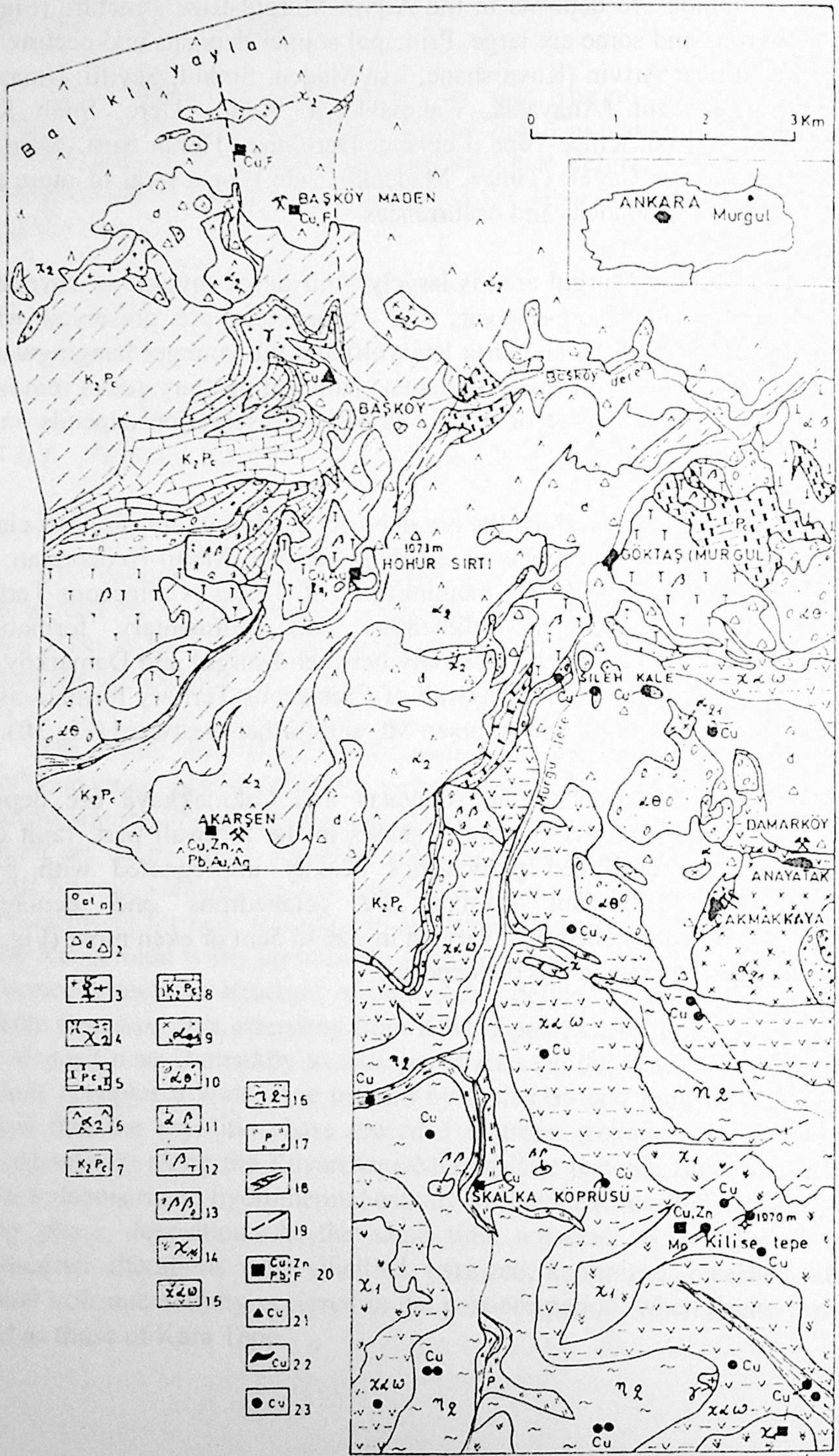

Balıklı yayla
Cu,F
BAŞKÖY MADEN
Cu,F
BAŞKÖY
Başköy dere
1071 m
HOHUR SIRTI
GÖKTAŞ (MURGUL
SİLEH KALE
Murgu dere
DAMARKÖY
ANAYATAK
ÇAKMAKKAYA
AKARŞEN
Cu,Zn,
Pb,Au,Ag
İSKALKA KÖPRÜSÜ
Cu,Zn
Mo
Kilise tepe
1070 m
0 1 2 3Km
ANKARA
Murgul
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Cu,Zn Pb,F 21 22 23

Fig. 30. Geological map of the Murgul area proper (according to B u s e r, 1970, and Š t e r n, 1971. data).

1.Alluvium; 2. Delluvium; 3. Quartzdiorite; 4. Rhyolite 2 (Paleogene); 5. Limestone and marlstone (Paleocene); 6. Andesite 2, dacite andesite tuff, agglomerate, brecc ia (upper volcanic, volcanic-sedimentary, and sedimentary sub-complex); 7. Marlstone (Cretaceous-Paleocene); 8. Thin-bedded limestone bearing inocerams; 9. Dacite 1; 10. Dacite agglomerate and tuff; 11. Albite trachyte and its pyroclastics; 12. Spilite, basalt, and diabase with chert (Lower or diabase-basalt-spilitoid sub-complex); 13. Augite basalt; 14. Rhyolite 1; 15. Rhyolite and rhyodacite pyroclastics (Malm-Neocomian); 16. Keratophyre, quartz keratophyre and their pyroclastics; 17. Sandstone, tuffogene sandstone, andesite 1 (andesite flows); 18. Fault zone; 19. Major fault; 20. Copper vein deposit; 21. Skarn sulphide occurrence; 22. Impregnated, stockwork, and massive copper ore deposit; 23. Volcanic, volcanic-sedimentary and stratiform copper ore occurrence and deposit.

Upward in the section follows a zone of much brecciated rocks: silicified and highly mineralized tectonic and volcanic breccias. Chalcopyrite, pyrite, and quartz are cement particles of breccia. This is the richest part of the ore deposit (formed by recrystallization, Vujanović, 1976). Cementing breccia fragments, chalcopyrite and pyrite locally form vein-like bodies of a few meters in length and half a meter thick, and can be quarried in blocks of 40x50x30 cm.

The breccias are overlain by mineralized pyroclastics that grade upward into low sulphide mineralized rhyolite pyroclastics as part of the mineralized pyroclastics. The uppermost member in the Anayatak and Çakmakkaya ore deposits is dacite of Kara Tepe more than 50 m thick. Both ore deposits were subsequently much altered, especially regenerated was Anayatak deposit that includes amethyst (Fig. 38) or other quartz veins mineralized by chalcopyrite and pyrite with a copper content of 0.8% or less. The Çakmakkaya ore-deposit similarly has occurrences of quartz-chalcopyrite veins, with chalcopyrite crystals to 1 cm in size.

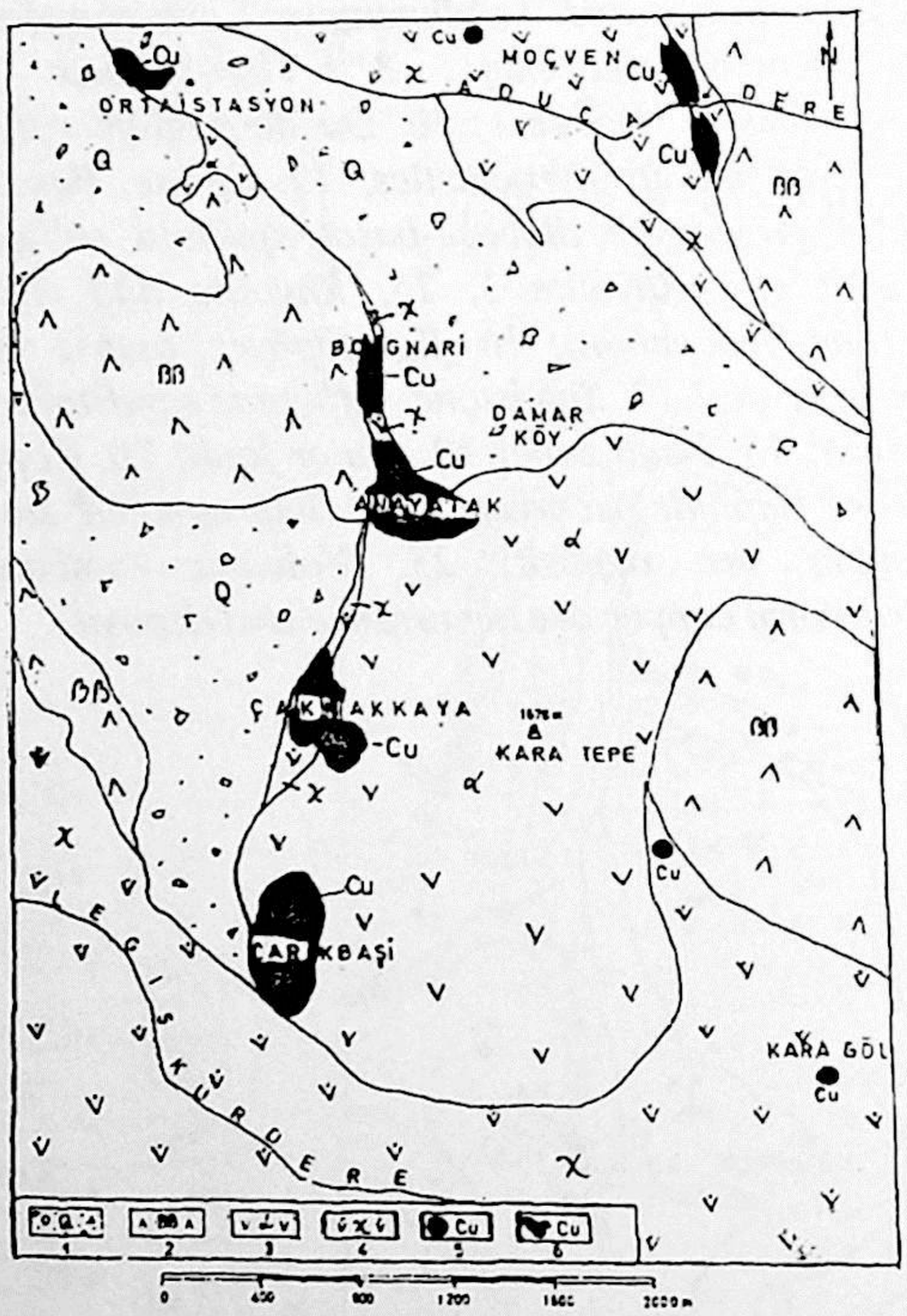


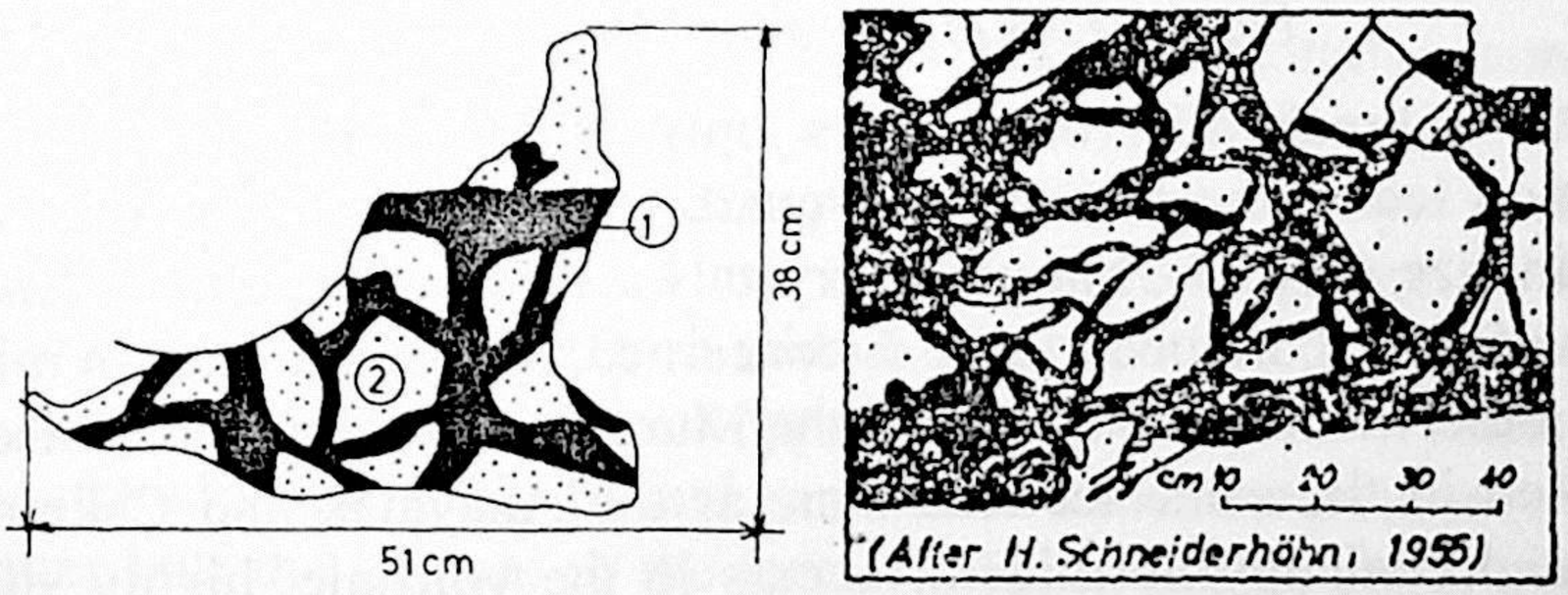
Fig. 31. Geological map of the Anayatak-Çakmakkaya ore field.

1. Debris (Q); 2. Basalt and spilite (ββ), 3. Kara Tepe Dacite (α); 4. Rhyolite volcanic rock (χ); 5. Cu-ore occurrence; 6. Cu-ore deposit.

The Kara Tepe dacite was much discussed in 1970 by the explorers (Turks, Japanese, Germans, Yugoslavs) in field. Some argued that Kara Tepe was a volcanic neck, and others refuted the argument. In order to verify the point, T. S a w a 1971. located a borehole by the "neck". The hole penetrated dacite (in columnar jointing, which some explorers interpreted as a neck) and entered the underlying clay part of the fault, or ore, zone, thus proving that the Kara Tepe dacite was not a neck. It also approved that the ore zone extends southward under dacite into Karagöl area. Unfortunately, it is only the footwall part (Fig. 37) of the ore zone. Besides, the drilling data indicated that the ore deposits and the fault zone formed before the Kara Tepe dacite was extruded.

The fault zone is generally dipping to NW at angles from 16° to 40° (hangingwall). The zone is very thick in places, where the ore body may be as thick as 200 m.

Most of the explorers describe the Anayatak and Çakmakkaya as stockwork and stockwork-impregnation or massive ore bodies, but others interpret them as veins (which I think unbelievable). The prevailing opinion is that Anayatak ore occurs in the forms of mineralized breccia, massive, stockwork, less in stockwork-impregnation, and impregnation in mineralized pyroclastics. In Çakmakkaya deposit, ore forms only stockworks. The two deposits also differ in other characteristics not only in the mode of occurrence. In Anayatak, the main ore minerals are pyrite and chalcopyrite, then sphalerite and subordinately other ore minerals, commonly occur as (tectonic and volcanic) breccia cement, which may look like an impregnation or stockwork-impregnation, or only stockwork, whereas it is the mineralized breccia including rocks interpreted by many explorers as massive chalcopyrite (Fig.32), though the deposit has parts that are impregnated or stockwork-impregnated type of mode occurence.



R. P o p o v i ć H. S c h n e i d e r h ö h n, 1955.

Fig. 32. Mode of ore occurrence at Anayatak.
1. Massive ore; 2. Impregnated ore.

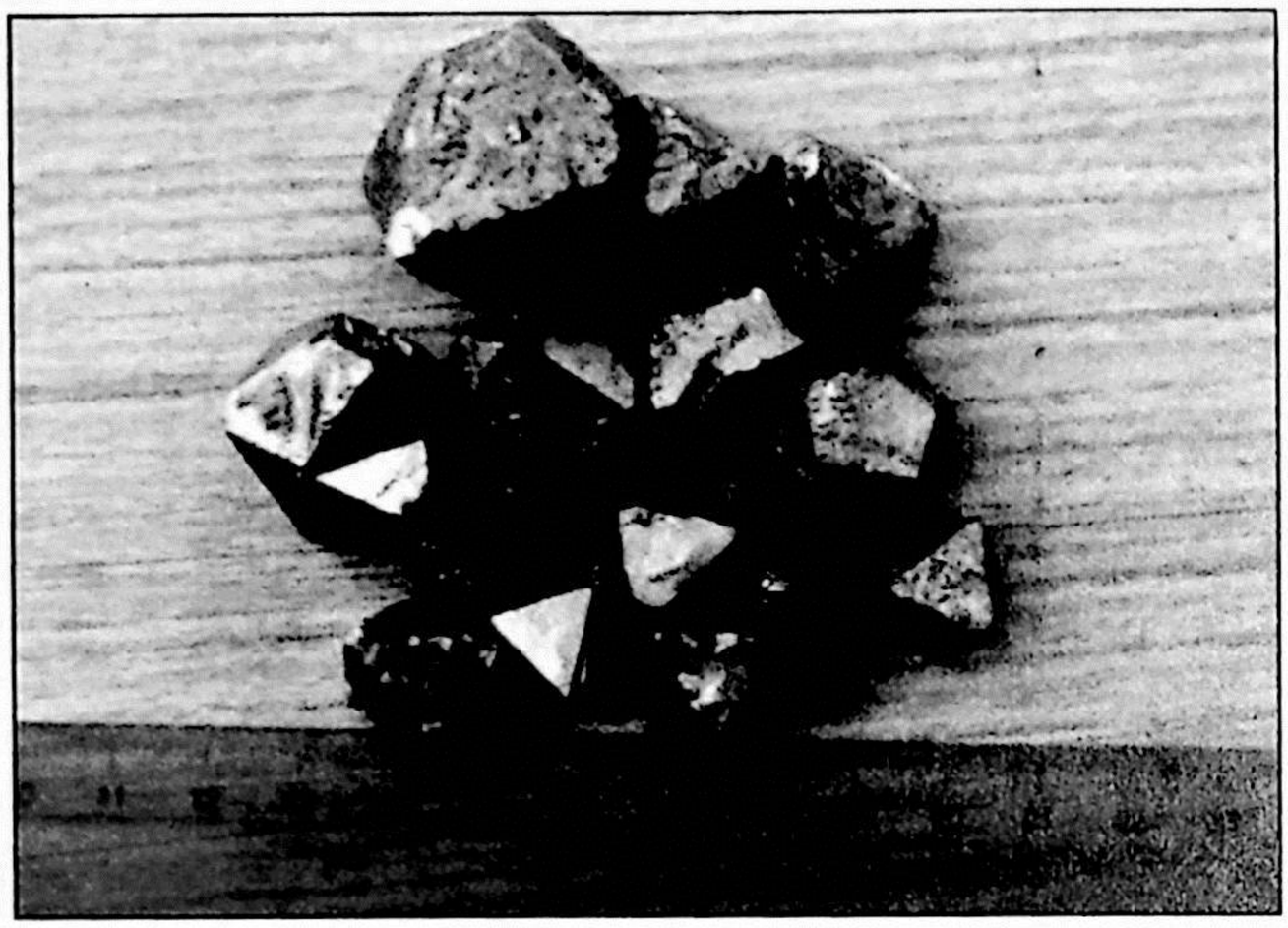


Fig. 33. Octahedron and pentagonaldodecahedron (pyritohedron) pyrite crystals.

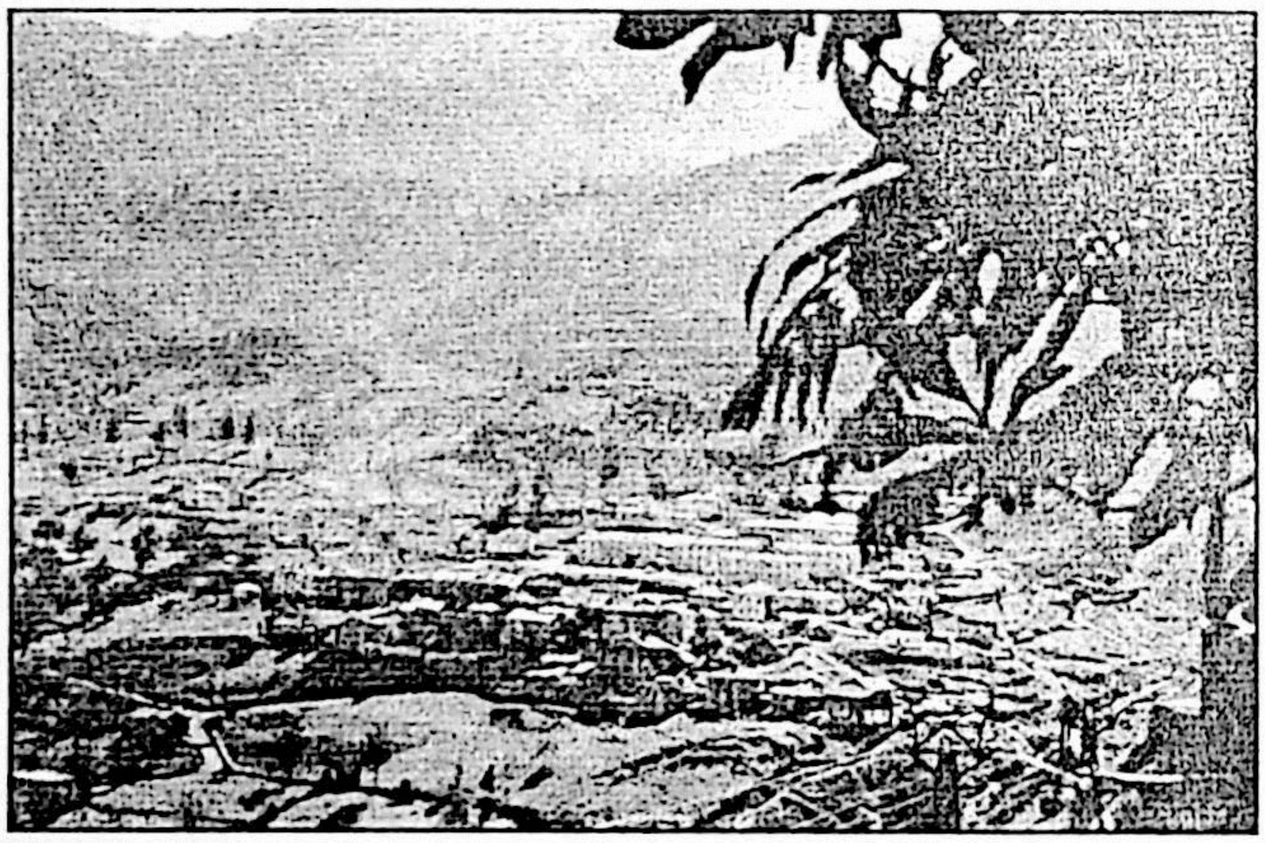


Fig. 34. View of Damarköy (new settlement).

At Çakmakkaya, ore occurs only in stockwork form. The ore regeneration led to the formation of quartz veins with chalcopyrite crystals of 1 cm in size (Fig.39), but pyrite crystals are not as large as at Anayatak. Where the form of ore occurrence is concerned, one should bear in mind that there are other forms in deposits of the Murgul area. Thus, on Kilise Tepe, also located in the same tectonic zone as the Anayatak and Çakmakkaya, impregnated chalcopyrite mineral occurs in the volcanic, highly silicified, breccia. Also in rhyolite pyroclastics, stratified chalcopyrite ore bodies and quartzdiorite sills appearance and other minor extrusions of the same rock, irregular in shape, are mineralized by sphalerite and chalcopyrite, suggesting likely presence of a porphyric sulphide-ore deposit.

Various forms of occurrence, and the origin that is not identical in all ore deposits, result from multiple mineralization in Murgul area.

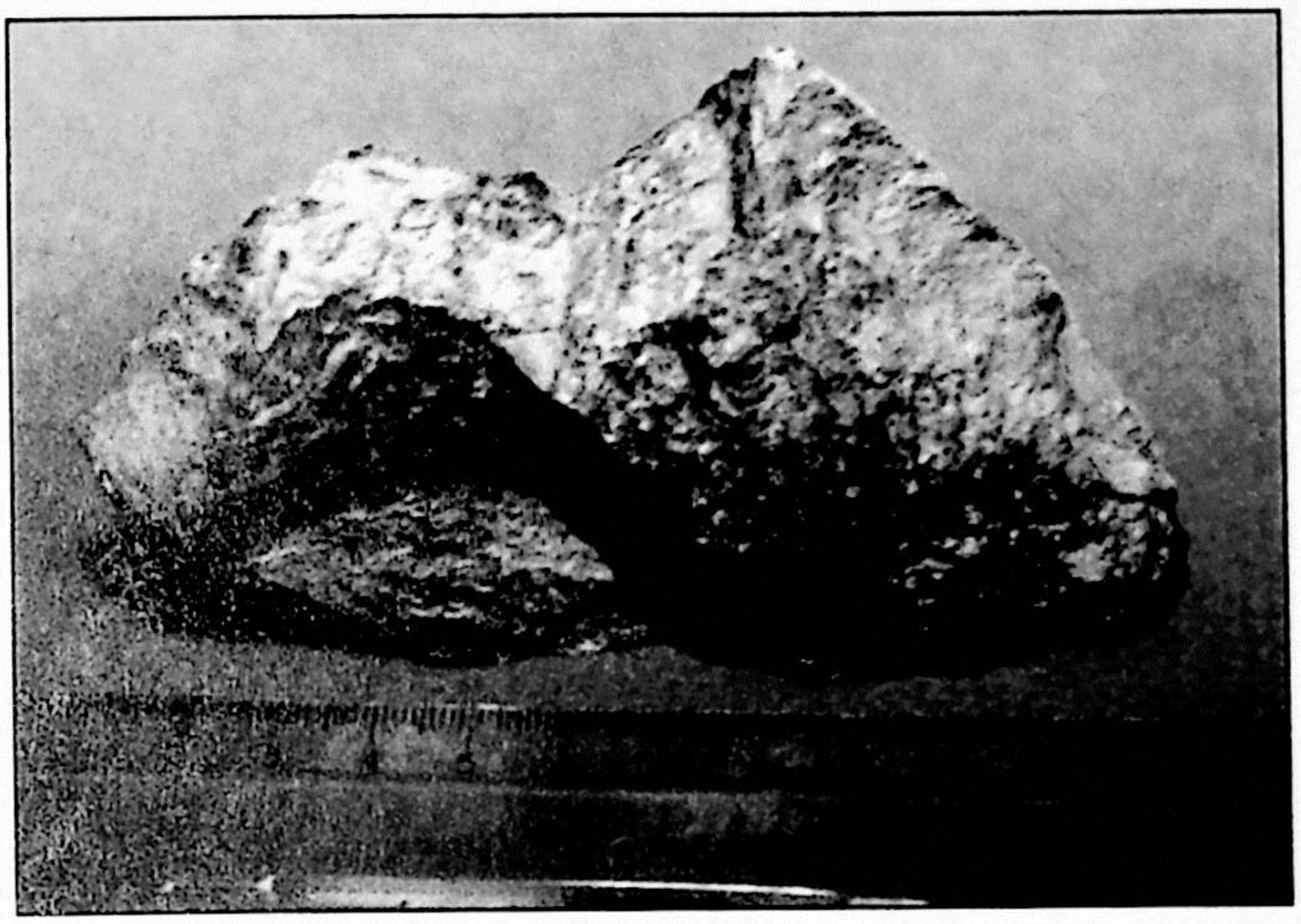


Fig. 35. Specimen of massive chalcopyrite from Anayatak

Ore Deposits

1. Anayatak. Main mineralization in Anayatak is associated with rhyolite breccia and rhyolite tuff. The non-mineralized part of the latter rock represented primarily the hangingwall of the ore deposit. The volcanic rocks are so crushed that the mineral substance, or the so-called massive chalcopyrite, is the cement for fragments of volcanic or tectonic breccia (Fig.32). Blocks of chalcopyrite can be found, 40x50x30 cm in size, containing copper to 23.85%, even higher than the flotation concentrate cited by Griffith (1966, in: Pejatović, 1975/79) or in my tests of flotation concentrate (Table 9). The copper content in amethyst is relatively high (0.83%) and in mineralized tuff (to 6%), which belong to the main mineralization. Rhyolite breccia should also be mentioned, in the same ore bearing zone, because it contains copper by 0.15%. Pyrite crystals contain copper: octahedrons to 0.124%, and pentagonal dodecahedron only 0.064%, or the latter half the amount of the former. This indicates the unevenly and multiphase distribution of copper. Also, pyrite crystals are multiphase and the content of copper is reduced in comparison with other analyzed samples. Pyritohedron of Anayatak occurs in highly altered tuff, which principal component is fault clay, and this lithological environment belongs to a mineralized zone of more than 150 m total thickness at Anayatak.

Table 9. Chemical composition of Anayatak ore deposit.

	%					ppm		
Sampl sort	Cu	Zn	Pb	As	Ba	Cd	Bi	Mo
Chalcopyrite (massive) with low pyrite	23.85	2.5	0.04	0.034	0.11	-	70	500
Mineralized rhyolite tuff	6.00	1.5	0.12	x	x	x	x	40
Amethyst	0.83	0.063	0.063	0.25	0.60	x	-	5
Rhyolite tuff breccia (ore zone)	0.15	0.20	0.004	x	x	x	x	15
Rhyolite tuff hangingwall (ore body)	0.03	0.02	0.025	x	x	x	x	2
Pyritohedron (pentagonal dodecahedron)	0.064	0.03	0.143	0.017	0.13	-	-	-
Pyrite crystal (octahedron)	0.124	0.083	0.046	0.022	0.085	-	-	-
Flotation concentrate (pyrite+chalcopyrite)	5.77	2.120	0.243	0.144	0.32	0.29	-	-
Flotation concentrate (chalcopyrite+pyrite)	10.00	2.75	0.367	0.174	0.32	-	320	60

x – not analyzed.

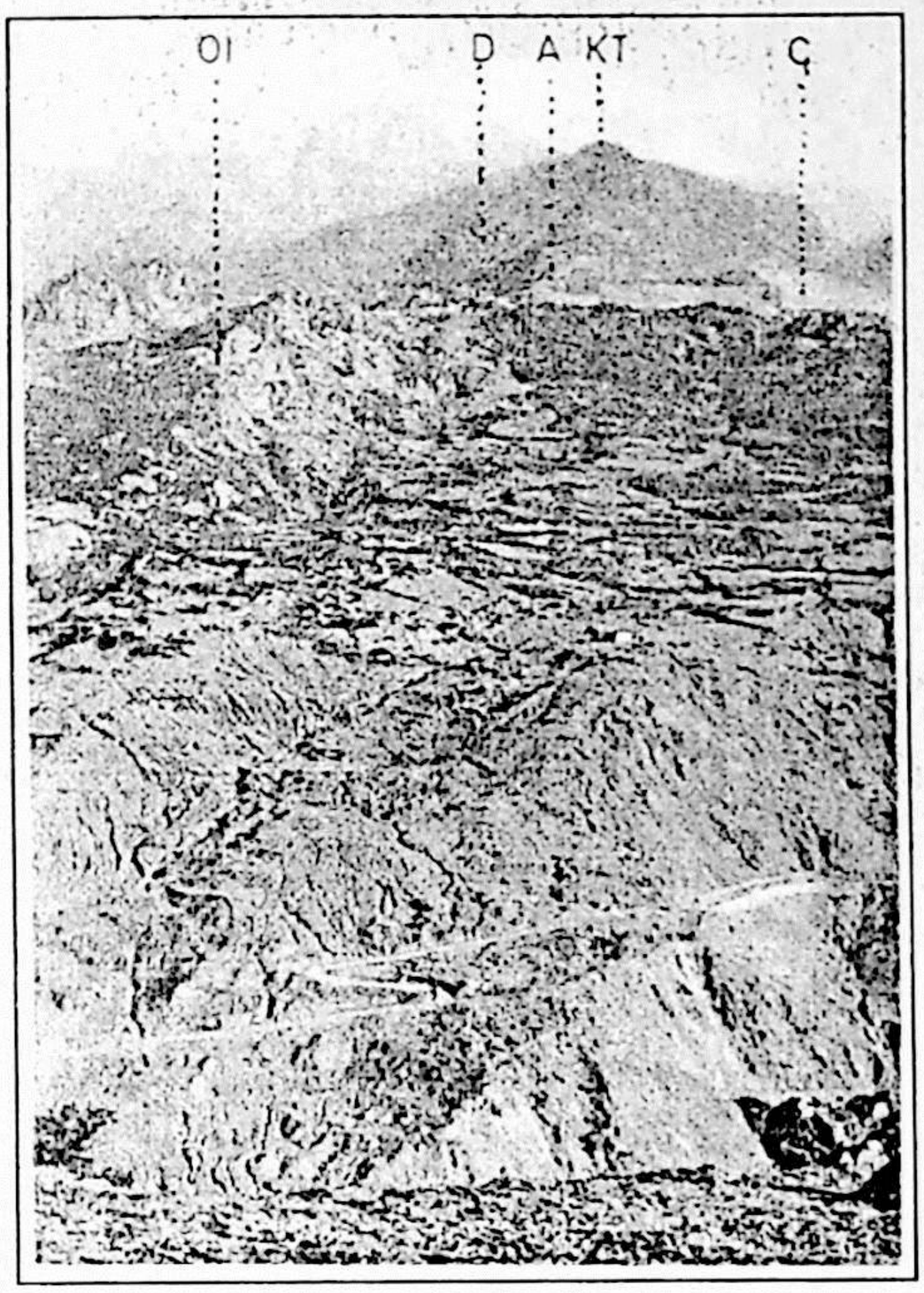


Fig. 36. View of copper deposits of Anayatak (A) and Çakmakkaya (Ç), dacite of Kara Tepe (KT), Orta Istasyon (OI) and Damarköy (D) from Petek Köy, 1970.

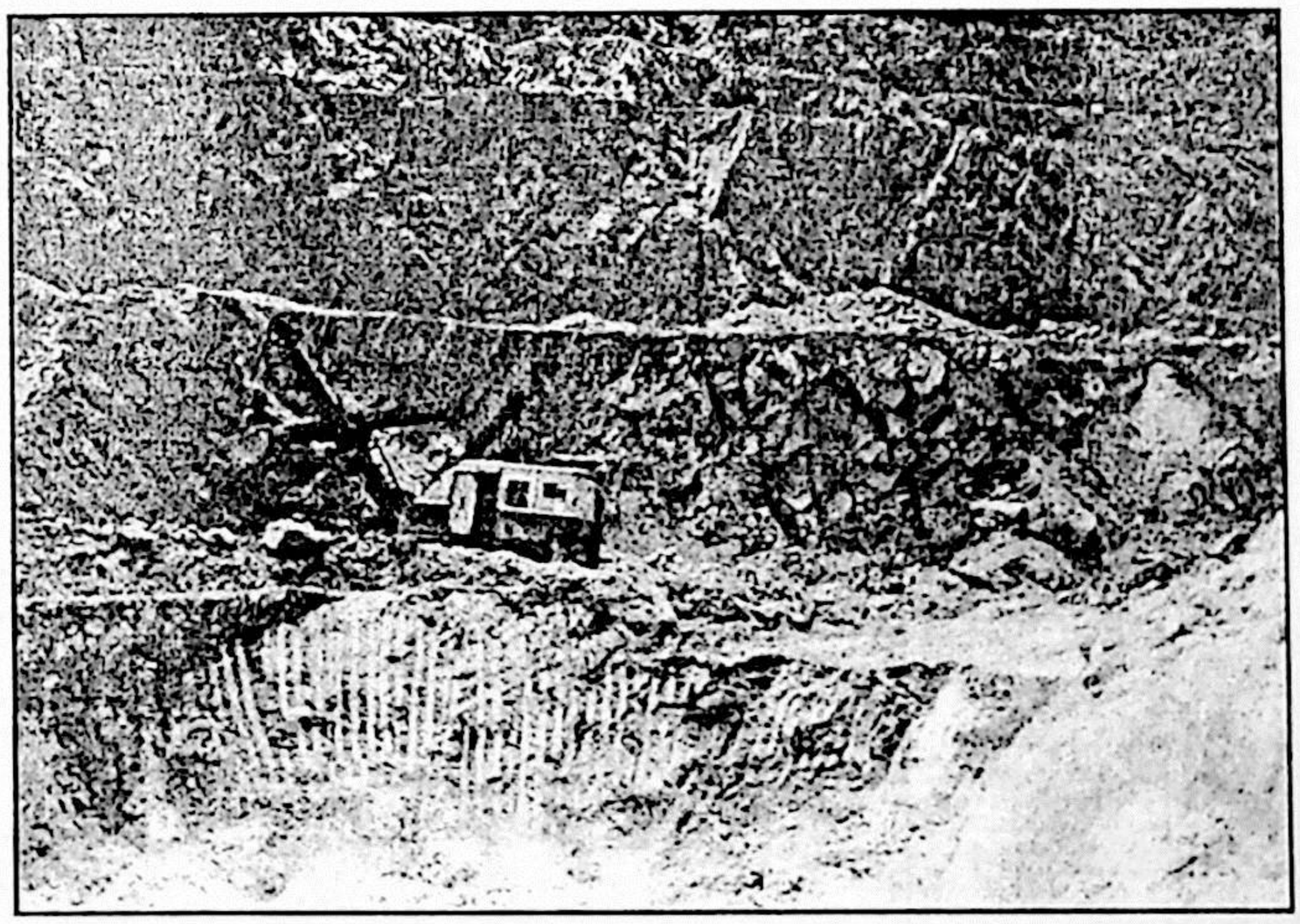


Fig. 37. Anayatak open pit (1971).
1. Footwall part of the deposit with large pyrite crystals (lower, brighter part of photo):
2. Mineralized rhyolite breccia with massive chalcopyrite and mineralized rhyolite pyroclastics (upper, dark part of the photo)

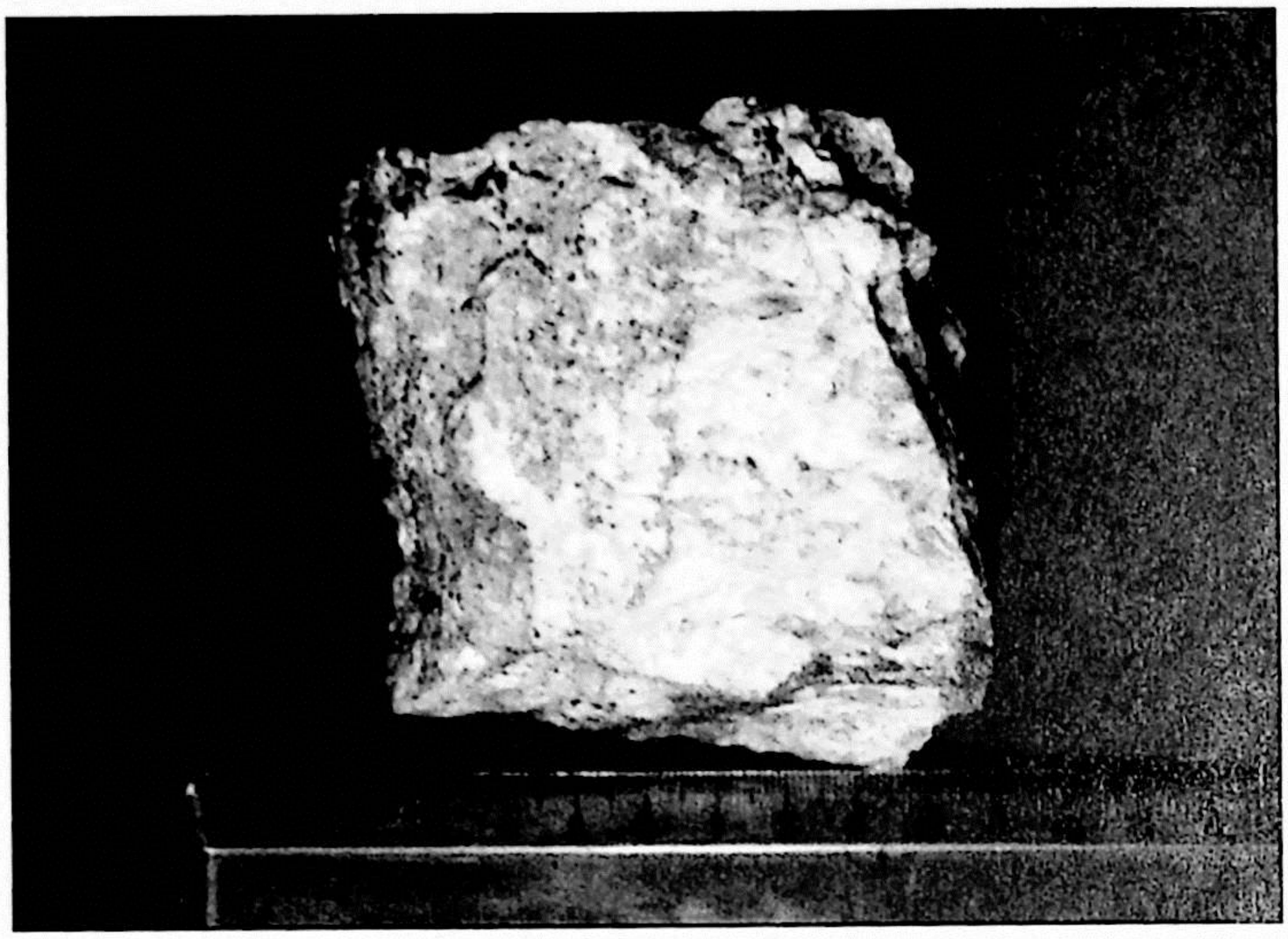


Fig. 38. Mineralized amethyst.

Table 10. Contents of microelemens in Anayatak ore (ppm)

	Mineralized amethyst	Massive chalcopyrite	Pentagonal Dodecahedron pyrite	Octahedron pyrite
Cu	5000	23.85%	320	316
Pb	629	700	1429	457
Zn	1000	2200	800	1000
Mg	2000	4200	2000	1500
Ba	600	1100	1300	850
Ag	2	180	trace (1)	3
Ga	-	20	-	-
Bi	-	70	-	-
Mo	5	500	-	-
Zr	trace	130	320	170
As	254	340	170	220
Co	3	50	5.5	17
Ni	2.5	trace	2	5
Cr	trace	-	-	4

G r i f f i t h' s (London) and ours lead concentrations are similar, and so are those of more metals – zinc, titanium, partly aluminium, manganese and bismuth, but other elements differ greatly. The difference is believed to be due to the different sampling times and different places of ore extraction and to the mixing of ores from other deposits (in the seventies, ore was delivered to the flotation plant from Anayatak and from Başköy). Even small amounts could have affected the test results. Also, the samples we used were from deeper parts of the Anayatak ore body than those that gave the concentrate five or six years earlier (Table 11).

Table 11. Microelements in flotation concentrate sampled in 1966. and 1970 (in %).

Chemical Element	Chalcopyrite+pyrite (flotation concentrate, 1970)	Pyrite +chalcopyrite (flotation concentrate,1970)	Chalcopyrite flotation concentrate (after Griffith, 1966)
Ag	61 ppm	80 ppm	785 ppm
Au	0.88 ppm	0.53 ppm	12 ppm
Cu	10.00	5.77	19.43
Pb	0.367	0.243	0.34
Cd	-	0.29	0.03
Bi	0.032	-	0.007
As	0.174	0.144	0.06
Sb	-	-	0.006
Sn	-	-	0.04
Se	-	-	0.02
Al	> 1	0.20	0.55
Ti	0.010	0.004	0.01
Mn	0.008	-	0.005
Zn	2.75	2.12	2.75
Ni	0.0003	0.0007	0.03
Co	0.007	0.01	-
B	0.32	0.32	0.5
Mg	0.035	0.20	-

In addition to the difference in the sampling time, Murgul flotation plant used an obsolete technology that was responsible for the loss of a good part of all metals (Cu, Au, Ag, etc.) to gangue (**muck**). Massive chalcopyrite also contained pyrite, sphalerite and tetrahedrite (tennantite). Chalcopyrite is compact, locally slightly cracked (Fig.39), with sphalerite or collomorphic pyrite in cracks and fissures. In this association, pyrite occurs as gel forming micrometric globules and colloforms no bigger than 5 mm size. In some cases, colloidal pyrite contains low chalcopyrite. Sphalerite is mainly scarce, mostly xenomorphic in chalcopyrite, and rarely in xenomorphic pyrite. Tetrahedrite is commonly tennantite, very rare, enclosed in gel-pyrite. The paragensis includes other ore minerals of minor importance.

According to the amounts of extracted ore at Anayatak, the total ore reserves must have been about thirty million tons, and the average copper content higher than 1.5%.

2. Ç a k m a k k a y a. In contrast to Anayatak, Çakmakkaya was geochemically explored for distribution of Cu, Zn, and Pb in rhyolite pyroclastics. This ore deposit located 500 m southeast of Anayatak is a typical example of highly silicified and mineralized (by chalcopyrite, pyrite and less sphalerite) rhyolite breccia. The deposit is smaller than the Anayatak. Its ore reserves are less than ten million tons with the average copper content of about 1%. Other authors estimates vary from about eight million tons (P e j a t o v i ć, 1973, 1975/79) to twenty-five million tons (A k i n c i, 1980) to ninety-nine million tons (E n g i n, 1986). It is believed that the latter estimates, though assigned to Çakmakkaya, refer to both Anayatak and Çakmakkaya, or even more likely to the total reserves of Murgul area.

