GEOLOGY AND MASSIVE SULFIDE ORES OF THE KÜRE AREA, THE PONTIC RANGES, NORTHERN TURKEY

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ABSTRACT.— This study deals with the rocks and the massive sulfide deposits of the Küre area, situated on the western flank of the Pontic Ranges, northern Turkey. Paleomagnetic aspects are treated in a special publication. The Küre area is chiefly made up of eugeosynclinal accumulations comprising subgraywacke and black shale and a submarine basalt complex. Chemical analyses of the various basaltic rocks and related dikes have been made. A geochemical study of the basaltoids indicates that they represent an abyssal, tholeiitic magma. A major north-southerly fault system has been a duct for hydrothermally deposited massive sulfide emplacements along zones of weakness in the basaltic sequence adjoining the eugeosynclinal sediments. The hydrothermal ore solutions caused metasomatic alterations in the basaltoids. These include chloritic alteration, silicification, replacement brecciations, argillic alteration, uralitization, albitization, and calcitization. The massive sulfide ores consist of pyrite, chalcopyrite, bornite, covellite, sphalerite, digenite, marcasite, tennantite, and carrollite and have average copper contents of 6 % in the Bakibaba mine and 3 % in the Aşıköy mine. Paleomagnetic determination in the different units suggests that this part of the Pontic Ranges was rotated ca 70° counterclockwise since the Permian.

INTRODUCTION

The Küre area is situated approximately 50 km (road distance 59 km) north of Kastamonu at about 33.7° E and 41.8° N. The present study covers 19.1 km^2 of a very mountainous terrain, where the elevations range between 650 m and 1450 m. In this area, a large extrusion of submarine basaltic rock occurs among the eugeosynclinal accumulations of subgraywacke and black shale, which belong to the mobile belt of the western flank of the Pontic Ranges. The massive cupriferous deposits of the Küre area replace the basaltic sequence along the contacts with an adjacent subgraywacke-black shale unit. Of the three hitherto discovered deposits, two have been mined in recent time. The annual yield is more than 205 000 tons of massive cupriferous pyrite ore. The average grade is 6 % Cu in the Bakibaba mine and 3 % Cu in the Aşıköy mine. Notwithstanding the fact that the Küre copper deposit is the third in size in Turkey, it is geologically little studied. Hitherto only one article has been published (Kovenko, 1944). Apart from that, only short and sometimes incorrect communications on the geology of the deposits have been circulated from time to time. It is hoped, that the study reported in this paper will lead to a better understanding of the relationships between the altered wall rocks and the massive ores and contribute to our knowledge of the mode of occurrence of this type of copper deposits, thus aiding and in further prospecting and exploration work in the Küre area.

SOME NOTES ON THE HISTORY OF MINING AND ORE PROCESSING IN THE AREA

The Bakibaba ore bodies were exploited extensively by the Greeks, Romans, Genoeses, Byzantines, Seljuks (İsfendiyaroğulları), and Ottomans. Testimony of the ancient works is found in the shape of two million tons of slag lying on the slopes, and in the discoveries of coins and sledges in the old mine galleries (Halil Kumral pers. com.). According to Dinçay et al. (1973), the old tunnels in the Bakibaba mines have patterns and sizes like those used by Greek and Roman miners.

Mehmet the Conqueror used copper and iron from Küre to make the cannons employed in the conquest of İstanbul in 1453 (Dinçay et al., 1973). There exist cannons preserved from that time stamped «Küre-i-Nühas» (copper from Küre). Shortly afterwards, when he sent a fleet to Sinop to fight against the Pontic Empire, all of the military equipment was provided by İsmail Bey, the ruler of İsfendiyaroğulları, who reigned the Kastamonu vilayet, in which Küre was included, between the years 1290 and 1462.

Between 1659 and 1845, the Ottomans intermittenly worked the Bakibaba mines. According to the Ottoman Empire Register of 1715, copper was brought each year from Küre to İstanbul in order to make cannons. In 1845 the mining activities ceased owing to the caving-in of a mine, which cost the lives of several miners and frightened away the survivors.