The Çakmakkaya deposit is in form of ellipsoid, its longer NE-SW axis is more than 500 m long. In its central part, at the surface of the ore body, after the stripping for mine opening purposes, its width was about 250 m and the thickness (in 1970) estimated to about 100 m.

Table 12. Contents of base metals in mother rock at Çakmakkaya (in ppm)

Rock	Cu	Zn	Pb	Mo
Rhyolite tuff	70	500	20	2
Rhyolite	1000	250	20	2
Rhyolite breccia	80	250	20	2
Ore body	> 1%	1000	60	50

In a geochemical cross section perpendicular to direction of the ore body samples were collected from adjacent rocks, the contact with the ore, and from the ore body, but also from the contact between the muck to ore. The results are given in Table 12.

Notably anomalous proportions of copper occur only in rhyolite. Because ore material was predominantly deposited in tuffogene rocks (dominantly rhyolitic in composition), the contrast between the ore and the adjacent rock is distinct. This is particularly true for the footwall parts of the ore body. But the hangingwall consist mostly of rhyolite with an increased amount of copper (1000 ppm). This phenomenon could be explained in more than one way: (1) The rhyolite hangingwall flows were preceded by hydrothermal solutions rich in iron, copper, sulphur and less zinc; (2) Rhyolite extrusion was followed by hydrothermal solutions abounding in mentioned metals; (3) Rhyolite flow and ore are at present in inverse position, that rhyolite extrusion is in fact the footwall of the ore body which were affected by hydrothermal solutions, which is not likely; (4) Subsequent to ore body formation, new hydrothermal processes developed and partly leached copper in the primary ore and carried it into the hangingwall rocks thus enriching rhyolite with iron, copper, and far less zinc.

The fracture structure was certainly the place of ore precipitation and a channel of the mineralized solution flow, which, with the formerly created favorable physico - chemical conditions, for the formation of a large ore body such as the Çakmakkaya. In any case, the formation of this ore deposit evolved during the Malm-Neocomian rhyolite or rhyodacite volcanism.

Note that molybdenum amount in the ore is increased in relation to the rock environment, which so far has not been well explained.

The ore deposit of Çakmakkaya is a stockwork type of ore body. It clearly shows a subsequent re-crystallization manifested by the formation of younger crystalline chalcopyrite in association with younger quartz. Chalcopyrite crystals are to 1 cm in size (Fig.39), supposed to be regenerated chalcopyrite. The minerals identified in the ore body are the most abundant pyrite, chalcopyrite, sphalerite, less bornite, chalcocite, covellite, Cu-limonite, tenorite and limonite. All primary minerals (the former three) are fine-grained, excluding the regenerated ore minerals.

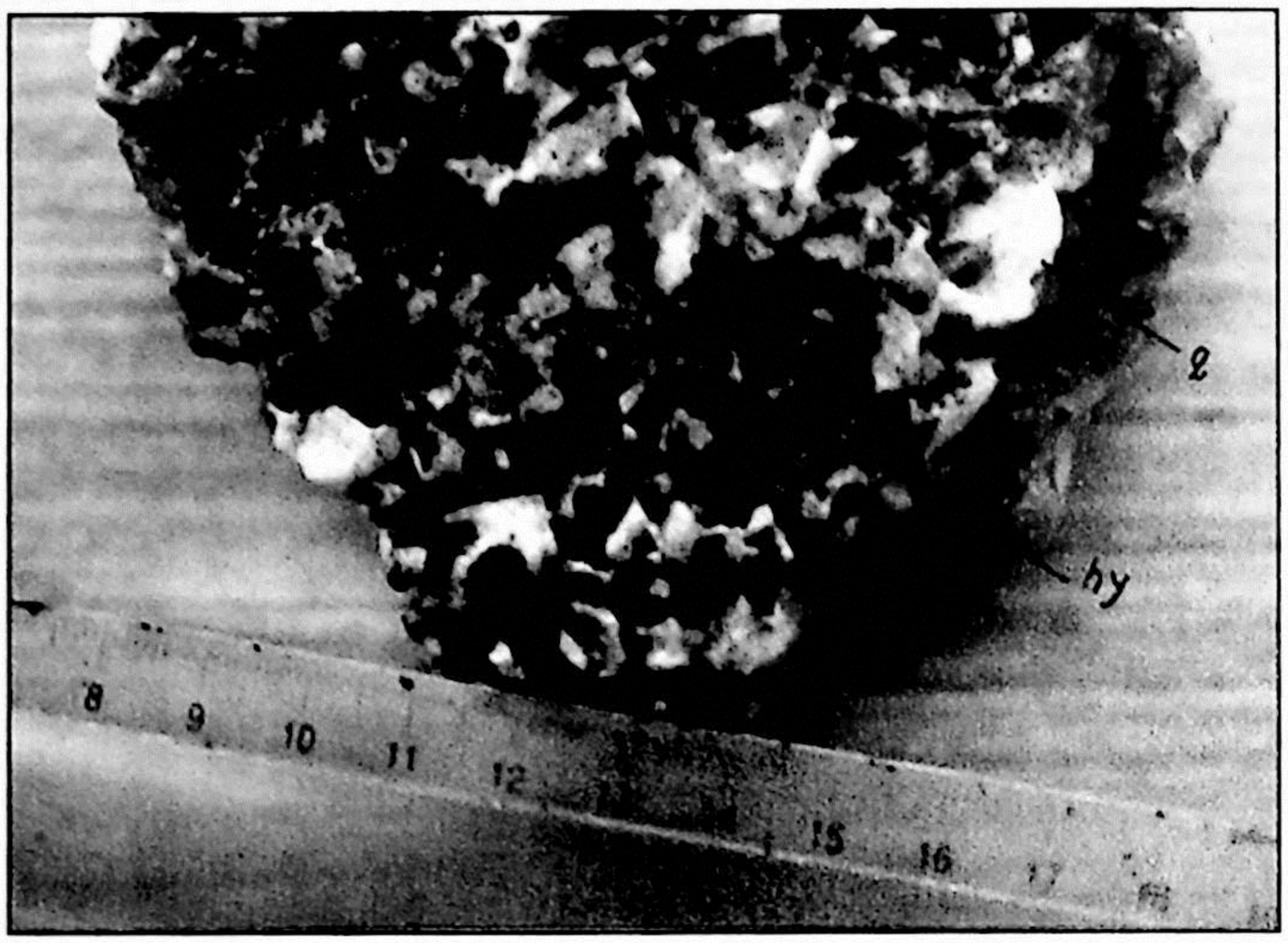


Fig. 39. Chalcopyrite crystals (hy, dark yellow) in quartz vein (q, white) from Çakmakkaya mineral deposit.

Analytical data for microelements in crystalline chalcopyrite and in the quartz vein associated with it are presented in Table 13.

Table 13. Contents of trace elements in quartz vein and the associated crystalline chalcopyrite (in ppm)

	Al	Fe	Mg	Ti	Mn	Pb	Ga	Cu	Ag	Zn	Zr	Co
Quartz	5000	1000	480	-	-	tr.	-	300	3	-	-	-
Chalco-pyrite	5500	> 1%	500	120	tr.	tr.	20	>1%	12	tr.	120	30

tr.traces

The ore bodies of Anayatak and Çakmakkaya, though near one another, formed at the same time, and deposited in identical lithological and tectonic environment, differ in the reserves and size, mode of occurrence, quality and mineral composition.

The copper ore deposits in Murgul area are the largest in Pontic region. These deposits are Anayatak and Çakmakkaya and many others, inadequately explored, but perspective for search of new, larger copper ore reserves.

The two deposits (Anayatak and Çakmakkaya) seem to be clearly delimited from adjacent rocks in which they are emplaced. However, the base constituents in the association of chemical elements are iron, copper, zinc and sulphur, and less some other elements. Among the microelements, barium is one of the highest, from 850 ppm to 6000 ppm, followed by arsenic from 170 ppm to 1740 ppm. Molybdenum is low, from 2 ppm to 500 ppm. The ore flotation concentrate from Anayatak contains cadmium 0.29%. Gold content in the ore is from 0.03 ppm to 0.45 ppm, and silver concentrations are from 1 ppm to 180 ppm.

Based on published information (S c h n e i d e r et al., 1988) the ore from Anayatak and Çakmakkaya can be classified by both mode of occurrence and copper concentration. Thus, copper content ranges in disseminated ore from 0.20% to 0.70%, stockwork from 1.00% to 2,50% , and massive ore from 5% to 10%, respectively.

3. B o g n a r ı. Bognarı is a small sulphide copper deposit (some zinc and even less lead) about 500 m north of Anayatak (Fig.31). The deposit is similar to those of Anayatak, or even a part of Anayatak. Bognarı ore is located in crushed rhyolite volcanic rocks much hydrothermally altered principally by silicification, argillization and pyritization. The deposit was found near Murgul among other newly discovered ore bodies (late sixties and early seventies). It was explored by drilling and delineated and its reserve estimated at less than half a million tons. M a d o (1972) estimated its reserve together with Anayatak and Çakmakkaya at about forty million tons of ore with the average of copper 1.25%, zinc 0.10%, silver 25g/t and gold 0.2 g/t. The Bognarı mineral deposit is believed to be an erosion remnant of a largest ore body. The evidence of a nearby hangingwall as that over the Anayatak and Çakmakkaya – remains of thick dacite flow, may support this M a d o' s argument. A larger erosion remains are found in close proximity, on Orta Istasyon. There is also another opinion that this ore body is what remained after the hangingwall erosion of the Anayatak (Ö z g ü r, P a l a c i o s, 1990), which is not much likely.

The paragenesis of the ore body includes the same minerals as the Anayatak or Çakmakkaya, Aduca Dere, and the others of the same volcanogenic or volcanogenic-sedimentary type of ore. All these bodies, Bognarı included, contain dominantly pyrite, and chalcopyrite, much lower sphalerite, and subordinately galena. Like in other or deposits of Murgul area, tetrahedrite is always associated in a very low proportion. The trace minerals contained are bismuth sulphosalt, silver telluride, lead selenite, and scarce native gold. Ö z g ü r and P a l a c i u s (1990) write that W i l l g a l i s and S e i g m a n n (1989) determined these rare metals using

electronic microprobe, which confirms its mineralogical similarity with the ore of Anayatak.

The ore body of Bognarı certainly belongs to the same ore field as the Anayatak and Çakmakkaya, Aduca Dere, Çarkbaşı and Gölbaşı. But Bognarı body is much deformed and eroded – remains of a larger ore body. Therefore the hypothesis is refuted that it is a product of degradation, the redeposited upper part of the Anayatak deposit. On the contrary, together with Anayatak, Orta Istasyon, Sileh Kale, probably Aduca Dere and an occurrence under Moçven (northern bank of Aduca Dere east of Murgul), Bognarı is one in the string of ore bodies, to which Çakmakkaya and other bodies should be added.

4. A d u c a D e r e. This is known to be the next largest copper ore deposit after Anayatak and Çakmakkaya in Murgul area. It is located northeast of Anayatak on either side of the Aduca deresı, on the western slopes of Kızıl Kaya. The deposit was explored in the beginning of the seventies when its size was determined, and the ore reserves calculated at more than a million tons with the average copper content of about 1%. Unlike the preceding ore deposits, this one is deep-lying and has a thicker overburden than Anayatak and Çakmakkaya or particularly thicker than Sileh Kale, which may suggest a greater potential reserve than has been known up to day. Its average depth is about 130 m (P e j a t o v i ć, 1975/79), located in the same petrogenic environment as the ore deposits of Anayatak, Çakmakkaya, Bognarı and other ore bodies of the same stage of development. It occurs in rhyolite volcanic rocks at near or in the lower contact with Kara Tepe dacite. The contact is tectonic like in the other similar ore deposits. The ore body occurs in two stockwork and stockwork-impregnated bodies about 250 m apart, with increased copper in the rocks between the bodies. Because it is evidently not a sterile environment it should, perhaps, be included in the account of the total ore reserves, even regardless to diluting the ore substance. Additional research works would probably result in new copper concentrations, even if lower, it can provide a better knowledge of the deposit. In that case a composite set (both ore bodies and sterile rocks in between) would give ore of a lower copper content, but a higher ore reserve. This ore deposit, as mentioned before, may be considered well marked with the so far provided total ore reserves of various categories of about a million tons, and the average copper concentration of about 1%, similar to the Çakmakkaya ore deposit.

The ore paragenesis of the deposit includes pyrite, as the most abundant mineral, and chalcopyrite, less abundant, sphalerite subordinate, and other minerals only in traces or in concentrations similar to the accompanying minerals in the main ore bodies of Anayatak and Çakmakkaya.

The Aduca Dere deep-seated ore body at the altitudes between 900 m and 950 m and the Cu-mineral occurrence at the altitude of about 900 m on the southern slope of Moçven peak (1009 m) and the Cu-mineral of Orta Istasyon at the same elevation seem to be spatially connected which is promising for search of larger ore reserves in the area.

5. Sileh Kale and Orta Istasyon. Sileh Kale is located by the Murgul-Damarköy road near Orta Istasyon where also a small copper ore deposit was found. Both occurrences are in the same tectonic zone where Anayatak and Çakmakkaya ore bodies are emplaced. The only difference is that the hangingwall of the Sileh Kale and Orta Istasyon has been almost completely destroyed and even the ore body has been partly eroded. But the degree or depth of erosion in the ore body has not been established. The copper ore occurrences of Sileh Kale, Orta Istasyon, Aduca Dere, Çarkbaşı and Lebiskur Dere are indicated as likely genetically and spatially related. Except in the two largest ones, Anayatak and Çakmakkaya, explorations in other ore occurrences and deposits have not been completed. Sileh Kale is one more occurrence in the Jurassic-Neocomian rhyolite rocks explored (1970) by the author of this text. There are several Cu-mineral occurrences 1 km south of Murgul by the road to Damarköy, or to Anayatak and Çakmakkaya. The Sileh Kale is 100 m west of the road. East of Sileh Kale. B u s e r (1970) and his collaborators registered two more outcrops of Cu-mineralization. All these occurrences are in Malm-Neocomian rhyolit volcanic rocks. These and all the before mentioned, including the Anayatak and Çakmakkaya deposits,were formed under volcanogenic conditions, when also hydrothermal solution rich in copper and silica "soaked" the lower parts of rhyolite pyroclastics.

The thickness of rhyolite volcanites is best estimated between Lebiskür dere and Kilise Tepe – more than thousand meters (including rhyolite volcanic rocks contact with the older underlying rocks at the altitude of about 500 m, whereas Kilise Tepe peak exceeds 1900 m). But it can be observed in the Murgul dere westerly bank section all the way to Budiyet Köprüsü that it was on that side that the rock complex thickness was reduced, roughly to several hundred meters. The reduced thickness can be explained partly by erosion, which continued between the Lower and Upper Cretaceous, and partly by the non-uniform distribution of the rehyolite volcanic rocks. This is a problem, only mentioned presently, that has not been studied and that remains open for future exploration.

Explorations of ore occurrences in the two localities are very difficult, because they are located in the footwall part of the regional reverse structure, all Malm-Neocomian and Upper Cretaceous-Paleogene formations have been

heavily eroded and affected by land-slides. Rhyolite volcanic rocks are hydrothermally much altered mainly by silicification, kaolinization, argillization, pyritization. The copper mineralization outcrop itself is highly silicified and emplaced in much argillized and kaolinized rocks.

Contents of copper, zinc and lead in rhyolite tuff based on geochemical examinations are given in Table 14.

Geological map (Fig.40) of Sileh Kale-Orta Istasyon area shows a string of four Cu-mineralization occurrences. One is in the western Murgul dere bank, near Murgul town, the next is Sileh Kale, a quite large iron hat represents the third, and the fourth is near Orta Istasyon. All four occurrences are in rhyolite volcanites near its hangingwall either of dacite flow or Upper Cretaceous rocks.

These occurrences clearly indicate that new amounts of copper ore are likely to be found where hangingwall of rhyolite volcanites with Cu-mineral has been preserved. Two outcrops were found in Sileh Kale itself, which contained dominant pyrite, then chalcopyrite, some sphalerite, and secondary malachite, covellite, chalcanthite, limonite and plenty of sulphur bloom. Generally, secondary minerals are not abundant due to heavy erosion.

Pyrite occurs in octahedron and pentagonal dodecahedron crystals mostly smaller than 1 cm^3, like in Anayatak. Chalcopyrite is fine-grained impregnated in the rock; locally chalcopyrite accumulations contain copper of 1% or more.

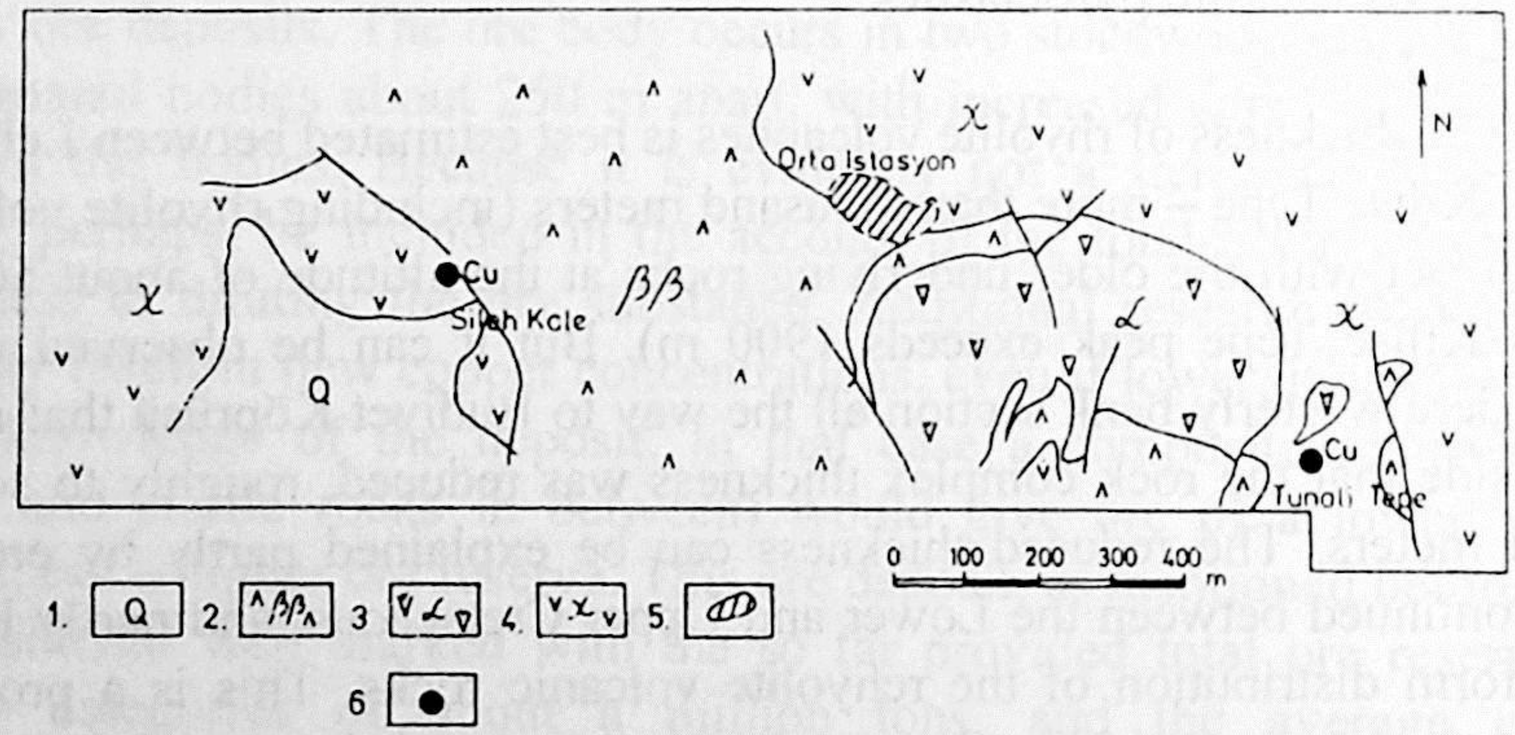


Fig. 40. Geological map of Sileh Kale-Orta Istasyon.

1.Debris; 2. Basalt-spilitoid volcanites; 3. Dacite flow; 4. Rhyolite volcanites; 5. Iron hat Cu-mineralized; 6. Cu-mineralization outcrop.

Table 14. Results of geochemical examinations of rhyolite tuffs a Sileh Kale

ppm		
Cu	Zn	Pb
80	250	80
72	520	325
44	400	80
320	64	>50
136	128	>50
150	<1600	400

A copper-mineralized block, either an outcrop or only a displaced block, larger than 100 m^3, is located southeast of the preceding occurrence. Copper mineralization in it is a stockwork-impregnated and impregnated type. An iron hat of 120x40 m in size is located about 800 m east of the block. The iron hat was formed above the mineralizations with iron sulphide, at the contact with Upper Cretaceous formations, or Upper Cretaceous basic volcanic rocks that lie over Upper Jurassic-Lower Cretaceous rhyolite volcanites. A sample from the iron hat contained copper of 0.08%, zinc 0.16%, and lead 0.04%. The Tunali Tepe Cu-mineralization occurrence should be added, about 700 m SE of the iron hat. It is probably related with the Bognarı ore deposit (about 100 m north of Bognarı). Thus, all ore deposits and occurrences in the Anayatak-Çakmakkaya ore field are related in time and space, in origin and mode of occurrence, in mineral and chemical composition, which indicates the high potentiality degree of the ore field for discoveries of new Cu-ore reserves.

6. Ç a r k b a ş ı. An inadequately explored copper deposit, though ten or twelve test holes were drilled, is located about 500 m to 600 m south of Çakmakkaya. The holes were drilled for the purpose of prospecting the area, and were not projected for calculation of ore reserves. A similar case was with the drill holes between Çakmakkaya and Çarkbaşı deposits (six holes between the two deposits). The drilling data indicated a pyrite mineral deposit at Çarkbaşı with low copper concentration. Like the Aduca Dere, this deposit is deeper with ore in rhyolite pyroclastics. P e j a t o v i ć (1973) considered it as mostly eroded, with only its roots preserved, broken into ore blocks. The facts are undoubtly: the deposit is located in the ore zone of Aduca Dere, Anayatak and Çakmakkaya (Fig.31). The zone is about 10 km long, but it is extending to Kilise Tepe and includes pyrite ore occurrences, adding to the extremely high potential of the ore zone. The ore reserves calculated in the Aduca Dere, Anayatak, Bognarı and Çakmakkaya amount

to forty million tons, and the potential ore reserves to twice that much. This is all the more so that the ore reserve in rhyolite volcanic breccias on Kilise Tepe is estimated to between ten and twenty million tons of poor copper ore (so far known concentration is to 0.3% Cu).

P e j a t o v i ć (1975/79) gives an interesting information about the Çarkbaşı ore deposit. He mentions that associated with the principal ore are siderite and sporadically barite, and that it occurs in stockworks which are economically uninteresting. But according to mentioned data, this estimation about Çarkbaşı ore deposit, couldn't be accepted.

7. K a r a T e p e. Kara Tepe is a mountain peak built up of dacite flow. The columnar jointing of dacite was formerly interpreted as a neck around which copper deposits were distributed. However, in 1971 dacite was penetrated by a drill-hole that entered into the tectonic zone in which all the described ore deposits were emplaced. This provided an argument to refute the hypothesis of the Kara Tepe neck. A few hundred meters SE of the peak, a tectonic zone is probably part of the structure emplacing the mentioned copper ore deposits. Mylonite of the tectonic zone bears minor amounts of copper mineralizations, mainly in an undetermined mode of occurrence; nowhere a true outcrop has been noted, but fragments of copper mineralizations in a mechanical dispersion halo. The presence of rhyolite pyroclastics, however, indicates a possible occurrence of primary Cu-mineralization outcrops. This has not been explored, but is mentioned to bring it to the attention for future explorers.

8. K a r a g ö l. A Cu-mineralization occurrence, referred to as Karagöl (Black Lake), is located about 2 km SE of Kara Tepe (Fig.31). Unlike the Kara Tepe, this occurrence was drilled by three bore holes 300 m to 400 m apart. Drill-core from one bore hole contained Cu-mineralization in rhyolite pyroclastics, much crushed and highly pyritized. Pyrite occurs impregnated or in thin veinlets of 1 mm, rarely thicker (to 3 cm). Associated with the pyrite mineralization there is a low chalcopyrite at depths from 90 m to 100 m. This mineralization contained 0.1% of copper.

In the area of Karagöl, rhyolite formations frequently alternate with Upper Cretaceous basic volcanic formations, as a result of both faulting and folding deformations. Folds are often, "decimetric" up to "hectometric"-sized, with b-axis in NE-SW direction gently dipping to SW.

Potential Estimation of Anayatak - Çakmakkaya Ore Field

In the present state of knowledge the Anayatak-Çakmakkaya ore field includes eight copper ore deposits of the Malm-Neocomian age. Only few of the deposits were explored in detail, while others are very interesting and it could be explored in detail also.

The Anayatak and Çakmakkaya are the most significant ore deposits in the Pontic metallogenic province. The Anayatak was discovered before more than a hundred years and worked from the beginning of the 20th century, when also the flotation and smeltering plants were established. The Çakmakkaya was uncovered in the late fifties, and mined in the beginning of the seventies of the last century.

Many geologists made round trips or explored ore deposits in the Anayatak-Çakmakkaya ore field, including myself during 1970-1972. Although the deposits are almost exhausted (and the mining stopped), many problems have remained unsolved. True enough, in the late sixties and the early seventies, when large-scale exploratory drillings were performed, it was a great opportunity to clarify many questions, but the opportunity was missed. That is why there still are controversies about the ore reserves (published sources give approximate information) and the origin of ore deposits. It is believe that the most realistic estimates of the ore reserves are those from the beginning of the seventies: Anayatak more than 20 million tons (probably 30 million t.) with more than 1.5% of copper, and Çakmakkaya calculated about 8 million tons with average copper concentration of 1% (exactly: 0.86%). The potential copper reserve is higher than suggested by the mentioned estimate. The Anayatak and Çakmakkaya ore field also includes the deposits of Aduca Dere (over 1 million tons of ore with about 1% copper), Bognarı (more than 0.5 million ton of ore with about 1% copper), Orta Istasyon (incomplete exploration, copper to 1%), Sileh Kale (unexplored occurrence with copper less than 1%), Çarkbaşı (over 2 million tons of ore with copper content below 1%). Kilise Tepe should also be added with the estimated ore reserve from 10 to 20 million tons of poor ore (copper less than 0.5%) associated with highly silicified volcanic breccia.

All in all, disregarding other ore occurrences and deposits associated with Upper Cretaceous-Tertiary magmatism (volcanism), the potential

copper ore reserves are certainly exceeding 50 million tons, with an economically significant copper concentration.

The footwall of ore mineral deposit consists of kaolin and argillite as the products of either hydrothermal alteration or faulting. This footwall clayey material contains mainly crystalline pyrite and far less chalcopyrite. The hangingwall of the ore body are rhyolite pyroclastics overlain by dacite flow of the Kara Tepe type. The mineral paragenesis of Anayatak includes primary pyrite (dominant), chalcopyrite, subordinately sphalerite, sparse galena, and even scarcer tetrahedrite and arsenopyrite. The secondary minerals are bornite, chalcocite, covellite, tenorite, and less malachite, azurite and Cu-limonite. Note that tenorite is an interesting secondary mineral that occurs in all copper deposits and occurrences in the large Murgul area. It is commonly higher than other secondary minerals.

Unlike Anayatak, the Çakmakkaya is characterized mostly by a smaller ore reserves and a lower copper concentration, then by heavy silicification and deficiency in mineral types: pyrite and chalcopyrite as primary ore minerals with a low proportion of sphalerite and very low galena. The deposit contains chalcopyrite crystals formed through regeneration, noted only in quartz-chalcopyrite veins.

To the estimated ore potential of Malm-Neocomian formations of the Murgul area, one should add the several occurrences in the Murgul dere left bank reported by B u s e r (1970). K r a ë f f (1963) noted one in Bakiket locality. It was explored in the past as suggested by an adit, but there isn't any detailed information available. It was probably explored at the time of sulfide ore exploitation at Akarşen.

II. K i l i s e T e p e O r e F i e l d

Several morphological, by the form of occurrence, and possibly also genetic types of Cu-mineralizations are found on Kilise Tepe. The identified **volcanogenic** type is associated with volcanic breccia, in which the copper content is relatively low (0.2% in outcrops, and reserve estimate from 10 to 20 million tons). **Vein** type is found in rhyolite pyroclastics (variable copper up to 4%). These minerals contain high molybdenum and zinc and are everywhere deposited along low grade fractures.

The **stratiform** type of copper mineral is represented by pyrite-chalcopyrite with the copper concentration of 2% (2 m long test). The

complete picture of the ore occurrences on Kilise Tepe is accomplished by mentioning oreclasts of undetermined origin, which are supposed to belong to the stratiform type of ore deposit. If so, their origin might be volcanogenic-sedimentary. There is also an opinion that oreclasts originate from a pre-existing deposit that was destroyed during a volcanic explosion and its fragments occurred in pyroclasts (P e j a t o v i ć, 1973, 1975/79). Finally, the last genetic and morphogenic type is **porphyric,** which has not been found but its presence is presumed on the zinc (10%) and copper (from 0.2% to 0.5%) mineralization in the ore bearing **quartzdiorite.**

The deposits of Kilise Tepe, Çarkbaş, Çakmakkaya and Aduca Dere (and others in Damarköy area) and further eastward the occurrences and deposits in Kuvarshane zone and westward to Madenköy near Çayelı are believed to lie in the same ore zone.

B u s e r and his associates first observed in 1969/70 the copper mineralization traces in the Kopitvan dere valley. They noted strongly silicification and pyritization in the Kopitvan dere source area and found out many fragments and rounded pieces of chalcopyrite with pyrite, later defined as oreclasts. A detailed prospecting, including trenching, revealed only locally increased copper and single oreclasts in argillized zones, but not the source of chalcopyrite-pyrite fragments that were believed to have originated from a chalcopyrite ore body. The prospecting in 1971 and geochemical examinations, however, localized ten unknown copper and two zinc ore occurrences and a zone of high molybdenum content.

All the twelve ore occurrences in Kilise Tepe (Church Peak) are located in an area of varied surface configuration and the altitudes from 900 m to the highest Kilise Tepe peak of 1970 m. There are three more conspicuous peaks in the area: Kurtumele Önü 1962 m, Kopuk 1794 m and Yeşil Tepe 1635 m.

The area can be reached by a cross-country vehicle from the town of Murgul upstream the Murgul river (dere) to the Kopitvan dere mouth, further about 1000 m upstream the Kopitvan and there from on foot along the previously cleared paths.

As can be seen in Figs. 3 and 41, the ground is densely overgrown with rhododendrons from which only the hundred years old conifers sporadically stand out. The ridges of Kurtumele Önü-Kilise Tepe, Kilise Tepe-Kopuk and Kilise Tepe-Yeşil Tepe are overgrown with very dense bilberry thickets as much as 2 m high. The ridges are very narrow in places

as a result of very heavy water erosion (abundant rains, slightly cemented volcanic rocks and marked hydrothermal and supergene alterations). Movement along the ridges may be very risky. The mountain streams are water abundant for most of the year. Rain and fogs are almost daily occurrences in the summer (June, July, August, and well into September). The ground is very steep, the measured slope varying from 30° to 50°. In these conditions any exploration in the area is a real achievement. So far only geologists of Geoinstitut of Belgrade explored it. V. S t e v a n o v i ć and R. P o p o v i ć explored the area in 1971 by setting up a network of geochemical sampling points in the maximum possible density – 850 irregularly distributed points.

Basic geological characteristics of the Kilise Tepe Ore Field

The area of Kilise Tepe is a part of the extensive rhyolite volcanogenic and volcanogenic-sedimentary petrogenic complex. The oldest rocks in the ore field are sandstones and tuffaceous sandstones in the SW part of the field. The rocks belong to the complex that is the most widespread in the Murgul dere valley (Iskalka Köprü), classified into Malm (Oxfordian-Kimmeridgian). Over them lie the rhyolite volcanogenic and

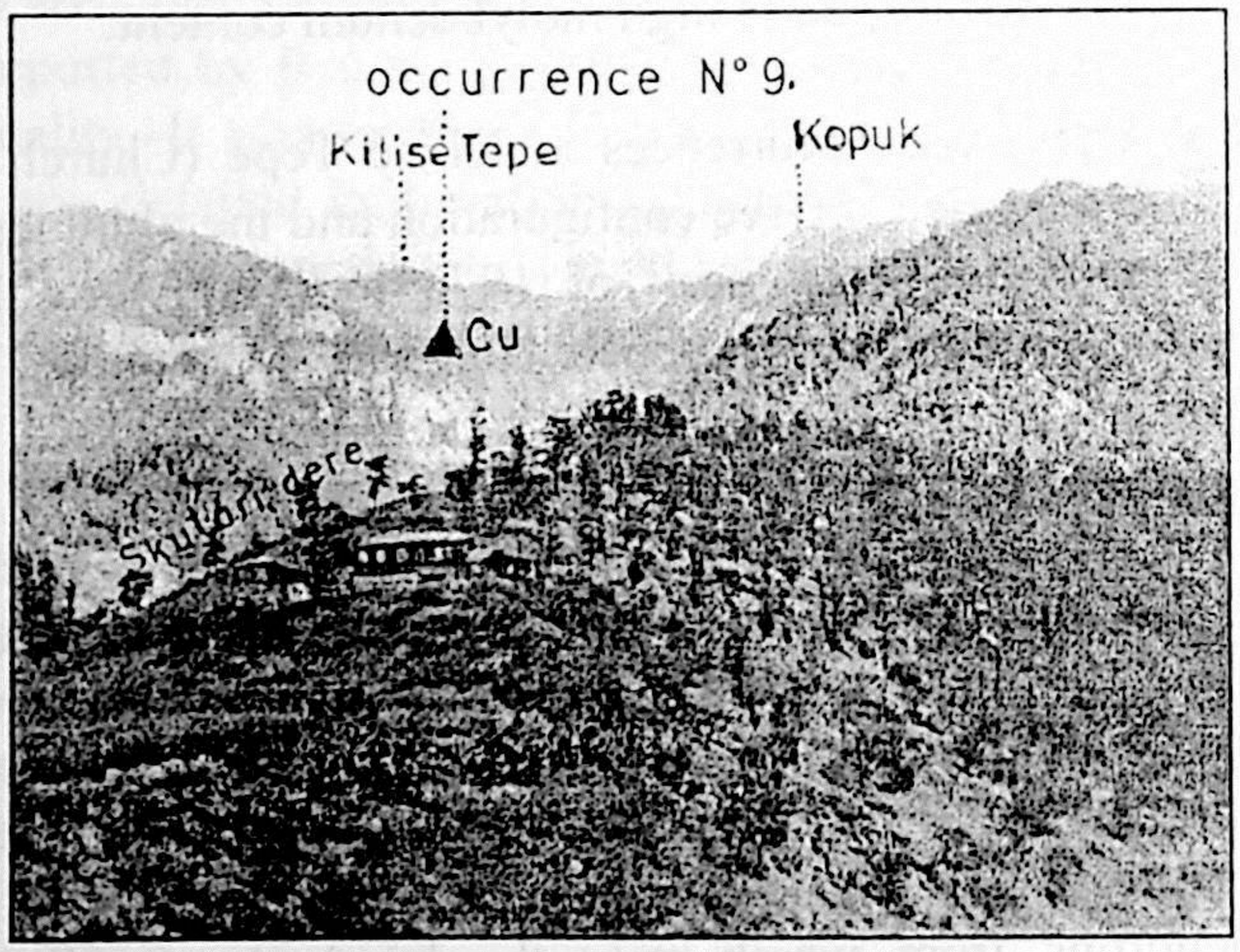


Fig. 41. View of Kilise Tepe southwestern slopes and the Skutari dere source area Including Cu-mineralization occurrence.
Basic geological characteristics of the Kilise Tepe

volcanogenic and volcanogenic-sedimentary formations so mixed that it is difficult to separate them individually. Rocks of the complex are intruded by quartzdiorite in many places. Volcanism that produced rhyolite volcanites was both submarine and subareal. All these formations – rhyolite, rhyodacite, dacite flows, tuff, agglomerate, breccia, and redeposited volcanic rocks, which commonly alternate with tuffaceous sandstone, conglomerate, quartz sandstone, chert (bearing radiolarians) are very interesting. The extensive zones of mylonitization, tectonic breccia and debris are separate geological bodies. Volcanic rocks mainly formed in the upper Malm (Tithonian) and the Neocomian, but the debris are of recent origin and appear in all sizes of fragments and blocks, from a human fist size to blocks of ten or more cubic meters. Excluding debris, other rocks may look like forming a single volcanogenic complex composed of the parts characteristic of strong explosive volcanism represented by flows, tuffs, breccias, succeeded by calm stages when rocks were redeposited and when layers of sandstones, conglomerates were formed, mainly deriving from volcanogenic materials formed in preliminary volcanic activities. During the calm intervals between volcanic activities, chert is formed bearing radiolarians and other fossil remains (Figs. 42a, 42b).

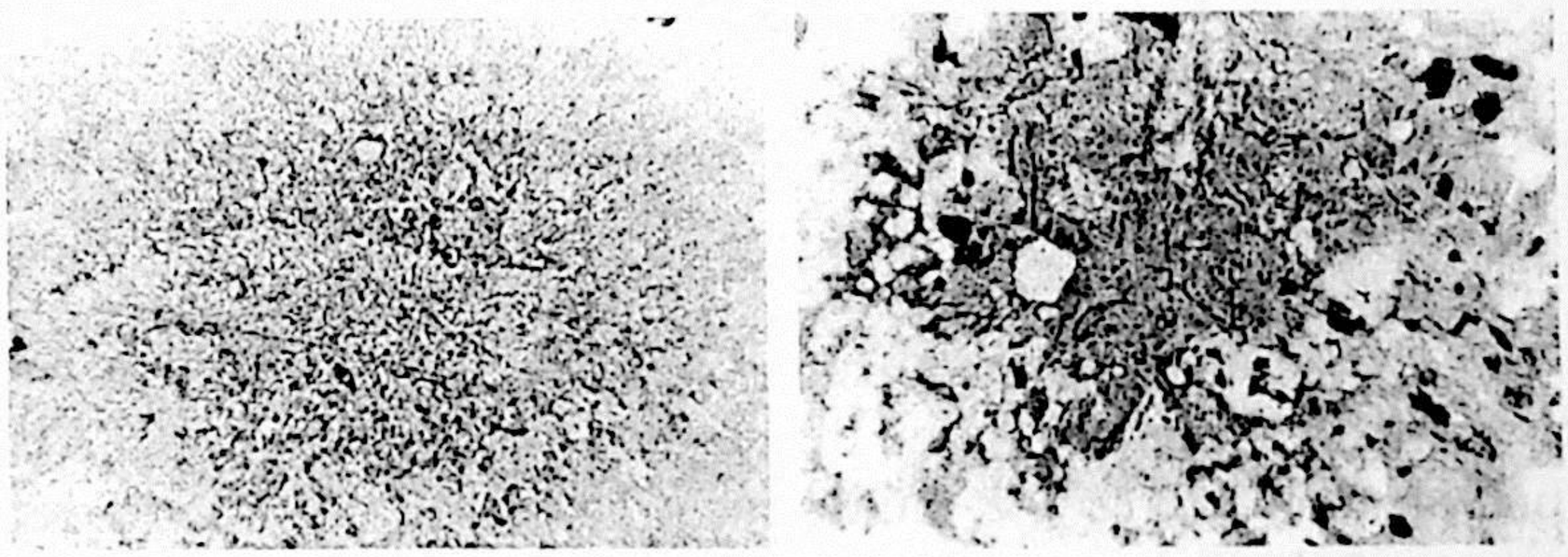


Fig. 42. Rhyolite volcanogenic material with fossil remains (after, P o p o v i ć, 2000).

The volcanogenic and volcanogenic-sedimentary formations were subsequently faulted and intruded by small or large sills, dikes or other small irregular quartzdiorite bodies. The intrusions commonly occurred along faults.

The entire region was affected by tectonic deformations that resulted in numerous fractures of various intensity and minor folds. Many ruptures were synchronous with the volcanism, and others developed in the intervals of the volcanic inactivity or after its end. An evidence of the probably Paleogene or Neogene tectonic events are the folds in the redeposited (or sedimentary) formations. Contact metamorphism is less developed in Kilise Tepe area, but there are relatively many smaller quartzdiorite bodies. Rock

alteration into hornfels is noted only locally. A part of pyritization, silicification and individual Cu and Zn mineralization also can be associated with contact metamorphism that diminishes with the distance from the contact. The size of intrusive bodies and the grade of contact metamorphism indicate the magma already have been cooled and that hydrothermal solutions could subsequently influence the formation of the youngest sulfide mineralization. This is all the more so that volcanites were affected by multi-staged hydrothermal alterations, manifested in silicification and pyritization as the advanced alterations, and later by argillization, carbonatization (calcitization), sericitization, epidotization, etc. Many Cu and Zn ore occurrences are associated with the mentioned alterations.

Within the volcanogenic-sedimentary part of this complex, though difficult to note, are true chert and quartz sandstone, which together with other lithologic constituents characterize petrogenic of the area. Considering that the biggest part of the petrogenic complex is under disintegration, it is very significant to note that pyramid-like erosion remnants have been formed that rise 5 m or more above the rhododendron thicket and represent a morphologic characteristic of the area (Fig. 3).

Ore Occurrences

The geological map of Kilise Tepe (Fig. 43) clearly shows that copper and zinc mineralizations occur mainly along the faults, located all relatively high in the relief. Some of the occurrences are impregnations in rocks, but in such events the fault structure is bounding the mineralized environment. A horizon, or a formation of conglomerates, composed of rounded rhyolite (this is not agglomerate), is visible on the map (Fig.43), under which any copper or zinc sulfide occurrence has not been found. This indicates the relative age and stratigraphic position of Cu, Zn mineralizations in the general area of Kilise Tepe.

All copper and zinc occurrences can be divided into the ore occurrences of copper mineral and the ore occurrences of zinc with copper.

The ore occurrences are numbered, because there are few toponyms (Kurtumele Önü, Kopuk, Kilise Tepe, Yeşil Tepe, the Kopitvan dere and the Skutari dere) in the area for their reference.

From Southeast to northwest, i.e. from Kurtumele Önü peak via Kilise Tepe-Kopuk ridge to Yeşil Tepe, there are twelve Cu and Zn ore

occurrences and three geochemical anomalies of molybdenum. All occurrences are divided into (A) **copper mineralizations and (B) zinc and copper mineralizations,** which are associated with quartz diorite and will be considered in the section about the intrusive rock complex.

Note that dacite samples did not contain increased copper, zinc or any other metal concentration.

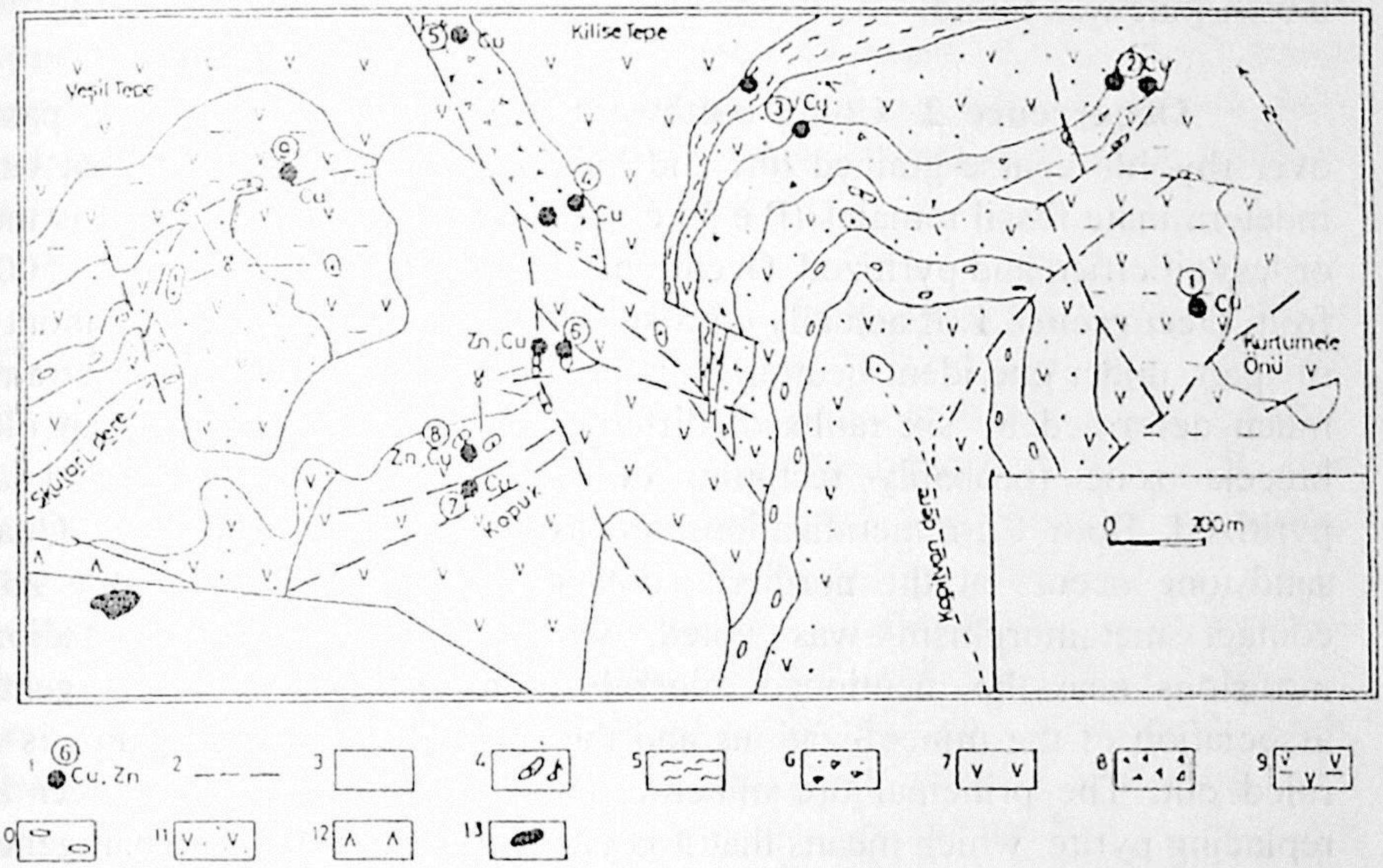


Fig. 43. Geological map of Kilise Tepe (after Popović, 2000).

1.Sulfide mineralizatios; 2. Conspicuous fault; 3. Debris: 4. Granitoid rock; 5. Mylonite zone; 6. Tectonic breccia; 7. Rhyolite; 8. Rhyolite·volcanic breccia; 9. Rhyolite tuff, breccia and tuffaceous sandstone with chert; 10. Tuffaceous sandstone and conglomerate; 11. Rhyolite and rhyodacite tuff, breccia and tuffaceous sandstone; 12. Epidotized sandstone and tuffaceous sandstone; 13. Slag dump.

A. Copper Mineralization

Occurrence 1 is located on Kurtumele Önü NW slopes (Fig.43), about 200 m from trigonometric point 1962 m. The mineralization occurs along a fault observed in a length of about 200 m. The mineralization consists mainly of pyrite. Minor constituents are chalcopyrite and traces of limonite formed by pyrite oxidation. The mineral occurs in the form of a vein, 5 cm thick or less, and localized along the fault in a length of about

100 m. Chalcopyrite concentration in the mineralization is not uniform, as indicated by the copper variation from 0.07% to 2%. Unlike chalcopyrite, pyritization has affected adjacent rocks about 20 m wide on either side of the fault that has approximately the north-south strike. The rock cut across by the mineralized fault is rhyolite tuff.

About 250 m east of **Occurrence 1** an outcrop of hydrothermally altered rhyolite with Cu-mineralization that contained 0.3% copper and 0.05% zinc was found.

Occurrence 2. Going northward from **Occurrence 1** one passes over rhyolite coarse-grained tuff and local occurrences of chert that bears indeterminate fossil remains (P e š i ć, in P o p o v i ć, 1972). Tuff is more or less silicified and pyritized. Occurrence 2 is located about 400 m to 500 m from **Occurrence 1**. It actually consists of two similar occurrences about 80 m apart, under one identification number (Fig.43). This part of the terrain is much deformed by six faults of different strikes that cut across an older breccia zone (probably tectonic) of highly silicified, kaolinized and pyritized. Both Cu-mineralizations are associated with this zone. Quartz sandstone occurs at the northern contact of the zone. Within the zone, contact metamorphism was noted, which derives from quartzdiorite intrusions near the mentioned mineralizations. The likely direct genetic association of the mineralizations and the small quartzdiorite bodies is not ruled out. The principal ore mineral is chalcopyrite prevailing over and replacing pyrite, which means that it is younger than pyrite. The paragenesis also includes hematite (specularite) and sparse sphalerite grains. Secondary minerals contained are chalcocite and sparse malachite. Pyrite grains are commonly broken, which indicates the time of their formation relative to chalcopyrite and to tectonic events that formed the breccia.

Cu-mineralization were noted in an area of about 10 m^2. Copper and zinc concentrations in two samples, each 0.20 m long, varied from 0.28% to 1% and from 0.017% to 0.12%, respectively. In respect of the mode of occurrence (vein-impregnation), environment (tectonic breccia) and geochemical limitation (primary dispersion halo), this occurrence would not be particularly interesting but for its location in the same breccia zone as **Occurrence 3** the zone should be systematically studied particularly in view of its large dimensions and the presence of quartz diorite bodies with which the mineral occurrences are genetically associated.

Occurrence 3. Like the former two, this occurrence consists of three mineralization emplacements, one of which is represented only by

chalcopyrite fragments defined as oreclasts. All three emplacements are located in the source area of the Kopitvan dere. Basically, it is one ore zone of advanced silicification and pyritization, affected by intensive oxidation, and located in the tectonic zone at the southern and southeastern slopes of Kilise Tepe (Fig.43). Tectonic zone is marked by dominantly argillic mylonite and silicified breccia. The entire tectonic zone can be provisionally divided into two sub-zones separated by rhyolitic volcanogenic-sedimentary formation, which merge into one in SE. Hence the inference that it was one and the same zone with large development of all three dimensions. Three copper ore occurrences are found in it, one in the upper and two in the lower parts. Should the geochemical anomalies of the primary dispersion halo (copper in excess of 500 g/t) were taken into consideration, there could be five or six or even more Cu-mineralizations.

Another outcrop of Cu-mineral was found in mylonite about 300 m SE of Kilise Tepe. The outcrop was partly trenched for sampling. A sample of 1 m in length contained 0.43% of copper. Another sample of half a meter, collected some 15 m south of the trench, contained copper by 0.23%. Zinc content in either sample was less than 100 ppm. The principal, or almost only ore minerals were pyrite and less chalcopyrite. The lower part of the tectonic zone, strongly affected by silicification, pyritization and oxidation, also was trenched, but only single fragments of chalcopyrite mineralization were found, which contained 17.90% of copper and zinc less than 100 ppm. The source of the fragments (oreclasts) was not located. The tectonic zone could have crushed a large ore body, and the displacements along the fault zone moved the fragments, or oreclasts, to the recent base level of erosion. Or there was or still is a stratiform ore body (like in **occurrence 9**) in the volcanogenic-sedimentary formation, under the tectonic zone, cut through by tectonic movements, wherefrom came the specified fragments. These are not the only possible explanations of the rudoclasts derivation. A weak mineralization was registered about 300 m to the west, with 0.08% of copper, then zinc and lead about 100 ppm or less. The whole area (east of Kilise Tepe-Kopuk ridge) is poor in zinc, copper being the only metal (excluding iron) that occurs in increased amounts. In the Kopitvan Dere source area, the highest minerals are chalcopyrite and pyrite. Chalcopyrite is prevailing in oreclasts and pyrite in all other mineralizations. It is interesting to note that in places where pyrite was the principal mineral, chalcopyrite occurred along the cracks, where also some hematite was observed. The secondary minerals present everywhere are covellite and limonite. Pyrite crystals, commonly octahedrons and pentagonal dodecahedrons vary in size from microscopic to 0.5 cm.

Occurrences 4 and 5 (Fig.43) are commented together, because they are associated with the same grey-violet, silicified rhyolite breccia on the western slopes of Kilise Tepe. The mineralized breccia is extending north - south over a length of more than 600 m and about 140 m in width (thickness not measured). It is bounded in the west by a fault zone and gradually passes into a formation of rhyolite and the older rhyolite breccia in the east.

In this hardly accessible land, three Cu-mineralization outcrops were found (two outcrops in the south are identified as **occurrence 4**, and the outcrop in the north is (**occurrence 5**). The breccia is defined as a geological unit or sub-formation, because it is highly silicified, pyritized, contains Cu-mineralization, and differs in color from the rest of rhyolite and rhyolite breccia formation.

Unable to make a consistent sampling, only chips of 0.20 m were collected from the mass of violet, silicified and mineralized rhyolite breccia. Mineralization in the eastern occurrence contained 0.2% copper, and the western, 150 m from the former, 0.1% Cu.

Copper mineralizations are is located at a fault zone near the contact of rhyolite breccia and rhyolite pyroclastics (Fig.43). The identified ore minerals are principal pyrite and much lesser chalcopyrite. The most abundant non-ore mineral is quartz, younger than pyrite and chalcopyrite.

Occurrence 5 is located in the northwestern slopes of Kilise Tepe, some 500 m north of **occurrence 4**, in the same silicified rhyolite volcanic breccia. It extends further northward, but we could not prospect along its extension for the lack of adequate topographic maps and the difficult terrain.

A mineralized outcrop is exposed in an area of about 5mx3m. Trenched by using explosive a recess 0.5 m deep was made for a horizontal sampling of 1.5 m (homogeneous mineralization). The copper and zinc amounts in the sample were 0.21% and 0.1%, respectively, and lead was found only in traces (70 ppm).

The ore paragenesis includes dominantly pyrite, and chalcopyrite, sphalerite, and very low galena. Pyrite occurs in this and in other occurrences in cubes and pentagonal dodecahedrons.

According to lithological environment, the mode of occurrence of Cu-mineralization (stockwork – impregnation), ore paragenesis, types of

pyrite crystals, it could be concluded that Cu-mineralization in this volcanic breccia and in the hangingwall of the Anayatak deposit, are very similar. It also seems that the mineralized and silicified (rhyolite) breccia belongs to the same zone as the Anayatak and Çakmakkaya deposits. The wide-spreading of volcanic breccia (more than 600 m in length and150 m in width), in spite of relatively low amounts of copper (from 0.1% to 0.21%), is an important potential, particularly because of the massive copper-ore body, identified as **occurrence 9**, that lies under the breccia.

Occurrence 7[2] is located on the northern Kopuk slopes (height 1795 m, Figs. 43 and 44). It is connected with the fault zone on one side and as an impregnation with the area between this and the next parallel fault on the other. The two faults are spaced about 60 m apart.

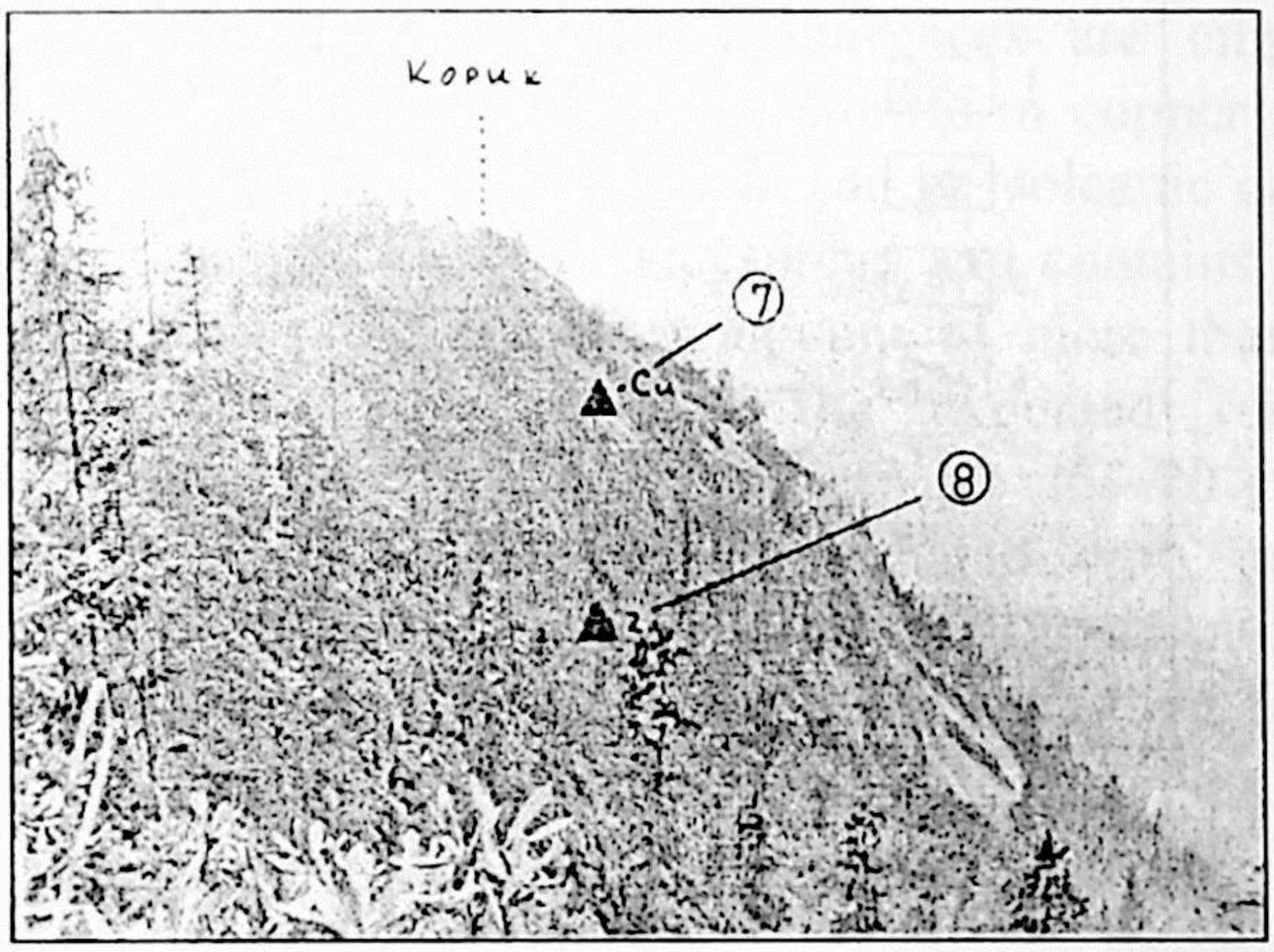


*Fig. 44. View of Kopuk with Cu and Zn mineralization (**Occurrences 7 and 8**)*

A half a meter thick ore vein is emplaced within the fault zone which is 1 m thick. Its principal minerals are pyrite and chalcopyrite, and there are traces of sphalerite and galena (only sporadically). The ore vein was followed for only 10 m after which the steep slope made it impossible to proceed. Metal contents in a 0.5 m long sample were copper of 0.3%, zinc 240 ppm and lead 100 ppm.

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[2] Occurrences 6 and 8 will be considered in the section about mineralizations associated with the intrusive petrogenic complex.

Occurrence 9 is located in the Skutari dere source area (Fig. 41, 43 and 46), about 700 m to 800 m west of Kilise Tepe (1970 m) respectively. It is emplaced in a volcanogenic-sedimentary formation composed of coarse-grained rhyolite and rhyodacite tuff, breccia and tuffaceous sandstone with radiolarian chert. This formation is one of the most widespread formations which are locally pyrite-impregnated (particularly near fault zones). A copper ore occurrence is found between two sub-parallel faults. The ore body seems to be stratiform, the observed thickness of about 2 m and length of 5 m (Fig. 45). Mineralization is emplaced in coarse-grained rhyolitic rocks, which is silicified, sericitized, chloritized and slightly argillized. The impregnated copper mineralization appears as impregnations and with gradual descending into the adjacent rock.

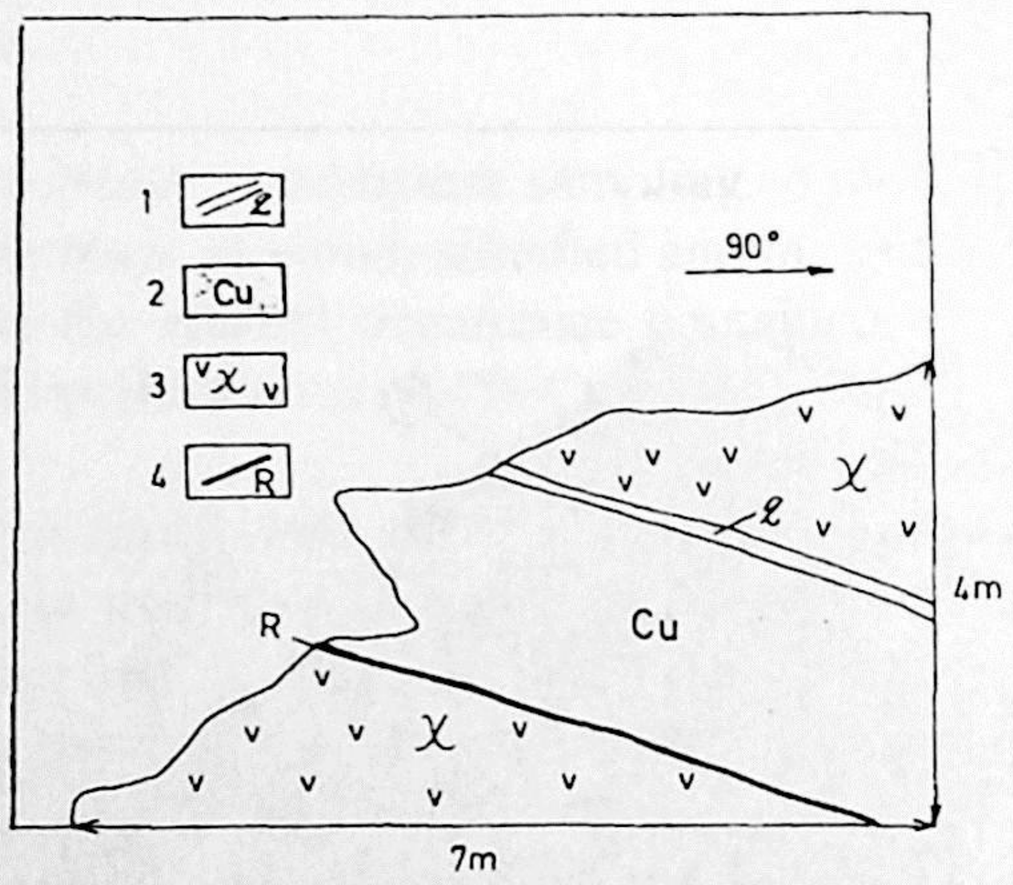


Fig. 45 Cross-section through Cu-mineralization occurrence 9.

1.Quartz vein; 2. Cu-mineralization; 3. Rhyolitic volcanic rock; 4.Fault.

Two samples (each 2 m long) contained copper of 1.8% and 2%, and very low zinc (less than 150 ppm) and lead (10 ppm). The identified ore minerals are: abundant pyrite, followed by chalcopyrite and secondary tenorite, covellite and limonite.

The Potential Estimation of Kilise Tepe Ore Field

The country between Kurtumele Önü in SE and Yeşil Tepe in NW is made up largely of volcanogenic and volcanogenic-sedimentary complex and less of quartzdiorite in the form of small intrusive bodies at the surface. According to mode of occurrences and lithologic setting there are four types of mineralization. First, there is the vein type of copper mineralization that contain small amounts of zinc and lead. The veins are extending everywhere along the fault zones and contain a relatively high rate of copper (up to 2%). Second is the high-grade Cu-mineralization represented by oreclasts found in the Kopitvan dere and in copper mineralization-**occurrence 9**, which is supposed to be stratiform. The two occurrences are emplaced in the volcanogenic-sedimentary complex where stratiform copper mineralization is reasonably expected. The third type that can be volcanic occurs in violet silicified rhyolite breccia, which is widespread and contains relatively low copper in two outcrops, but a higher amount of more than 0.5% Cu is expected deeper below the surface. The expected reserve of the provisionally low-copper ore is at least 10 to 20 million tons. Mineralizations of the fourth type is associated with intrusive rocks (discussed in the section about the intrusive petrogenic complex). Mineralizations of this type may be **porphyric** according to the form of occurrence and the environment emplacing them.

Beside the earlier mentioned also should be noted a presence of geochemical molybdenum anomalies zone along the western part of the Kilise Tepe-Kopuk ridge. The presence of the zone is deduced from the primary dispersion halo. The amounts of molybdenum varied up to 1000 ppm. The zone is coinciding with the zinc and copper occurrences, thus can be associated with the quartz diorite bodies.

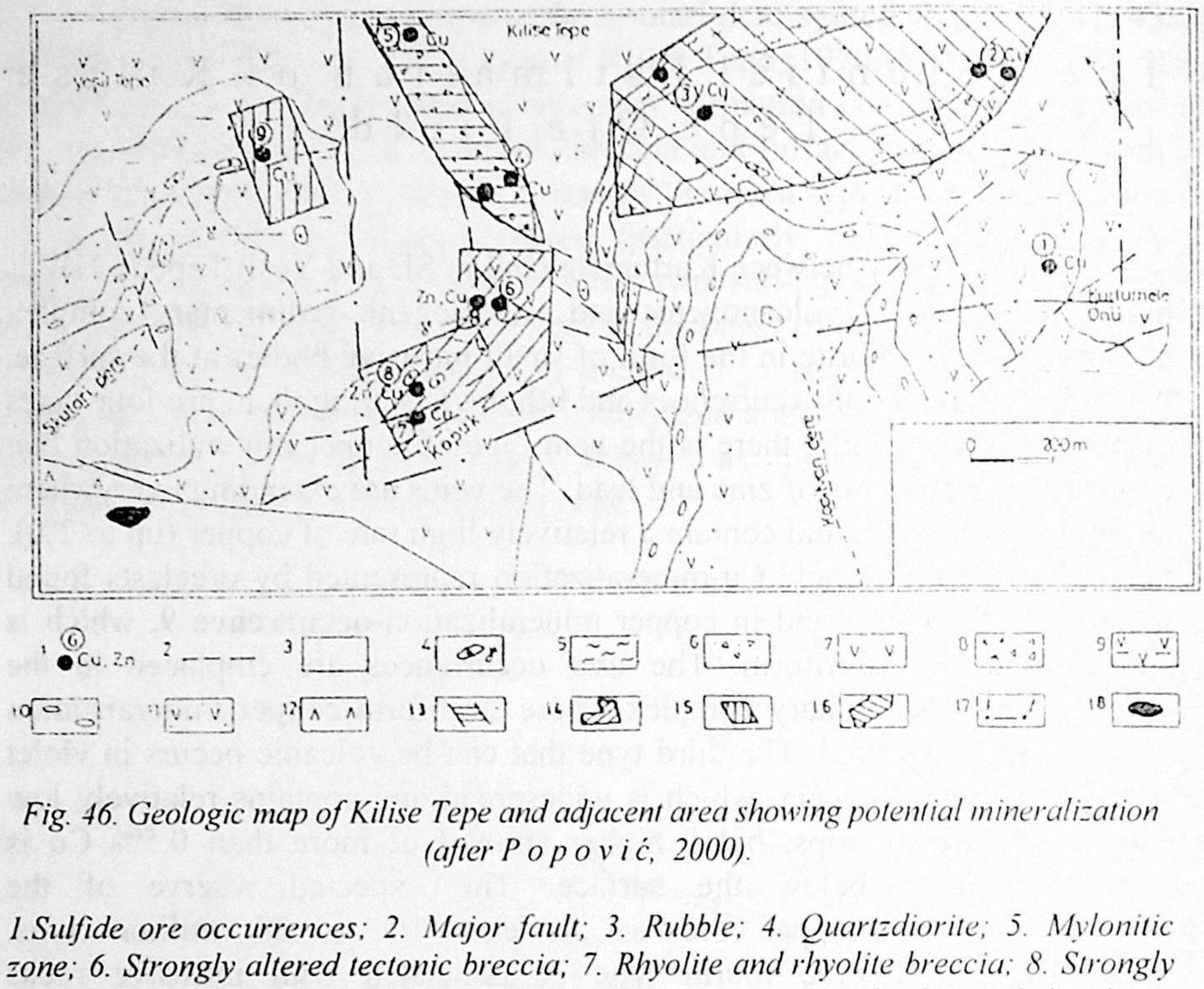


Fig. 46. Geologic map of Kilise Tepe and adjacent area showing potential mineralization (after P o p o v i ć, 2000).

1.Sulfide ore occurrences; 2. Major fault; 3. Rubble; 4. Quartzdiorite; 5. Mylonitic zone; 6. Strongly altered tectonic breccia; 7. Rhyolite and rhyolite breccia; 8. Strongly silicified (violet) and mineralized rhyolite volcanic breccia; 9. Rhyolite and rhyodacite tuff, breccia and tuffaceous sandstone with chert and indeterminate fossil remains; 10. Tuffaceous sandstone and conglomerate; 11. Rhyodacitic tuff, breccia and tuffaceous sandstone; 12. Epidotized sandstone and tuffaceous sandstone; 13. Volcanogenic type of Cu-mineralization; 14. Vein type of sulfide mineralization (Zn-Cu-Mo); 15. Stratiform type of Cu-mineralization; 16. Chalcopyrite oreclasts; 17. Area of expected porphyryc type of Cu-Zn mineralization; 18. Slag dump.

Finally, a strong indication of the high potential Cu and Zn mineralization is the presence of a slag dump about 600 m to 800 m west of Kopuk. The dump occupies an area of about 200 m^2 and its visible thickness is more than 1 m. Slag fragments show malachite and covellite coatings. Chemically analyzed a slag fragments contained copper 4%, zinc 0.6% and lead 0.04%. This information and the secondary copper minerals clearly indicate that the slag derived from copper ore that was extracted by some primitive method, because it still contained a high amount of copper. Who and whereabouts of the exact loci of the excavation of the ore is not known. But fragments of rhyolite found in the slag suggest that the slag derivation originate from the same lithological environment. It is also certain that the

ore was not transported from a lower topographical level, or from the area east of Kilise Tepe-Kopuk ridge. It is reasonably assumed that the slag remain ore originates from the areas west and northwest of the ridge Kilise Tepe - Kopuk.

It follows from all the above stated that the Kopitvan dere source area and the land west of Kilise Tepe-Kopuk ridge are representing a very significant potential of copper and zinc ores which ought to be further consistently explored, particularly because they are an extension of the Anayatak-Çakmakkaya orebearing zone. Between the two deposits on one side and the occurrences on Kilise Tepe there are many Cu-mineralization occurrences in the Lebiskur dere valley noted by B u s e r (1970). The valley actually intersected the Anayatak-Çakmakkaya-Kilise Tepe orebearing zone. Moreover, many characteristics or similarities suggest a zonal continuity such as: in lithology, stratigraphy, age, structural fabric, ore occurrences and deposits and other features.

It is believed that Kilise Tepe, Çarkbaşı, Çakmakkaya, Anayatak and Aduca Dere (as well as others near Damarköy) and further eastward, including ore occurrences and deposits of Kuvarshane zone, and westward to Madenköy at Çayelı, lie in one and the same orebearing zone. Also the possibility should not be ruled out that Tunca deposit near Ardeşen belong to this zone, where an economic reserve of about a million tons was found with almost 1.5% of copper, and whose mode of occurrence and genetic type resemble the mentioned ones. This zone would be longer than 100 km and about 10 km wide on average. It includes the largest deposits of copper, and zinc, sulfides of the extreme eastern Pontides, characterized by relatively large ore reserves and high copper contents. All things considering, the Murgul orebearing area is a large copper potential.

HOPA AREA



Fig. 47. View of Hopa (photo, 1970).

The copper ore occurrences of Peronit, Sivrikaya, Kavak and some others in Hopa area can be assigned to the Upper Jurassic-Lower Cretaceous volcanogenic and volcanogenic-sedimentary rhyolite complex. These occurrences are of the same type, age, mode of occurrence and proximity so that they all can be considered as the Peronit-Sivrikaya ore field (Fig.48).

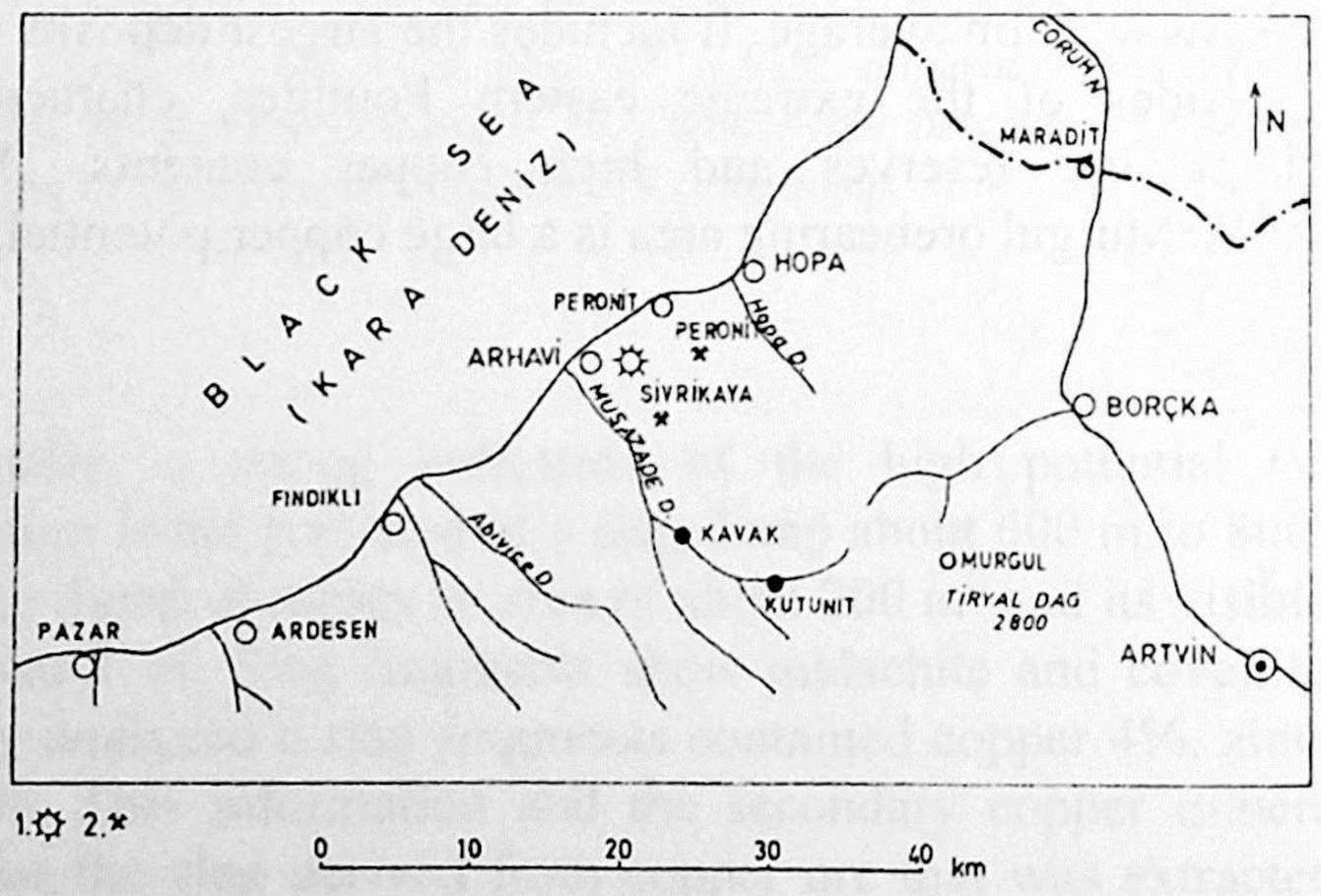


Fig. 48. Sketch map of copper ore deposits in Hopa area

1.Paleovolcanic neck (?), 2. Copper ore deposit.

Peronit–Sivrikaya Ore Field

The sulfide mineralizations of copper near Hopa have been known for a long time (almost hundred years). There are several occurrences of which the most interesting are Peronit, Sivrikaya and a few at Kavak. The occurrences were explored by mine workings in the former half of the 20th century. Struve (1902), Zimmer (1937), Kovenko (1941) left records about the discovery of ore occurrences and deposits, later Kraëff (1963), Pejatović (1973, 1975/1979) and Koprivica (1977 and later) published the completed data.

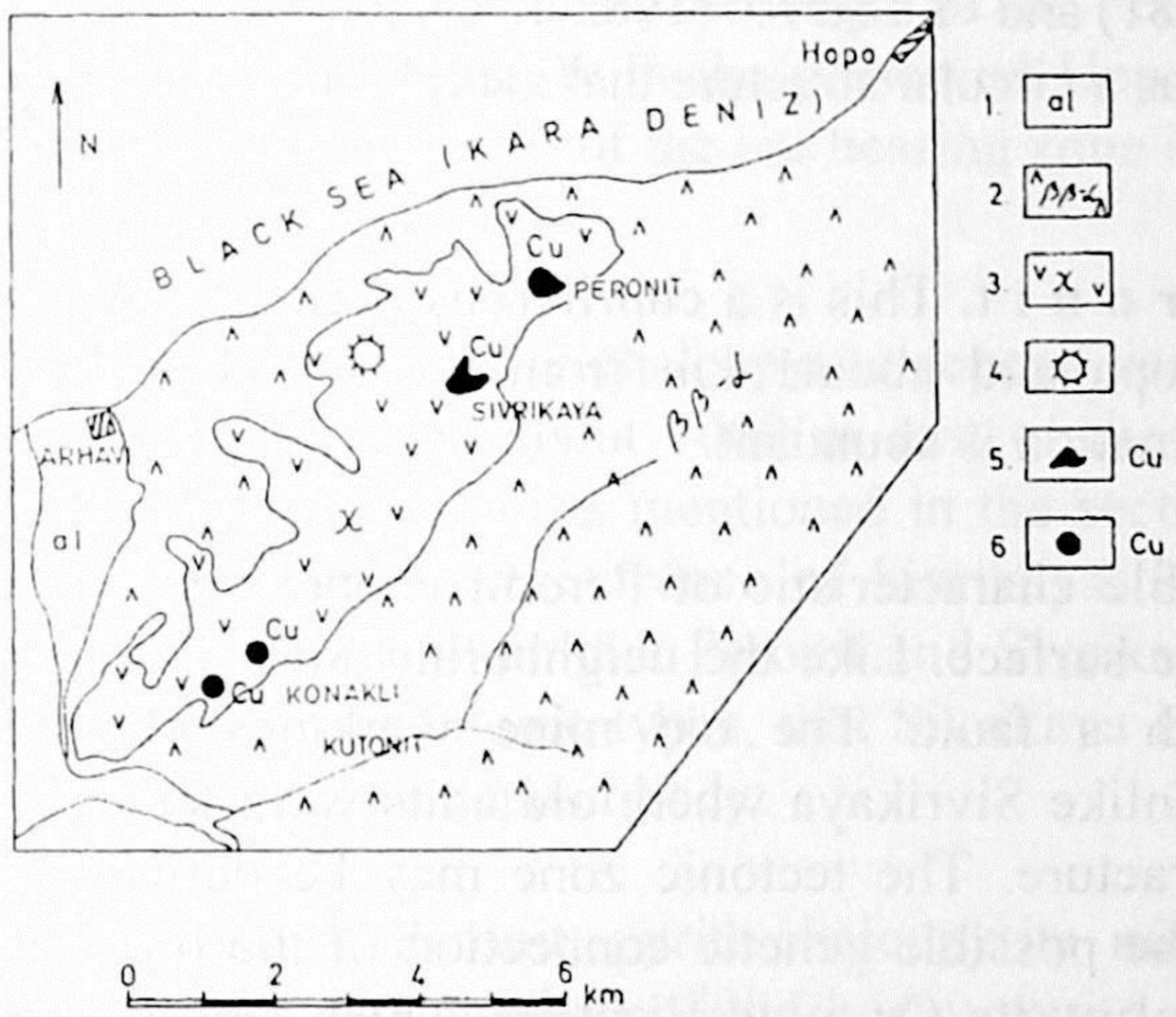


Fig. 49. Geological sketch map of Peronit-Sivrikaya ore field.

1.Alluvium; 2. Upper Cretaceous-Paleogene volcanogenic, volcanogenic-sedimentary and sedimentary petrogenic complex (Senonian-Paleogene, ββ-α); 3. Upper Jurassic-Lower Cretaceous (Malm-Neocomian, χ) volcanogenic and volcanogenic-sedimentary complex dominantly of rhyolitic composition; 4. Volcanic neck (?); 5. Copper ore deposit; 6. Cu-occurrences.

Mineralizations in Hopa area are associated with rhyolite and less with rhyodacite volcanic rocks in the Jurassic-Neocomian petrogenic complex. Contrary to other published sources, Koprivica assigns these volcanic rocks to the uppermost Maastrichtian and Lower Paleocene. Because Cu-mineralizations are associated with acidic volcanites, the

interpretation has been generally accepted on the basis of their identity with all other copper deposits in Murgul and adjoining regions that they belong to the Jurassic-Neocomian volcanogenic complex. Moreover, having studied the zonal distribution of ore deposits in the eastern Pontids, P o p o v i ć (1976) assigned Cu-mineralization of Hopa and Arhavi to the Cu-Zn zone. There has not been any additional information that would require a revision of this classification. As to the geology in general, the age of all formations considered in this text is discussed at length elsewhere so that any further discussion at this point would be unnecessary.

All considering, the occurrences (or deposits) of Sivrikaya and Peronit can be associated with the volcanic activities that formed the rhyolite neck of Sivri Tepe (K o p r i v i c a et al, 1971; K o p r i v i c a, 1977). H e n d e n (1980-1981) and Y ı l d ı z (1982-1983) identified on satellite images of the same area, as a circular structure that includes the Sivri Tepe paleovolcanic centre.

1. P e r o n i t. This is a cupriferous pyrite deposit, located about 7 km SW of Hopa and about1 km from the sea (Fig.49), for which the available information is abundant.

A notable characteristic of Peronit copper deposit is the advanced oxidation at the surface. Like the neighboring Sivrikaya deposit, Peronit is associated with a fault. The old mine workings were located in the hangingwall, unlike Sivrikaya where old adits were located in the footwall of the same fracture. The tectonic zone may be defined as an ore zone, regardless of the possible genetic connection of the ore and fracture zone. This is a typical pyrite Cu-mineralization, which consists largely of pyrite, some chalcopyrite, and minor sphalerite. Galena and tetrahedrite are sparse constituents. K r a ë f f (1963) and K o p r i v i c a (1977) described the mineralization as the vein type in mode of occurrence. The vein thickness is varying from 0.50 m almost to 2 m. Other authors believed that the mode of appearance is here stockwork. Copper mineralization is found in hydrothermally much altered (argillized, kaolinized, silicified and pyritized) rhyolite volcanic rocks. Limonitization is the most widespread supergene alteration that provided the development of the iron hat about 150x250 m in size at the surface. Other secondary copper minerals identified are covellite, bornite, some malachite and azurite.

Sphalerite of the Peronit mineral deposit contains inclusions of some galena and tetrahedrite (tennantite) and chalcopyrite exsolution from sphalerite. Among the ore minerals also sparse enargite was noted, which is

generally rarely found in the copper ore deposits of Artvin-Murgul-Hopa-Maradit region, in Eastern Pontids.

Samples from the old adit waste rocks contained copper up to 5.025%, zinc locally as high as 35.35%, but these contents are not applicable to the deposit as a whole; it is more likely that the sample was selected for the high amount of sphalerite. The lead content does not exceed 0.5%. It is supposed that the average content of copper in the whole deposit is about 0.5%.

The old mine workings provided information in the Peronit ore zone thickness (80 m) and the ore body extent of a few hundred meters. Considered together with Sivrikaya, which anyway forms a unified ore field with Peronit though about 2000 m apart, the length of the Peronit-Sivrikaya ore zone is a greater then 2.5 km. With the preserved Upper Cretaceous-Paleogene hangingwall, the potential of the ore bearing zone is much higher than the present estimation.

2. S i v r i k a y a. This pyrite-chalcopyrite deposit lies about 1.5 km to 2 km SW of Peronit, located about 1000 m east of the paleovolcanic centre (Sivri Tepe). All the geologists mentioned in the section on Peronit explored the copper-bearing ore occurrence of Sivrikaya. K o v e n k o (1941) and other explorers maintain that Peronit and Sivrikaya are belomg to the same genetic and morphologic types, that Sivrikaya is only the SW extension of Peronit copper ore deposit body.

In Sivrikaya, like in Peronit, pyrite-chalcopyrite mineralization is covered by gossan, which is a product of the heavy pyrite oxidation. The oxidation zone is extending over about 200 m in length and about 50 m in wide. The fracture zone in which sulfide mineralization was developed is more than 100 m thick in Sivrikaya. It contains crushed rhyolite volcanic rocks affected by hydrothermal alterations: argillization, kaolinization, silicification, and pyritization. The supergene alteration – limonitization – is a result of extesive pyrite oxidation and it forms an iron hat (gossan).

The ore occurrence at Sivrikaya was explored by excavating adits from the beginning to the middle of the 20th century. It is estimated to be economically insignificant for its content of sulfides, foremostly copper, and partly zinc, and in my opinion also for the unexplained mode of occurrence and origin.

What could be observed in the old adits' waste rocks is the stockwork – impregnation with thin veins or stringers of quartz pyrite and minor chalcopyrite. The veins and veinlets are 5 mm thick, which was the reason why many geologists interpreted the mode of occurrence in the form of veins, thus reducing its potential. Many samples from the waste rocks of the old adits are rich in copper, up to 5%. In the zones of mineralized breccia, copper is much lower, from 0.14% to 0.18%. K o p r i v i c a (1977) reports that in richer samples from the waste rocks, of old adits, the copper content was up to 3.71% and zinc varied from 0.52% to almost 8%. One thing is certain; the value of copper mineralization in this location has not been finally estimated.

The paragenesis is identical as that of Peronit. Pyrite is the most abundant mineral, chalcopyrite is lower and sphalerite is only locally high concentrated. Galena is sparse. It is believed that Peronit and Sivrikaya have direct genetic connection with the paleovolcanic centre of Sivri Tepe. In other words, both ore deposits are of the same volcanogenic, partly probably volcanogenic-sedimentary origin. If so exactly, then the economic potential of these deposits is much greater than estimated earlier.

MOLYBDENUM

MURGUL AREA

Kilise Tepe. When referring to the metallogenic character of the western part of Artvin Province, at least the basic information about molybdenum occurrences should be given. Until 1971 there was no information about the molybdenum mineralization in the given region available. Only the geochemical survey in rhyolite volcanites on Kilise Tepe, near Murgul, indicated appreciable accumulations of molybdenum in the mentioned volcanic rocks. If it considers the number of geochemical sampls, 145 samples molybdenum content from 10 ppm to 49 ppm, 10 samples from 50 ppm to 99 ppm, 5 samples from 100 ppm to 200 ppm, and one sample Mo-content of 1000 ppm. A reasonable assumption is that there are molybdenum concentrations, which are probably associated with some of copper, zinc or any other sulfide mineral. The geochemical copper and zinc anomalies indicate this possibility, because molybdenum content from 100 ppm to 1000 ppm is everywhere associated just with the anomalies of the two metals. Even the lower concentrations are always related to the anomalies of the two metals. The high molybdenum content is associated with pyrite-chalcopyrite mineralization. But the maximum content of 1000 ppm is associated with the geochemical anomalies of copper content of 100 ppm, zinc 180 ppm and lead 500 ppm, which is somewhat peculiar. Italso should be mentioned that the geochemical anomalies of molybdenum, b esides occurring near quartzdiorite intrusions, are associated with fault zones.

The geochemical sketch map (Fig.50) shows that the narrow molybdenum anomalies of mainly northeast-southwest trend are notable in the middle of the Kilise Tepe-Kopuk ridge and lesser and sparse elsewhere.

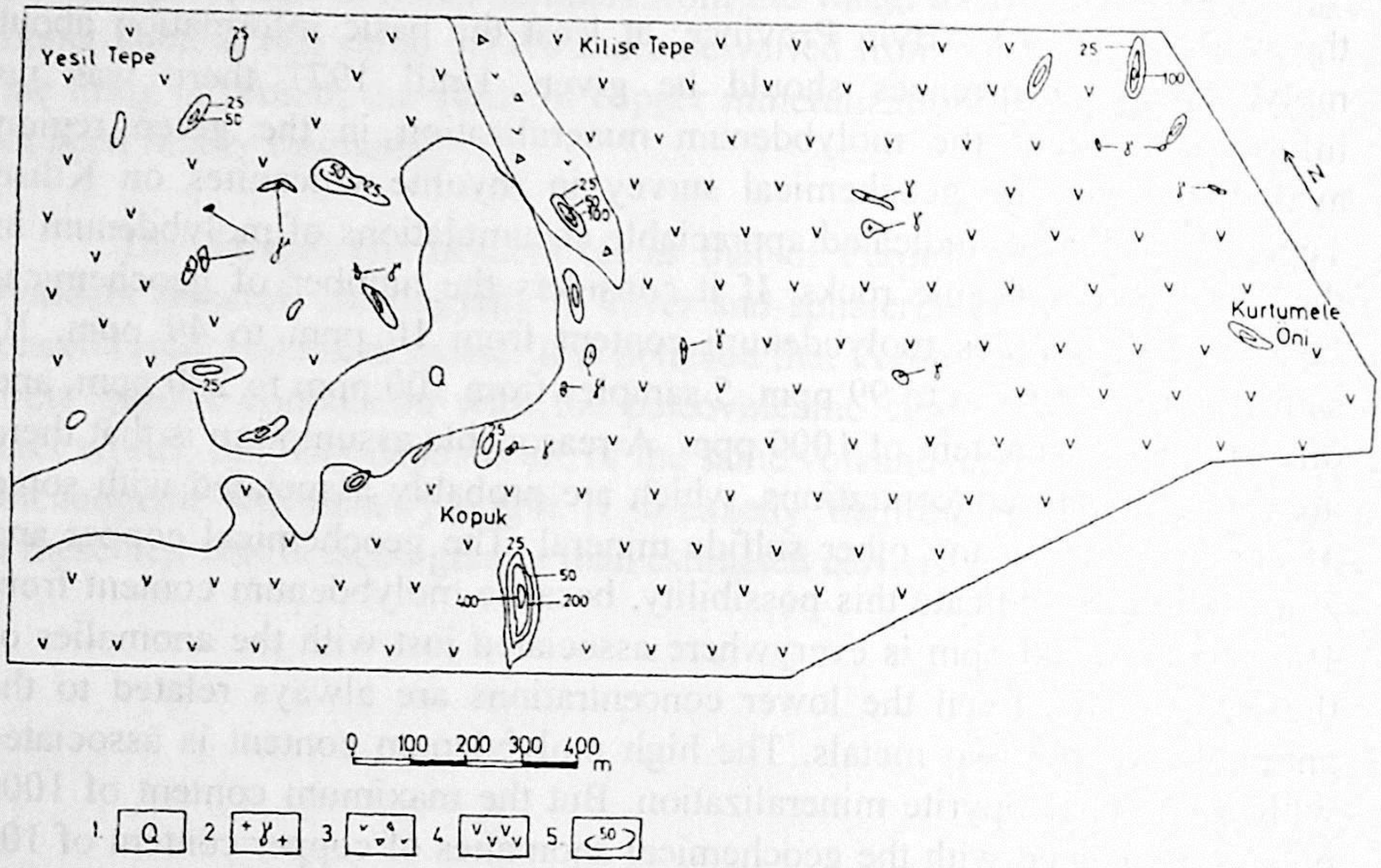


Fig. 50. Geochemical sketch map of molybdenum.