Between 1895 and 1913 several foreign companies worked in the Bakibaba area. Prospecting and Mining Ltd. investigated the slag-heaps with the help of shafts and found that they contained about 1.5 million tons of ore with 1-1.25 % Cu and 200 000 tons with 2-2.5 % Cu. After World War I, in 1924, the Balya-Kara Aydın Mining Co., controlled by French interests, explored three of the old levels obtaining ore from the middle level. Shortly after the establishment of the Republic of Turkey in 1923, Nikitin was employed to make a geological study of the Küre area and to propose a program for its exploration. In 1939, MTA (Mineral Research and Exploration Institute of Turkey) initiated a new program by sending Kovenko to study the geology and suggest further exploration. He found the gossans of the Aşıköy and Kızılsu areas and recommended that these as well as parts of the Bakibaba area be studied by geophysical methods. From 1955 the Aşıköy open cast was mined by Küre Pyrites-Turkish Joint Stock Company, but in 1959 it was turned over to Etibank.

In the course of prospecting, electromagnetic surveys and drilling activities have sporadically been going on in the area since 1963. In 1963 and 1964, Etibank made spontaneous-polarization and electromagnetic surveys, which resulted in new drilling proposals in the Bakibaba and Kızılsu areas. After calculations of the reserves of the penetrated ore bodies in the Bakibaba area, the Black Sea Copper Works Corporation (KBİ) started mining in 1968. In recent years the annual production of cupriferous pyrite was about 90 000 tons at an average of 6 % Cu in the Bakibaba underground mine and about 115 000 tons at an average of 3 % Cu in the Aşıköy open-cast.

PREVIOUS WORK

The first, unpublished geological report on the Küre deposits was given by Nikitin in 1926. His investigations were mainly carried out in the now cavedin galleries at the 894 m, 1014 m (zigzag), and 1094 m levels (metres above sea level), where he also took samples of ores and ancient slags for analysis. The construction of a shaft in the galleries was proposed by Nikitin, but the work was never carried out. Nikitin described the host rock as «diabase» (the basaltic sequence of this paper) and designated all the dikes as «diorite», which includes diabase, quartz diabase, and peridotite. In 1938 and 1944 Kovenko studied the area for MTA. He mapped the old Bakibaba gallery at the 1014 m (901 m was used in earlier work, which was based on an older topographic survey) level (caved adit), which is termed the zigzag gallery, and the gallery at the 1074 m (961 m) level in Aşıköy, and comprehensively surveyed almost the whole area to a scale of 1:5000. He analysed chemically one sample each of «diabase» (basaltic sequence), «gabbro» (diabase), serpentinite, peridotite, and «diorite» (possibly a variolitic pillow basalt of albite-rich composition from the zigzag gallery at the 1014 m level). He also described the «white albitic dike» (dacite dike) in Aşıköy. In bis report, the contacts of the mentioned rocks were not outlined or defined, but only estimated roughly. After the initial studies of Kovenko, several geologists of the MTA conducted geophysical mapping and prepared reports that include some geological information. Almost none of the material contained in these reports has ever been published. At the initiative of the MTA, a new geological study of the Küre area was made in the summer of 1966 by a CENTO group (Sarıcan, 1968). This group spent 40 working days in the area, where it carried out field mapping, drew cross sections, prepared rock descriptions, and estimated the ore reserves. The objective of the participants was principally training. Therefore, the study of mapping methods was considered more important than an extensive study of all the aspects of geology and mineralization in the area. The group concluded that the «mafic rock» (basaltic sequence) comprised two different intrusions, the eastern part having been formed during an older and the western part during a younger magmatic episode. The dikes related to the basaltoids, i. e. diabase, amphibolitized diabase, quartz diabase, and peridotite were described as «gabbro and diorite rock».

WORK DURING THE PRESENT STUDY

During the study reported here, the Küre area was remapped to a scale of 1:10 000 using an unpublished topographical map also showing 10 m isolines. This map was found by the writer at the KBİ office and had probably been drawn by the topographers of the MTA. The petrological investigation is based on the study of outcrops which are mostly found in roadcuts and along water courses.

Whole-rock chemical analyses were made at the Geochemical Laboratory of the Geological Institute at Lund, Sweden. The normative mineral compositions were calculated using a Fortran program. In addition, four chemical analyses of ores were obtained from the analytical laboratory of the Geological Survey of Sweden.