1. Debris; 2. Quartzdiorite; 3. Violet silicified and mineralized rhyolite volcanic breccia; 4. Volcanogenic and volcanogenic-sedimentary rhyolite formation; 5. Isolines of geochemical Mo-anomalies

GOLD AND SILVER

The Artvin Province (Artvin, Murgul, Hopa, Maradit, Fig.51), an area of interest and exploration in the last hundred years, was not considered important for search of gold and silver. During the explorations of copper, zinc, lead and iron sulfide mineralization, infrequent laboratory analyses registered the silver and gold, but except the information by K r a ë f f (1963) on the two metals content in the poly-metallic ore deposit of Akarşen, the 1966. M T A monograph on Kuvarshane mineral deposit, K o v e n k o' s data of gold in Sinkot near Artvin cited by N o v o v i ć (1979), then the information in E r s e ç e n (1989), Ö z g ü r (1992) for Anayatak and Çakmakkaya deposits, there have not been serious studies of the concentration, distribution and other characteristic of precious metals in this Province.

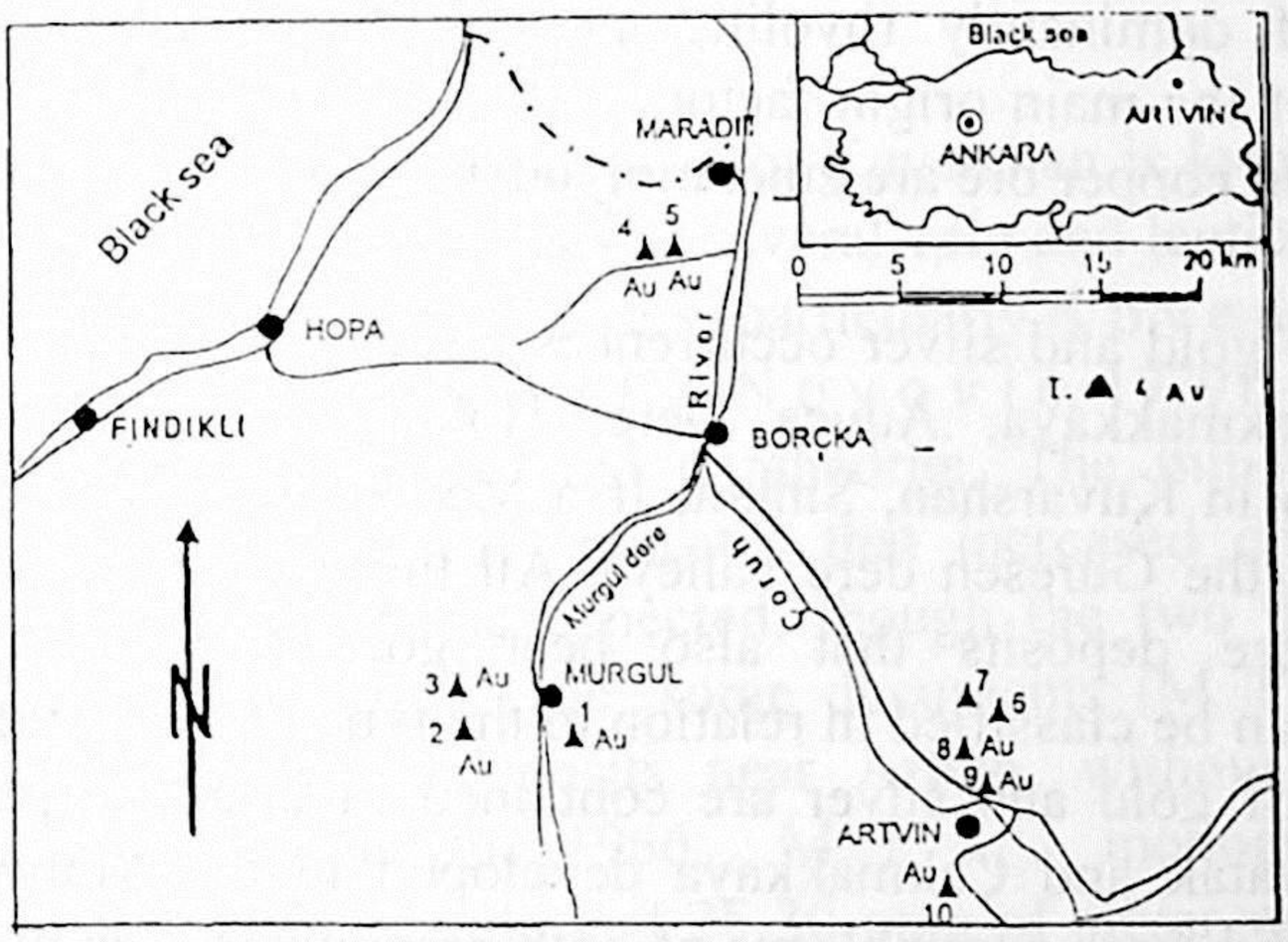


Fig. 51. Location map of the gold-bearing ore, NE Turkey.

1 .Sulfide ore deposits and occurrences bearing gold and silver:

1. Anayatak and Çakmakkaya; 2. Akarşen; 3. Hohur Sırtı; 4. Pehlivan Köy; 5. Çavaşlu; 6. Kuvarshan; 7. Irsa Maden; 8. Sinkot; 9. Seyitli and Umasen Mahalesi; 10. The Melo dere gorge.

During the seventies, author of this text gathered for his own collection many Cu, Zn and Pb mineralization samples from different places in the area between Murgul, Artvin and Maradit and from the Madenköy sulfide ore deposit near Çayelı, and also collected samples from the flotation concentrate. All these samples examined gave interesting results. I found

out, also from the saved records and from the scanty reference data, that some auriferous copper occurrences are a very interesting.

According to our results of examinations for some sulfide ore deposits in Artvin Province indicate that the Province should be given a priority in the search of gold and silver.

Principal Geologic and Metallogenic Characteristics of Malm–Neocomian Auriferous Mineralizations

Large Malm-Neocomian copper ore deposits of Artvin Province are followed by some gold and silver concentrations. These are mainly volcanism, of dominantly rhyolitic composition, which was, as far as known, one of the main origin factors of the copper sulfide mineralization. Trace metals in copper ore are zinc, molybdenum, gold and silver.

Major gold and silver occurrences are found in the ore deposits of Anayatak, Çakmakkaya, Aduca Dere, Hohur Sırtı and Akarşen (near Murgul), then in Kuvarshan, Sinkot, Irsa Maden, etc. (Artvin area) and in Maradit area (the Güresen dere valley). All these locations are known for cupriferous ore deposits that also bear gold and silver. Auriferous occurrences can be classified in relation to the type of sulfide mineral. Small assemblages of gold and silver are contained in large copper ore bodies, such as Anayatak and Çakmakkaya developed in the Malm (Tithonian)-Neocomian, and large assemblages of both precious metals in poly-metallic ore deposits. A separate type is the epithermal ore deposit found only following chalcopyrite impregnations in andesite.

The oldest auriferous mineralization are associated with the copper deposits formed during the acidic volcanism, dominantly rhyolitic in composition, in the Malm (Tithonian)-Neocomian. Their mineral paragenesis included tennantite (argentiferous tetrahedrite), but gold had not much concentrated in that period, unlike the sporadically quite high silver contents. There are many such ore deposits near Murgul, besides Anayatak and Çakmakkaya, but they have not been adequately explored. Unfortunately, the distribution of precious metals was explored only in Anayatak. Similar in mineral composition, other ore deposits are expected to contain similar amounts of gold and silver.

ARTVIN AREA

In Artvin area, precious metals occur mainly in copper sulfide mineralization of Kuvarshan, Irsa Maden, Sinkot, Seyitli, Umasen and Kürdaze-Melo. Like in Murgul area, the auriferous mineralization are classified by the formations in which they occur: rhyolite volcanogenic and volcanogenic-sedimentary complex (Malm-Neocomian) and Upper Cretaceous and Paleogene rock environment. The former include sulfide mineralization occurrences and copper deposits, less zinc and even less lead which are located in the eastern Çoruh bank. The latter are associated with granitoid rocks near Kürdaze-Melo, the Melo dere gorge.

1. K u v a r s h a n O r e Z o n e. As mentioned earlier, this ore zone includes several ore occurrences and deposits. The best known is the deposit in Kuvarshan on the eastern Çoruh bank, after which the ore zone, about 10 km long, was named. The ore zone is characterized by hydrothermal alterations, particularly pyritization, kaolinization, silicification, bleaching, etc. (Fig.51).

The copper-bearing ore deposit of Kuvarshan is located about 4 km east of the Çoruh River. It consists of several vein and lenticular ore bodies. The ore, according to earlier explorers (particularly K o v e n k o, 1942; K r a ë f f, 1963; S i m o n o v i ć, 1972, N o v o v i ć, 1979), contains copper and zinc and far less galena and tetrahedrite. The mineral tetrahedrite, specifically tennantite, clearly indicates that increased concentrations of silver and lower gold can be expected, though the two metals were not systematically searched for. True, some documents (M T A monograph, 1994) mention auriferous deposits near Artvin, without specifying the location. Another source (the 1966. M T A monograph) gives the information that 1 ppm of gold and 25-30 ppm of silver was found in one sample. This and other information on copper ore deposits of similar mineralogic, stratigraphic and genetic types suggest the likely occurrence in Kuvarshan of the two precious metals in increased amounts. The increased gold content at Sinkot supports this assumption. Sampling by S i m o n o v i ć (1972) for copper and zinc, unfortunately did not include gold and silver.

2. S i n k o t. The ore occurrence of Sinkot is located 2.5 km SW of Kuvarshan. It is characterized by marked hydrothermal alteration, and developed iron hats over parts of the ore body with a high proportion of pyrite and less chalcopyrite. Gold and silver amounts in the ore are important for the potentiality in this locality and in whole Kuvarshan ore zone. K o v e n k o (in: N o v o v i ć, 1979) reports gold concentrations from 0.25 ppm to 0.50 ppm, which makes the deposit worth exploring for

gold and silver, the metals earlier neglected by the explorers. The presence of tennantite in all deposits adds to a favorable high estimate. N o v o v i ć (1979) gives the following amounts of gold (Tab.15) for Sinkot ore deposit.

Table 15. Contents of gold and copper in Sinkot (N o v o v i ć, 1979).

Au (ppm)	0.50	0.25	0.28
Cu (%)	0.80	0.07	0.24

3. S e y i t l i a n d U m a s e n M a h a l l e s i. These two localities are situated in the extreme south of the Kuvarshan ore zone (Figs.26, 27, 51). Several outcrops of copper mineralization over a length between 1 km and 2 km were repeatedly explored in the past. Like in the preceding occurrences, the paragenesis of minerals include primary: pyrite, chalcopyrite, sphalerite, rarely galena and tennantite, and secondary chalcocite, covellite, malachite and limonite.

Because all the described ore deposits and occurrences contain tennantite and some of them also increased gold and silver, it is reasonably expected that the entire zone was auriferous and argentiferous from Kuvarshan to Sinkot to Seyitli and Umasen Mahallesi.

MURGUL AREA

1. A n a y a t a k a n d Ç a k m a k k a y a. These two are the largest and the richest copper ore deposits, not only in the Murgul district but in the all of Pontids. As to their auriferous ore, the information available is heterogeneous. D a n i e l s G r i f f i t h' s Co, London (1966, in: P e j a t o v i ć, 1975/79) reports 12 ppm of gold 785 ppm of silver in the flotation concentrate of the Anayatak ore. Later in M T A e x p e r t s of Ankara in the Geology and Mineral Resources of Turkey (C o l l e c t i v e a u t h o r s h i p, 1994) mention gold occurrences in Artvin and Murgul areas but also the lack of more specific data on its amount. Ö z g ü r (1992) cites the respective gold and silver contents of 0.20 ppm and 25 ppm, but not where they were found, Anayatak or Çakmakkaya (probably Anayatak).

My research provided a more detailed analysis. The analyzed samples from Anayatak were very interesting. Leaving aside the mineral composition and the essential elements (Cu, Zn, Pb, Fe, etc.), gold and silver were separated from the samples collected in different materials: chalcopyrite with low pyrite (provisionally rich chalcopyrite ore),

mineralized amethyst, pyrite crystals (pentagonal dodecahedrons and octahedrons), rhyolite tuff (hangingwall of the ore), mineralized rhyolitic tuff breccia, mineralized rhyolite tuff, flotation concentrate of pyrite and chalcopyrite-pyrite (the latter two samples were collected in 1970 from the Murgul flotation plant). The contents found in the samples from Anayatak deposit are given in Tab. 16.

Table 16. Content of Au, Ag, As, Bi and Mo in ore and in flotation concentrate from Anayatak ore deposit (in ppm)

	Au	Ag	As	Bi	Mo
Chalcopyrite and low pyrite (rich ore)	0.45	76-180	340	70	500
Pyrite crystals	0.03	2	170	-	-
Amethyst mineralized by pyrite and chalcopyrite	0.05	1	250	-	5
Chalcopyrite-pyrite flotation concentrate	0.98	63	1740	320	60
Pyrite flotation concentrate	0.53	61	140	-	-

The table above shows low gold contents and somewhat better silver. These data differ from those cited by P e j a t o v i ć (1975/79) and from D a n i e l s G r i f f i t h' s Co. (1966) for flotation concentrate. From a sample of 100 kg flotation concentrate they recovered 1.2 g gold and 78.5 g silver. Compared, the two results give notably different amounts. This may be partly explained by the obsolete technology in 1970, when the old flotation plant of Murgul was far less efficient than when it was new not only in separating gold and silver, but the essential copper as well. The low contents of gold or silver in the dominantly chalcopyrite ore cannot be high in the flotation concentrate. In our case, a large amount of copper begun with pyrite concentrate (as much as 5%), which explains the low contents of precious metals. As can be seen in Table 16, gold in pyrite concentrate was 0.53 ppm; almost 50% of gold was lost as compared with the amount in chalcopyrite concentrate. There are certainly other reasons for this, but we do not know them. Neither the history of tennantite has been explained. It seems reasonable to suppose that a part of this mineral was lost in waste.

Arsenic and bismuth, commonly associated with gold, were noted in the ore composed of chalcopyrite and low pyrite and in chalcopyrite-pyrite concentrate. Peculiarly, bismuth was not identified in pyrite concentrate in which the gold amount was 0.53 ppm, and copper more than 5%. This information also differs from other data. Bismuth content in the

chalcopyrite-pyrite concentrate was 320 ppm, and D a n i e l s G r i f f i t h' s (in: P e j a t o v i ć, 1975/79) reported that bismuth content was only 70 ppm. The given data lead to the conclusion that the Anayatak copper ore deposit is basically poor in gold, and not so poor in silver. The two metals in other samples were not of significant interest.

As far as other micro-elements are concerned, arsenic content is high, particularly in the flotation concentrate. Molybdenum is generally low, except in chalcopyrite with low pyrite, where it is 500 ppm.

If gold and silver amounts were compared with the ore reserve of Anayatak, it would mean that: only twenty million tons of copper ore containing 0.25 ppm gold would have given at least five tons of gold, and containing only 50 ppm of silver would have given at least thousand tons of silver. These are notable amounts of gold and silver that were contained in Anayatak, and the indicators of a large potential in all copper ore deposits in Murgul area. Moreover, the high losses of gold and silver in pyrite concentrate during flotation indicate a new and very important potential – the so-called technogenic raw material. Flotation of ore from the Anayatak and Çakmakkaya is, in any event, a serious perspective for extraction of additional copper and precious metals at low production cost.

2. K i l i s e T e p e. Sulfide mineralization of Kilise Tepe is located in the same zone as those of Anayatak and Çakmakkaya. The three locations are part of the same volcanogenic phase of origin, mineral composition and occur in the same lithologic environment. Precious metals, however, were not examined on Kilise Tepe. Only two samples were analyze: one of pyrite-chalcopyrite impregnated in rhyolite tuff with content of gold 0.10 ppm and silver 7 ppm, and the other in mineralized quartzdiorite (lead 506 ppm, copper 810 ppm, zinc 1.27%) in which gold was only 0.02 ppm and silver 3 ppm. It could be said that high concentrations of precious metals can be expected.

The presented data indicate that Malm-Neocomian metallogeny is not characterized by high concentration of gold, but sporadically increased contents of silver especially in chalcopyrite. Also the presence of tennantite in the ore paragenesis of each copper ore deposit suggest general conclusion that concentration of Au, Ag represent high economic potential. But, on the other side, gold does not occur in crystalline pyrite. The situation with silver is similar. Note that the contents of precious metals increase with the increased zinc content however this correlation has not been proved yet. Also, increased gold and silver were found where arsenic was increased.

Other minerals that bear gold and silver were not especially studied, but it is supposed that in addition to tennantite and chalcopyrite, arsenopyrite and partly sphalerite may also be auriferous.

GENESIS OF MALM - NEOCOMIAN ORE DEPOSITS

Finalizing the subdivision of the description of Malm (Tithonian)-Neocomian ore deposits something should be added about their genesis, though it was not a subject of the study. Some of the considered ore deposits were known for more than fifty or hundred years, but many researchers have variously interpreted their origin. Several models have been hypothesized, more or less different, but only in fine details. The earliest were K o v e n k o (1942) and W i j k e r s l o o t h (1946), who maintained that the Kuvarshan deposit was metasomatic. Z i m m e r (1938) believed the Murgul (Anayatak) ore deposit is a plutonic product, and E g e r a n (1946 classified it into the epithermal type of deposits (similar to the modern model). S c h n e i d e r h ö h n (1955) writes that the Anayatak deposit was formed during a subvolcanic hydrothermal activity assigning it to the sub-volcanic hydrothermal type. K r a ë f f (1963) associates its development generally with the dacite volcanism, and O v a l ı o ğ l u (1969) classifies Anayatak into the massive sulfide deposits of the eastern Pontides, defining it as an exhalative-sedimentary disseminated hydrothermal ore deposit. G ü m ü ş (1970) interprets these ore deposits as telethermal and epithermal, then V u j a n o v i ć (1976) defines them as volcanic-sedimentary hydrothermal, and some of them as contact-metamorphic. P e j a t o v i ć (1975/79) describes them as massive sulfide ore deposits, which include stratiform and stockwork-impregnated types formed during a volcanic activity nearby a volcanic dome, and associates them largely with fumaroles and solfataras. In reference to the Murgul ore deposits of Anayatak and Çakmakkaya, P e j a t o v i ć (1975/1979) writes that they are associated with a stratovolcanic dome, which collapsed and formed a caldera. N o v o v i ć (1979) writes about the ore deposit in Kuvarshan that it is a pyrite-copper hydrothermally epigenic-contact type of ore. P o p o v i ć (1979) defines these ore deposits as subvolcanic-hydrothermal, associated with a large tectonic zone, along which hydrothermal fluids altered rocks, originating in the magmatism that produced Eocene granodiorites. Contrary to the mentioned authors, Ö z g ü r, P a l a c i o s (1990) and Ö zg ü r (1992) maintain that the ore were subvolcanic, same as S c h n e i d e r h ö h n (1955). Later, other models followed. G e d i k o ğ l u, Ö z g ü r (1992) interpret Murgul ore deposits as subvolcanic hydrothermal that exceed westward into submarine

hydrothermal. Ö z g ü r (1992) writes: *"... fluorine, titanium and manganese are excellent indicators of volcanogenic sulfide deposit in the East-Pontic metallotect"*. Finally, G ö k ç e (2001) states, on the basis of the latest analysis of oxygen and hydrogen isotope compositions, that "the Çakmakkaya and Damarköy (Anayatak) ore deposits are typical examples of the **Kuroko type** volcanic sulfide ore deposits", considering that meteoric water is in the hydrothermal solutions. He writes: *"... it may be assumed that meteoric water circulating through the underlying basement of the volcano-sedimentary rocks, has acted as mineralizing fluid, and leached the metals (Fe, Cu, Zn, Pb etc.) and sulphur from surrounding volcanic rocks and precipitated along the fractures within the brecciated dacite host rocks and the surface of the sea floor"*. This is an entirely new model. However, it cannot be applied to all ore deposits. Our concept is similar, excluding the origin of the fluid. Hydrothermal waters could not all be of the meteoric origin. There were waters that could be connate or juvenile waters. Either of them had the same effect of moving, transporting and later precipitating metals that formed the ore deposits. Metal precipitation in the form of sulfide minerals, in fault clays, breccias and rhyolitic volcanic rocks, evolved under the sea surface, mainly in the volcanic area, either near or at the sea floor, near a volcanic centre or far from it, providing for the formation of subvolcanic, volcanic, volcanic-sedimentary or sedimentary (distal in relation to volcanic centre) types of sulfide ore deposits. Where the fault structure was open in the sea floor, the metals in sulfide form precipitated directly on the sea floor.

Different interpretations of the origin of sulfide ore deposits in Murgul area are a consequence of the lack of systematic exploration. Fact is that rhyolitic and rhyodacitic (Jurassic-Neocomian) volcanic rocks were subsequently or contemporary mineralized, but also the truth is that it happened within only one regional fracture. Now, should we take into consideration that the peripheral parts of the Tiryal Dağ-Tatos Dağları granodiorite pluton were mineralized by copper, zinc and silver, which has been proved in many places (Iskalka Köprüsü, Kilise Tepe, Başköy, the Melo dere gorge, etc.), a plausible explanation is that granodioritic magma was the main dynamic in origin of the mentioned ore deposits.

The models of the many geologists who studied the origin of the ore deposits are different, but all are modified versions of the above-mentioned ones. Also where the origin is concerned, arguments are different: the common opinion is that volcanism was the principal factor of the supply of copper and associated metals, but the interpretations vary from subvolcanic and volcanic hydrothermal deposits to volcanogenic-sedimentary hydrothermal and sedimentary origin. The fact is that all the mentioned genetic types were identified in the given area, but there are regenerated

types associated with subsequent ore veins. The phases of mineralization are also very important. At least five (5) phases of ore bearing are distinguished. An illustration of the phases of ore formation is the massive chalcopyrite and pyrite, in large crystal forms of the two minerals, and regenerated chalcopyrite with quartz and amethyst veins. Chalcopyrite and pyrite also occur as cement of volcanic and tectonic breccias, and there are occurrences of mineralized overlying tuffs of rhyolitic composition in the form of fine-grained impregnation.

The models discussed are only of the Malm-Neocomian ore deposits, associated with the rhyolite volcanogenic and volcanogenic-sedimentary complex. This volcanism was explosive in the Murgul area, characterized by large amounts of pyroclastic materials as indicated by the exploration data for Kilise Tepe and southern area of the Murgul Dere in general. It has been mentioned that this complex locally exceeds the thickness of 500 m. The thickness is not uniform, but varies depending on the base level of erosion and the range of the volcanic material distribution beyond the supply channels. A rough estimate is that redeposited or in situ pyroclastic materials are dominant over the lava flows. The ratio of pyroclastic materials (tuffs, breccias, agglomerates, volcanic ash, etc.) to lava flows (rhyolites, rhyodacites, less dacites) could be estimated approximately 5:2, or the occurrence of pyroclastic materials are 2.5 times higher than the lava flows. As a result of explosive volcanism, both lavas and pyroclastics were formed as highly porous. Subsequent hydrothermal fluids penetrated the porous rocks. Solution riches in sulphur, iron and copper, less in other metals, filled the interstices in a closed system of pores, without emerging on the surface, and while the pressure and temperature fall, and metals and sulphur concentration rise in the solution (according to G ö k ç e, 2001, in respect of NaCl, $CaCl_2$ and $MgCl_2$, chlorohydric acid was dominant in the solution). This also led to precipitation (at a previously increased pH in the solution) of sulfides, iron (pyrite), iron and copper (chalcopyrite), zinc (sphalerite), etc. The so formed mineralization is the cement of pyroclastic fragments. The volcanic rocks presently considered were ejected on the Earth surface, specifically on the sea floor, and permeated with hydrothermal fluid from which ore substance had already precipitated. In any event, hydrothermal fluid permeated all volcanic rocks and surplus fluid spread over the sea floor or further from the volcanic vent. Some of ore material precipitated from the fluid on the sea floor near the volcanic centre, and some of the ore materials were carried away by the currents for even more than 10 kilometers. That is how volcanogenic, stratiform and volcanogenic-sedimentary ore deposits were formed. But which of these are part of the Jurassic-Neocomian metallogeny of the Artvin-Murgul-Hopa area is difficult to say without some reservation

(Fig.52). Hydrothermal solutions contained also silica and precipitated silica cement in addition to pyrite and chalcopyrite cement. The mentioned physico-chemical conditions provided in some places for slow crystallization from the solution first, pyrite crystallized at higher temperatures into octahedrons, and later, at reduced temperatures, into pentagonal dodecahedrons of identical sulfide. The crystals are large, octahedrons 3 cm and pentagonal dodecahedrons 5 cm in diameter. Chalcopyrite crystals of up to 1 cm (Fig.39) were formed later. The question of the origin of the ore matter stays. The data collected from many geochemical analyses of granitoids from Kilise Tepe, Iskalka Körpüsü, the Çoruh valley, and the Melo dere gorge indicated that quartz diorite, a variety of granodiorite that is a constituent of Tiryal Dağ-Tatos Dağları batholith, contained an increased concentration of copper and zinc. This is interpreted as a result of the following sequence of events: during the oceanic crust subduction, hybrid magma formed in the upper mantle, which mobilized, from the preexisting (probably transitional and partly continental) crust, iron, copper, zinc, lead and molybdenum (the latter two elements indicate the continental Earth's crust affected partially by melting). This is probably what enabled the supply of metals in the extrusion level during the Malm-Neocomian stage of magmatism. The resulting ore deposits of this derivation are few in the Murgul area. The vein pyrite and stratiform pyrite-chalcopyrite mineralizations of Iskalka Köprüsü and on Kilise Tepe do not correspond to the mentioned model. Stratiform mineralizations are believed to have been formed under volcanic-sedimentary conditions, because they occur in redeposited volcanic rocks (with chert). The deposits are supposed to have been located near a volcanic centre wherefrom hydrothermal solutions spread onto the bottom of the sea basin and precipitated mineral matter that formed stratiform ore deposits.

The most abundant secondary Cu- mineralization in Murgul area is copper oxide – **tenorite**, particularly in Anayatak, Çakmakkaya and on Kilise Tepe. In view of the presented model, this secondary copper mineral could have been formed during volcanic activities, and also in the oxidation zone. As a result of heavy erosion, other secondary minerals such as covellite, malachite, azurite, chalcanthite, etc. are rapidly wasted away, whereas tenorite is capable of resisting the washing agents. Tenorite occurs everywhere in the ore deposit, which is not a sufficiently reliable but is an indicated of the volcanic origin of the deposit. It is believed that this mineral was not formed during the volcanism, but is a post-ore, secondary mineral.

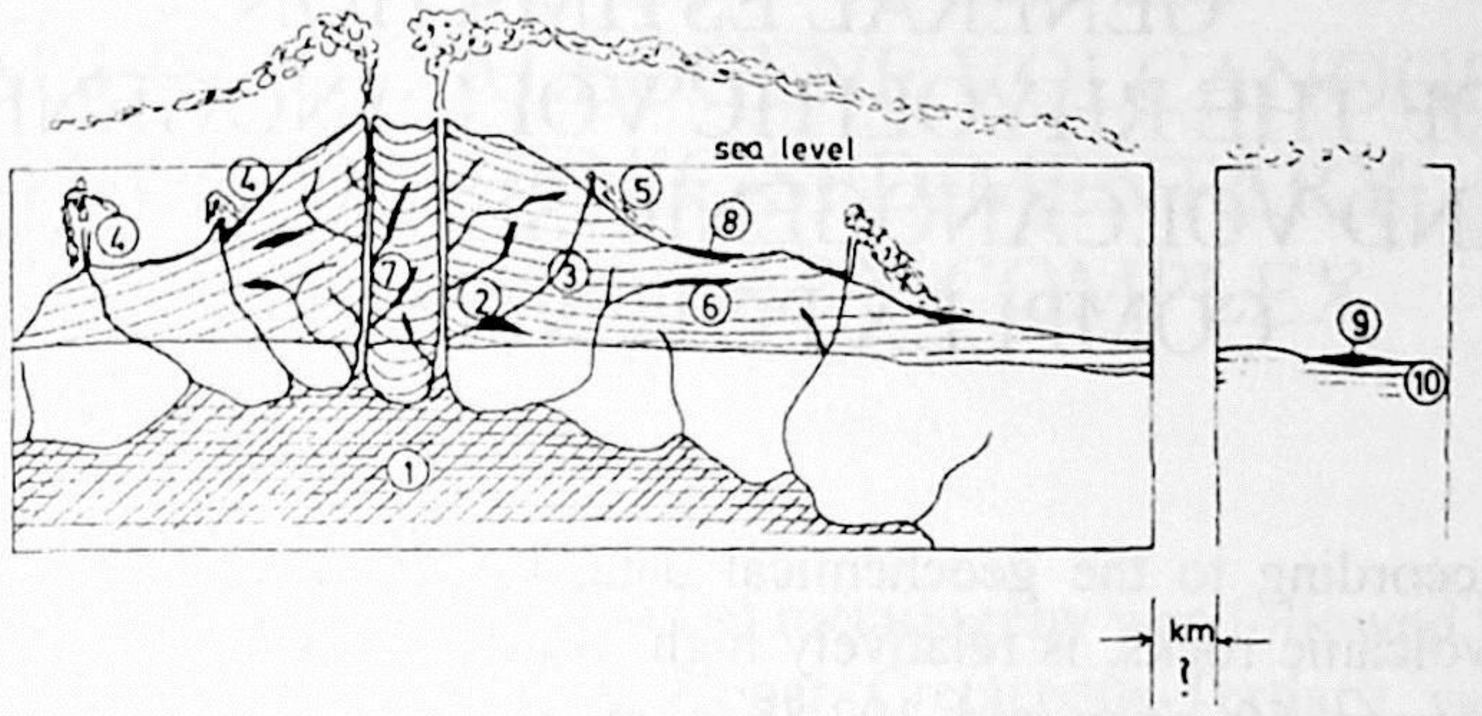


Fig. 52. One of possibility model of copper ore deposit origin in eastern Pontids.

1. Magma chamber; 2. Volcanic rocks; 3. Lateral bringing volcanic chanel; 4, 5. Volcanic emanation; 6. Volcanic (stratiform) ore deposit; 7. Volcanogenic vein ore deposit; 8. Volcanic-exhalative ore deposit; 9. Sedimentary ore deposit; 10. Marine sediments of redeposited volcanic materials.

In some places, e.g. the Kuvarshan area, the post-ore tectonic events complicated the relations, which were noted by many explorers who worked there. Similarly, ore deposits in Murgul area is affected by tectonic disturbances, which should be remembered. Tectonic deformations (folding, reverse faulting and thrusting) were intensive during the Pyrenean and Savian tectogenesis. The deformations were particularly notable in the formations and deposits developed during the Upper Cretaceous-Tertiary.

The ore deposits formed in the volcanogenic level occur in impregnation, stockwork-impregnation, or stockwork, vein, stratiform and massive types. In places where volcanic rocks were cavernous and the cavities formed a closed system filled with ore-solutions under pressure, massive ore could have been formed. There are many such cases on Anayatak; pyrite-chalcopyrite blocks of as much as 0.25 m^3 were locally noted that contained more than 20% copper. These are typical examples of irregular cavities filled with the ore-forming fluid rich in copper. Many of these occurrences on Anayatak may lead to incorrect conclusion about the morphologic type of mineralization. There are similar occurrences of massive ore on Çakmakkaya, but they are smaller. Also the so-called oreclasts (pebbles, in P e j a t o v i ć, 1975/1979) on Kilise Tepe (the Kopitvan dere source area) and their relative numerous presence in the mechanical dispersion halo indicate this form of occurrence. Only tectonic events before and erosion after the ore origin transformed it into a relatively large mechanical dispersion halo of oreclasts varying in size up to 30x20x20 cm with the copper contents even over then 23%.

GENERAL ESTIMATION OF THE RHYOLITIC VOLCANOGENIC AND VOLCANOGENIC-SEDIMENTARY COMPLEX POTENTIALITY

According to the geochemical data, the average copper content, in rhyolitic volcanic rocks, is relatively high. In different locations this content varies between 50 ppm and 102,55 ppm. Compared with the theoretical content, is 2.5 times higher, or compared with the intermediate magmatic rocks, 1.43 times higher (V i n o g r a d o v, 1962, cites 20 ppm for average content of acidic magmatic rocks, and 35 ppm average copper content in intermediate rocks: diorites and andesites). An extrapolation of these data for the area only between Artvin and the Murgul dere gives interesting data. One example could be explained trough: The distance between Artvin and the Murgul dere is about 50 km; if rhyolite complex in this area is no more than 200 m thick on average and at least 10 km wide, a simple calculation gives a geological body in which, during its development, at least twelve million tons of copper could have had accumulated. So much copper could have been disseminated throughout the complex; this syngenetic copper could partly penetrate into the volcanogenic and volcanogenic-sedimentary deposits. Subsequent tectonic events and new volcanism (magmatism) activated the hydrothermal fluid (juvenile, connate or meteoric water), which dissolved primary copper and with this copper also sulphur, iron and silica produced regenerated ore deposits as those of Anayatak and Çakmakkaya, partly Kilise Tepe, Kuvarshan area, Peronit, Sivrikaya, etc. That is why all the mentioned ore deposits include quartz, pyrite and chalcopyrite as cement to the volcanic and tectonic breccias appear.

Furthermore, it is known that all ore deposits in Artvin and Murgul areas contain an ore reserve (known – including extracted and potential) of less than hundred million tons with the average content of 1.5% Cu (slightly exaggerated). This gives only about 1.5 million tons of copper metal. Where are other amounts? The answer is simple: **not yet discovered.** In support to this opinion are the facts that Upper Cretaceous formations have been preserved in a large area and they are underlain by Malm-Neocomian ore-bearing formations. This and the known deposits and occurrences of copper ore (explored and unexplored) clearly indicate a large potential of total rhyolite petrogenic complex for copper-ore and followers zinc, silver, gold, and probably molybdenum.

ORE BEARING OF UPPER CRETACEOUS –PALEOGENE VOLCANOGENIC, VOLCANOGENIC-SEDIMENTARY AND SEDIMENTARY COMPLEX

The Malm-Neocomian period of metallogeny was followed by a new one, directly associated with the Upper Cretaceous-Tertiary volcanism, characterized by complete development of formations from basic then intermediate to acidic differentiates. According to P e j a t o v i ć (1975/79) this volcanism belong to tholeiite series. Poly-metallic (copper, zinc, lead) ore deposits, the relatively high concentrations of gold and manganese occurrences are associated with this volcanic activity as an important metallogenic characteristic. The metal (Cu, Zn, Pb) deposits here are of lesser economic importance than the ores associated with the Upper Jurassic-Lower Cretaceous volcanism.

This entire petrogenic complex is discordant to the older Upper Jurassic-Lower Cretaceous volcanogenic and volcanogenic-sedimentary complex. The discordance is tectonic - erosional.

The volcanism that began in the Lower Cretaceous continued to the Eocene, but the magmatism had not ceased. On the contrary, in the late Eocene, new magmatism resulted in the intrusion of a large granodiorite mass of Tiryal Dağ-Tatos Dağları pluton in the eastern Pontids.

The Upper Cretaceous-Paleogene volcanogenic, volcanogenic-sedimentary and sedimentary complex occupies a relatively large area and has a great thickness - more than thousand meters. The complex formed in marine and in subareal environments, with intensive sedimentation in the episodes of reduced or ceased volcanism. Under these general petrogenic conditions, relatively many formations developed, e.g. volcanogenic, volcanogenic-sedimentary and sedimentary. According to the great vertical mixture of sedimentary and volcanogenic formations, a classification into two main stratigraphic divisions could be made: **lower and upper sub-complexes**. The **lower subcomplex**, consisting of basalt, spilite, diabase followed by carbonate and siliceous sediments (chert), can be defined as **diabase-basalt-spilite-chert (basic) sub-complex**. The **upper sub-complex** composed of intermediate acidity, dominantly andesite rocks that pass upward into the acidic: dacite and rhyolite rocks. They are defined as

andesite (of intermediate) sub-complex. Like the former, this sub-complex includes carbonate (limestone, marlstone and marl sediments) and clastic-tuffaceous formations, which are not uniformly developed, though locally are very thick, hundreds of meters.

The estimated thicknesses of the two sub-complexes are 500 m (lower) and more than 1000 m (upper). The complex is ending with acidic volcanic rocks and pyroclastics of dacite and rhyolite composition but they do not occupy big space.

Principal Geochemical Characteristics of the Lower (Basic) Sub–Complex

The lower or basic (diabase-basalt-spilite-chert) sub-complex was formed in the Maastrichtian, which was determined on the paleontological material preserved in sedimentary rocks, which is associated to the subcomplex.

The volume of sampling and chemical analysis of various rocks in Murgul area in 1970 amounted to the level of regional geochemical analyses. It still did not suffice for a full geochemical interpretation of each formation, because it lacked the local background for metals, treshold and the anomaly itself. Nevertheless, the collected data can be used for an information about the copper and zinc behavior in some of the sub-complex formations, for example, the distribution of Cu and Zn in diabase, basalt, spilite at the mountain top Akarşen. The copper concentration in diabase was within the range common for this rock, from 10 ppm to 80ppm. Zinc similarly was contained by less than 240 ppm, except two samples (collected 250 m west of Akarşen peak) that contained zinc 240 ppm.

In the same sub-complex, slight pyrite mineralization was noted in several places, but not any other sulfide mineralization. Copper and zinc in far higher amounts than common for these rocks were found locally in an primary dispersion halo, in the Gonuli dere valley (westerly from Murgul) during the geochemical exploration in diabase-basalt-spilite-chert formation, the contents of copper in seven spots varied from110 ppm to 360 ppm, or from 10 ppm to 260 ppm more than the average content in basalt (100 ppm according to V i n o g r a d o v, 1962). In the same rocks and the same spots, zinc varied from 130 ppm (background, according to V i n o g r a d o

v, 1962) to 360 ppm, and although low it still indicates an increase of this metal to 230 ppm. The two metals, at the present stage of our knowledge, are not high enough for economic significance estimation of copper and zinc sulfides in this area. However, besides the manganese mineralization and thin hematite crusts on chert, the data about locally increased assemblages of pyrite and locally anomalous contents of copper and zinc is important metallogenic characteristic of the sub-complex. A similar situation was found in Artvin area (the Melo).

Other metallogenic features of this sub-complex are primarily characterized by manganese mineralizations and almost negligible hematite occurrences. This type of mineralization is generally characteristic of the diabase-spilitoid formations, especially so-called diabase-chert formation of Balkan Peninsula. Hematite mineralization in it has only a mineralogical significance. It occurs together with chert, in the form of slight crusts(coating), but it is hematite that gives the characteristic red color to the diabase-basalt-spilite-chert sub-complex. Rocks of this sub-complex are the most important for manganese occurrences, especially in the Hopa-Artvin area. In this area alone, K o p r i v i c a (1971, 1977) reported more than ten manganese occurrences, some of which were intensively explored by mining works, as for example occurrences in west and southwest of Peronit. He specified that four occurrences, about 1 km from Çomli köy, belong to this sub-complex (Fig.53).

Manganese mineralizations is the main metallogenic characteristic of the basic rocks (diabase-basalt-spilite) sub-complex. Manganese was found at Artvin, Murgul, Hopa and Arhavı. The contained sulfide mineralizations are less important. Impregnated pyrite noted SW of Murgul (Akarşen area), anomalous amounts of copper and zinc and a sizable occurrence of copper and zinc near the Melo (Artvin) characterize the sub-complex as a real potential of ore, which all metallogenic examinations indicated.

A particularly interesting mineralization occurrence, not yet precisely classified (assumed Tertiary in age), is represented by the copper-mineralized andesite rock near Pehlivan Köy. It contains high copper and increased gold, but its interesting feature is the characteristic alteration – adularization – used to determine the epithermal type of the ore deposit. The occurrence will be presently considered as a separate type of mineralization.

Ore deposits and Occurrences

COPPER AND ZINC

ARTVIN AREA

Kürdaze–Melo. Sulfide mineralizations of copper and pyrite were found only in Kürdaze-Melo, where the diabase-basalt-spilite sub-complex bears increased pyrite concentration in several places. The mineralizations are supposed to have been syngenetic with the flow of the rocks. Two Cu, Zn - occurrences in the Balıkaya Dere, previously explored, are ore veins, most probably epigenetic in these formations. The main metallogenic characteristic is Mn-mineralization noted in a left tributary of the Sarıbudak Dere.

The copper and zinc mineralizations, probably formed in the Paleogene, occur in a branching fault zone - splitting in two branches. The ore minerals identified in the ore paragenesis are pyrite, chalcopyrite, sphalerite (to marmatite), but galena and barite are occuring in the upper horizons.

S i m o n o v i ć (1972) mentions geochemical exploration in Kürdaze-Melo, which included 49 samples from diabase, basalt and spilite. Anomalous contents of copper, lead and zinc were found in as many as 30 samples. The lower limits of the anomalies were accounted as average contents of the respective elements in basic magmatic rocks (after V i o g r a d o v, 1962): copper 100 ppm and zinc 130 ppm. Anomalous amounts of copper in this location (S i m o n o v i ć, 1972) varied from 100 ppm to the very high 2000 ppm (the latter in the pyritized part of basalt breccia). The anomalous amounts of zinc in the same rocks varied from 130 ppm, then 500 ppm, 600 ppm, 6000 ppm and 8000 ppm to the so-called ore concentration up to 2.5%. All the cited zinc contents were found in pyritized basalt breccia. Lead content exceeding 80 ppm also was anomalous, because five samples contained 100 ppm, 150 ppm, 200 ppm, 250 ppm, 500 ppm and 600 ppm, which was highly anomalous for basic rocks. These high contents of Cu, Zn, Pb are an evidence of ore occurrence in some places. This data classified the formation as of ore-bearing potentiality.

The above data give an impression that the mineralizations, regardless the mode of appearance, were not syngenetic with those in basalt and spilite or their breccias, but it is not ruled out. There is the hypothetical

alternative that the mineralizations were epigenetic, the ore matrial (copper, zinc and lead) being supplied during the younger, intermediate volcanism when the hydrothermal fluid rich in these metals permeated basalt and spilite and their breccias mineralizing these rocks.

Moreover, a part of the lower, basic sub-complex consists of sedimentary formations including reddish thin-bedded limestones formed between two volcanism phases when basalt, diabase and spilite were not extruded. Limestone abounds in faunal remains that were useful in giving the Maastrichtian age to the sub-complex.

MANGANESE

In the scope of the present consideration of the metallogeny of NE Turkey (Artvin Province), some other ore occurrences in the Province should be mentioned. Manganese mineralization occurs where there are diabase-basalt-spilite formations with cherts. Though mentioned earlier, these formations developed in the Upper Cretaceous and that the manganese mineralizations are of the same age. They are registered in the areas of Artvin, Murgul, Hopa and Arhavı.

ARTVIN AREA

Kürdaze–Melo. Hristov and Markov (1970) reported findings of two outcrops of Mn-occurrences about 800 m NW of Melo village, the upper reaches of a left tributary Melo dere, in diabase-basalt-spilite formations with cherts, which is one of major metallogenetic characteristics of the sub-complex. The occurrences are located on either side of the stream, but their economic value is estimated very low.

Cu-Zn mineral in spilite, about 1000 m north of the two Mn-occurrences, was explored from a trial adit. Gümüş (1970) mentions also other Mn ore occurrences in Artvin area, but gives no further details.