In the petrographic descriptions, the grain-size terms are defined as follows: coarse-grained > 5 mm, medium-grained 1-5 mm, fine-grained 0.05-1 mm, microcrystalline < 0.05 mm.

THE BASALTIC SEQUENCE

Occurrence and petrography

In the description of the geological map of the Sinop area (Ketin, 1962), the basaltic rocks of Küre are called diabase. This term was also used in the first, unpublished geological descriptions of the Küre area by Nikitin (1926) and Kovenko (1944), whilst the CENTO group (Sarıcan, 1968) employed the designation "mafic rocks". The minimum thickness of the effusives can be estimated to be over 2 km. The, lower levels of the basaltic rock sequence mostly consist of massive flows. Upwards, the massive flows are gradually replaced by pillow lavas, pillow breccias and, finally, tuffaceous chloride masses.

Rocks of the basaltic sequence occupy roughly half of the investigated area (Fig. 1). They have been intruded by numerous rocks of various compositions and generations, which occur in the shape of dikes. Generally, the basaltic sequence has been subjected to considerable hydrothermal alteration. The alteration products are irregularly distributed throughout the complex. However, many altered rock varieties retain relics of original igneous textures. Because there are small, partly concordant and partly discordant occurrences of black shale among the basalts, the basaltic sequence appears to have been formed largely under water.

As a rule, the pillow lavas grade downwards into relatively non pillowed, massive flows, which usually occur below the 750 m height level. Especially well developed pillows occur at about the 850 m level and decrease successively upwards. Laterally they disappear towards the black shale-subgraywacke contacts, where the chilled margins exhibit a successive transition to very fine-grained rock.

The pillows range in size from about 5 to 250 cm in diameter. Their color is greenish gray to greenish black, the shape being loaf-like or bun-shaped. In cross-section, the loaf -like pillows are more or less elliptical and often exhibit radial textures. The longest pillow axes may be three to four times as long as the shortest axes, which usually coincide with the original vertical direction. The ellipsoidal outlines of the cross-sections are distorted by downward protrusions resulting from the molding of the lower surface against the tops of underlying pillows. Along the highway to İnebolu, the long-axis orientation of the loaf-shaped pillows is approximately N40E/15E but the strike/dip changes from one locality to the other. Generally, the pillows are either closely packed with very little interpillow matrix material (e.g. along the highway to İnebolu) or tightly molded against each other (e.g. at the KBİ crosswork), but in a few places they were found to be partly or wholly separated by a matrix.

Isolated or displaced single pillows, rarely larger than 25 cm in size, and broken fragments of pillows in a tuffaceous chloritic matrix, which can be termed pillow breccias as proposed by Carlisle (1963), are very abundant in the upper and outer parts of the basaltic sequence and gradually disappear downwards. Large areas, especially beneath Kızılsu, along the highway to Kastamonu, and to the south of Bakibaba peak, are occupied by such pillow breccias. Sometimes it can be seen that the amount of soft chloritic matrix tends to increase upwards in the sequence. However, such rocks are generally poorly exposed, which is due to their relatively easy destruction by weathering. In exceptional cases, round clasts in a tuffaceous matrix may consist of up to eight small hexagonal pieces. Usually, however,the pillows are not jointed. Where joints are present, they mostly exhibit no regular pattern, or have a radial arrangement. In rocks where the pillows are not tightly packed and molded to each other, irregular calcite and chlorite masses sometimes occupy the intervening voids. Up to 5 mm thick calcite crusts commonly develop around large individual pillows, e.g. around the bun-shaped pillows in the gallery at the 920 m level in Bakibaba mine. Chlorite masses form an interpillow matrix, found mostly between the smallest, greenish gray type of pillows, (e.g. at the bridge over Zemberekler brook). There are indications to suggest that this matrix material originally consisted of Mg-rich glass that was later converted to chlorite. However, most of the interpillow matrix material has not been examined in detail during the present study. The pillows contain varying amounts of chlorite and calcite. In the central part of the pillows, there are almost always igneous textures of the variolitic, doleritic and subdoleritic types.