MURGUL AREA

A few Mn-occurrences in diabase-basalt-spilite-chert sub-complex near Murgul have not an economic value. Some of them are located on the Gonuli south bank, about 3 km NW of Akarşen peak. The diabase-basalt-spilite-chert sub-complex occupies an area of about 700x700 m and bears about ten minor Mn-occurrences associated with chert thin-crusted (coated) by hematite. One of all these Mn-occurrences was sampled for chemical analysis that gave the manganese amount of 10%.

Although economically insignificant, the Mn-occurrences in the Gonuli dere are mentioned here primarily for the metallogenic character of the lower, basic volcanogenic and volcanogenic-sedimentary sub-complex of the Lower Cretaceous (Maastrichtian) age.

K r a ë f f (1963) mentions also other Mn-occurrences near Murgul but without any detail, not even the location, considering them uneconomical.

HOPA AND ARHAVI AREAS

Manganese mineralizations near Hopa and Arhavi spread over a relatively large area. More than ten have been reported. Some of the occurrences are in fact ore deposits that were exploited. Their estimated ore reserve is tens of thousand tons with economical significance of Mn-content.

Manganese mineralizations are everywhere accompanied with hematite and assembled chert that occurs with spilite in the lower or diabase-basalt-spilite-chert sub-complex, analogous to the diabase-chert formation on Balkan Peninsula. According to K o p r i v i c a, 1971 contents of manganese vary from 8.24% to 35.58%.

K r a ë f f (1963) defines two types of manganese mineralizations:

1. Manganese mineralization associated with dacite tuff (ore?) and
2. Manganese ore associated with spilite.

As an example for the first type K r a ë f f (1963) mentioned an old mine, about 2.5 km SE of Peronit village, which was exploited in the first half of the 20th century. Its annual production "was about 2000 tons of manganese ore with an average of 48% Mn". The ore is associated with violet, silicified dacite tuff. The most interesting information given by K r a ë f f (1963) is the occurrence of Mn-nodules of 1-2 cm in diameter. He interprets it as the submarine-exhalative type of mineralization, the so-called 2nd magmatogenic cycle, which may suggest an acidic volcanism, but it does not seem likely.

The other type of Mn-mineralization is associated with spilite. Occurrences of this type are located in the village of Kuledibi near Hopa. K r a ë f f (1963) describes the occurrences as composed of pyrolusite, with the contents of manganese 33.34%, SiO_2 27.89% and phosphorus 0.02%.

Another occurrence of **Mn-mineralizations**, mentioned by K o p r i v i c a (1971, 1977), is at Kise (**No.5** in Fig. 53), also in the diabase-spilite sub-complex, which was explored by a trial adit. The manganese content of 15.62% in it has not been considered of economic significance.

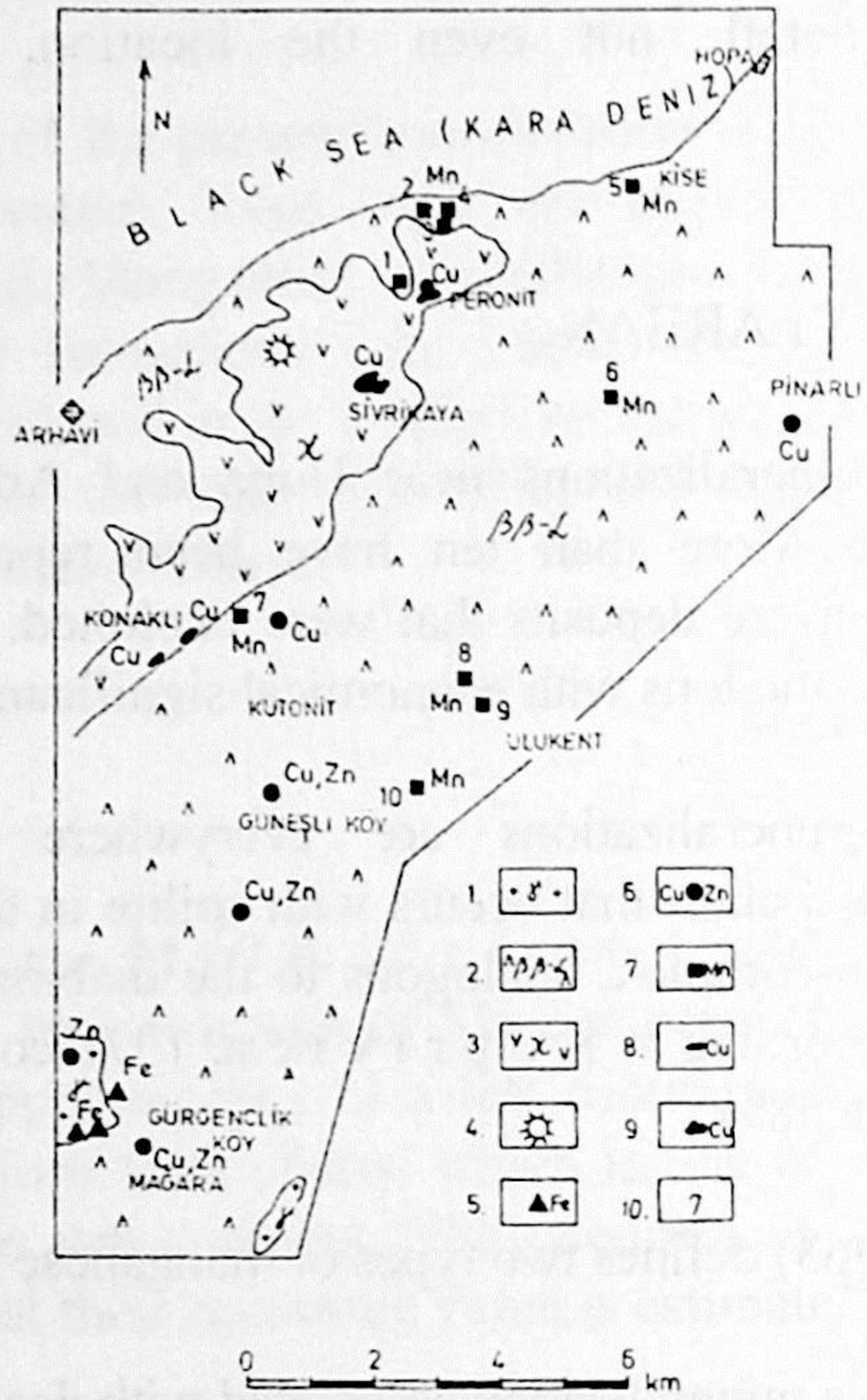


Fig. 53. Geological sketch-map of ore deposits and occurrences of copper, manganese and iron between Hopa and Arhavı (K o p r i v i c a, 1971, 1977, modified by P o p o v i ć).

1. Granitoids; 2. Upper Cretaceous-Paleogene volcanogenic, volcanogenic-sedimentary and sedimentary petrogenic complex; 3. Malm-Neocomian volcanogenic and volcanogenic-sedimentary petrogenic complex; 4. Paleovolcanic centre; 5. Skarn Fe-occurrence (magnetite); 6. Upper Cretaceous-Paleogene Cu, Zn-occurrences; 7. Upper Cretaceous Mn-occurrence; 8. Malm-Neocomian Cu-occurrence; 9. Malm-Neocomian copper ore deposit; 10. Number of manganese ore occurrence.

Mn-occurrences Nos. 2, 3, 4 (Fig. 53) are located west of the village of Çamlı Köy also in the diabase-basalt-spilite-chert sub-complex. K o p r i v i c a (1971, 1977) writes that S t r u v e (1902) identified pyrolusite, and Z i m m e r (1938) reported manganese contents from 31.37% to 44.30% and SiO_2 from 14.05% to 16.09%. One wonders why the occurrences at Çamlı Köy (also called village Peronit) were not further explored. Especially if it is known that

high contents of Mn must be explored. Note that the **Mn-mineralization number 1** is emplaced in the diabase-basalt-spilite sub-complex less that 200 m westward from the Peronit copper-ore deposit. This is an evidence that the diabase-basalt-spilite has been preserved over the Jurassic-Neocomian rhyolite volcanic rocks, which means that the copper ore potential of Peronit is much greater than acknowledged. Copper and manganese mineralizations are located in the same ore field but belong to different periods of creation.

The manganese **mineralization number 5** is located about 500 m SW of the village of Kise and about 2.5 km also SW of Hopa. Like the preceding, this occurrence lay in the diabase-basalt-spilite formation. It was explored by a trial adit in front of which was a waste rock from which K o p r i v i c a (1971) reported the manganese content of 15.62%.

The **Mn-occurrence number 6** (Fig.53) is located at Pancolköy in the Kise deresi valley. This mineral occurrence consists of pyrolusite (S t r u v e, 1902, in: K o p r i v i c a, 1977) emplaced in diabase-basalt-spilite-chert sub-complex. The mineralization is lenticular with content of manganese to 42.56%.

The **Mn-occurrence number 7** is located west of the Kutonit Cu-Zn mineralization. Like all the preceding ones, this mineralization is emplaced in the diabase-basalt-spilite-chert sub-complex. The mineralization is exposed in two outcrops. K o p r i v i c a (1977) describes it as a bedded Mn-mineralization, being 1 m thick in the outcrops. It also was explored by trial adits. The same author cites the manganese content to 45.80% or less (the manganese contents given by K o p r i v i c a are derived only from the metal-rich parts of the ore body, never their average contents).

The **Mn-occurrences number 8 and 9** are located from 500 m to 600 m NW of Ulukent village. They are also emplaced in the diabase-basalt-spilite-chert sub-complex associated with hematite crusts (coating) on spilite and chert. K o p r i v i c a (1977) collected two samples, one from each occurrence on its NW side, which contained manganese 42.42% and 47.13%. He mentions an occurrence of a third vein(?), suspecting its descendent origin, and its manganese content of about 45%. The three ore occurrences are small, as far as we know, and their high manganese contents are a result of the selection only of the manganese-rich samples.

Finally, **Mn-occurrence number 10** is located about 800 m to 1000 m SW of Ulukent. This is a descendent manganese mineralization from dacite-andesite volcanic rocks of no economic value.

Some Geochemical Characteristics of Intermediate (Upper) Volcanogenic Sub–Complex

The upper part of the volcanogenic, volcanogenic-sedimentary and sedimentary petrogenic complex, defined presently as the upper sub-complex of Upper Cretaceous-Tertiary (Paleogene) age, or the andesite and dacite-andesite and sedimentary rocks, is of major economic significance because it includes a great number of sulfide ore deposits distributed all over the region (considered in this monograph). It is a part of the petrogenic complex that consists of andesites, dacite-andesites, andesite tuffs, agglomerates, commonly intercalated with tuffaceous sandstones, sandstones, marly sandstones, tuffaceous marl sediments, pelites, limestones and other sediments.

In the sulfide ore deposit of Akarşen, ore-textures of the sedimentary type of mineralization were found. These are oolitic textures and mineralized bacterias. Pyrite and copper mineralizations were found in several places on Balıklı Yayli in the uppermost parts of the volcanogenic-sedimentary complex.

Volcanic rocks are much widespread, dominantly andesites in composition with pyroclastics prevailing over flows, which indicates an explosive volcanism. The numerous of ore occurrences, the pyritization grade and all other types of hydrothermal alterations (kaolinization, argillization, carbonatization, silicification, etc.) all indicate strong gas-liquid emanations what reflected to the high metallogenetic importance of this sub-complex.

The study of volcanic and sedimentary rocks of the sub-complex included limited geochemical explorations in the western part of the Murgul area. Of about fifty geochemical samples from the primary dispersion halo, many contained copper by more than 100 ppm, which is about three times higher than in andesite rocks (according to V i n o g r a d o v, 1962, average Cu-content in andesite is 35 ppm). For the other analyzed metal, zinc, the anomalous content considered was 100 ppm, which was about 1/3 higher in the average content than that of V i n o g r a d o v (1962, Zn 72ppm). The analysis included andesite and andesite pyroclastics. In twenty samples from Akarşen area the lowest copper content was 100 ppm and the highest 360 ppm. Zinc, in the same samples, was contained by 100 ppm to 240 ppm. One sample of andesite from Akarşen peak contained copper by 340 ppm. According to the above data, copper distribution, and its volcanogenic supply, was more abundant than those of zinc. Situation is similar in Balıklı Yayla area, where some samples contained as much as 400 ppm of zinc. All this is an evidence of the enormously abundant supply of the two metals during the andesite volcanic

emanations. Besides these geochemical characteristics, there are two more important factors. One is the extensive pyritization, which, combined with other hydrothermal alterations, has impregnated to a lower or higher grade all volcanic rocks of the sub-complex. The other, more important, is the numerosity of copper, zinc and lead ore deposits accompanied by precious metals (gold and silver) and locally fluorite. In the present state of knowledge, there are more than fifteen polymetallic (Cu, Zn, Pb and precious metals) occurrences and deposits in the Upper Cretaceous-Paleogene volcanogenic and volcanogenic-sedimentary sub-complex. Generally, the metallogeny of the sub-complex has not been adequately studied.

The most important metallogenic characteristic of some formations in this petrogenetic sub-complex is impregnated pyrite, locally followed by copper, then zinc and lead minerals sporadically associated with fluorite, barite, and sulfide mineralizations in sediments. These are related to volcanogenic-sedimentary and sedimentary formations, particularly tuffaceous sandstones, sandstones, pelites, tuffaceous sandy and marly rocks, which are in many places (e.g. at Başköy Mine) impregnated by pyrite with more or less chalcopyrite. On Hohur Sırtı, marly sedimentary rocks yielded increased copper (100 ppm) and zinc (150 ppm), and lead – 100 ppm in some spots. Another example is even more instructive. A sample from tuffaceous sandstone contained copper 556 ppm, zinc 3000 ppm and lead 2200 ppm, and also gold 0.11 ppm, silver 2 ppm and arsenic 217 ppm. The given data are certainly neither incidental nor neglected. They indicate the volcanogenic-sedimentary creation of most of the Cu, Zn, and Pb mineralizations in these formations.

One more example of anomalous Cu and Zn contents in sedimentary rocks of the Murgul dere corroborates the model of mineralization. Twenty-two geochemical samples from primary dispersion halo in pelites, tuffaceous sandstones, locally marly, contained copper in excess of 70 ppm in seven samples, the maximum being 240 ppm, and more than 100 ppm zinc, classified as anomalous (Table 17), in twelve, or more than 50% of samples. The zinc contents varied from 140 ppm to 350 ppm.

All geochemical samples with anomalous contents were found west of Akarşen peak to the Gonuli dere, eastward to Petek Köy, and north on Balıklı Yayla area. The given example excludes tuffs, and refers only to sandstones, pelites, marly sandstones, and redeposited tuffaceous materials.

Table 17. Results of geochemical examination of sedimentary rocks west of the Murgul dere.

Ppm	
Cu	Zn
28	88
32	20
28	56
56	25
20	50
40	64
72	120
180	80
76	128
52	112
40	136
40	80
44	160
48	128
250	200
128	350
44	128
16	64
56	128
84	136
100	104
36	96

The above geochemical data for Cu, Zn, Pb in primary dispersion halo in the intermediate volcanogenuc and sedimentary rocks of Artvin-Murgul-Hopa-Maradit area and the number of metal assemblages in an even broader area of the entire metallogenic province of the Pontids lead to a safe conclusion about a great economic significance of the raw material potentiality, which could have been far greater if better explored. Excluding single metalliferous mineral deposits, which were beneficiated by opening mines and their only sporadic presentation in literature, formations of this sub-complex have been little explored. This sub-complex and the Jurassic/Neocomian formations will probably be explored more seriously and the exploration results will indicate new amounts of ore .Also new researches will reveal, yet unknown deposits of base and precious metals associated with them, which will provide proofs of an extremely great economic importance of the sub-complex.

POLYMETALLIC ORE DEPOSITS (ZINC, LEAD AND COPPER)

Generally, all ore occurrences are associated with andesite volcanogenic, volcanogenic-sedimentary and sedimentary formations of the given sub-complex. The occurrences have the following mode of appearances as: veins, impregnations, stockworks, and stockwork-impregnations. The genetic types of ore are volcanogenic (vein), volcanogenic-sedimentary (impregnated or stockwork-impregnated), epigenetic (veins and impregnations), exhalative-sedimentary, and epithermal. The main characteristic of the ores is the gold and silver enrichment. A regional correlation with the Carpatho-Balkanides is possible, only the older, Jurassic-Neocomian ore-bearing formations have not been found so far in eastern Serbia.

Generally scrutinized, sulfide ore deposits must be classified by the type, and mode of appearance, principal metal, origin, and economic value. According to up to day knowledge, all ore occurrences and deposits associated with formations of this sub-complex can be divided into four morphogenic types, viz.:

I. The deposits of Irsa Maden (near Artvin), Akarşen and Hohur Sırtı (near Murgul), the occurrences of Kutonit and other (at Hopa, Arhavı); possibly Madenköy deposit (near Çayelı), though not belonging to the Artvin Province which is the subject of this monograph. These are dominantly volcanic and volcanogenic-sedimentary deposits of different modes of appearance;
II. The occurrences near Maradit (Çavuşlu and Pehlivan Köy) classified into epithermal type, of the vein and stockwork-impregnation mode of appearances;
III. The copper ore deposits on Balıklı Yayla (Başköy Maden and the Didgele dere near Murgul) of the vein (anticline) mode of appearance with fluorite.

I. Morphogenetic Type

ARTVIN AREA

Irsa Maden is located about 6 km north of the Kuvarshan copper ore deposit (Figs. 22, 24). Relatively small, it was explored in the 20th century like all the other locations in Kuvarshan area. Together with the Kuvarshan

deposit it may be considered to belong to one ore zone, or both deposits could be classified in to a unified ore field. As suggested by old adits, this deposit was not only explored but exploited as well. K r a ë f f (1963) describes it as having a "horst" form composed of rhyodacite overlain by Upper Cretaceous spilite. Its copper contents vary from 2% to 4% and zinc from 15% to as much as 25%, accounting for the reference to a deposit of zinc and copper rather than vice versa. The deposit was explored by four trial adits at different levels: 780 m, 830 m, 960 m and 990 m. S i m o n o v i ć (1972) describes it as a polymetallic deposit of pyrite, chalcopyrite, sphalerite and galena as a chief ore minerals. The paragenesis also includes tetrahedrite, bornite, enargite, covellite, and chalcocite. The deposit is believed to be similar to the Akarşen deposit near Murgul, which consists of two types of ore: copper and lesser zinc, and Pb-Zn and lesser copper, the latter presumably formed in the Upper Cretaceous-Tertiary.

According to the geochemical examination of this locality, anomalous contents of copper varied from 150 ppm up to the so-called ore concentration (of 1000 ppm or more) and zinc from 500 ppm up to 1%, respectively. In single outcrops, copper was 1.86% and zinc up to 34.6% (S i m o n o v i ć, 1972).

Even if sampling was not systematical, the copper and zinc contents in samples from some outcrops and from waste rock of adits (at different levels) are sufficient to convince that the contents of copper, zinc and lead are high in the deposit. To this effect S i m o n o v i ć (1972) gives the following data (Table 18).

Table 18. Chemical composition of ore in IrsaMaden (from old waste rocks), after S i m o n o v i ć (1972) in %.

	Adit level (m)	Cu	Zn	Pb
Waste dump	990	7.33	25.13	6.03
	960	5.62	27.12	4.82
	830	1.86	34.64	-
	780	0.01	0.32	-

The above table shows that dominantly metal-rich samples were collected, so that the copper, zinc and lead contents were not representative (related to average content), but in any event, the paragenesis in Irsa Maden suggests high zinc, copper and lead contents in parts of or in the whole ore body. The deposit as

a whole can be taken for polymetallic by its mineral and chemical compositions. Though not average contents, the given amounts indicate that copper and lead, and partly zinc are decreasing with the depth. As given in Table 18, lead is lacking at the level of 830 m and downward, whereas copper and zinc are high. V u j a n o v i ć (1976/1977) obtained similar results by ore microscopic analyses of samples from the waste rocks. He found pyrite-chalcopyrite mineralization and associated tetrahedrite in rhyolite and rhyodacite volcanic rocks from the lower (primary) part of the ore deposit. The upper, younger part included hydrothermal (remobilized) chalcopyrite needles in bornite. These minerals occur in assemblage with pyrite. A distinctive feature of the deposit is the carbonate groundmass of the this deposit, also including sphalerite that is being replaced by younger galena, and partly tetrahedrite which occurs as derived out of sphalerite. Enargite also occurs, which is not common in the given area of the Pontic metallogenic province.

MURGUL AREA

1. H o h u r S ı r t ı. During the exploration of sulfide mineralization in Murgul area, this author had the opportunity to explore more in detail the sulfide ore occurrences on Hohur Sırtı. The exploration consisted of detailed geological mapping, geochemical prospecting and a small volume of trenching and sampling from natural and artificial outcrops. There are few written records and even less published references about this location that could give minimum information about the mineralization. An exception is S t e r n (1971) who reported some data from the M T A archives in Ankara, and a few reported by B u s e r (1970) and P e j a t o v i ć (1973). Ore occurrences were known for a long time which is indicated by the old mine workings (shallow shafts, pings, caved-in mines, etc.) and metallurgical remains represented by slag dumps. These may be an evidence of a remote past, but as when and who left it we do not know.

Sulfide mineralizations on Hohur Sırtı and the sulfide ore deposit of Akarşen are located on the same mountain ridge, connected by a track – the only road 2.5 km long between Hohur Sırtı and the small town of Murgul (Fig.29). Sulfide mineralizations are all on the northern slopes at the altitudes between 800 m and 1150 m. The northern side of Hohur Sırtı is mainly a gentle slope over which intermittent waters flow to NW into the Gonuli dere, this tributary into the Başköy dere, and further into the Murgul dere that flows into the Black Sea.

The ore-bearing area can be reached from Murgul only by using a cross-country motor vehicle on a very poor forest road heavily overgrown. Hohur Sırtı is separating valleys of the Gonuli dere and the Murgul dere.

About a square kilometre of the area where sulfide mineralizations of copper, zinc and lead occur is made-up of dominantly volcanogenic-sedimentary formations formed during the Upper Cretaceous and Paleogene. The oldest rocks

belong to the so-called **"upper basic series"**, or the Upper Cretaceous-Paleogene petrogenic complex of reddish basalt, amygdaloidal spilite, diabase, agglomerate, tuff, tuffaceous sandstone, carbonate sedimentary rocks composed of reddish and dark-grey limestones, marly limestones, and marlstones formed in the Maastrichtian (lower sub-complex). These are discordantly covered by different volcanogenic-sedimentary formations composed of andesite, dacite, and their pyroclastics (agglomerate, tuff, volcanic breccia), also tuffaceous sandstone, pelite and limestone of Paleogene age (upper sub-complex).

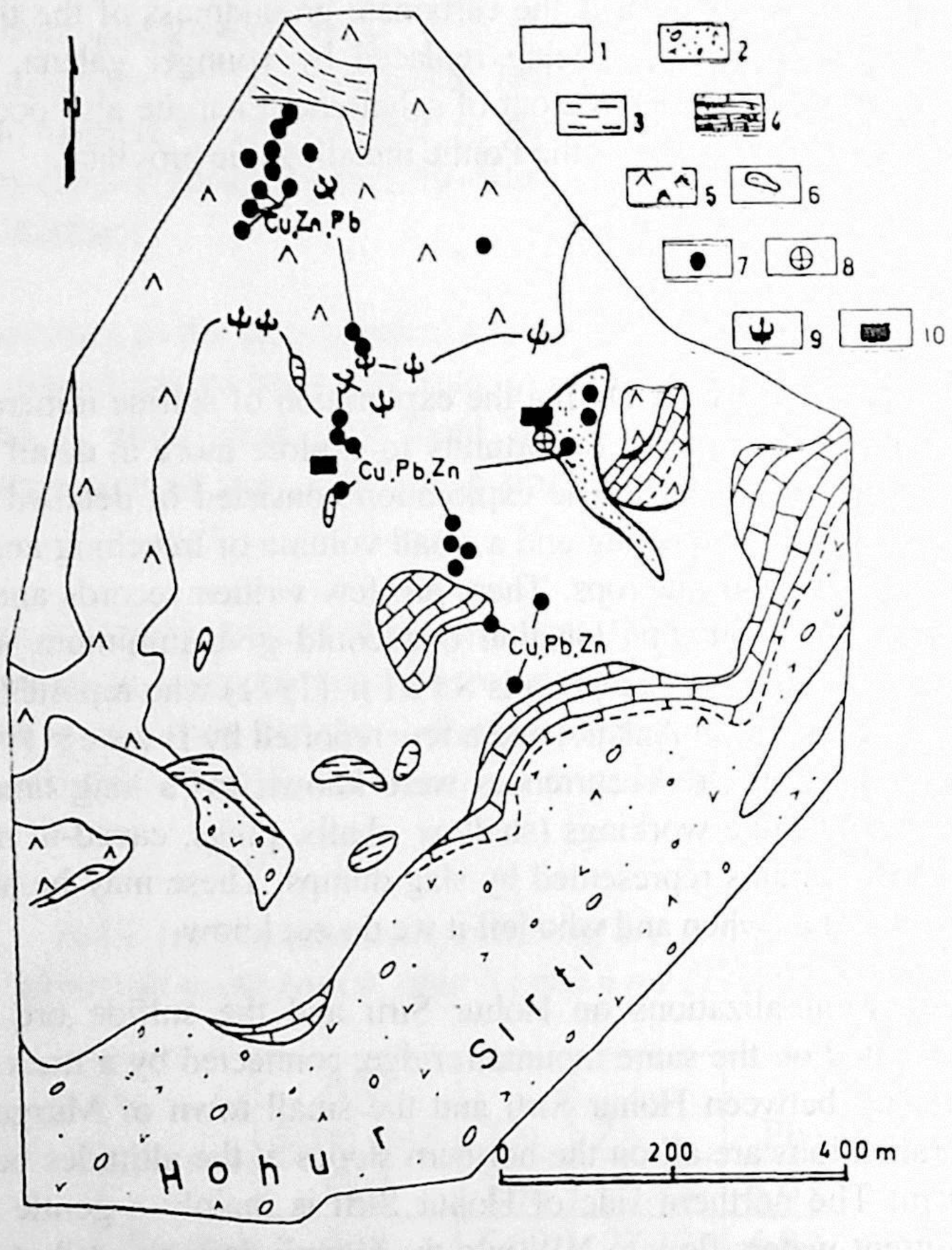


Fig. 54. Geologic map of Hohur Sirti (after, P o p o v i ć, 2002a).

1. Delluvium; 2. Andesite, dacite-andesite pyroclastics (agglomerate, tuff, tuffitic brccia , tuffaceous sandstone – Paleocene-Eocene age); 3. Marl and marly limestone (Upper Cretaceous-Paleocene); 4. Dark-grey marly, tabular limestone sporadically silicified (Upper Cretaceous); 5. Basalt, spilite (so-called ***"upper basic series"****) or lower sub-complex – Upper Cretaceous age); 6. Strongly pronounced silicification with copper-mineralization; 7. Cu, Zn, Pb occurrences; 8. Old shaft (mining); 9. Landslide; 10. Slag dump.*

During a short break in the volcanic activity in the Upper Cretaceous, first tuffaceous, pelitic and marly sediments were deposited in the sea basins where previously submarine volcanism of basic composition evolved. Subsequent sediments were thin plated inoceramus limestone which indicated the Upper Cretaceous age (uppermost Senonian-Maastrichtian). Then, the deposition continued of dominantly marly, pelitic and tuffaceous sediments, determined as the Maastrichtian-Paleogene.

Unlike the basic sub-complex of less than 500 m of estimated thickness, the upper or intermediate rocks (dominantly andesite-composed volcanic rocks) sub-complex is estimated about a thousand meters thick.

Delluvial deposits more than 30 m thick in places, however, occupy a large area. This newest formation on Hohur Sırtı is largely characterized by un-tectonic deformations that caused many landslides, as many as ten larger and smaller landslides in an area of about 1 km^2. They are supposedly controlled by a fault zone of the approximately NE-SW direction. It is interesting to note that mineral occurrences were identified "in situ" as outcrops, including those moved by slides, assembled in the centre, as shown in the geological map (Fig.54), forming a zone of 100 m in width and about 700 m in length in the general direction NW-SE.

Dacite andesite is also very important for the copper and zinc mineralization. The rocks are much hydrothermally altered (kaolinized, silicified, argillized, carbonatized, pyritized, etc.). Though observed only where sulfide-mineralization was found, its distribution under the delluvium is believed much larger. Beyond the limits of the explored area, rocks of the sub-complex are widespread, including the Akarşen ore deposit to which this occurrence resembles in the association of chemical elements, paragenesis, gold-bearing, and time of respective magmatism from which derive both mineralizations.

Geochemical explorations

Geochemical explorations of the pedological **"B"** stratum was carried out in a network of 100x25 m and the results are given in the geochemical map (Fig.55). The map clearly shows the orientation of geochemical anomalies, which allow a general division of two principal zones in roughly NW-SE direction and both of them are very closely spaced. Partially another zone is indicated by zinc contents (the lowest zinc content of 144 ppm was the reference amount). It extended in the same direction, only 250 m to 300 m SW

from the former two. Closely scrutinized, the geochemical map shows one more anomalous zone at an angle of about 45° to the other zones of geochemical anomalies, in the direction NE-SW. Like the former two, this anomaly is identified by copper contents higher than 93 ppm. The location where this anomaly is intersecting the former two zones of geochemical anomalies fully corresponds to the area of mineral outcrop, old mine workings and an old slag dump.

The reference metal contents were minimum 100 ppm for copper and 144 ppm for zinc. As to the lead, its anomalous contents were only spot sampled and only those higher than 100 ppm were taken into account. The spot anomalies fitted those of copper and zinc anomalous zones, therefore are not presented on the geochemical map. Besides, outside the zones of the geochemical anomalies, several isolated copper and zinc anomalies were registered, interpreted as increased assemblages of these metals in a secondary aureole as a result of disintegration of rocks in which the background of the metals was increased. It may be quite safely stated that geochemical anomalies are the ore anomalies in the central exploration area.

It cannot be safely stated that real outcrops of all copper, zinc and locally lead occurrences were identified ("in situ"). Most of the occurrences are associated with a large mechanical dispersion halo. Even in places of trenching, real outcrops were questionable. Only in the old, shallow shaft that was opened by trenching one can speak of an outcrop, which was sampled. In all other places, only single samples from a mechanical dispersion halo were analyzed. Because it is a very large mechanical dispersion halo, one of the largest in Murgul area, it indicates the very likely presence of sulfide mineralization of copper, zinc and lead on Hohur Sırtı and their direct genetic and paragenetic relation with andesites. The geochemical anomalies suggested the same.

According to the field data, copper and zinc are principal metals followed by lead, gold and silver. The most abundant ore mineral is pyrite, then chalcopyrite and sphalerite. Galena is less abundant, tetrahedrite sparse, and argentite was also found.

Pyrite occurs in shapeless grains, commonly crushed by tectonic, then in colloid (melnikovite) round forms. It locally pyrrhotite separated from pyrite.

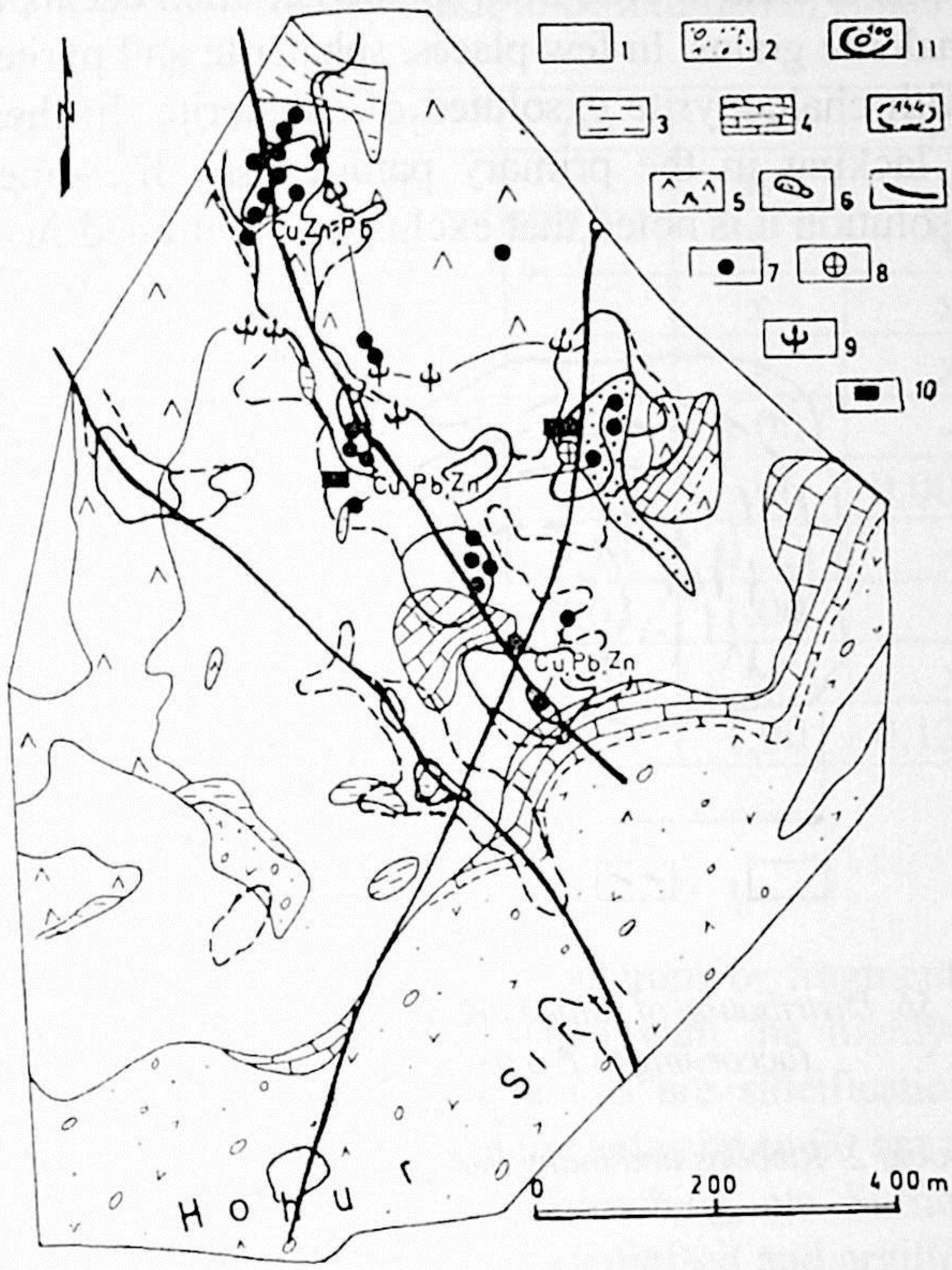


Fig. 55. Geochemical map of Hohur Sirti (P o p o v i ć, 2002a).
1 .Delluvium; 2. Andesite, andesite and dacite-andesite pyroclastics; 3. Marl and marly limestone; 4. Dark-grey marly and tabular limestone; 5. Basalt, spilite; 6. Strongly pronounced silicification with Cu-mineralization; 7. Cu, Zn, Pb - occurrences; 8. Old shaft (mining); 9. Landslide; 10. Slag dump; 11. Isolines of geochemical Cu-anomalies; 12. Isolines of geochemical Zn-anomalies; 13. Axes of principal geochemical anomalies.

The second most abundant, in analyzed samples, is chalcopyrite. It occurs commonly in fine grains that form irregular aggregates. Tectonically crushed pyrite grains were subsequently cemented by chalcopyrite, which is another mode of occurrence this mineral, and an evidence of more than one generation of chalcopyrite. Chalcopyrite cement belongs to a younger generation.

Sphalerite is commonly equally or even more abundant than chalcopyrite, which is reflected on the chemical composition of the mineral (Table 19).

Exsolutions of chalcopyrite from sphalerite, often occurs on or into the periphery of sphalerite grains. In few places, sphalerite and pyrite are the only ore minerals, with chalcopyrite exsoluted of sphalerite. In these instances, chalcopyrite is lacking in the primary paragenesis. In some cases with chalcopyrite exsolution it is noted that exclusion of tetrahedrite occurs.

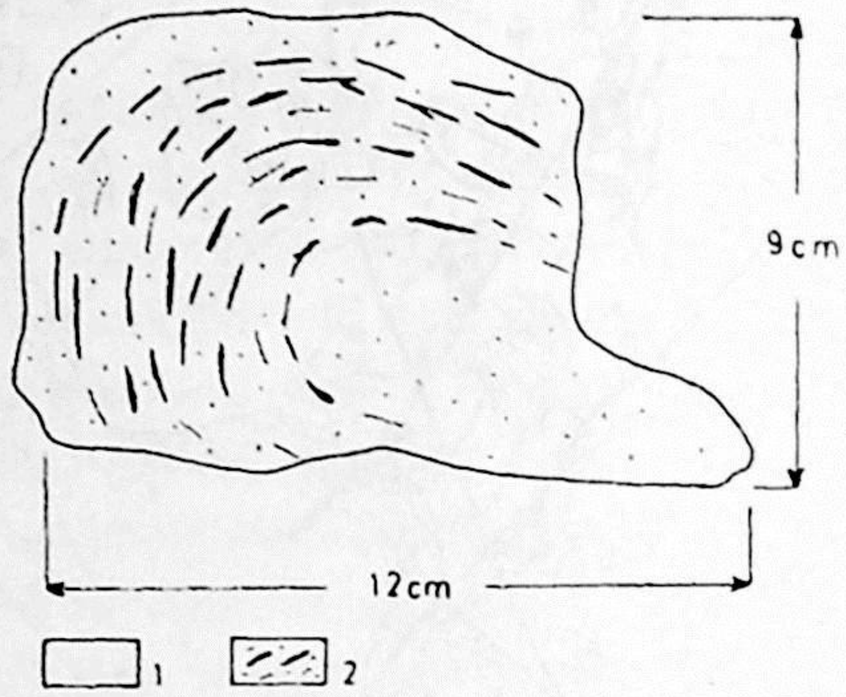


Fig. 56. Distribution of sulfide ore minerals in silicified rock (according to P o p o v i ć, 2002a).

1. Silicified rock; 2. Ribbons and individual grains of pyrite and chalcopyrite.

Galena grains are sparse, but local accumulations of the mineral contain as much as 1% of lead.

Tetrahedrite (tennantite) is relatively common indicating the enrichment of this mineralization with noble metals. Argentite was found in one sample, also adding to the potentiality of precious metals.

Besides the mentioned minerals, the paragenesis of sulfide mineralization on Hohur Sırtı locally registered other minerals: marcasite, bismuth sulphosalt, then secondary chalcocite, covellite and limonite. These minerals are developed over chalcopyrite and pyrite grains or along the grain fissures. Arsenopyrite was identified as a very rare mineral.

Sulfide mineralization on Hohur Sırtı is ribbon-impregnated by the mode of occurrence. Highly silicified rock clearly shows pyrite and chalcopyrite ribbons. The ribbons orientation resembles the semi-circular distribution of ore minerals. Single grains of ore minerals in smaller or bigger accumulations impregnate the rock between the ribbons (Fig. 56).

Table 19. Metal contents in sulfide mineralization of Hohur Sırtı (%)

Cu	Zn	Pb	As	Ba	Cd
3,34	0,096	tr.	x	x	x
3,49	0,30	tr.	x	x	x
2,14	0,054	tr.	x	x	x
0,054	2,40	tr.	x	x	x
4,84	7,75	0,25	0,10	1,00	-
2,72	13,70	0,02	0,04	0,06	0,0042
1,26	0,60	0,26	0,13	0,32	-
2,11	0,41	1,03	0,03	1,00	-
2,88	4,05	0,11	0,08	x	x
1,00	1,50	0,26	-	1,00	0,128

x - not analyzed;

tr.- content in traces.

Sulfide mineralization, either in outcrops or fragments in mechanical dispersion halo are everywhere associated with the highly hydrothermally altered rocks. The highest grade alterations are silicification, kaolinization, calcitization (locally in fault zones, calcite veins up to 20 cm thick bear calcite crystals larger than 1 cm^3), pyritization, bleaching, etc. Sulfide mineralization are commonly emplaced in silicified, or kaolinized and argillized environment reminding of a fault zone.

Contents of the main and some trace metals are given in Table 19.

The metal contents in the table above are relatively high for copper and zinc, and mostly low for lead. Arsenic is relatively low (less than 0.2%), which is important for the technology of this type of sulfide mineralization, particularly where the precious metals are concerned.

Finally, cadmium is interesting. Despite the locally high zinc content, this metal was identified only in two samples: 42 ppm in one and as much as 1280 ppm in the other. For example, the sample that contained 13.70% of zinc had only 42 ppm of cadmium, and the other with only 1.5% zinc contained 1280 ppm of cadmium.

According to what the prevailing conditions on Hohur Sırtı allowed us to see, the sulfide mineralization is associated with a fault zone, on one hand, and the parent rock is a volcanic rock of andesite composition, on the other.

A particular characteristic of the terrain are sediments with the feeble impregnated sulfide mineralization. The Marly sediments contain increased amounts of zinc (150 ppm) and copper (100 ppm) and in some spots increased lead (100 ppm). These data show that metals obviously were supplied during the volcanogenic-sedimentary events. It is also indicated by metal contents in tuffaceous sedimentary rocks: copper 0.0556%, zinc 0.29%, Lead 0.22%, gold 0.11 ppm, silver 2.25 ppm and arsenic 217 ppm.

Mineralization, formed through volcanogenic-sedimentary conditions, on Hohur Sırtı were subsequently affected by hydrothermal fluids, partly or fully regenerated and integrated with the younger vein mineralizations.

All data considered the ore occurrence of Hohur Sırtı resembles mostly to the Akarşen sulfide ore deposit. Therefore, the entire area between Hohur Sırtı and Akarşen is a prospect for further exploration, because similar deposits probably will be found.

2. A k a r ş e n. Murgul area has long been known for its copper bearing. Many deposits and occurrences of copper, and less of zinc and lead, located in the area of Murgul and around it, were exploited, some prospected, and others are expected explorers could be finally estimated.

One of the ore deposits that was repeatedly explored and mined in the past is polymetallic deposit of Akarşen. It is located in the extreme SW of the ridge between Hohur and Akarşen mountain peak. It is the highest peak of the ridge, 1759.68 m. From Hohur (1247 m) the ridge rises to this highest peak, which is also the highest point in the area. Akarşen ore deposits lay at the southern slope of the peak about 2 km from it. The deposit is located in the source area of a nameless stream that runs parallel with and about 500 m SW from the Akarşen Suyu. Both streams flow into the Murgani Hevi and than into the Murgul dere.

A poor village road of about 8 km long, leads from Murgul town to the ore deposit of Akarşen (Fig. 29) via Petek Köy.

The Akarşen ore deposit has been known from the end of the 19th century and periodically mined at the beginning of the 20th century. It was explored several times after the Second World War, but its geological and economical significance have not been fully defined. The deposit is polymetallic with notable concentration of precious metals (Au, Ag).

In the late fifties, K l a y (1959, in: K r a ë f f, 1963) studied the origin, mineral composition and age of the deposit. Based on his data, it was

believed that the ore consisted of copper-enriched pyrite and that it was associated with upper part of silicified albite dacite, partly covered by spilite, marlstone, limestone and tuff of Upper Cretaceous age, or that the ore was spatially associated with the rhyolitic volcanogenic and volcanogenic-sedimentary complex, which is presently interpreted as developed in the Malm-Neocomian.

The deposit was later, 1970/73, explored by experts of the Otto Gold from Köln (Germany), and mentioned in published papers by Vujanović (1975), Pejatović (1975/79), Popović (1976, 1979), Popović, Vakanjac (2002), and others. Though mentioned by many explorers, but without any serious analysis, the information is still insufficient for a final estimate of their economic significance.

Geological setting of the Akarşen ore deposit

Geologically, the ore deposit is probably related to two very complicated volcanogenic and volcanogenic-sedimentary petrogenic complexes. There are also other formations, in the area, some of which may have an influence on the ore deposit of Akarşen. The petrogenic complexes are the following:

1. Volcanogenic-sedimentary, formed in the lower Malm (Oxfordian-Kimmeridgian),
2. Volcanogenic and volcanogenic-sedimentary, formed in the upper Malm (Tithonian) and Neocomian,
3. Upper Cretaceous-Tertiary volcanogenic, volcanogenic-sedimentary and sedimentary,
4. Tertiary (Eocene) intrusive petrogenic complex.

It should be mentioned at this point that a part of the copper mineralization is emplaced in acidic, dominantly rhyolitic, or rhyodacitic volcanic rocks (assigned to Upper Jurassic-Lower Cretaceous petrogenic complex), and the other part is associated with the Upper Cretaceous-Paleogene complex.

In the part of the rhyolite, or rhyodacite complex, particularly the part placed in the tectonic contact zone, all major copper-ore deposits and occurrences of the Murgul area are located. The other, polymetallic part is

associated with Upper Cretaceous-Paleogene predominantly andesitic volcanism (Fig. 57).

K r a ë f f (1963) also marked the same structure without any further detail. This is a regional structure with characteristics of the imbricate structure or the reverse fault of high grade (P o p o v i ć, 1976). The Akarşen peak area is characterized by many faults, some of which are mineralized. Generally, the Akarşen ore deposit is complex in geology and mineralogy and should be considered as such. This will be more convincing if the noted folding of formations is added.