Mineralogy and textures

The variolites of the pillows are fine-grained, globular, radiating structures composed of slender fibers of albite, between which there occur subordinate amounts of microcrystalline quartz. There also occur a few minute plagioclase phenocrysts and laths, which are more of less completely replaced by calcite, chlorite, and quartz. In contrast, minute equidimensional grains or acicular crystals of clinopyroxene remain completely unaffected by alteration, but commonly display marked corrosion at their contacts with the groundmass. Fine-grained calcite and fibrous, non-pleochroic chlorite are common constituents in the variolitic matrix. The presence of chlorite determines the green color-shades of the rock.

Apart from the variolitic types, the preserved doleritic parts of relatively large pillows consist mainly of clinopyroxene and albite. However, in many cases up to 4 mm long labradorite laths are

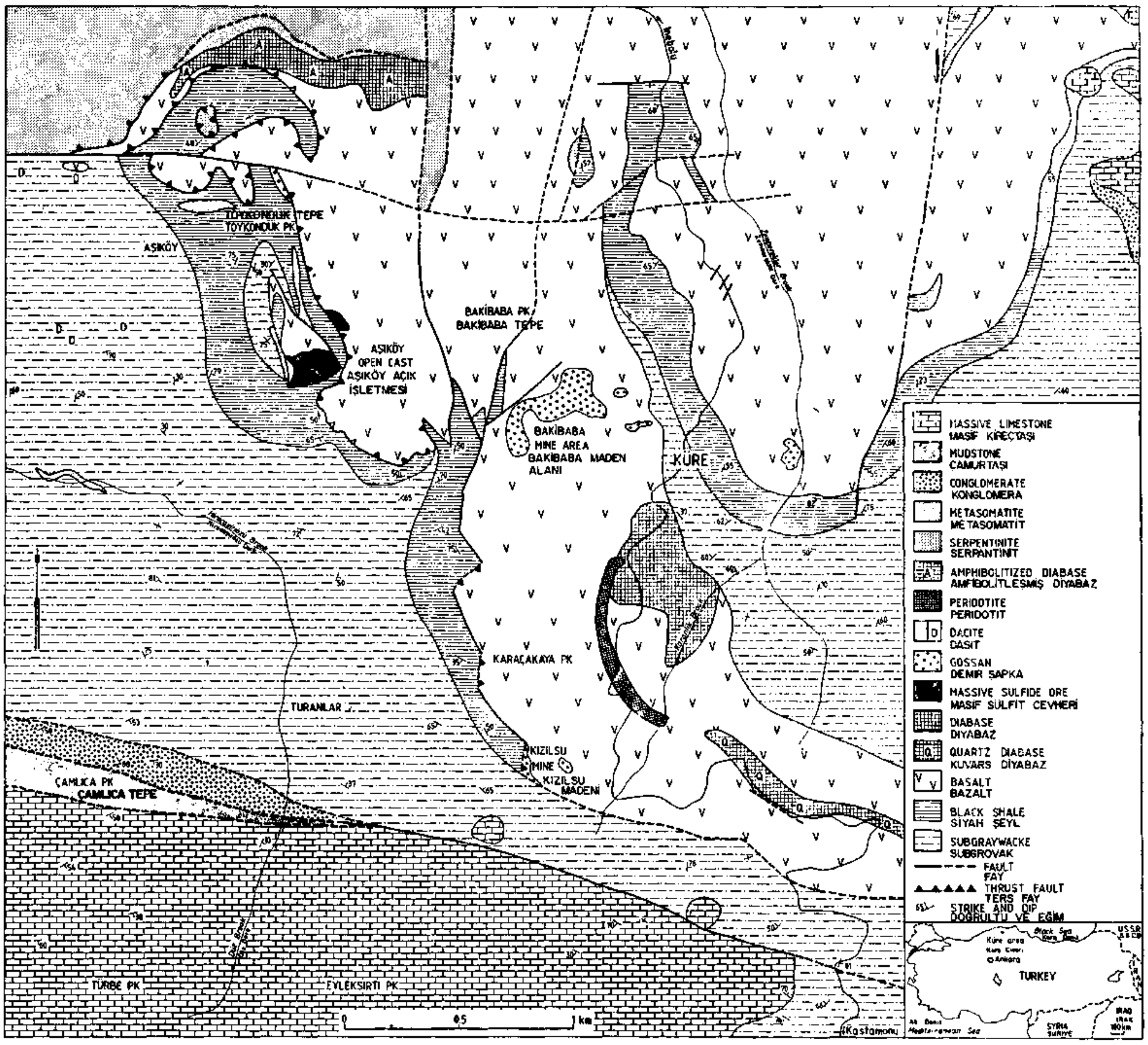

Fig. 1 - Petrological map of the Küre area.