As a result of all the mentioned circumstances, the polymetallic ore deposit of Akarşen is believed to include more ore bodies formed in different periods of time.

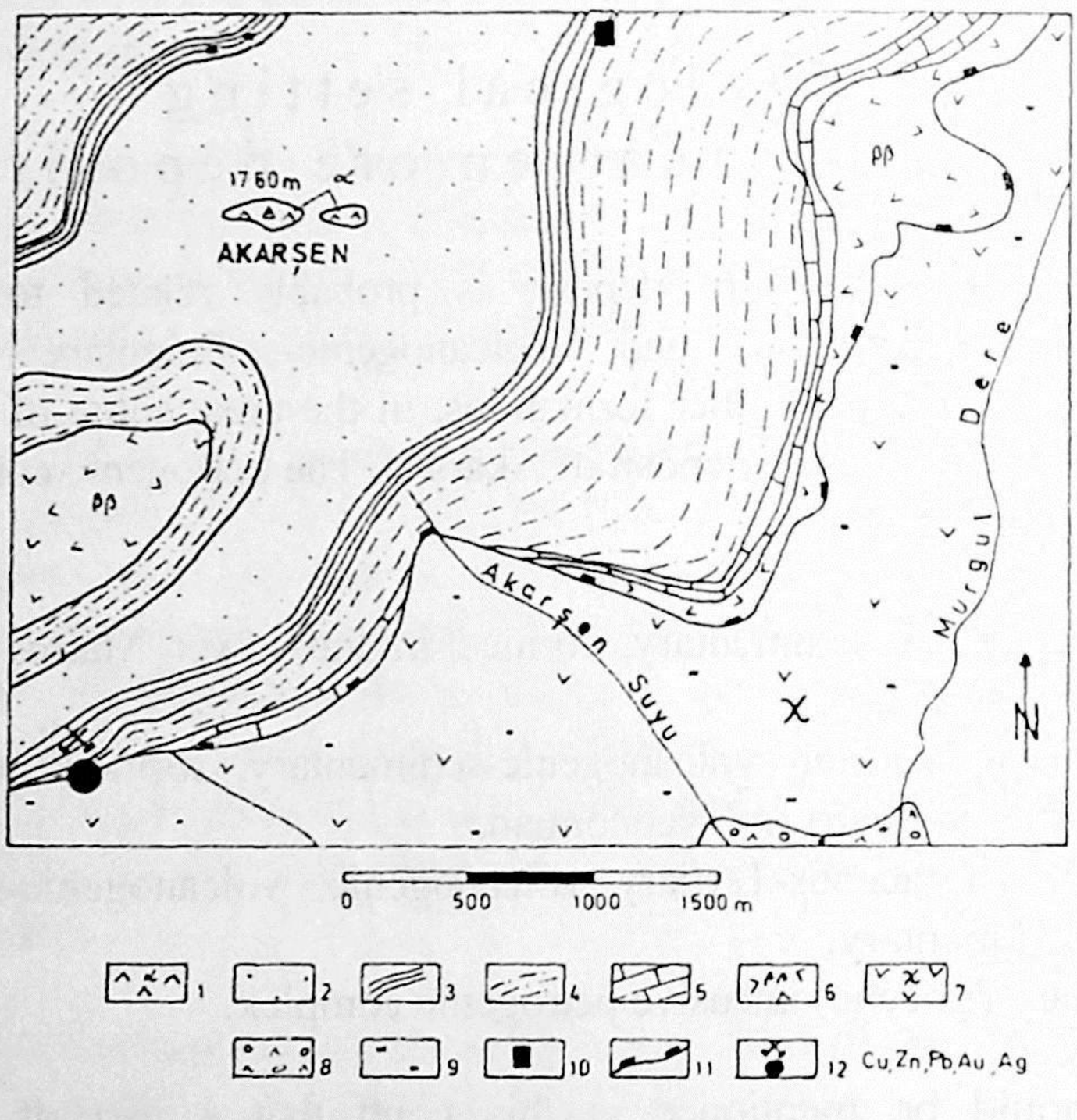


Fig. 57. Geological map of Akarşen area (after P o p o v i ć, 2003b).

1.Andesite; 2. Andesite pyroclastic; 3. Tuffaceous sandstone; 4. Marl; 5. Limestone (thin-bedded); 6. Basalt, diabase, spilite; 7. Rhyolitic and rhyodacitic volcanic rock; 8. Sandstone and tuffaceous sandstone (Oxfordian-Kimmridgian); 9. Pyritization; 10. Individual slag dump fragments; 11. Imbricate (?) structure; 12. Akarşen polymetallic ore deposit.

The polymetallic ore deposit of Akarşen has been systematically explored and mined for more than a century. Many old mine workings (adits) and sporadical metallurgical remains (slag dump fragments) are an evidence of how important this deposit was in the past. K r a ë f f (1963) writes that it was exploratory drilled by S i e m e n s C o m p a n y in the period 1912-1913. Later, E t i b a n k of Ankara continued the exploration and gave the first calculation of the ore reserve of about thirty thousand tons and about 3.5% of copper. The exploration by L. K l a y (1959), cited also by K r a ë f f (1963), proved that copper ore was emplaced in upper parts of the Upper Jurassic-Lower Cretaceous volcanogenic and volcanogenic-sedimentary complex and that pyrite, chalcopyrite, sphalerite and tetrahedrite were the principal ore minerals. He also writes that the deposit's ore reserves was about 300 thousand tons that contained copper from 3% to 5%, silver from 3.5 ppm to 338 ppm, and gold from 0.27 ppm to 7.2 ppm. The same author describes the ore deposit as about 170 m long, about 20 m wide, to the traceable depth of 30 m. K r a ë f f (1963) himself estimates the reserves on Akarşen at about three to four million tons of lower-grade ore.

P e j a t o v i ć (1973) writes that it is a small deposit of about 700 thousand tons of good massive copper ore, and also that the geological position of the deposit is not clear: either "Jurassic-Neocomian or the Late Cretaceous level".

The ore deposit was also explored in the period 1970-1973 by specialists of the mentioned O t t o G o l d from C o l o g n e, G e r m a n y, but their findings, unfortunately, were not available to us. It is know that they mapped in detail the deposit area, provided geochemical prospecting, recovered some old mine workings (adits), mapped them and sampled. In addition to this, they did several explorations drilling to the depth of 200 m. The deposit probably was estimate as economically insignificant, and further works were terminated.

Besides other lithologic units within the deposit, several minor quartz diorite masses were formed, one of which in the fault, ore zone that is dipping to the north at angles between 20° and 35°. The zone was penetrated at the depth of 200 m by exploratory drilling of O t t o G o l d, headed by F. P r o k o p, but the zone was thin and slightly mineralized. The ore zone direction is roughly east-west. It consists of mineralized rhyolite tuff, like other mineralization in similar rocks of the Malm-Neocomian age. Several hundred meters eastward to the Murgul valley these rocks pass into the rhyolitic volcanogenic and volcanogenic-sedimentary complex that extends in the southern part of Murgul region, and the ore zone itself is extending in the same direction.

Rhyolitic volcanic rock – the parent rock of one part of the ore-deposit in Akarşen – is not uniformly pyritized and chalcopyrite-enriched; chalcopyrite is relatively low even where pyrite was massive. However, waste dumps from the old mine workings (four adits) suggest that the deposit consisted only of pyrite and chalcopyrite, as reported by K r a ë f f (1963) and P e j a t o v i ć (1973), but also of sphalerite and galena; which was confirmed by fragments of almost pure galena in the Murgani Hevi stream which was founded by the author of this book. The remained salband and breccia fragments indicate their likely derivation from a galena vein at least 15 cm thick, probably from the Akarşen deposit.

Also, waste dumps from the old adits in the Akarşen ore deposit indicate massive pyrite, pyrite-chalcopyrite and massive galena-sphalerite ore. Their relationship is not yet clarified. The fact is that microscopic analyzed established a small concentration of galena in chalcopyrite ore and that chalcopyrite is subordinate in the galena part of the deposit, but sphalerite is relatively highly present in both cases. Such mineral composition affects the copper, zinc and lead contents. In the part of the deposit in which pyrite-chalcopyrite ore is dominant, copper content varies from 0.5% to 8%, and lead content from 20 ppm to 0.25% (2.78% in one place). Where sphalerite and galena are prevailing, lead content is 2.9% and zinc higher than 15%, whereas copper rarely exceeds 0.5%. In galena vein, from which a fragment was found in the Murgani Hevi, lead content is 75.52%, and zinc and copper only 0.07% and 0.91%, respectively.

The Akarşen deposit as a whole is barite-enriched (more than 1% barium), so that it can be characterized as a barite-polymetallic deposit.

Forms of ore mineral and sizes are varied. Chalcopyrite appears in various shapes and sizes and sometimes in veinlets. Sphalerite occurs in fine grains associated with chalcopyrite. Where galena is high, the mineralization is characterized by abundant pyrite, then galena, and much lower chalcopyrite. In contrast to pyrite-chalcopyrite ore, galena type contains pyrite in gel form (dominantly melnikovite) or in the form of "mineralized bacteria". Galena also shows not uncommon, gel forms in association with gel-pyrite, in alternating substitution. According to such characteristic this type remarkably differs from the pyrite-chalcopyrite type (Figs. 58, 59).

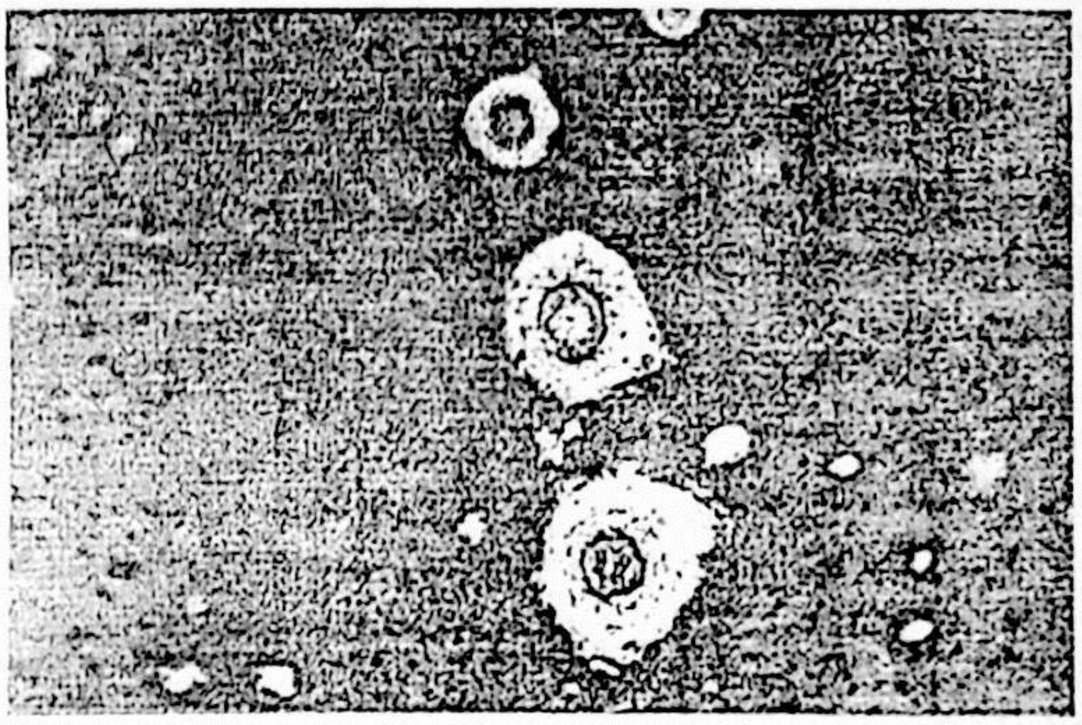


Fig. 58. Microphotograph of rounded ore graines from Akarşen deposit. "Enlarged 80x. In the pyroclastic volcanic rock groundmass three rounded grains are visible with concentric alternation of calcopyrite (light grey), galena (grey) and pyrite (light grey, pronounced relief)", after V u j a n o v i ć (1975).

This situation (refers to various concentrations and modes of ore mineral occurrence differing from one part of deposit to another) may indicate two genetic types of the ore. The older, associated with rhyolitic volcanic rocks, or a tectonic zone, can be classified to the volcanogenic type. The younger ore, containing galena, probably associated with volcanogenic-sedimentary complex (Upper Cretaceous-Tertiary) and belongs to the volcanogenic-sedimentary type of origin .

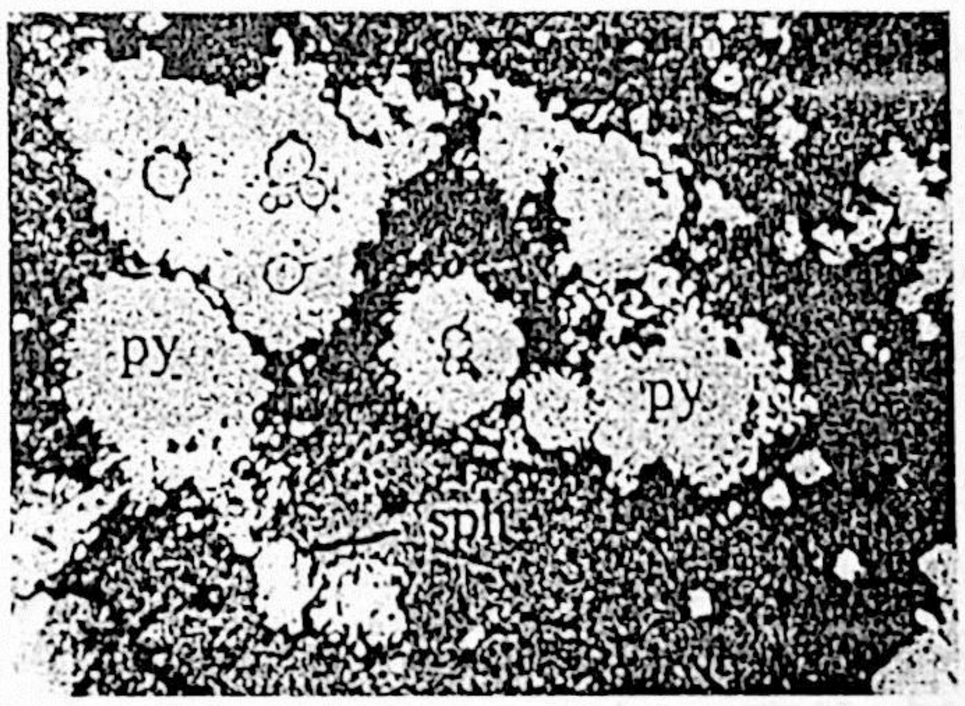


Fig. 59. Microphotograph of rounded ore grains from Akarşen ore deposit (P o p o v i ć, V a k a n j a c, 2002). Enlarged 50 x, // N. Pyrite spherulites (py) in sphalerite (sph).

The assumption is supported by the metal-enriched sedimentary rocks (tuffaceous sandstones), which belong to the andesitic volcanogenic and volcanogenic-sedimentary complex. For example in these rocks registered contain of copper is 0.056%, lead 0.30% and zinc 0.22%. All the data considered a reasonable conclusion is that there are two genetic types of sulfide ore on Akarşen, which opens better prospects for the Akarşen ore deposit.

Table 20. Contents of base metals in ore deposits of Akarşen, Hohur Sırtı, Maden Köy, Anayatak and Çakmakkaya

Location	Principal metals in ore	%				
		Cu	Zn	Pb	Ba	As
Akarşen	Cu, Pb	0,75	15,48	2,78	1	0,037
Akarşen	Cu, Zn	5,59	5,75	0,11	x	0,059
Murgani Hevi	Pb	0,91	0,07	75,52	x	0,012
Hohur Sırtı	Cu, Zn	4,85	7,75	0,25	x	0,102
Hohur Sırtı	Cu, Zn	2,72	13,70	0,023	x	0,043
Hohur Sırtı	Cu, Zn	2,11	0,41	1,03	x	0,025
Madeköy near Çayelı	Cu, Zn	3,29	7,62	0,36	0,50	0,034
Anayatak	Cu (chalcopyrite)	23,85	0,05	0,04	x	00,034
Anayatak	Cu (average content)	1,32	0,10	tr.	x	x
Çakmakkaya	Cu (average content)	0,98	0,10	tr.	x	x

x - not analyzed
tr. - traces (less than 100 ppm)

The ore deposit of Akarşen differs in character from the deposits of Anayatak, Çakmakkaya, Kilise Tepe and others, but is similar to Maden köy at Çayel, which is
also polymetallic and auriferous, and to the sulfide mineralization occurrence on Hohur Sırtı (Table 20).

The above contents show the similarity in chemical composition of Akarşen, Hohur Sırtı and Madenköy. The likeness is mostly in the polymetallic composition, relatively high precious metals (Au, Ag[1]) contents, presence of characteristic rounded forms of ore texture (suggesting volcanogenic-sedimentary origin), mineral association, etc.

Gold and silver are obviously characteristic for these deposits, because the contents of the two metals are much higher than in Anayatak or Çakmakkaya, and with relatively high barium, unlike the Malm-Neocomian ore deposits.

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[1] The two metal contents will be given in another section.

Chemical compositions, given in Table 20, fully correspond to respective mineral compositions – the reason why the mentioned three deposits are classified as polymetallic. The Malm-Neocomian deposits (Anayatak, Çakmakkaya, etc.) are classified as the dominantly copper-ore deposits, although zinc content in them is high.

Concerning the contents of the principal elements (copper, lead, zinc, gold and silver), Akarşen is the most important deposit in Murgul area. Although its ore reserves are estimated at about a million tons (massive ore about 600 thousand tons with 3.2% of copper and disseminated ore about 350 thousand tons with 0.34% of copper) the available data indicate a much larger potential reserve. A new research of this deposit will require a new concept of exploration adjusted to the genetic type of the deposit, petrogenic setting and time of origin of the deposits.

Although the number of analyses limited our examinations, the average copper content of 2.33% in Akarşen deposit is a factual data that differs from the 3.2% given by E r s e ç e n (1989). The two percentages are correlative, because we did not separate poor from rich ore. The deposit can be ranked among the rich ore deposits. The obtained contents are similar for the precious metals.

Finally, in view of the mineral and chemical compositions of Akarşen ore, and the contained precious metals, this deposit is almost identical in all metallogenetic properties with the sulfide minerals on Hohur Sırtı (also near it) and with the large deposit of Madenköy near Çayeli. It differs, however, from Anayatak and Çakmakkaya, Aduca Dere, Kilise Tepe and other deposits of the Malm-Neocomian age in Murgul area, and from the younger ore deposit Başköy.

A conclusion from all the above stated is that Akarşen surroundings and the area between Akarşen and Hohur Sırtı are highly prospective of new polymetallic ore deposits enriched in gold and silver and therefore with high commercial value.

HOPA AND ARHAVI AREAS

Upper Cretaceous-Paleogene ore deposits of the **morphogenetic type I** include some ore deposits in Hopa and Arhavi areas.

1. K u t o n i t is the third major deposit (or occurrence) of pyrite-chalcopyrite copper ore-bearing in the Hopa-Arhavi area (Fig. 53). It is located about 3 km SW of Sivrikaya. There are two more Cu-Zn occurrences near Kutonit, but this one is an outcrop more than 20 m long and about 5 m thick. Copper mineralization is associated with a fault zone more than 5 km long and about 2 km wide.

The occurrence was explored by mining works in the first half of the 20th century. Six mine adits were found and all of them tumbled down. Only samples from the waste rocks and from the outcrop near of old adit could be used for analysis of the copper mineralization. Because silicification has spread to the hangingwall volcanic rocks, it is supposed that this was a post-ore alteration, probably in Paleogene, as also suggested by the presence of the nearby quartzdiorite. If so, the occurrence is of the Akarşen type, a polymetallic ore deposit formed during the Upper Cretaceous-Paleogene volcanism. This interpretation is supported by the contents of lead as a result of high galena (much higher amounts than in the type of deposits such as Peronit or Sivrikaya).

Z i m m e r (1937) and K o v e n k o (1941) left extensive descriptions of the Kutonit polymetallic mineral. More interesting still is the A s l a n e r' s (1971) description of the mineral composition of Cu, Zn, Pb mineralizations. K o p r i v i c a (1977) described in detail the geology of the Kutonit area.

The sulfide mineralization of Kutonit consists of pyrite – most abundant constituent, and of chalcopyrite, sphalerite, galena, (primary and secondary) bornite and tennantite. The mineralization occurs in thin veins filling rock fractures and cracks. According to A s l a n e r (1971), other minerals had been identified: hematite, magnetite, neodigenite, chalcocite, covellite, malachite, and also gangue minerals: quartz, sparse barite, calcite, etc. A characteristic feature of the mineralization is the gel-structures that often occur in pyrite, and also found in chalcopyrite or sphalerite. Based of this, she supposed that the Kutonit deposit belong to the exhalative-sedimentary type. In some adits at Kutonit, according to A s l a n e r (1971), sphalerite veins are up to 0.80 m thick, subordinate followed by chalcopyrite, which, according to the same source (A s l a n e r, 1971), is exuded from sphalerite.

During the 1971 geological mapping, K o p r i v i c a and his associates collected samples from waste dumps in front of adits for chemical analysis (Table 21).

Table 21. Chemical composition of ore from Kutonit ore deposit (K o p r i v i c a, 1977).

%		
Cu	Zn	Pb
0,82	10,03	tr.
24.06	3.76	0.31
2.60	56.57	1.35

The contents in the table above are obviously from selected samples and cannot be used in a realistic estimate of the economic value of this polymetallic ore deposit. The high zinc percentage indicates that the sample came from the sphalerite vein. Still the above amounts show the maximum amounts of copper, lead and zinc at Kutonit.

Besides the Kutonit sulfide ore deposit, which formed in the Upper Cretaceous-Paleogene according to its chronostratigraphic position, there are other synchronous mineralizations similar or identical in mineral composition, genesis and mode of appearance. These are Yukarı Pınarlı, Konaklı, Güneşlı Köy 1, Güneşlı Köy 2. There are also the pyrite type appearances, such as Zn, Cu mineralizations of Mağara.

According to mode of appearance and mineral paragenesis mineralization of Kutonit resembles the polymetallic ore deposit of Akarşen (near Murgul). Only, according to the data given by K o p r i v i c a (1977), this polymetallic mineralization seems to occur in a vein-form. A s l a n e r (1971) also describes the vein type of copper mineralization emplaced in dacite-andesite volcanic rocks. It was not only explored, it was mined as well. Six adits were found there from which samples were collected that contained more than 7% copper (K o p r i v i c a, 1977). The same author borrowed the information from Z i m m e r that a sample of 2.5 tons from the adit 5 contained 6.18% copper, and another from a (pure) sphalerite vein contained 66.50% zinc. These extreme results cannot be taken into consideration as realistic.

The ore deposit was estimated economically insignificant, but the estimate was not based on sufficient exploration data, and therefore should not be accepted.

The genetic consideration of A s l a n e r (1971) is interesting. She maintains, on the basis of the colloidal structure of single chalcopyrite,

pyrite and sphalerite grains (ellipsoid form), that the deposit is of exhalative-sedimentary type by origin formed at lower temperatures, subsequently re-crystallized. This is not a groundless statement, because similar evidence was found in some other ore deposits (Akarşen at Murgul for one, and elsewhere).

In the area prospected in 1970 (published information in 1977) Koprivica noted mineral occurrences in Pınarlı, Kutonit, Güneşlı Köy (Yukarı and Aşağı) and Gürgençlik Köy.

2. P ı n a r l ı. This sulfide mineralization occurrence is located south of the village of Pınarlı (Fig. 53). It is pyrite impregnated in agglomerates and tuffs of andesite composition. Also a fault was noted including a zone of silicification, kaolinization with pyrite-chalcopyrite mineralization. K o p r i v i c a (1977) cites copper and zinc contents of 0.53% and 5.09% respectively in a sample. This occurrence is believed not to be the only one. Southeastward to Balıklı Yayla (near Murgul) other occurrences may be expected.

3. G ü n e ş l ı K ö y N o r t h. This occurrence, named **Güneşlı Köy 1** by K o p r i v i c a (1977), is located south of Kutonit. It is a much silicified, kaolinized and pyritized petrogenic environment. According to the same source, copper and zinc mineralizations are emplaced in brecciated andesitic volcanic rocks. Principal ore minerals, besides pyrite, are chalcopyrite and sphalerite. Local malachitization is also noted. The mineralizations are localized at the intersection of two faults. The respective copper and zinc contents of 1.40% and 7.80% are reported from one sample of mineralized tectonic breccia.

4. G ü n e ş l ı K ö y S o u t h. Like the preceding location, K o p r i v i c a (1977) denoted this occurrence as **Güneşlı Köy 2**, located about 1 km south of Güneşlı Köy. He describes it as an ore vein about 12 cm thick composed principally of pyrite, chalcopyrite and low sphalerite. Sulfides are impregnated in the ore vein and only 2 cm to 3 cm in the adjacent rocks. He believes the two occurrences, **Güneşlı Köy North and South**, are genetically associated with the nearby granitoid which are causing contact-metamorphic alterations of adjacent rock. Besides sulfides, garnet and magnetite also occur in the contact zone. K o p r i v i c a collected a sample in 1971, which contained 1.10% copper and 0.50% zinc.

5. G ü r g e n ç l i k K ö y. An occurrence of copper and zinc mineralization was found at Mağara northern slope, which was mentioned

by K o p r i v i c a (1971) as skarn, but its description of an outcrop of about 10 m^2 represented by mineralized andesite breccia virtually renounces it. His assumption of the skarn type is based on some noted alterations in carbonate rocks that resemble skarn wherefrom he deduced the contact metamorphic copper and zinc mineralization. A sample from the outcrop gave copper of 0.40% and zinc 7.40%.

II. M o r p h o g e n i c T y p e

Epithermal mineralizations of proved adularization are classified into this type of sulfide occurrences. Only in the Maradit area of the Artvin Province this type has been identified. There are some other inferred ore occurrences and deposits but they have not been proved yet.

MARADIT AREA

During the research of sulfide ore deposits in NE Turkey, the occurrences of zinc, lead and copper in Maradit area were only prospected. Of the six occurrences, only two in the Güresen Dere valley were examined. The mode of ore appearance, petrogenic environment of the ore emplacement, size of occurrences, and metal (Cu, Pb, Zn) contents indicated a highly potential prospect. The collected information about these occurrences has not been published, only mentioned (P o p o v i ć, 1976; 2002b).

The village of Maradit is located about 15 km north of Borçka in the Çoruh valley, extreme NE of Turkey, which is the borderline of Turkey and Georgia (Fig. 60). A macadam road runs from Maradit to Borçka, wherefrom roads lead to Artvin, Murgul and Hopa (on the Black Sea).

About 2.5 km to 3 km before Maradit, a macadam road branches upwards the Güresen valley along which copper, zinc and lead sulfide mineralizations were located.

Same as many other sulfide mineral raw occurrences, these also were explored in the near or remote past. Unfortunately, this author does not know when and who explored the mineralizations. An occurrence in the village itself was explored by an exploratory well (shaft) that revealed a slight Pb-Zn mineralization. Another **occurrence**, denoted **Çavuşlu No.1** after the nearby village, was explored by an adit

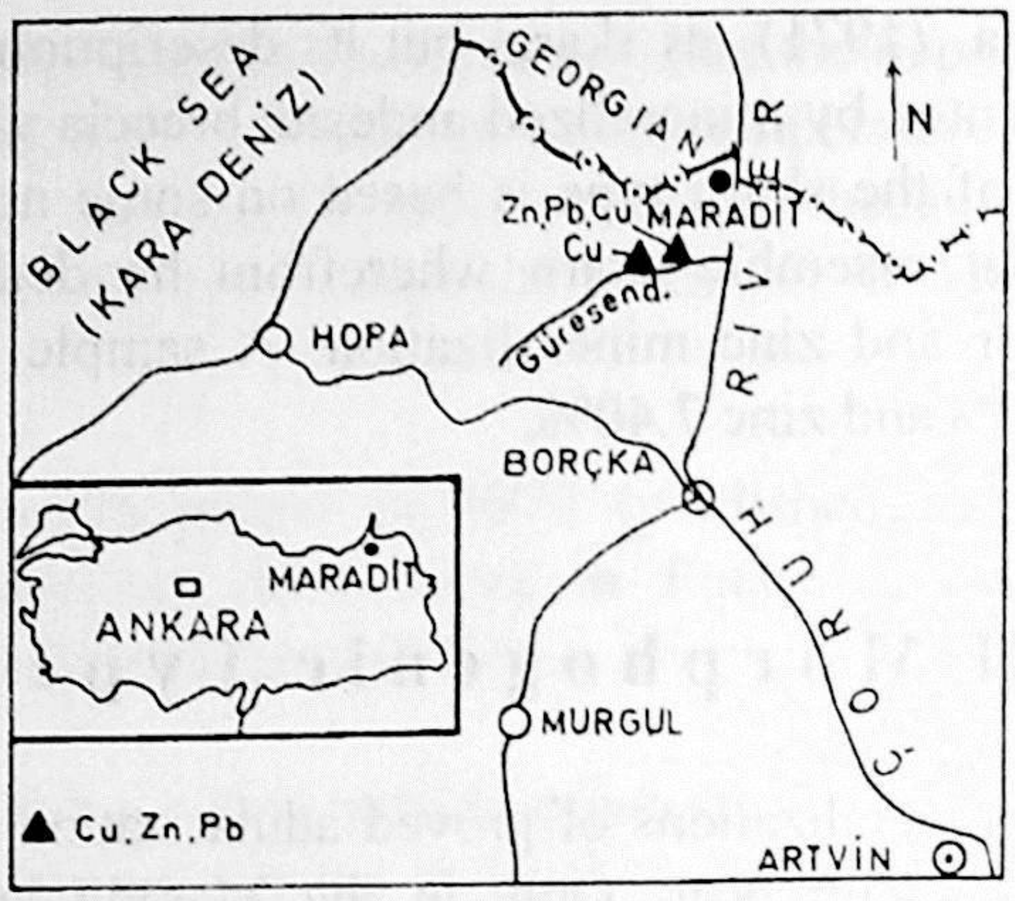


Figure 60. Location map of Cu, Zn, Pb minerals near Maradit.

There are other Pb,Zn - occurrences in Güresen area (Fig. 61), but we have not any sufficient data about them.

The Güresen dere valley and its Cu, Pb Zn mineralization is located on a terrain of hilly – mountain at the altitudes not higher than 880 m. The lowest parts, between 150 m and 250 m, are in the river bed of Güresen dere, a small river running east-west collecting many streams from both northern and southern sides. The Güresen dere source is about 15 km far from Hopa. All streams in the area are water-abundant over the year.

Basic geological characteristics of the Güresen dere valley

The ore-bearing area of Güresen dere has a surface of about 30 km^2. It is built up predominantly of volcanic rocks andesite in composition and minor quartzdiorite intrusions. In the valley, also marly, pelitic and tuffaceous sedimentary rocks were noted, and contact -metamorphic rocks (skarn) at the contact zone of sedimentary rocks and quartzdiorite.

All volcanogenic and intrusive rocks belong to the Eocene magmatism, and sedimentary rocks were formed during the Paleocene and the Eocene.

Andesite and andesite pyroclastics (tuff, agglomerate, Fig. 61) are far prevailing rocks over a large area, mostly hydrothermally altered: argillized, kaolinized and partly pyritized. Also, sulfides are limonitized and chalcopyrite

malachitized, particularly on supergene enrichment of copper mineralization in **occurrence number 2**, named **Pehlivan Köy** after the nearby village.

To complete the picture of the lithological composition, four quartzdiorite intrusions are located in the mid-distance between Çavuşlu Köy and Pehlivan Köy.

An alluvium-covered area occupies the eastern part of the Güresen deere, near its confluence with the Çoruh river.

Finally, the tectonic features in the area are faults, presumably associated with the volcanic or magmatic activity, some of which are filled with ore veins.

Ore Occurrences

The available data proved six ore occurrences: one containing copper, one bearing zinc, lead and copper, and four containing lead and zinc. One is in Maradit village, another Pb-Zn occurrence in the Gami dere (southern tributary that flows into the Güresen dere at Pehlivan Köy), and the other Pb-Zn occurrences are in small streams that form the Başköy dere, another right tributary of the Güresen Dere. Two major **occurrences** are denoted by numbers **1 and 2,** located in the Güresen dere northern bank, first **number 1** going from Çavuşlu Köy to Pehlivan Köy and then about 1 km further upstream **number 2.**

1. Çavuşlu Köy. The mineral occurrence **number 1** is named after Çavuşlu Köy located about 3 km westward from it (Fig. 61). It is emplaced in the Güresen dere north bank, in the escarpment of the road connecting Pehlivan Köy and Çavuşlu Köy with the Maradit-Borçka road. The occurrence is a zinc-lead-copper vein type emplaced along a fault zone in NE-SW direction and the dip to NW at an angle of 50°. The vein is about 1 m thick, observed for about 2.5 m in vertical direction. The fault zone emplacing the ore vein cuts andesite volcanic rocks of the Cretaceous-Tertiary age. The assemblage of ore minerals – pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, tetrahedrite, locally pyrrhotite, is abundant. The ore minerals are supported by quartz and calcite as predominantly non-metallic minerals. Sphalerite is the principal mineral occurring in large grains and aggregates. Single grains are commonly corroded on rims by younger quartz and carbonate (calcite) and in places replaced by galena and chalcopyrite. While chalcopyrite exuded from sphalerite appears in two different forms this can suggest the

likelihood of two generations of chalcopyrite. One generation occurs in shapeless forms or larger grains, and the other in small lenticular separations of distinct orientation. Another characteristic of sphalerite is that often it encloses pyrite grains. Elsewhere, pyrite is represented by irregular cataclastic, presumably older, and by hypidiomorphic, younger grains. Many of the former pyrite grains are inter-grown with sphalerite, and the latter (hypidiomorphic) grains are cemented with chalcopyrite and galena. There is a third; newest generation of pyrite that includes chalcopyrite grains.

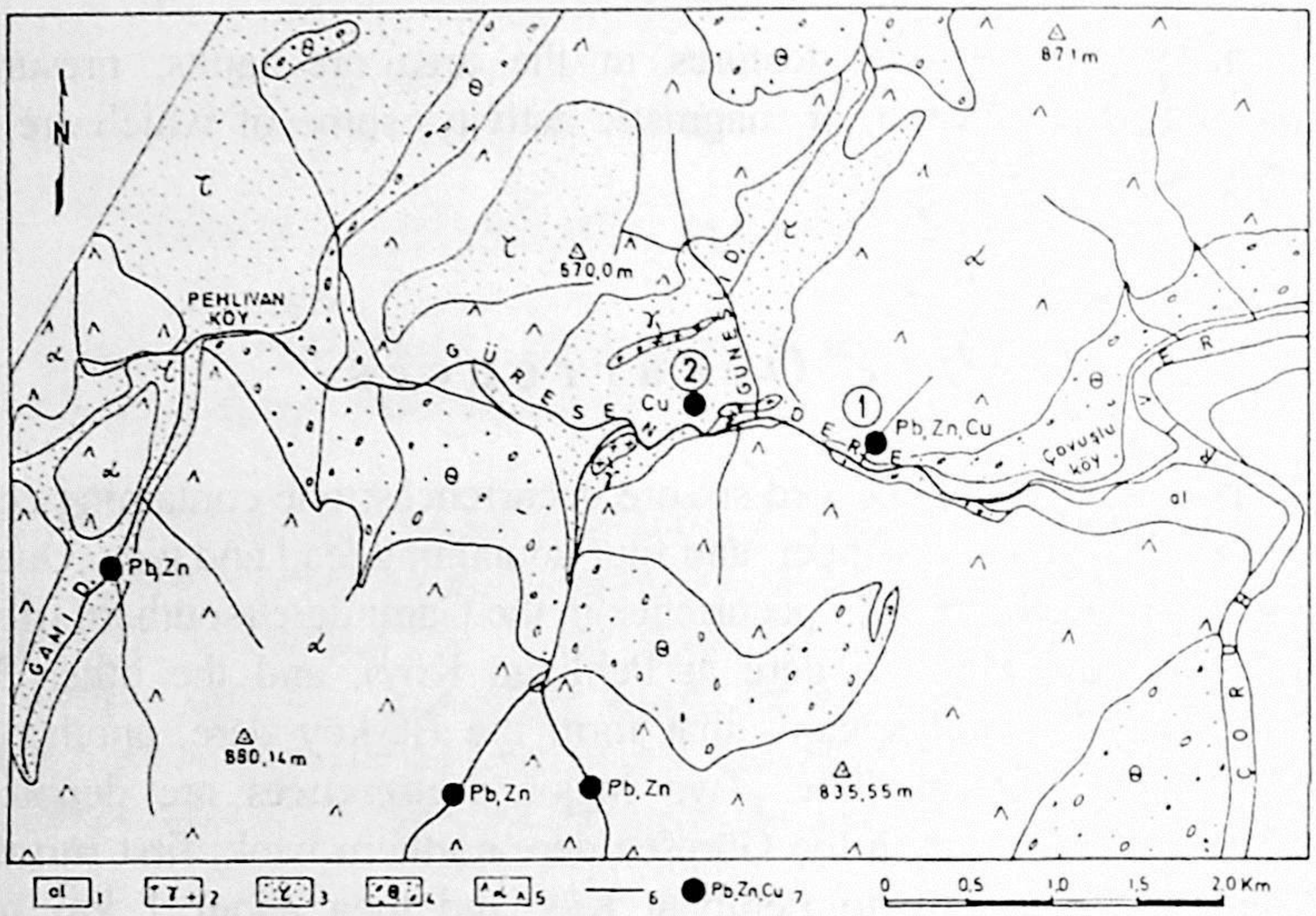


Fig. 61. Geological map of the Güresen dere valley (after P o p o v i ć, 2002b). 1. Alluvium; 2. Quartzdiorite; 3. Andesite tuff; 4. Andesite agglomerate; 5. Andesite; 6. Fault; 7. Pb,Zn, Cu ore occurrence.

The next most abundant mineral is galena that occurs in shapeless forms, in many places inter-grown with sphalerite or included in calcite. Characteristically, galena includes oval grains of chalcopyrite and tetrahedrite, which may have interesting genetic implications. Tetrahedrite grains are commonly small and sparse. Pyrrhotite is also scarce, and arsenopyrite even scarcer.

Although the ore vein was earlier explored by an adit that ran along the vein length but has caved in, the given mineral contents (Table 22) are found in two samples, each 1 m long, from an outcrop.

The ore vein contains high contents of zinc, lead and copper, much silver (65 ppm or less), and relatively high percentage of microelements (e.g. magnesium 1% or more, nickel up to 65 ppm, chromium as much as 200 ppm). Barium and strontium are also relatively high – 1900 ppm and 1700 ppm respectively, but these contents, from two analyzes only, will not be presently considered only mentioned for some future exploration

Table 22. Testing results of ore ***occurrence 1*** *(after P o p o v i ć, 2002b).*

Length (m)	Test number	%				ppm			
		Zn	Pb	Cu	Mg	Ni	Cr	Ba	Sr
1	1	8.00	2.10	0.62	1.00	14	18	700	57
1	2	10.00	1.50	3.50	1.00	65	200	1900	1700

2. P e h l i v a n K ö y. Pehlivan Köy is located about 1 km west of the preceding occurrence, near the Güresen dere, a north-western tributary of the Güneşli dere. Westward, upstream the Güresen dere valley about 5-6 km from **Occurrence 2** lays Pehlivan Köy (Fig. 61) after which the occurrence was named. The occurrence is of a copper mineralization associated with highly altered andesite, abundantly impregnated by pyrite and chalcopyrite and bearing much malachite on the surface. The mineral outcrop was observed on a length of about 20 m in a road escarpment. The occurrence is also observed about 5 m in vertical direction. The area is affected by hydrothermal alterations, a potential ore-bearing, has a surface of about 800x500 m.

The mineralized area proper is built-up, like the preceding one, of andesitic volcanic rocks and small quartz diorite masses, and local small masses of monzonite and diorite varieties. Andesitic rocks are highly hydrothermally altered by kaolinization, carbonatization, pyritization and supergene limonitization and malachitization. Adularization is also an important alteration of undetermined extent. The hydrothermal alterations seem to have preceded the contact metamorphism that occurs around the intruded granitoids.

Other lithologic constituents are pelitic, marly and tuffaceous sedimentary rocks. Where intruded by granitoids, the rocks are changed by contact metamorphism forming skarn or hornfels, with feeble sulfide mineralization.

Andesite is particularly interesting for its abundant copper minerals. Impregnated by pyrite and chalcopyrite the mineralization is of the impregnation and/or stockwork-impregnation type by the mode of occurrence. Concentration of ore minerals is mostly variable from 5% to 15%. The most abundant are pyrite, chalcopyrite, pyrrhotite, magnetite and titanium minerals. Secondary abundant minerals of copper are malachite, covellite, Cu-pigment, bornite, chalcocite (the latter two are both primary and secondary minerals). Adularia was also proved in the mineralized andesite, a product of low-temperature alteration (adularization), which indicates epithermal mineralization. This is very important information about the mineralization in general, and the epithermal auriferous mineralization in particular. This mineral occurrence sharply differs from the former, which contains dominantly zinc and lead and also highly copper. They differ in the mode of occurrence as well. In the former occurrence zinc and lead are most important metals, but in this case they are absent. Copper, gold and silver are almost the only metals of economic interest. The two mineralizations must have formed in different stages of a magmatic activity and have different modes of occurrence, different mineral and chemical compositions, but most likely are of the similar genetic – epithermal type. At that, the former is younger and the copper-bearing mineralization is presumably older.

Sampling of copper mineralization were not systematical; only two samples, one 2 m and the other 3 m long were obtained and they were not continuous but only spot sampled at every ten to fifteen centimeters. The collected specimens, unified and analyzed, gave the following contents:

Table 23. Testing results of ***occurrence 2*** *(Pehlivan Köy, after P o p o v i ć, 2002b).*

Length of test (m)	%		
	Cu	Pb	Zn
2	11,35	0,056	0,0028
3	2,75	0,090	-

The contents of zinc are very low (28 ppm in one sample and none in the other). Lead is similarly low. Even if one sample contained lead by 900 ppm, its contents between 560 ppm and 900 ppm were not estimated as economically significant. Copper, however, was very high as a result of the given mineral composition and partly the supergene enrichment.

Inconsistently sampled, the outcrop of about 100 m^2 contained copper up to 11.35%.

Copper mineral **occurrence 2** in volcanic rocks of hydrothermally altered andesite over a relatively large area (about 800x500 m) is expected to be an important potential of copper sulfides but not uniformly distributed in the area.

According to all of data it could be estimated that the terrain in question shows excellent conditions for discovering high concentrations of copper, gold and silver that are economically significant.

Unlike Murgul area, where Cretaceous-Paleogene polymetallic ore (Hohur Sırtı and Akarşen) and Tertiary copperiferous ore (Başköy) are dominantly associated with volcanic-sedimentary and sedimentary formations, the ore occurrences at Maradit, in the Güresen valley, are associated only with andesite rocks. This mineralization differs from the deposits in Murgul area, in the mode of occurrence, mineral composition, genesis, but are similar in the contents of precious metals. That is a reason for distinguishing it into a separate morphogenic type

Finally, in view that there are also other ore occurrences in the area, foremost of zinc and lead the total ore potentiality of the area is increased. The estimation is very roughly given, but still it can be expected that this area can offer very significant amounts of copper, zinc, lead, gold and silver and that its commercial value is very high.

III. Morphogenetic Type

Ore deposits of this group differ from any preceding type. These are vein deposits that may include ore impregnated between the veins. The principal metal is copper with the associated fluorite. This type of mineral was found only on Balıklı Yayla near Murgul of the entire Artvin Province, and also only in Başköy copper ore deposit fluorite was determined.

Copper mineralizations in Başköy ore field were probably formed in the Eocene (perhaps later). It cannot be classified into deposits of the same type as Anayatak, Çakmakkaya, or the Akarşen type, because it differs in occurrence, mineral composition and age, and is a type itself could be classified as: pyrite-chalcopyrite-fluorite type.

Başköy Ore Field

Sulfide mineralizations of this type are located within the Başköy Mine and west of the Mine in the Didgele dere. The principal structural feature in the ore deposit area is a recumbent hectometric anticline whose apex fractured into a system of fissures perpendicular to the fold b-axis. Chalcopyrite with fluorite is emplaced in that part of the fold. It is a typical anticline type of ore-bearing where fissures are filled with pyrite-chalcopyrite vein in the anticlinal apex fractures. Between the veins, rock is impregnated with pyrite and less chalcopyrite, it is everywhere associated with fluorite. This mineral is not much important.

Two sulfide ore occurrences have been known about in the Başköy ore field. Both are located on Balıklı Yayla southern slopes and were mined in the beginning of the 20th century, the evidence of which are old adits and shallow shafts. One is the Didgele dere and the other Başköy Mine. The latter deposit was mined through the 20th century, but never was explored in detail to give information about its economic value: ore reserve and average metal content in the ore. Even so, most explorers believed it a small ore deposit. A private concessionaire who was satisfied with the primitive and small production exploited ore at the time. Chalcopyrite was separated by hand from the excavated ore. The selected ore gave high copper concentrations of more than 10% and the rest was dumped as gangue. The Murgul smelter demanded delivery only of the ore that contained 1% copper or more, because its outdated technology could not recover lower metal contents. The annual ore production from the Başköy deposit in the seventies was less than 2000 tons, and most of the ore was discarded as waste.

The two copperiferous ore deposits (Başköy and the Didgele dere) on the southern slopes of Balıklı Yayla lie at the altitudes between 1120 m and 1190 m (Fig. 62). The mountain ridge above is more than 1800 m high and slopes northward decreased to the Black Sea and southward to the Murgul valley. There are no perennial streams on the southern slopes, only intermittent flows of melted snow or rain drained by the Başköy dere to the Murgul dere to the Çoruh river and into the Black Sea. The village of Başköy is the only settlement in the area between Murgul and the mine named after the village.

The Başköy Mine and the Didgele dere can be approached by a poor village or forest road trafficable only by cross-country vehicles or lorries (camions) adjusted to the road condition. The distance from the mine to the flotation and smelting plants in Murgul is about 5 km NW (Fig. 29).

The local climate is characterized by cool summers with daily rainfalls and mists and high snowfalls in the winter. Geological exploration and mining exploitation in this climate are possible through nine months of the year.

Though known for a long time, there is no published information about the Didgele dere and Başköy ore deposits. There are few records, the most informative being the 1971 Report by Š t e r n.

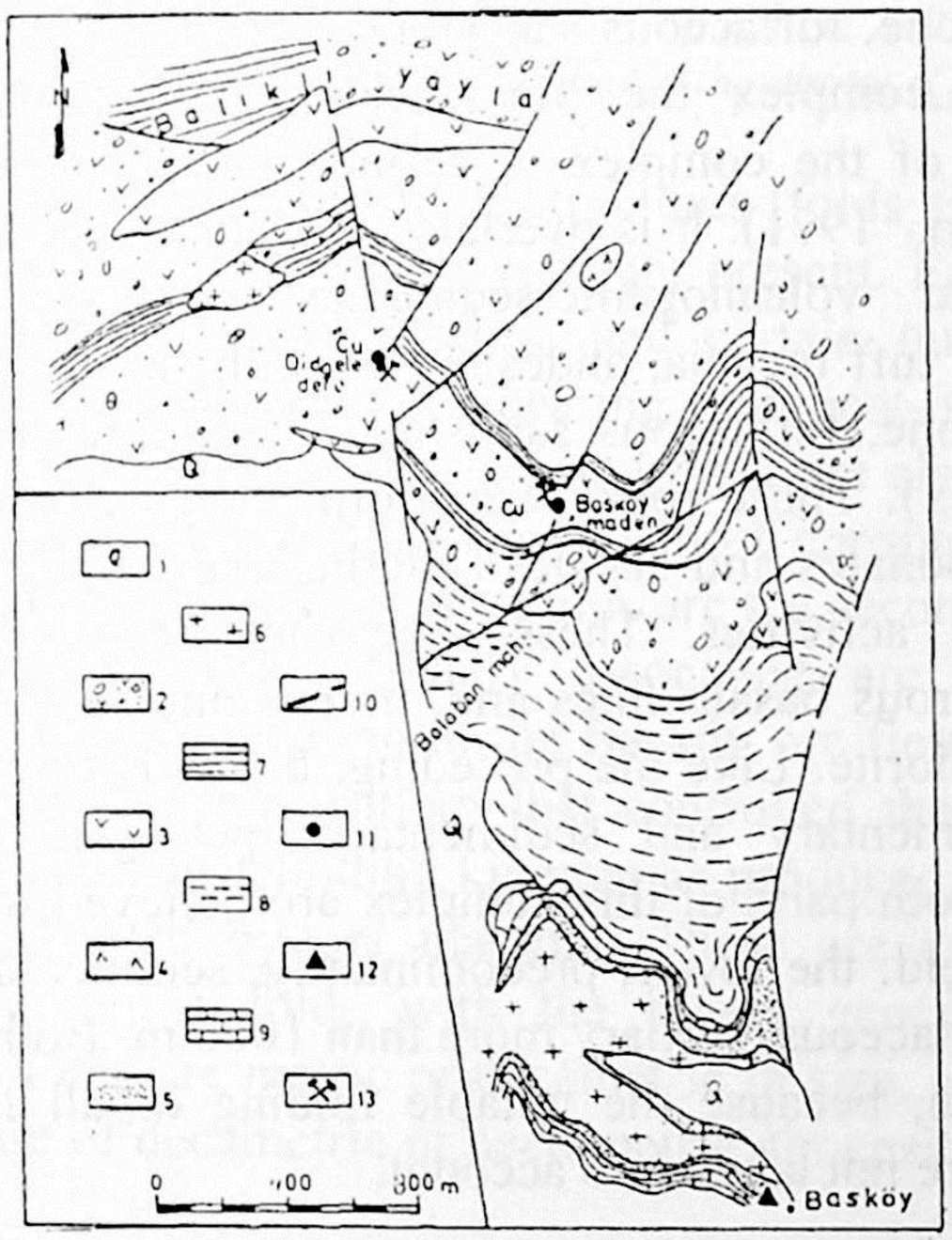


Fig. 62. Geologic map of Başköy ore field (after P o p o v i ć, 2002c).

1.Quaternary (alluvium, diluvium); 2. Andesite agglomerate and tuff; 3. Andesite; 4. Diabase; 5.Skarn; 6. Quartzdiorite; 7. Marly limestone and tuffaceous sandstone; 8. Marly limestone, tuffaceous sandstone with basalt intrusions; 9. limestone with inoceramus; 10. Fault; 11. Vein and vein-impregnation deposit type; 12. Skarn mineralization type; 13. Old mine workings.

Geological Composition and Structural Fabric of Başköy Ore Field

The Başköy Ore Field occupies a surface of about four or five square kilometers. It is generally built up of volcanogenic, volcanogenic-sedimentary and sedimentary formations of the Upper Cretaceous-Paleogene age (the upper sub-complex) and an intrusive and diluvium complexes. The latter complex is mentioned only for its coverage of almost a quarter of the ore field and for several old slag-dumps in its SW part.

Volcanogenic and volcanogenic-sedimentary formations of this sub-complex represent largest petrogenetic unit. It consists of dominantly Cretaceous-Paleogene heterogeneous volcanic and sedimentary formations. Most widespread are the formations of marlstone, marly limestone, marly sandstone, sandstone, tuffaceous sandstone. Faunal fossils are used to give this part of the complex the Maastrichtian and Paleogene ages. The sedimentary part of the complex is defined as flysch in some reference literature (Š t e r n, 1971). It is overlain by a complex petrogenetic unit of volcanogenic and volcanogenic-sedimentary formations of andesite agglomerate, tuff, tuff breccia, andesite flows, then interbeds and lenses of marlstone, limestone, tuffaceous sandstone, sandstone and pelite (defined upper sub-complex). These rocks were formed in marine environment by deposition of carbonates and clastics (interbeds and lenses) in the intervals between volcanic activities. These, like the preceding formations are intruded by numerous basalt dikes and, more important, by large or small masses of quartzdiorite. Like the preceding, this part of the (volcanogenic, volcanogenic-sedimentary and sedimentary) petrogenic sub-complex is relatively thick. Both parts of this complex are believed to be very thick in the Başköy ore field: the lower, predominantly, sedimentary part to 500 m and the upper, Cretaceous-Tertiary more than 1000 m. Both thicknesses may be only superficial, because the notable folding of all formations of the Başköy ore field are not taken into account.

The intrusive petrogenic complex is represented by granitoid formations.

The youngest complex consists of debris, moraine material and diluvium in general and alluvial deposits. Its importance is in that it covers a relatively large area of the Başköy ore field (Fig. 63).

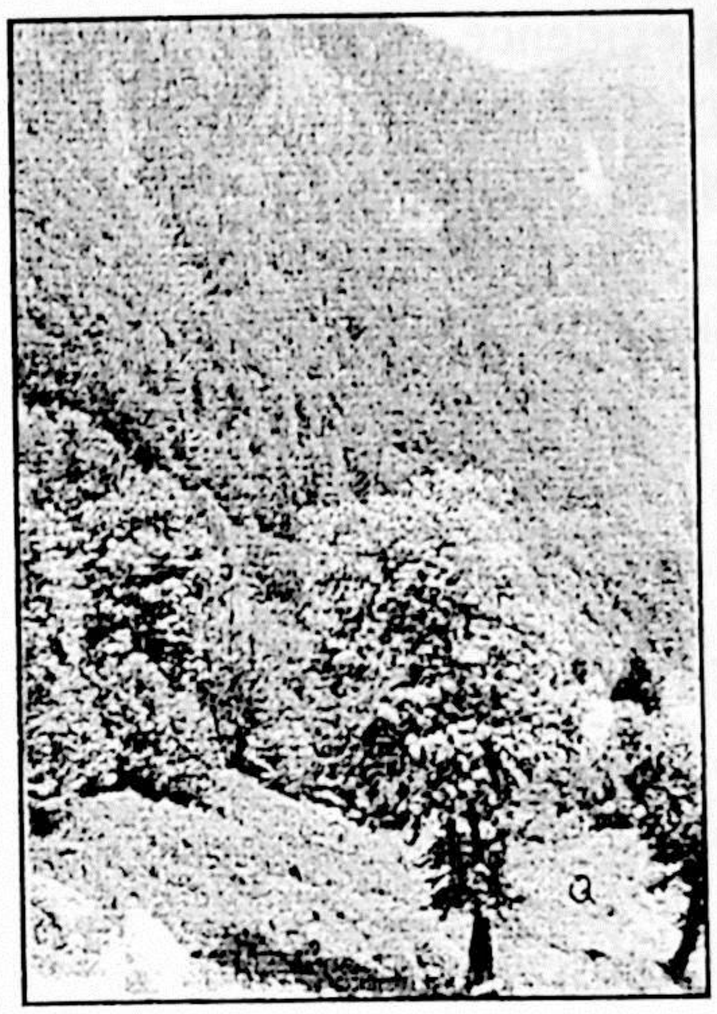


Fig. 63. A view of Balıklı Yayla (P o p o v i ć, 2002c).
Diluvium is visible at the bottom of the photo. (Q).

Both types of the main tectonic structures (folds and faults) are well marked in the ore field. All rupture types are present. Faults are principal features in the general structure fabric and certain number of them is mineralized. There are both pre-ore bearing and post-ore bearing faults. Their general strike direction is NE-SW, and there are also faults of N-S or NW-SE trend. Folding was also strong and most conspicuous in this area and in whole Murgul district (Fig. 64). Folds are the second most developed features, because with them directly associated are the development processes of copper mineralization in the Başköy ore field. It is the folding that resulted in the structural pattern that controlled the areas of mineral deposition. It is believe that folding kinematics produced the rupture fabric which made space filled by ore material. These are commonly flexure, overturned or recumbent folds with the b-axis generally in east-west direction. Flexure folds are metric or decametric in size, and recumbent and overturned folds are of decametric or hectometric dimensions.

Low grade ruptures resulting from folding are the commonest places of ore material deposition and formation of thin or thick ore veins.

Two ore occurrences, Başköy Mine and the Didgele dere, have been known so far in the Başköy ore field.

1. B a ş k ö y O r e D e p o s i t. This ore deposit is located in the about 1.5 km north of Başköy village and about 500 m SW of the Mine in old Balaban Mahalesi hamlet (now completely deserted) four slag dumps

were found, an obvious evidence of the ore melting in primitive smelter indicating old metallurgy. One of the four slag piles, is in a depression that supposedly was used for the primitive smelt-plant. All the four slag dumps are in an area of about 500 m long, spaced about 100 m apart. The area extends NE-SW including the SW margin of Balaban Mahallesi and Parih deresi.

During the last period (seventies and eighties of the twentieth century) of the Başköy Mine, ore was excavated in an open pit, which uncovered ten or so old adits probably from the beginning of the 20th century. The open pit extended about 70 m in length and about 50 m in width, about 30 m deep (Fig. 64).

The Başköy ore deposit is embedded in tuffaceous sandstones more or less pyritized and silicified formations. Together with other volcanic and volcanic-sedimentary units this formation is folded into decametric to hectometric folds. A vein or vein-impregnation copper ore deposit formed in one of folds (Fig. 64). The folding result was a system of ruptures perpendicular to the fold b-axis (approximately east-west direction and gentle eastward dip) filled with chalcopyrite veins of 1 cm to 10 cm in thickness.

Space between the veins got impregnated with primarily pyrite, less chalcopyrite and even less with fluorite – an important accessory of this copper ore in this deposit.

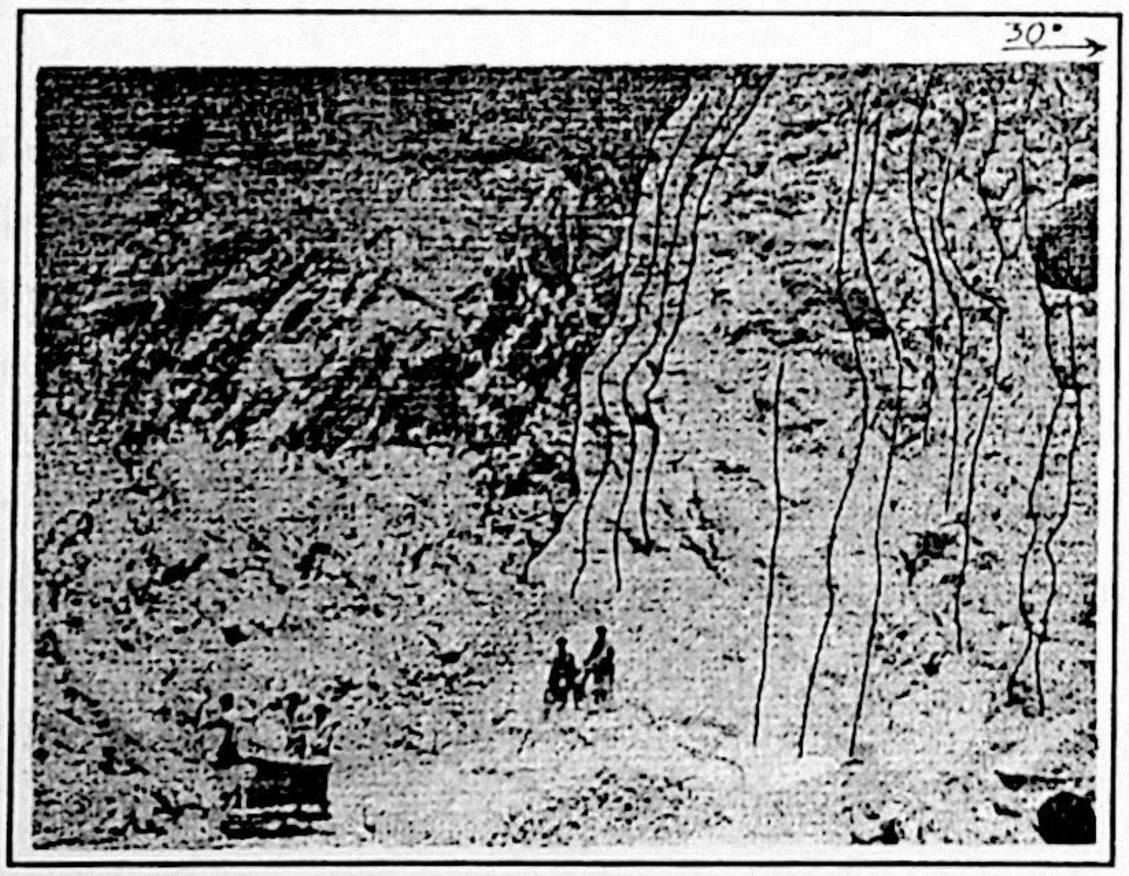


Fig. 64. Başköy open pit mine showing old adits (after P o p o v i ć, 2002c). A recumbent fold in the left; chalcopyrite veins (black lines) and interspaces impregnated with pyrite in the right half.

Major hydrothermal alterations are silicification, pyritization, carbonatization and one might say fluoritization. In this instance, fluorite is one of important characteristics of the deposit; because it is the only deposit in Murgul area and adjacent regions that fluorite occurs in appreciable amounts. It occurs in very nice crystals in the size of 1 cm^3 in different colors. The commonest colors are all shades (from pale to dark) of green, then pink shades, and colorless. Fluorite is the most often accompanying mineral in chalcopyrite veins, in places also impregnated between veins. Thus the occurrence is both vein and impregnated in type.

Paragenesis of the ore deposit is essentially simple. Pyrite is most abundant, followed by chalcopyrite and low sphalerite, and secondary limonite, malachite, etc. However, though a non-metallic mineral, fluorite should be included into the paragenesis as the third highest, disregarding other gangue minerals (quartz, calcite, etc.).

The pyrite-chalcopyrite constituent obviously formed in two phases: earlier, pyrite and sparse chalcopyrite grains impregnated in tuffaceous sandstones, and later, chalcopyrite veins supported by fluorite, calcite and quartz. The latter phase was also identified in the impregnated part of the ore deposit; of newer chalcopyrite enclosing older pyrite and gangue grains. Chalcopyrite occurs in relatively large grains and aggregates, mostly shapeless. Locally, older pyrite grains are fragmented in the newer chalcopyrite cement.

The deposit's principal metal is copper, rightfully referred to as the copper deposit, in which chalcopyrite veins are the main copper "source". The copper content in veins is commonly 10% or more, occasionally less. Density of chalcopyrite veins is not uniform; generally it is high, varying from one place to another (Fig. 64). In parts of high concentration, there are more than ten veins in one running meter. Unlike chalcopyrite veins of high copper content, vein interspaces contain impregnated copper by less than 1%, as given in Table 24.

Table 24. Chemical composition of impregnated part in Başköy copper deposit.

	%				ppm	
Cu	Zn	Pb	F	Ba	Au	Ag
0,18	0,02	tr.	X	x	x	x
0,99	tr.	tr.	X	x	x	x
0,90	0,03	tr.	0,24	0,17	0,02	1,6-3

tr. - traces

x - not analyzed

As shown above, essential chemical elements are copper and fluorite; barium could also be added, and partly silver though its concentration is not high. Zinc is low, and lead occurs only in traces (less than 50 ppm).

Concentrations of precious metals are negligible, particularly gold (in one sample only 0.02 ppm) and silver (maximum 3 ppm), far below the contents in other mineral deposits of Murgul area.

Consequently, the Başköy copperiferous ore is a typically vein and impregnation, or vein-impregnation and with locally fluorite-high concentrations. In few places, fluorite proportion in individual chalcopyrite veins is even higher than chalcopyrite. But the cases are very rare. In such circumstances veins with fluorite druses appear in up to 4 cm thickness. But the fluorite presence as a raw material nevertheless is insignificant (at least in the part of the deposit exploited in the seventies). The increased barium content in the deposit indicates the probable presence of barite, by which (among other things) this deposit differs from Çakmakkaya and Anayatak. It also differs in character from all other known copper mineralizations in Murgul area. This ore deposit is therefore interesting for further studies and may be even more potential than estimated so far. It may not be even the only one of the kind, because the area has not been adequately explored and the same type of ore occurs in the Didgele dere. A larger area ought to be explored. This is even more so because we know that sulfide mineralizations also occurs on the northern side of Balıklı Yayla ridge and there aren't even basic data about it. The formations are of the same type, and also it can be expected that they share a similar or the same type of mineralizations.

In spite of the absence of systematic examination, the average content of copper in chalcopyrite veins and impregnations exceeds 1%, and the copper ore reserves are at least one million tons.

2. The Didgele Dere. Copper mineralization in this location was found about 500 m NW from Başköy Mine, and the mode of occurrence, mineral paragenesis, and rocks environment fully correspond with Başköy Mine. This is why a connection between them should not be ruled out. Hence also the hypothesis that the Didgele dere occurrence is a NW extension of the Başköy ore deposit, which cannot be verified without further explorations.

In any event, copper mineralization of the Didgele dere is emplaced in tuffaceous sandstones through the form of dominant impregnations. Veins

are rare and thin (less than 1 cm thick). Agglomerates in this location are more abundant than tuffaceous sandstones and than in the preceding deposit. This may be an indication that the principal ore in Başköy deposit (tuffaceous sandstones) is located stratigraphically somewhat lower than the Didgele dere mineral deposit. The topographic position of the two locations also suggests different levels. The Başköy Mine (or Başköy Maden) is located at altitudes between 1170 m and 1190 m, and the Didgele dere between 1180 m and 1200 m. Another difference between them is in the old adits: located in mineralized faults in the Didgele dere, and in ore veins in fractures perpendicular to the fold b-axis in Başköy Mine. Rocks identified in mineralized faults in the Didgele dere are fault breccias and with rock fragments cemented by ore material (tuff, tuffaceous sandstone, limestone as facies in tuffaceous sandstone formation, followed by agglomerates and other rocks of the volcanic-sedimentary part), and pyrite mineralization in the kaolinized part of the faults.

Partial testing (only a few samples) gave the following contents:

Table 25. Chemical composition of coppermineralization in the Didgele dere.

%

Cu	Zn	Pb
0,40	0.038	tr.
0,18	0,095	tr.
0,62	0,066	tr.
0,22	0.028	tr.
0,91	0,130	tr.
0,51	0,070	tr.

tr. – traces

Mineral paragenesis of the Didgele dere includes pyrite and chalcopyrite as principal minerals. Fluorite was not identified, which does not mean that it is lacking.

The above percentages give the average copper content of about 0.5% in the Didgele dere, which adds to the prospect of Başköy ore field.

GOLD AND SILVER

Upper-Cretaceous – Tertiary (Paleogene) Auriferous Mineralizations

Auriferous mineralizations from the Upper Cretaceous-Paleogene geological period occurs in a large area of extreme NE Turkey. A zone about 150 km long is extending in NE-SW direction and width of about 40 km in NW-SE direction. But it begins in the NE at Maradit and ends in SW on Çamur Yayla. It is generally believed that the zone extends further to Madenköy at Çayelı. All auriferous mineralization from the mentioned period are associated with volcanogenic and volcanogenic-sedimentary formations to which are associated polymetallic deposits and occurrences (Fig. 51). Compared with the Upper Jurassic-Lower Cretaceous volcanogenic and volcanogenic-sedimentary complex, sulfide ore deposits in this, Upper Cretaceous-Tertiary complex, contains a greater gold concentration.

Auriferous occurrences of the latter period are located in the area bounded by the Turkish - Georgian border, the Çoruh river, and the Black Sea coast. The locations are near Artvin (Irsa Maden and the Melo dere gorge), near Murgul (Hohur Sırtı and Akarşen), near Maradit (Çavuşlu and Pehlivan Köy), and the polymetallic auriferous deposit of Madenköy at Çayeli also should be added although it is beyond the scope of this monograph.

ARTVIN AREA

I r s a M a d e n. As mentioned before, this ore deposit, like Kuvarshan, was repeatedly explored in the 20th century. S i m o n o v i ć (1972) writes that Irsa Maden is the richest ore deposit in Kuvarshan area. It is an Upper Cretaceous-Paleogene polymetallic ore deposit with notable amounts of tennantite, which suggests high contents primarily of silver, or possibly gold. But we have not sufficient data about precious metals in this ore deposit.

MURGUL AREA

So far as we know, the auriferous and argentiferous mineralizations, of this type, have been located, in Murgul area, only on Hohur Sırtı and on Akarşen as followers of polymetallic mineralization of the same geological and geographic space. These are the major gold and silver occurrences in the Murgul area.

1. H o h u r S ı r t ı. Auriferous sulfide mineralizations of Hohur Sırtı are located on a ridge between Hohur and Akarşen. The occurrences are associated with copper, zinc and lead sulfides.

In the area of a large coverage with Diluvia-sediments and active landslides, only one occurrence can be taken for an outcrop *in situ*. Mechanical dispersion halo, however, allow the assumption of several outcrops. A team of explorers, including this author, excavated a well into the ore occurrence in 1970 and established that it belonged to an ore zone of about 200 m long in approximately north-south direction (P o p o v i ć, 2002). Besides the principal ore minerals (pyrite, chalcopyrite, sphalerite, galena, etc.), the paragenesis includes argentite and tetrahedrite. The latter is commonly enclosed in chalcopyrite and in sphalerite. Also marcasite and bismuth sulfursalt were found in traces.

Consistent testing from trenches gave gold contents that vary within a wide range from 0.44 ppm to more than 5 ppm. Silver also isn't uniformly distributed. Its contents vary from 16 ppm to 84 ppm, probably depending on the presence of higher or lower argentite and tennantite (Table 26, from P o p o v i ć, 2002a)

The mineralization is ribbon-impregnated in the mode of occurrence, bearing appreciable amounts of gold and silver. Sporadic fragments from mechanical dispersion halo outside the outcrop contained smaller or equal amounts of both precious and non-ferrous (base) metals.

Table 26. Gold and silver contents on Huhur Sırtı ppm (P o p o v i ć, 2002a)

Au	Ag	As	Bi
5,32	84	1000	220
0,44	20	400	-
0,85	22	1300	-
0,48	16	300	-
x	82	-	-

x – not analyzed

In addition to the outcrop, sulfide mineralization also with increased gold and silver (Table 27) were found in the horizon of tuffaceous sandstone on the ridge between Hohur and Akarşen.

Table 27. Metal contents in tuffaceous sandstone.ppm

Au	Ag	Pb	Zn	Cu	As
0,11	2,25	2200	2950	556	217

The auriferous mineralization (in spite of the low gold) in sedimentary rocks is certainly of volcanogenic-sedimentary origin. Lead and zinc are more important than copper in that petrologic environment (sedimentary and volcanogenic-sedimentary), but the given contents of precious and non-ferrous (base) metals indicate an important prospect in the Murgul metallogenic district.

2. A k a r ş e n. About 4 km to SW from Hohur Sırtı raises Akarşen peak. The polymetallic ore deposit is located near the peak.

The paragenesis of the ore deposit includes pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, and argentite. The present tetrahedrite variety seems to be tennantite, which with argentite is the principal bearer of precious metal.

K r a ë f f (1963) reports gold and silver contents in ore: gold vary from 0.25 ppm to 7.20 ppm (the highest in Murgul area) and silver 338 ppm. E r s e ç e n (1989) gives the data of 1.5 ppm gold and 28 ppm silver. Our contents are between 1.9 ppm and 3.84 ppm for gold and between 53 ppm and 75 ppm for silver (Table 28).

Table 28. Precious metal and some microelement contents on Akarşen (ppm)

Au	Ag	As	Bi	Cd
1,90	53	590	1700	40
3,84	75	x	x	x

x – not analyzad

All available data considered the expected reserves of the deposit are greater than a million tons of ore with high contents of copper, zinc, lead, gold, silver, and bismuth. The expected gold and silver reserves are between two and three tons, and more than fifty tons, respectively. The reserve estimates are a great challenge and incentive for explorers and for investors.

It should also be mentioned that a fragment of galena containing gold of 0.03 ppm and silver of 350 ppm was found in the Murgani Hevi stream. A potential estimate of the precious metals reserve on Akarşen deposit should take this data into account.

MARADIT AREA

In respect of gold and silver, the copperiferous occurrence at Pehlivan Köy deserves particular attention. In addition to high copper content, it bears an increased amount of gold, but its importance is in the type of rock alteration – adularization, for which the occurrence should be considered as a separate genetic type.

The occurrences west of Maradit are found only in Paleogene volcanic rocks. Several sulfide mineralizations of copper, zinc and lead are found in the same area. Gold and silver, associated with these metals, have been examined only in the outcrops at Çavuşlu and Pehlivan Köy in the Güresen dere valley (Figs. 51, 61). The two occurrences are 1 km far one from another.

Some of these ore occurrences have been known from before. Information of M T A Spec. edition from 1966 refers to an unspecified occurrence of ore containing copper 9.23%, lead 5.86% and zinc 0.81%, and gold from trace to 3.5 ppm and silver of 41 ppm. The zinc and lead contents suggest the likelihood of the vein ore occurrence at Çavuşlu.

1. Ç a v u ş l u. The ore occurrence is an outcrop of galena-sphalerite vein about 1 km thick that consists of galena, sphalerite, pyrite, chalcopyrite, arsenopyrite, pyrrhotite, tetrahedrite (likely tennantite). Two samples, each 1 m long, were collected (P o p o v i ć, 2002b) and analyzed. The gold and silver contents are given in the Table 29 below. Silver is a more important precious metal than gold, and it is believed to be associated with tennantite. Gold is low in both samples, consequently less important.

Table 29. Gold and silver contents in Çavuşlu ore vein

Test number	Ppm	
	Au	Ag
Test 1	0,04	47
Test 2	0,07	65

2. P e h l i v a n K ö y. Highly hydrothermally altered andesite volcanic rock impregnated with pyrite and chalcopyrite is located about 1 km west of Çavuşlu toward Pehlivan Köy. One of andesite alterations is strong malachitization, despite low chalcopyrite, which explains its high copper constituent. This ore occurrence greatly differs from the preceding

one. The Çavuşlu ore consists of a sphalerite-galena vein, and this of only stockwork-impregnated copper mineral. Finally, a peculiar characteristic is the occurrence of adularization, for which it is assigned to the epithermal type of mineralization. Despite the morphogenic, mineralogical and chemical differences between the two ore occurrences and both belong to the epithermal genetic type.

Even without systematic testing, according to all of data, some impression of precious metals potentiality could be made. The gold content in the outcrop was 0.72 ppm in one sample and silver from 14 ppm to 50 ppm in two samples (Table 30, P o p o v i ć, 2002b). An optimistic estimate is that the occurrence deserves greater consideration for its copper and precious metals content.

Table 30. Gold and silver contents
in Pehlivan Köy ore occurrence (P o p o v i ć, 2002b).

Length of test (m)	content (ppm)	
	Au	Ag
2	0,72	14,00
3	x	50,00

x – not analyzed

Because this ore occurrence belongs to Paleogene volcanogenic and volcanogenic-sedimentary formations, it suggests the probable epithermal genetic type of many synchronous occurrences in the Murgul-Artvin-Maradit area and thereby a higher potential of sulfide mineralizations with which precious metals are associated.

ÇAYELI AREA

M a d e n k ö y. During our prospecting tour, we visited the large polymetallic ore deposit of Madenköy near Çayeli and collected several ore samples that were analyzed for precious and non-ferrous metals. Being located in the same tectonic and metallogenic zone as Hohur Sırtı, or Akarşen, the found metal contents are interesting to mention at this point. This even the more so that high gold and silver assemblages were found at Madenköy. These contents were up to 11.43 ppm for gold and 241 ppm for silver. The content of precious metals in the ore reserve of this deposit is very high and indicates the increased economic value of the deposit.

ORE BEARING OF FORMATIONS BELONGING TO THE INTRUSIVE PETROGENIC COMPLEX

Metallogenic analysis of formations of this complex is based mainly on geochemical analysis of primary dispersion halo and the frequency of greater concentrations of base, precious and other metals in individual formations, including the overall metallogeny of the Pontids. All informations lead to an estimate of the potential in ore-bearing formations, especially in this case the metallogenic estimation of formations belonging to the intrusive complex.

The complex of intrusive rocks is represented by granioid formations. The most abundant intrusive rock, according to the findings, is quartzdiorite. The largest mass of this rock is located in the Çoruh River and Başköy dere valleys, and minor masses all over Artvin Province. Granitoid rocks everywhere had altered adjacent rocks at the contact and formed skarn or hornfels and weak sulfide or magnetite minerals.

The largest mass of the complex is Tiryal Dağ-Tatos Dağları batholith (larger than 10,000 km^3, P o p o v i ć, 1976) surrounded by many smaller or larger intrusions, or lateral intrusions in the form of minor masses. Petrogenetically, the complex is not simple. It formed from more than 257 million to 25 million years before the present, i.e. from the Permian/Triassic to Miocene (M o o r e et al., 1980), through many phases of magmatism, each specific in character. All volcanic rocks in Murgul and adjoining areas (Artvin, Hopa, Arhavi, Maradit, etc.) are directly related with the magmatic phases, therefore minor intrusions, found at the recent base level of erosion, must also be of some importance. Because Cu, Zn and Pb mineralizations were identified in many places in granitic rock[1] *sensu stricto*, which are a constituent of the intrusive rock complex of Murgul and adjoining areas, its metallogeny will be briefly considered.

Without systematic geochemical examinations, the collected data suggest the need of a serious study of intrusive, granitoid formations.

Partial geochemical examinations were carried out for granitoids (quartzdiorite) in Iskalka Köprüsü, on Kilise Tepe, on Akarşen, in Başköy (all near Murgul), then in the Melo dere gorge (by the road Mele-Çoruh river), and in the Çoruh valley by the road Artvin-Borçka, but most samples

[1] Meaning small, lateral intrusive bodies.

were collected in Kilise Tepe. Copper contents in the samples varied from 50 ppm to the ore concentrations, or 0.5%. In this case average copper content was almost 200 ppm, exactly 196 ppm, and the ore concentration to 0.5% or higher, far above (almost ten times higher) the average content for granite rocks (only 20 ppm, in: V i n o g r a d o v, 1962). Similarly, average zinc content in quartzdiorite at Murgul was 277 ppm, or almost five times higher than the V i n o g r a d o v's (1962) average content in the same rocks. Only for these contents, samples that contained 0.15%, 0.25%, 10% or extremely high contents were not taken into account.

Table 31. Geochemical data for quartzdiorite of Kilise Tepe

ppm				
	Cu	Zn	Pb	Mo
Diorite	50	150	60	2
Quartzdiorite	200	400	35	4
"	80	350	15	7
"	500	150	20	7
"	0,50 %	1,00%	40	5
"	500	0,15%	120	20
"	300	0, 25%	20	6
"	500	10,00%	300	3
"	80	120	120	2
"	50	110	20	2
"	120	130	20	2
"	120	150	60	2
"	100	120	10	2
"	100	140	100	2
"	100	60	80	2
"	140	220	20	2

As to lead, its average content of 65 ppm was much lower than the average content for similar rocks of the Earth's crust (83 ppm, in: V i n o g r a d o v, 1962). Lead clearly proved uncharacteristic of quartzdiorite of Murgul area. However, outcrops of single quartzdiorite bodies on Kilise

Tepe contained lead 0.5% or less, zinc from 0,15% to as much as 10%, and showed sphalerite that "soaked" the rock (Table 31). True, this was an extreme case but still it should not be ignored.

In other places, e.g. Iskalka Köprüsü about 3 km west of Kilise Tepe, copper content in quartz diorite varied from 80ppm to 200 ppm (six samples analyzed). This maximum content, four times higher, indicates anomalous metal content in quartzdiorite (Table 32). In the same place and the same rock, zinc varied from 70 ppm to 300 ppm, fitting the general geochemical pattern where the content of the metal increased from zero to five times. Lead content was low.

Table 32. Several geochemical data for quartz diorite of Iskalka Köprüsü

ppm			
Cu	Zn	Pb	Mo
120	80	30	2
200	300	10	2
110	80	10	2
70	120	20	2
80	90	15	2
100	70	30	2

A similar situation is in Akarşen area where fewer quartzdiorite masses contained increased amounts of some metals. Four samples contained copper from 80ppm to 200 ppm, and zinc from 100 ppm to 750 ppm.

The anomalous contents of the two metals indicate similarity of the rocks containing them with those on Kilise Tepe and elsewhere. At the contact with adjacent rocks, slight skarn or hornfels mineralization was noted.

It follows from the above data that in all three locations copper and zinc occur in increased amounts, which suggests a general geochemical character of granitoid rocks. In contrast to other places, copper at Başköy (ten geochemical samples) varied from 5 ppm to 200 ppm. Two samples only contained 100 ppm and 200 ppm. Despite locally anomalous amounts of copper, the estimate for this granitoid rocks is not similar to those of the

preceding locations in general geochemical character. Unlike copper, zinc contents in quartzdiorite at Başköy were lower than 120 ppm, which corresponded to the theoretical contents. The sample containing 200 ppm of copper, contained as much as 1230 ppm of zinc, which indicated their geochemical association in this rock.

Anomalous copper contents were found also in single samples by the road Melo-Çoruh river (in the Melo gorge) and in quartzdiorite from the Artvin-Borçka road escarpment.

In conclusion one may say that granitoid rocks of Murgul and adjacent areas are geochemically characterized by copper and zinc specializations and in some formations lead as well. The given data, particularly those for Kilise Tepe quartzdiorite, strongly indicate the presence of porphyry-type copper and zinc. This indication is a problem yet to be solved.

Volcanogenic and volcanogenic-sedimentary formations were subsequently, during magmatic phases, faulted and intruded by sills, dikes or other commonly smaller quartzdiorite bodies. Intrusion frequently occurred along faults and seemed to have been only apical parts of a large intrusive mass that is directly related to the Tiryal Dağ-Tatos Dağları batholith. All varieties are determined, from diorite to granodiorite and quartzdiorite.

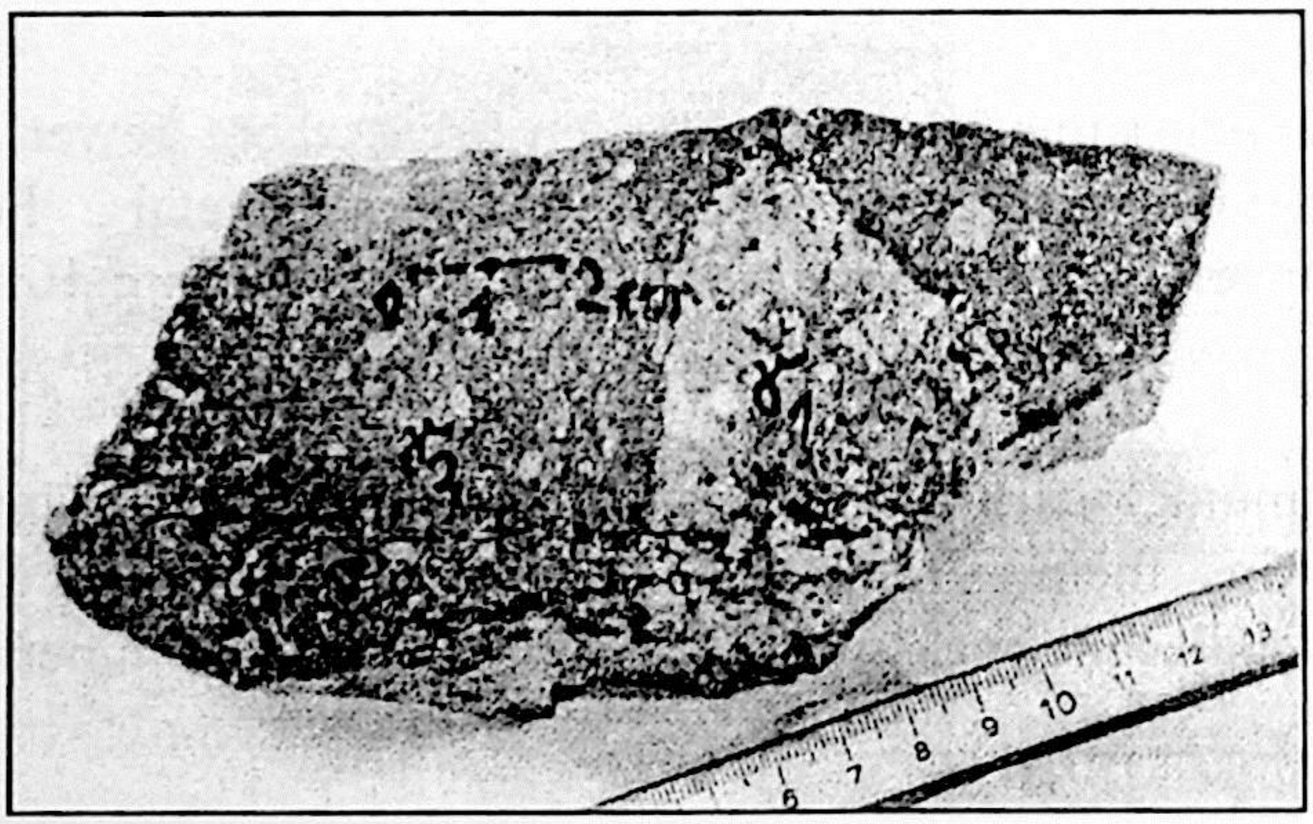


Fig. 65. An inclusion of older granite, γ_1, in younger quartzdiorite, γ_2 (P o p o v i ć, 1972).

Concerning granitoids in the given area, it should be mentioned that older rock inclusions (Fig. 65) are locally found, which indicates a newer granitization and rejuvenation of granitic rocks through their evolution. It

further suggests a genetic relation of sulfide mineralizations in granitic rocks with processes of granitization, and with mineralization of the intrusions through their evolution.

Mineralizations Associated With Intrusive Petrogenic Complex

B. ZINC AND COPPER

Unlike copper mineraliztions of Kilise Tepe classified under A and genetically associated with Malm-Neocomian rhyolite volcanism, zinc and copper mineralizations under B are associated dominantly with granitoid rocks of one of the latest magmatic phases. Group B includes mineralized granitoid rocks denoted by numbers 6 and 8 on geological maps (Figs. 43, 66).

MURGUL AREA

Kilise Tepe. Occurrence 6 is located on the western slopes of the ridge Kilise Tepe-Kopuk (Fig. 43, p. 90, Fig. 67). **Occurrences 6** and **8** form one zone of zinc mineralization and may be presented together, but the discontinuity and the distance between them of more than 200 m were the reason for presenting them separately.

Principal formations are of volcanic rocks, rhyolitic in composition, locally intruded by small masses of mineralized quartzdiorite.

The ore bearing zone is extending parallel with the Kilise Tepe-Kopuk ridge. Higher or lower Zn-mineralization was found at this zone. Increased zinc occurs not only in quartz diorite, but in adjacent volcanic rocks as well. The ore zone containing zinc in excess of 500 ppm is more than 400 m long. Zinc is high in quartzdiorite, but is 0.1% in volcanic rocks.

Sulfide mineralization, associated with granitoid rocks, is developed so far as we know in quartzdiorite on Kilise Tepe, in Iskalka Köprüsü, perhaps Akarşen, in Başköy valley and elsewhere. However, so far as at least the recent base level of erosion is concerned, the mineralized granitoid rock bodies are small. The metallogenesis of the intrusion complex has been

less studied to produce an accurate estimate of its potential sulfide mineralization, but it certainly should not be neglected.

The most important ore occurrences, i.e. small quartzdiorite body assemblages are located on western slopes of the Kilise Tepe-Kopuk mountain ridge. Several outcrops of mineralized quartzdiorite are known. The extreme northern outcrop of quartzdiorite, near the copper **Occurrence 4** (Fig. 66), contained about 500 ppm of copper and only 150 ppm zinc. Other outcrops of the same intrusion are located about 300 m SW of **Occurrence 4.** All three quartzdiorite outcrops are denoted **Occurrence 6**. Zinc and copper contents in the northern outcrop were 0.15% and 0.05%, respectively. About 30 m SW of **Occurrence** 6 another quartz diorite outcrop may have been unified with the former, but a fault thrust across separated them. The latter outcrop contained zinc 0.25% and copper only 0.03%. About 40 m east of the two outcrops, a quartzdiorite sill (Fig. 67), mineralized by yellow sphalerite, extends in the observed length of about 20 m and has variable thickness from 0.30m to 3 m. The sill extends roughly in north-south direction. Secondary copper minerals are notable on the sill and the adjacent rocks. The rock is highly calcified, chloritized and lesser malachitized. Secondary minor minerals are chalcanthite and covellite. The rock has a porphyric texture where plagioclase phenocrystals are completely calcitized. Identified ore minerals are pyrite, chalcopyrite and sphalerite. A sample, half a meter long, contained zinc of 1% and copper 0.5%. Another minor quartzdiorite outcrop which could belong to former sill contained 1% copper and very low, only 0.024%, zinc.