present instead of albite. The plagioclase laths are often partly replaced by chlorite, which grows particularly along the symmetry planes. They may also contain minute inclusions of leucoxene and chlorite. As is the case in the variolites, the clinopyroxene remains relatively unaffected by chloritization even in pillows where chlorite is very abundant and where it, together with some calcite, forms the interstitial matrix between the plagioclase laths and the clinopyroxene crystals. Quartz, prehnite, epidote, and sericite are very uncommon in fresh rocks of this type.

The isolated pillows in the pillow breccias are richer in vesicles and labradorite than the other pillows. The labradorite laths are slightly zoned and largely replaced by chlorite. Again, clinopyroxene is only insignificantly affected by chloritization. In these rocks, there are also interstitial quartz euhedrons which exhibit corrosion at their boundaries with the chlorite-calcite matrix that occupies the interstices between the labradorite and chinopyroxene crystals. As different from the labradorite-rich isolated pillows, the fine-grained variolitic or doleritic textures of albite-rich isolated pillows are often strongly pigmented by iron oxide. In these fine-grained, albite-rich rocks, clinopyroxene is subordinate or entirely absent. The few laths or phenocrysts of plagioclase occurring here are largely altered to albite, epidote, clinozoisite, sericite, quartz, and calcite. The amounts of quartz, chlorite and calcite vary from one isolated pillow to the other in conformance with the degree of hydrothermal alteration and the type of texture. Large vesicles, reaching 15 mm in size, are found only in the isolated pillows. They contain chlorite, calcite, quartz, epidote and clinozoisite in various proportions. Sometimes, peripherally situated vesicles are filled by chlorite cores and marginal rims of calcite or quartz.

A deviation from the mineralogy and chemical composition of the common pillows and isolated pillows is found in relatively small, spherulitic pillow structures (MG06 and MG17), which are composed mainly of devitrified glass with minor amounts of albite. These rocks have chemical compositions very similar to that of the andesine-hornblende cumulate (MG23).

There is some textural uncertainty regarding the precise demarcation between true massive flows and rocks where the pillows have been welded together to the extent of losing their characteristical features. However, the massive flows arc rather different in mineralogy and chemical composition from the welded pillow flows. The mineral compositions and the medium-grained, doleritic textures of some massive flows are only found in some of the isolated pillows.

The textures of the massive flows are typically doleritic. Here, the labradorite laths are euhedral, clinopyroxene occupying strictly interstitial positions. The labradorite crystals are sligthly zoned. There appears to exist a general reverse relationship between the chloritization of the labradorites and clinopyroxenes. Where one mineral is strongly chloritized, the other remains essentially unaffected. In cases of intense ehloritization, especially in the medium-grained rocks, the labradorite crystals break-down to cloudy albite, clinozoisite, epidote, quartz, and sericite. Normally the content of clinopyroxene in the massive flows varies from 20 % to 35 %, whilst the chloritization product may make up about 35 % of the rock volume. The fibrous chlorite masses often associate with quartz and leucoxene and in all cases with calcite. Calcite is a principal component of the interstitial matrix between the labradorite and clinopyroxene crystals. The borders of the large, euhedral quartz crystals are commonly corroded by chloritization.

Differing in mineralogy and chemical composition from the average basaltic rock, a narrow compositionally layered andesine and hornblende cumulate (MG23) was found among the fresh, massive flows in the lower reaches of the Zemberekler brook valley. The lense-shaped cumulate is only 3 m long and 20 cm thick. It is medium-grained in the center but gradually becomes fine-grained toward the margins. Normally, the andesine laths are partly replaced by chlorite, quartz, and prehnitc. They usually contain minute inclusions of leucoxene and epidote: The hornblende is strongly altered to chlorite. Titanite is common. A matrix of chlorite, quartz, titanite, leucoxene, and calcite fills the interstitial spaces between the andesine and hornblende grains.

In the upper part of the basaltic sequence, an alteration zone is developed near a contact with a quartz diabase dike, presumably situated in a minor fault zone. This rock (MG24) has the same chemical composition as the average basalts (MG46). However, the original texture of the rock is destroyed by complete alteration to chlorite, quartz, calcite, and a dust of iron oxides.