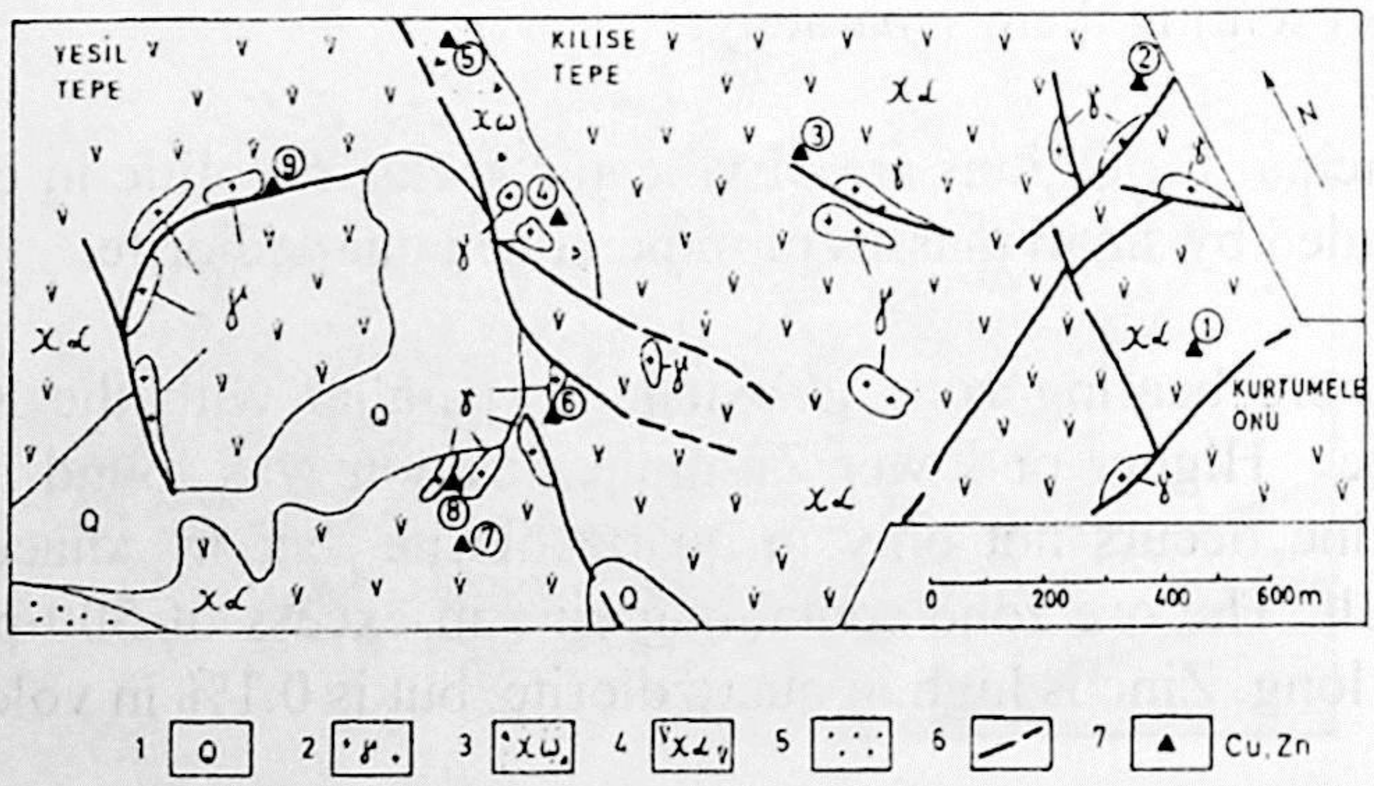


Fig. 66. Geological sketch map of Kilise Tepe with quartzdiorite.

1. Rubble; 2. Quartzdiorite intrusion; 3. Silicified and mineralized rhyolite breccia; 4. Rhyolitic volcanic rock; 5. Tuffaceous sandstone; 6. Principal fault; 7. Zinc and copper mineraliztions.

The next occurrence, or quartzdiorite outcrop, is located on Kopuk NW slopes. Mineralized quartzdiorite bodies are noted as **Occurrence 8.** The bodies are located about 140 m from the trigonometric point (1795 m) or about 50 m north of copper **Occurrence 7** (Figs. 43, 66). Again, this is a mineralized sill of quartzdiorite, observed over a length of 4 m, about 1 m thick. Quartzdiorite is impregnated with metasomatic sphalerite associated with a little, finer-grained chalcopyrite replacing sphalerite. Sphalerite grains are larger then chalcopyrite. Letter one occurs also exsoluted from sphalerite. Like in preceding occurrences, quartzdiorite is intruded into rhyolitic volcanic rock. In one sample collected from this mineralization, and content of zinc were 10% and of copper 0.05% and 0.03% of lead.

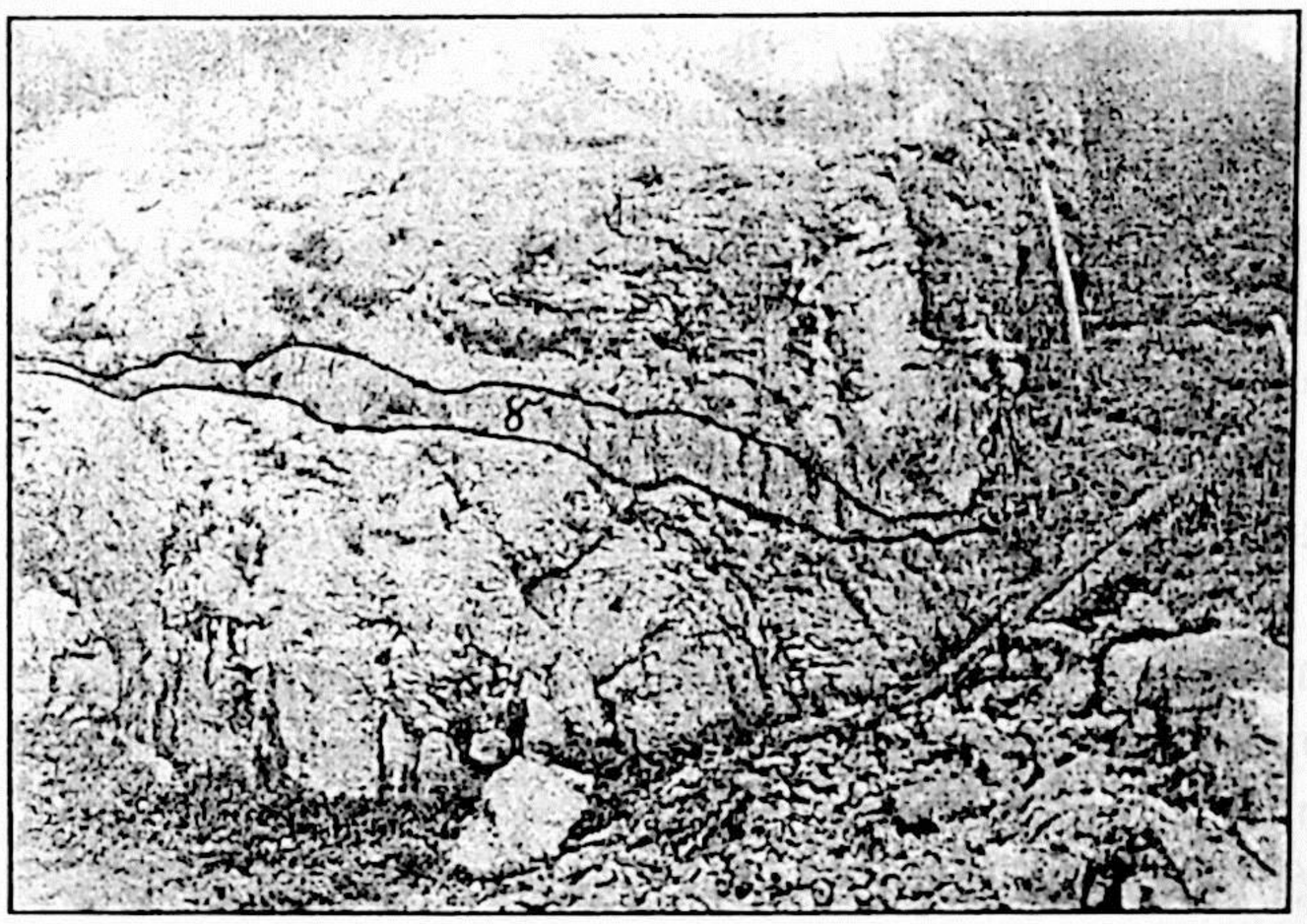


Fig. 67. A sill of mineralized quartzdiorite, - γ (S t e v a n o v i ć, in: P o p o v i ć, 1972).

The parent rock was determined under the microscope as microdiorite affected by strong chloritization, calcitization, sericitization, argillization, and weaker silicification. The rock is also highly mineralized by sphalerite grains as large as 3 mm.

On the whole, the area from **Occurrence 6** to **Occurrence 8** is notable for zinc and lower copper mineralizations directly associated with quartzdiorite intruded in faults. Hydrothermal fluids had led to the formation of mineralizations after quartzdiorite had intruded the faults of north-south to east-west trends.

The given data may suggest the likely presence, at depth, of a large diorite to granodiorite mass with porphyric type of mineralizations, primarily zinc, and possibly copper.

The geological map (Fig. 66) shows that the principal formations rhyolitic volcanites (rhyolite, rhyolite tuff, breccia, etc.) are locally intruded by small masses of mineralized quartzdiorite.

The ore occurrences indicates Kilise Tepe-Kapuk ridge as an ore zone that is parallel or better said coincident with the ridge. It consists of more or less zinc-mineralized rocks. Increased zinc occurs in quartzdiorite, and in volcanic rocks, because the subsequent mineralization could have affected both intrusive and the pre-existing extrusive rocks. The zinc content of more than 500 ppm gives a zone of more than 400 m, in which volcanic rocks contain zinc by 0.1% at the most.

No other occurrences are known. It can be mentioned that in some places quartzdiorite rocks locally containing increased zinc occurred, like in the Melo dere gorge. At this locations granite rock with copper mineralization has been registered represented by chalcopyrite, lower pyrite, and secondary copper mineral (malachite) containing copper by 0.63% and lead by 70 ppm, but also silver 7.2 ppm and gold 0.03 ppm. Another spot sample from the granite rock, outside of this occurrence, contained only 20 ppm of copper, 50 ppm of zinc and 200 ppm of lead. In the Artvin-Borçka road escarpment, only one sample from quartzdiorite contained 0.02% of copper, 0.25% zinc and lead 0.10%. K o p r i v i c a (1977) reports a zinc ore occurrence associated with granite rock at Gürgençlik Köy (Arhavı) with 1.3% of zinc.

This could be the fourth morphogenic type. The mineralized granitoid rock locally with relatively high amounts of metals, suggest the possible existence of a large mineralized granitoid mass at some depth. It supports the assumption of a porphyry-type of zinc and copper ore deposit. In that event, the small mineralized quartz diorite bodies could be only the apical parts of a larger mineralized granodiorite mass.

Therefore all the mentioned data fit into a unified viewpoint that granitoid rocks in Murgul and adjacent areas should be studied for their metallogeny.

Contact–Metamorphic Ore Occurrences

It has been generally known that numerous intrusions of granitoid rocks in Artvin Province have effected contact-metamorphism resulting in skarn and hornfels. The rocks are more or less mineralized by sulfides or oxides. This type of mineralization is the most recent; being developed at granitoid rocks determined Eocene or post-Eocene. The mineralization itself must be of the same age.

So far as we know, skarn occurrences are found in Iskalka Köprüsü in the Murgul valley, on Akarşen, at Basköy, near Hopa and Arhavi.

MURGUL AREA

Skarn mineralization near Murgul is located in Iskalka Köprüsü, on Akarşen and at Basköy. Except for pyrite traces in hornfels, no other mineralization was found in Iskalka Köprüsü. On Akarşen, similarly, skarn occurs only on non-ferrous metal traces at quartz diorite intrusions. Contents of the three principal metals (copper, zinc, lead) are lower than 200 ppm each.

Skarn Sulfide Mineralization at Başköy Village

First of all, quartzdiorite has an essential role in this location. It is a relatively large intruded mass of about 2 km^2 in surface area, which is believed to have exposed its apical part but has a larger extent. Quartz diorite at Basköy is found dominantly in deep erosion levels and it possibly had a controlling role in the structural shaping of volcanogenic-sedimentary and sedimentary formations.

The quartz diorite masses intruded in carbonate rocks, thin bedded limestone, effected contact-metamorphism that resulted in the formation of skarn in variable thickness. Unfortunately, the mineralization was not so strong as to produce appreciable amounts of ore minerals, foremost copper, zinc and lead sulfides. Essentially, skarns are slightly mineralized, with mentioned metals only sporadically increased. Thus, in some spot samples, the metal contents were: copper 0.40% and 0.18%, zinc 0.038% and 0.095%, and lead only in traces (less than 100 ppm). These metal contents may suggest that skarn could be of some interest, but sampling in a road escarpment near Başköy denied it, despite the malachite traces (Table 33).

Table 33. Skarn sampling results* for Başköy village (ppm).

Cu	Zn	Pb
76	72	50
20	60	50
44	112	50
60	112	50
64	180	50

*Analyzed in MTA laboratory, Ankara.

As one can see in the table above, copper varies from 20 ppm to 76 ppm, zinc from 60ppm to 180 ppm, and lead is only 50 ppm. These results are from some testes that illustrate mainly low contents of the three metals in this skarn, but it also confirms that the scarn is slightly mineralized. The paragenesis of the contact-metamorphic rocks includes the highest pyrite, followed by chalcopyrite and sphalerite, but all are contained in small amounts. The secondary constituent minerals are limonite and malachite, but only in thin crusts at the rock surface. In a sampling place gypsum was observed in thin crust. Hence, the skarn occurrence is interesting only for theoretical consideration of metallogeny characteristics of the Province. Still, there are places where skarn is more mineralized by copper, lead and zinc sulfides and iron oxides, like Arhavı area. Despite all the cases that had been explored, not one single data had been accomplished to support the potentiality of this mineralization, even so this type of mineralization should be mentioned.

ARHAVI AREA

In contrast to skarn of the Murgul area, skarn occurrences in Arhavi area (Fig. 53) are of metallogenic and a broader interest. The information given presently is borrowed primarily from K o p r i v i c a (1971). He mentions several skarn occurrences at the contact of small granite rock bodies west of Gürgençlik Köy, NW of Mağara peak (Fig. 53). He writes about an ore occurrence on Mağara western slope. It is Eocene in age; represents dominantly magnetite mineralization followed with iron, copper and zinc sulfides.

Other occurrences are located at microdiorite contact with adjacent rocks in the NW of Gürgençlik Köy. The same author mentions pyrite

mineralization with a little sphalerite, which contained zinc of 1.30% and neither copper nor lead.

Another occurrence was described (K o p r i v i c a, 1971, 1977) as magnetite mineralization with sulfides. This is mineralized skarn and hornfels show pyrite, chalcopyrite and magnetite. Garnet was associated with these ore minerals. A sample contained iron of 62.10%, copper of 0.12% and zinc of 0.30%.

About 300 m SE from this occurrence, another outcrop of similar mineralization, contained Fe up to 41.60% and Zn to 0.10%, without copper, but with pyrite and garnet. There are more minor skarn occurrences at the contact with granitoid rocks, but of no importance.

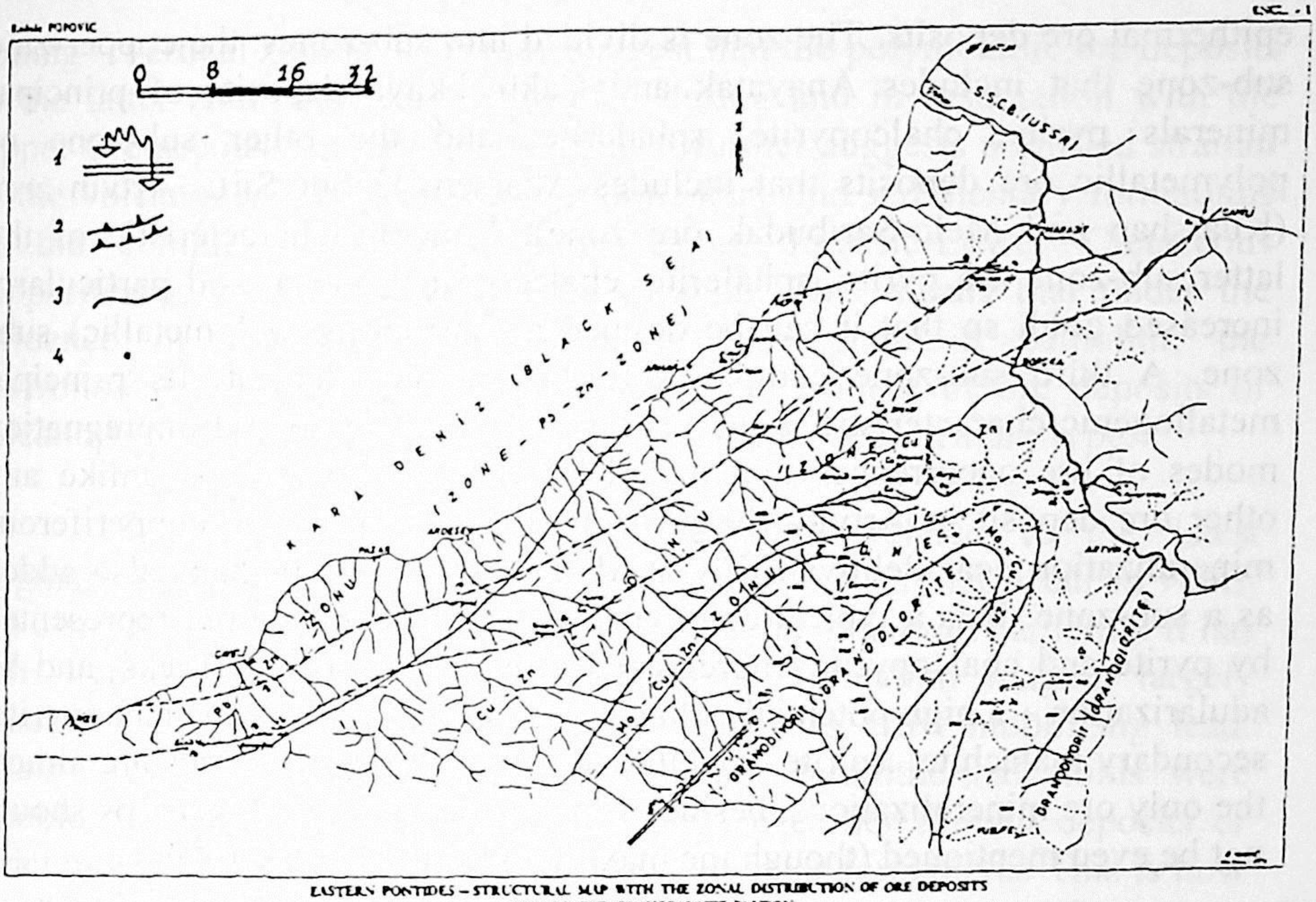
VI. ZONAL DISTRIBUTION OF ORE DEPOSITS IN ARTVIN-MURGUL-HOPA-MARADIT REGION

A mere glance upon the Geological Map, 1:500,000, Sheet Trabzon (G a t t i n g e r , 1962) and respective metallogenic maps by different authors of M T A suffices to note some variations in the distribution of ore deposits and even in some principal ore minerals. The zoning centre is the Tiryal Dağ-Tatos Dağları granitoid batholith, which was noted a long time ago and referred to by P o p o v i ć (1976, 1979). P e j a t o v i ć (1979) also noted the zoning of ore deposits and gave a general description of it.

One thing is certain; zoning of some metals and their ore deposits is distinctive in Murgul and other areas north and northwest of the Tiryal Dağ-Tatos Dağları batholith. In any event, as can be seen in Fig. 68, molybdenum – copperiferous zone where zinc is associated in an appreciable amount occurs adjacent to the batholith (in the area of its exo-contact). Also molybdenum, copper and zinc occurrences are marked on Kilise Tepe. Molybdenum content in geochemical samples varied up to 1000 ppm. Š. T a l i ć (1971, oral communication) noted several molybdenum occurrences on the SW side of the batholith.

On the whole, this zone has been least studied. It seems not to be very wide, i.e. it does not extend far from the batholith. A rough estimate of the zone width is between 2 km and 6 km.

The picture of the mineral paragenesis in the zone is the following: pyrite is the most abundant ore mineral, followed by chalcopyrite, sphalerite and molybdenum mineral (molybdic ocher or molybdenite?), then magnetite and hematite. On the basis of this composition P o p o v i ć (1979) identified a sub-zone characterized by the mentioned minerals, which does not necessarily implies a direct genetic relation of these metal and the respective paragenesis. On the contrary, the relation is probably indirect, because mineralization age is correlative with the age of magmatic phases of the granitoid rock.



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.

Fig. 68. Zonal distribution of ore deposits in Artvin Province (after P o p o v i ć, 1976).

1. Anticlinorium's axis; 2. Imbricate structure;
3. The Schematic zonal boundaries between the different ore deposits; 4. Ore deposit.

Copper, with lesser zinc as a principal following metal, ore deposits and occurrences (disregarding iron in pyrite contained in this and the preceding zones) represent the next zone. Unlike the preceding zone, this zone is laterally extensive including many large copper deposits. Its greater part, however, is concealed under a newer Upper Cretaceous-Tertiary formation. The prospect of the zone is therefore much larger than estimated so far. The largest copper deposits of the Pontides – Anayatak, Çakmakkaya, Aduca Dere, Çarkbaşı – and many smaller occurrences in Murgul and Kuvarshan areas, then Hopa (Peronit, Sirikaya), and deposits NW and west of Murgul area are all located in this zone. The copper ore reserves (including extracted ore) only in Murgul area are estimated to 100 million tons that contain copper of more than 1%.

The zoning, or Cu-Zn zone, includes all ore deposits formed from the Malm ending with the Paleogene. It includes pyrite-chalcopyrite deposits that bear zinc and in some cases are polymetallic. Thus the zone embraces volcanogenic, volcanogenic-sedimentary, sedimentary, and possibly

epithermal ore deposits. The zone is divided into sub-zones: the copper-zinc sub-zone that includes Anayatak and Çakmakkaya deposits of principal minerals pyrite, chalcopyrite, sphalerite; and the other sub-zone of polymetallic ore deposits that includes Akarşen, Hohur Sırtı, Artvin area (Kuarshan and Melo-Sarıbudak ore zone). Minerals characteristic of the latter sub-zone are pyrite, sphalerite, chalcopyrite, galena, and particularly increased gold, so that it can be defined as auriferous (polymetallic) sub-zone. A third sub-zone comprises Başköy copper deposit. Its principal metallogenic characteristic is the vein, vein-impregnation and impregnation modes of ore occurrences that include fluorite concentrations unlike any other ore deposit in Artvin-Murgul-Hopa-Maradit area. The copperiferous mineralization near Pehlivan Köy at Maradit should be perhaps also added as a sub-zone. It is a typical epithermal copper mineralization, represented by pyrite and chalcopyrite impregnated in andesite volcanic rocks, and by adularization – a high potential gold source. Primary pyrite and chalcopyrite, secondary malachite, azurite, covellite and other copper minerals are almost the only ore mineralizations, besides scarce galena, so that it perhaps should not be even mentioned (though the maximum lead content is 0.09%).

Finally, the zone Pb-Zn, is extending from Maradit (Turkey-Georgia state border) toward Hopa, disappearing under the Black Sea, emerging at Ardeşen and continuing further to SW (where also epithermal ore deposits are possible). Ore occurrences and deposits in the zone are of the vein type bearing lead and zinc often with associated increased copper. The principal minerals in the paragenesis are galena and sphalerite, pyrite and chalcopyrite. Silver also occurs in the zone, and gold only in traces. A long period of magmatic activity is notable and therefore also is the origin of ore deposits in connection to it. As the magmatism is multiphase, and the ore origin evolved in multiphase too. In view of this and the indisputable existence of a granitoid batholith that developed during the Permian-Triassic to the Oligocene, the obvious zoning is almost theoretical, controlled by phases of magmatism, thereby also by mobilization, transmission and deposition of metals and eventual creation of ore deposits. These are large copper ore deposits in rhyolitic volcanogenic rocks, or in the rhyolitic volcanogenic and volcanogenic-sedimentary petrogenetic complex, emplaced in a zone separated from the batholith by a narrow Cu-Zn-Mo zone and plunging laterally to the north under the Black sea. Another zone, characterized by polymetallic ore (copper, zinc, lead) and copper and fluorite ore deposits, though defined in the field as the other lateral geochemical zone, does not belong to the same phase of magmatism or mineralization. Moreover, it is younger by more than 15 million years. This long period between two magmatic phases influenced the other type of

zoning – vertical zoning. This may suggest that the polymetallic ore deposits in the latter zone were largely formed during and in association with the Upper Cretaceous-Tertiary magmatism. It further suggests a unified stratum of the volcanogenic, volcanogenic-sedimentary and sedimentary formations of the complex. The pre-existing Upper Jurassic-Lower Cretaceous copperiferous complex underlies the stratum. This means that under the influence of the Tiryal Dağ-Tatos Dağları granitoid batholith, the environment provided conditions for the development of ore deposits of volcanogenic, volcanogenic-exhalative or volcanic-sedimentary type.

The given zone is genetically directly related to the latest magmatism. It is the zone of lead and zinc, two metals that occur in veins, and also in stratiforms, located peripherally on the granitoid batholith. It has been hypothesized that during the batholith formation magma largely affected the continental lower part of the Earth's crust mobilizing lead. Passing into the area of lower temperatures, hydrothermal fluids were capable of leaching copper and zinc from the earlier formed deposits or enrichments and carry them with lead into younger formations. This is how the Pb-Zn ore veins and epithermal copper mineralizations were formed, as are found in Maradit, Ardeşen and elsewhere. In the course of the process, a characteristic alteration for lower temperatures developed – **adularization** – that provided the creation of epithermal sulfide mineralizations type followed by precious metals. To this type of ore deposits has not been given any consideration so far, but a study of adularization distribution may help discovering copper, zinc and lead sulfide ores that contain increased or even high amounts of gold and silver, or possibly other precious metals.

It also means that the magmatism ended with hydrothermal fluids of low temperatures but rich in copper, lead, zinc, gold and silver solutions. Therefore these processes that led to the development of ore deposits in the zone, were also the same processes that resulted in products of epithermal mineralization type of copper bearing gold. This type of mineralization has been lesser studied, though its gold-bearing aspect may be interesting, as indicated by gold occurrences at Pehlivan Köy (Maradit), on Hohur Sırtı, on Akarşen, at Madenköy, and probably at Ünye, far westward between Ordu and Samsum.

VII. CONCLUSIONS

The Artvin Province is an important, eastern segment of the Pontic metallogenic province. The region is built up of several principal petrogenic complexes formed during the Jurassic, Cretaceous and Tertiary ages, viz. All lithologic units can be classified into: Jurassic volcanogenic-sedimentary (likely Oxfordian-Kimmeridgian) complex; Upper Jurassic-Lower Cretaceous (probably Tithonian-Neocomian) volcanogenic and volcanogenic-sedimentary complex dominantly rhyolitic in composition; Upper Cretaceous-Paleogene volcanogenic, volcanogenic-sedimentary and sedimentary complex that includes all volcanic rocks, from basic (lower or basic sub-complex composed of diabase, basalt, spilite) over intermediate to acidic (upper or andesite sub-complex composed of andesite, dacitoandesite, dacite and rhyolite supported by high amount pyroclastics, particularly agglomerate and tuff andesite in composition). There are also sedimentary rocks: limestone, marlstone, marly sandstone, sandstone, tuffaceous sandstone, etc. The fourth petrogenic complex consists of intrusive rocks mainly formed in the Mesozoic and the Cenozoic. In the region considered in this monograph, this complex was formed before about forty to thirty million years.

The lithostratigraphy and chronolithology are given primarily for the existing ore deposits, which are associated with the mentionad petrogenic complexes.

According to all the exploration data, the economic value is higher for Upper Jurassic-Lower Cretaceous (Malm-Neocomian) rhyolitic volcanogenic and volcanogenic-sedimentary complex, and then lower for Upper Cretaceous-Paleogene volcanogenic, volcanogenic-sedimentary and sedimentary complex which consist of dominantly basalt-spilite and andesite in composition, while sediments consist of sedimentary carbonate and clastic rocks. However, Jurassic (lower Malm) volcanic-sedimentary complex of dominantly andesitic volcanic rocks, and the Tertiary intrusive complex should not be ruled out from the ore potentiality, because their metallogeny has not been sufficiently investigated.

The metal of the highest economic value is copper in the biggest ore deposits associated with the Malm-Neocomian rhyolite complex. In the present state of our knowledge, the complex contains deposits of the estimated ore reserves (potential and extracted) of almost 100 million tons with the average copper content of about 1%. The ore reserves are located near Artvin (Kuvarshan, Sinkot, Seyitli, Umasen Mahallesi, etc.), in Murgul area (Anayatak, Çakmakkaya, Aduca Dere, Çarkbaşı, etc.) and in Hopa area

(Peronit and Sivrikaya, Fig. 68). Concerning the ore potentiality in this complex, one should mention that the Upper Cretaceous/Paleogene capping the copperiferous Jurassic-Neocomian rocks had been preserved in a large part of the Artvin-Murgul-Hopa-Maradit area of about 7000 km^2. This implies an abundant prospect for research of copper ore deposits at greater, uncovered depths. The possibility is best indicated by Cu-minerals in the left (western) bank of the Murgul dere, where copper mineralization was found in rhyolitic volcanic rocks at Bakiket (east of Akarşen peak), and a Cu-ore occurrence, also in the Murgul western bank (east of Petek Köy).

Besides copper, the complex contains appreciable amounts of zinc in association with copper. The metal association also includes gold and silver, which may have an economic value in the total ore reserves of the principal metal. For example, the known gold content was 0.25 ppm in Anayatak where the known ore reserve was more than twenty million tons. The deposit contained at least five tons of gold. Extrapolated on the estimated total ore reserve in the region (up to hundred million tons), the gold reserve in all the known deposits initially was at least twenty-five tons; silver even more, tens or even hundreds of tons.

The presence of molybdenum, even unexplored, in the complex is worth mentioning, because it gives a better picture of the metallogeny of the complex.

Hence, **copper, zinc, gold, silver and molybdenum** characterize the Upper Jurassic-Lower Cretaceous (Malm-Neocomian) rhyolitic volcanogenic and volcanogenic-sedimentary complex.

The next (one), Upper Cretaceous-Paleogene complex, composed of diabase-basalt-spilite, andesitic and dacite-andesitic volcanic and carbonate, or clastic, rocks. It is characteristic by primarily **polymetallic ore deposits** distributed in the areas of Artvin (Kürdaze-Melo, Irsa Maden), Murgul (Akarşen, Hohur Sırtı), Arhavi (Kutonit, etc), Maradit (Çavuşlu and Pehlivan Köy), and finally the youngest copper-deposit with fluorite is characteristic for the Başköy Maden near Murgul. As far as we know, these are relatively small deposits (up to five million tons of ore), but proportionally frequent. In our estimate, all known deposits contain at least ten million tons of ore, and the average contents exceeding 1% of copper, over than 5% of zinc and over than 2% of lead. The little explored Pehlivan Köy copper deposit at Maradit is a particular example. It is an epithermal deposit of stockwork-impregnated. It could be estimated that the average content of Cu is about 1% and more than a million tons of possible ore reserve.

The petrogenic complex is particularly important for **gold** and **silver** assemblages associated with copper, zinc, lead and possibly iron sulfides. The gold content commonly varies from 0.7 ppm (Pehlivan Köy, near Maradit) to almost 8 (Akarşen). The supposed average gold content in the sulfide polymetallic ore of the complex is about 2 ppm and silver a few times higher (indicated by tennantite and argentite). Therefore, if the ore reserves in the complex within the area considered in this monograph were only about ten million tons, then the expected gold is at least twenty tons and more than hundred tons of silver. The most promising deposits are Akarşen, Hohur Sırtı, Güneşli Köy and Pehlivan Köy. The latter locality, owing to the specific type of alteration (adularization) characteristic of epithermal deposits, may be particularly important for its concentration of copper and precious metals.

The above does not exhaust the potential value of the complex. It also contains high amounts of **manganese**, particularly near Hopa and Arhavı. Though explored, also by adits and even mined, these ore occurrences were inadequately studied to provide information of their potential value. In any event, a systematic exploration is imperative particularly in view of the manganese demand for ferrous metallurgy.

Other types of mineralizations, e.g. skarn, are insignificant as non-ferrous metal ores. Some skarn occurrences may be interesting for the magnetite content but not economical, at least not in the present state of knowledge.

Finally, mineralized intrusive quartz diorite, or granitoid rocks in general, may be interesting only as bearers of porphyric copper and zinc sulfides, zinc in particular. This assumption is based on the evidence of Kilise Tepe (near Murgul) where single quartz diorite intrusive bodies are abundantly enriched in zinc and copper.

Theoretically, the area Artvin-Murgul-Hopa-Maradit is characteristic in lateral zoning, which allows a closer insight in the potential value of metals distributed in the lithostratigaphic complexes.

In general conclusion, the area Artvin-Murgul-Hopa-Maradit, of the Artvin Province, represents a segment of the eastern Pontic metallogenic province with extremely large economic potential of copper, zinc, lead, gold, silver, and possibly manganese ores. According to this estimation further exploration of this region (Artvin Province) is imperative due to the extremely huge economic potential of its mineral raw material complex.

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Author

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IZVOD

Radule Popović

METALOGENIJA MURGULA I SUSEDNIH PODRUČJA (ARTVIN, HOPA, MARADIT), SEVEROISTOČNA TURSKA

Metalogenija Murgula i susednih područja najvećim delom je rezultat sopstvenih istraživanja autora. Za ona ležišta i rudne pojave koje nije obišao ili istraživao, a u cilju kompletnog prikaza metalogenije, preuzeti su neophodni podaci iz literature ili fondovskog materijala. Ali svi su interpretirani po jedinstvenoj koncepiciji, koja je rezultat fundamentalnih istraživanja autora, kako u pogledu starosti formacija i ležišta, tako i u pogledu geološke i geotektonske pozicije, geneze i distribucije ležišta u vremenu i prostoru. Na osnovu toga izneta shvatanja mogu se ekstrapolovati na širi prostor od onog koji obuhvata ova monografija.

U prvom, ili Opštem delu, prezentirani su glavni podaci o geografskom položaju, klimi, vegetaciji, stanovništvu itd. Osim toga u istom poglavlju dat je detaljan prikaz razvoja istraživačkih i eksploatacionih radova kroz istoriju. Kao što je poznato najstarija eksploatacija, u području o kome je reč, datira od pre nekoliko milenijuma.

U drugom ili Geološkom delu difinisan je stratigrafski položaj najkrupnijih petrogenetskih jedinica (kompleksa). Reč je, dakle, o vulkanogenim, vulkanogeno-sedimentnim i sedimentnim formacijama čije je stvaranje počelo, verovatno, u donjem delu gornje jure. Njihov razvoj je išao do malma. Tada su stvoreni vulkaniti andezitskog i keratofirskog sastava. Okiseljavanje se nastavlja prelazeći postupno u kisele vulkanite riolitskog ili riodacitskog sastava. Stvaranje ovih vulkanita se okončava u donjoj kredi (neokomu). Ovaj drugi, kiseli vulkanizam je bio znatno snažniji i obilniji po količini vulkanogenog materijala. U asocijaciji sa oba tipa vulkanizma javljaju se veoma značajne mineralizacije bakra i cinka. U tom vremenskom razdoblju, koje je trajalo oko 30 miliona godina stvorena su najveća ležišta bakra u crnomorskoj oblasti. Može se smatrati dovoljo pouzdano utvrdjenom starošću kako srednjekiselih tako i kiselih vulkanita, a to je malm – nekomsko vreme. Posle ovog perioda usledio je, relativno veliki hijatus, u trajanju od oko 40 do 50 miliona godina, posle čega se javlja novi, veoma snažan magmatizam kako intruzivni tako i ekstruzivni. U tom

vremenu, koje je trajalo oko 40 milona godina, razvio se kompletan, u hemiskoj pogledu, vulkanizam, počevši od bazičnih (bazalti, spiliti), preko srednjekiselih (andeziti) zaključno sa kiselim vulkanitima (daciti i rioliti). U toku evolucije vulkanizma gornje krede – paleogena, u asocijaciji sa vulkanitima, naizmenično se javljaju i sedimentne formacije klastičnog i karbonatno sastava. U tim sedimentima nadjen je bogat paleontološki materijal na osnovu koga je pouzdano utvrdjena starost svih formacija, a na osnovu izotoskih ispitivanja to je uradjeno i za neke magmatske stene.

Sve magmatske faze praćene su odgovarajućim rudnim pojavama počev od mangana vezanog za spilitske vulkanite, preko bakra, cinka i olova sa zlatom i srebrom u asocijaciji sa andezitima, zaključno sa skarnovskim (uglavnom magnetitskim) mineralizacijama, nastalim na kontaktu granitoidnih sa okolnim stenama.

Što se tiče geotektonske sredine nastanka pomenutih formacija, sada je opšte prihvaćeno gledište da je reč o ostrvskom luku u kome su toleitski ipovi magmatskih stena prioritetni, a za asocirajuća rudna ležišta smatra se se mogu idenifikovati sa tipovima nastalim u savremenom japanskom trvskom luku.

Govoreći o ekstruzivnim magmatskim stenama, neophodnbo je istaći da ključnu ulogu igra Tiryal Dağ – Tatos Dağlarıski granitoidni batolit. Njegovo formiranje je počelo još u permu, što znači da mu evolucija traje sve do kraja paleogena, ali da je erozioni nivo relativno plitak, tako da se u okolini Murgula, tačnije rečeno u gornjme toku Murgul derea, nalaze najstarije magmatske stene, koje pripadaju gornjoj juri, a u dolini reke Çoruh registrovani su najstariji delovi pomenutog batolita.

Osvrćući se na lokalnu tektonsku gradju područja, koje je obuhvaćeno ovom monografijom, bitnu karakteristiku predstavlja još uvek jasno nedefinisana razlomna struktura duž koje se javlja veliki broj ležišta i pojava bakra. Ta struktura je, od strane autora ove monografije, praćena od Kuvasrhana, preko Murgula do crnomorske obale izmedju Çayelıa i Rize. Osim nje postoje i druge strukture istog genetskog tipa, ali i nabori, naročito u okolini Murgula. Sve to skupa komplikuje opštu geološku sliku murgulskog i susednih područja.

Kao što su izvršene stratigrafska i petrogenetska klasifikacija formacija na petrogenetske kompleksa kao najkrupnije petrogenetske jedinice, tako po istom pricipu izvršena je i klasifikacija rudnih ležišta i pojava.

Najstarije rudne pojave bakra registrovane su gornjem toku Murgul derea, u selu Iskalka Köprüsü. One su u asocijaciji sa vulkanogeno-sedimentnim kompleksom u kome se nalaze vukaniti andezitskog do keratofirskog sastava. Istraživanja ovih mineralizacija su pokazala da se one javljaju na dva načina: kao imregnacija (singenetska sa matičnom stenom) i epigenetska (žična) stvorena nakon fomriranja ovog kompleksa. Impregnacije se karakterišu prertežno piritskom mineralizacijom sa malo halkoprita, dok su žice sastavljene od pirtita i halkopirita u kojima sadržaj bakra varira do 2,5%, a njihova je debljina na izdanku do 0,5 m. Prvobitno data negativna ocena o potencijalnosti, ovih pojava, u monografiji je revidirana. Naime, kako je utvrdjeno da se debljina sulfidnih žica povećava sa dubinom, stalo se na stanovište da se negativna ocena ne bi mogla dati bez dodatnih istraživanja. U prvom redu to se odnosi na praćenje pomenutih mineralizacija po dubini, što je moguće uraditi samo istražnim bušenjem do dubine od najmanje 100 m.

Druge rudne pojave i ležišta gornjejurske – donjekredne, odnosno malm-neokomske starosti, vezana su za riolitske vulkanogene i vulkanogeno-sedimentne formacije. Ovde je reč o enormno velikom broju pojava i ležišta na celom području Pokrajine Artvin. Medju njima i dva najveća ležišta u celoj crnomorskoj oblasti: Anayatak i Çakmakkaya. Ova dva ležišta su sada van eksploatacije, ali iz njih je izvadjeno preko 30 miliona tona rude sa preko 1% bakra. Kako se za ovaj kompleks vezuju i ležišta Aduca dere, Bognari, Orta Istasyon, Çrkbaşı, Gölbaşı, Kara Tepe, Kilise Tepe, Kuvarshan, Beşagül, Sinkot Maden, Umasen, Seyitli, Peronit, Sivrikaya i čitav niz drugih slabo proučenih pojava, dolazi se do konstatacije o izuzetno velikoj potencijalnosti na bakar ovog petrogenetskog kompleksa. Većina istraživača smatra da se na prostoru, koji je predmet ove monografije, pored izvadjenih količina rude, mogu očekivati dodatne rudne rezerve od najmanje 50 miliona tona sa komercijalnim sadržajem bakra. Primera radi, spomeuće se da su istraživanjima, izvan dva glavna ležišta Anayataka i Çakmakkaye, već sada poznate rudne rezerve veće od 5 miliona tona sa sadržajem barka od oko 1%, uz to na Kilise Tepeu, u samo jednom tipu mineralizacije (a dokazano je postojanje još dva, moguće i tri tipa) vezanih za silifikovanu riolitsku breču, procenjuju se rudne rezerve, siromašne rude (sadržaj preko 0,15%), na preko 10 miliona tona. Uz napomenu da na tom terenu postoje stratiformni i žični tipovi sa sadržajima bakra preko 1%, takodje na istoj lokanosti registrovani su orudnjene kvarcdioritske stene u kojima se nalaze sadržaji cinka od 1% do 10% i sadržaji bakra od 0,5% do 1%.

Sve su to vanredno krupni pokazatelji koji ukazuju na izuzetno veliku potencijalnost, Pokrajine Artvin, na rude bakra.

Ovde treba dodati da se u vezi sa ovim kompleksom javljaju i mineralizacije molibdena u koncentracijama do 1000 ppm.

Najzad ne treba izostaviti ni dva plemenita metala: zlato i srebro. Iako je zastupljenost zlata u koncentracijama od samo 0,25 ppm (u ležištu Anayataka, a taj sadržaj može se ekstrapolovati na ostala ležišta), ipak obzirom na potencijalne rudne rezerve, predstavlja izvaredno velike mogućnosti. Procenjuje se da bi potencijalne rezerve zlata mogle biti veće od 10 tona, a srebra i znatno više obzirom da njegov sadržaj varira od nekoliko ppm do preko 100 ppm.

Sledeći petrogenetski kompleks nastao je u gornjekreno-paleogenom vremenu i sastavljen je od vulkanogenih, vulkanogeno-sedimentnih i sedimentnih formacija. Ima veliko rasprotranjenje i u asocijaciji sa njim javlaju se mnogobrojna polimetalična (bakar, cink i olovo) ležišta i pojave, praćene relatvino visokim sadržajem zlata i srebra. Ovom tipu ležišta pripadaju Irsa Maden, Hohur Sırtı, Akarşen, Başköy, Çayeli, Kutonit, pojave u okolini Maradita i mnogobrojne druge.

U ovoj grupi rudnih ležišta moguće je razlikovati nekoliko tipova: prvom tipu pripadali bi Hohur Sırtı, Akarşen, Irsa Maden, Çayeli, Kutonit, Çavuşlu, (kod Maradit), u kojima sadržaji olova variraju do 3%, cinka čak i preko 10% i bakra do 1%. Bitnu osobinu ovih ležošta predstavljaju koncentracije zlata koje variraju i do 10 ppm, a srebra i preko 200 ppm. U ovim polimetaličnim ležištima rudne rezerve variraju od 1 do preko 10 miliona tona.

Drugom tipu pripadala bi pojava Pehlivan Köy kod Maradita. Ona se svrstava u epitermalni tip u kome sadržaji bakra variraju preko 1%, dok cink i olovo praktično izostaju, ali se javlja sadržaj zlata od 0,7 ppm. Kako je ovde dokazana adularizacija, koja je karakterističan tip alteracije za epitermalna ležišta, smatra se da ova pojava predstavlja značajan potencijal andezitskih vulkanita na bakar i zlato.

Poslednjem , terćem, tipu ležišta bakra pripada žični morfogenetski tip nastao u rupturama nabora. Ovaj tip ležišta je registrovan blizu sela Başköy (okolina Murgul), na južnim padinama Balıklı yayle. Posebna karakteristika ovog ležišta je relativno visok sadržaj bakra (preko 1,5%) i u paragenezi, visoko učešće fluorita, što nije do sada zabeleženo ni u jednom

drugom ležištu Pokrajine Artvin. Inače u paragenezi se javlja i pirit, koji je i ovde vodeći rudni mineral po zastupljenosti. Ima malo i sfalerita, dok su drugi sulfidi, kao galenit, registrovani samo u tragovima.

Polazeći od svih poznatih podataka dolazi se do ocene o visokoj potencijalnost i ovog gornjekredno – paleogenog petrogenetskog kompleksa, ali na žalost nedovoljno istraženog kao što je slučaj i sa prethodnim kompleksima.

Posebno mestom zauzima intruzivni kompleks, koji je predstavljen kvarcdioritskim stenama, mestimično snažno orudnjenim sfaleritom, piritom i halkopiritom. U nekim slučajevima, kao na primer na Kilise Tepeu (Murgul) neka tela kvarcdiorita su intenzivno orudnjena sfaleritom tako da sadržaj cinka varira od 1% do 10%, a bakra od 0,5% do 1%. Ovakva situacija, logično, sugeriše pretpostavku da je moguće očekivati postojanje porfirskih tipova ležišta bakra. No, taj problem je tek otvoren i zahteva, u budućnosti, sistematska istraživanja.

U vezi sa granitoidnim itruzivima postoji veći broj skarnovskih tipova mineralizacija u okolini Murgula, Hope i Arhavia, ali sve te pojave su bez ozbiljnijeg ekonomskog značaja.

Govoreći o metalogeniji, nezaobilazan je bazični (ili donji) deo gornjekredno – paleogenog kompleksa. U vezi sa spilitima poznat je veći broj pojava mineralizacija mangana, od kojih su neke posebno zanimljive, kao na primer u okolini Hope i Arhavia, gde su i eksploatisane u prošlosti. Na žalost i ovaj tip rudnih pojava nije dovoljno proučen tako da taj problem ostaje budućim istraživačima da mu posvete veću pažnju.

Najzad u Monografiji je prikazan i lateralan zonaran raspored rudnih ležišta i pojava oko Tiryal Dağ – Tatos Dağlarıskog batolita.

Na osnovu svih relevantnih podataka proistekla je ocena da bi trebalo izvršiti sistematsko ispitivanje i istraživanje svih formacija koje leže ispod gornjekredno – paleogenih, jer postoje realne mogućnosti da se otkriju nova velika ležišta sa sadržajima bakra od ekonomskog značaja .

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