The whole Bakibaba mine area is almost completely chloritized, which is an effect induced by the ore-bearing solutions. Also outside this area, the occurrence of several other irregular earthy horizons (masked fault zones?) has been observed within the basalt complex. In these earthy, chloritized horizons, there occur some clots which consist of pure albite, chlorite, or quartz. As a rule, the chloritized rocks strike north-south and particularly follow the contacts with the black shale. They carry sporadic amounts of sulfide minerals, mostly pyrite. The color of the chlorite in the chloritized horizons is white and to some extent pale green.

Opaque minerals are common accessories in the fine-to medium-grained variety of basaltic rocks. Titaniferous magnetite and ilmenite are usually intergrown with a reticulated network of leucoxene lamellae. Chrome spinel, pyrite, chalcopyrite, hematite, and martite are minor accessories. The chrome spinel, which is euhedral, is not affected by the regional alteration in the basaltic rocks. It has a reflectance of about 12.0 %.

Aspects of geochemistry and their tectonic significance

Chemical analyses of the rocks of the basaltic sequence are given in Tables 1-3. The massive flows seem generally to be chemically homogeneous and are characterized by above-average contents of total Fe_2O_3, CaO, and TiO2 and a correspondingly low SiO_2 percentage. By comparison, the pillows carry rather variable amounts of SiO_2 and MgO. The isolated pillows in the pillow breccias have SiO_2 contents between 47 and 52 % and exhibit large variations in CaO and Na_2O. Consequently, the pillowy, submarine, basalt rock has probably been modified by low-grade hydrothermal alteration. The degree of chloritization is a control of the large variations of chemical composition. With the exception of TiO_2, P_2O_5, and MnO, all oxides have been mobile during the alteration process.

As is seen from Fig. 2-9 , a simple alkali-silica classification of the basaltoids shows no distinct appurtenance either to the tholeiitic/subalkaline or the alkaline types, but tholeiitic compositions dominate quantitatively. However, the extent of regional chloritization and the occurrence of the basaltoids in an originally subaqueous environment suggest that secondary alteration may have had substantial compositional effects, affecting particularly the more mobile elements. A special study was therefore made of the stable minor components Ti, P, Zr, Y, and Nb. Selected plots shown in Fig. 5-9 demonstrate that the Küre basaltoids have typically tholeiitic trace-element characteristics. It is therefore concluded that much of the chemical variability is due to secondary alteration processes. There is no substantial magma-type difference between the effusives and the dike rocks. The Küre tholeiites have ocean-floor affinities. Considering the geotectonic setting, it is suggested that they were generated by the expansion of the marginal basin of the Anatolian troughs. This suggestion is in line with the opinion of Brinkmann (1972) that the ophiolite troughs in Anatolia were originated by crustal tension. The general picture provided by that writer involves an Anatolian Tethys in the shape of a broad an relatively shallow oceanic channel. Several elongate, narrow, steeply-sloping troughs of more substantial depth were formed in the floor of this channel. The results of the present study are in good agreement with this model.

Table 1 - Chemical analyses and CIPW norms of basaltic rock from the Küre area (oxides in weight %, trace elements in ppm)

Oxide	*MG01*	*MG02*	*MG03*	*MG04*	*MG05*	*MG06*	*MG07*	*MG08*	*MG09*	*MG10*
SiO_2	47.50	47.13	46.97	47.29	48.87	62.03	51.65	49.30	51.33	49.27
TiO_2	1.41	1.60	1.71	1.72	1.25	0.67	0.58	0.95	0.48	0.82
Al_2O_3	15.11	14.13	14.98	14.45	14.99	15.07	15.43	15.28	16.57	15.02
Fe_2O_3	2.22	5.24	2.29	3.56	2.52	0.96	2.22	1.74	1.54	1.08
FeO	7.05	6.24	7.68	6.79	6.80	4.24	5.63	6.68	5.60	7.40
MnO	0.19	0.18	0.21	0.19	0.18	0.08	0.13	0.19	0.14	0.17
MgO	4.98	7.44	4.57	5.15	8.37	2.48	4.74	8.79	6.42	10.18
CaO	11.00	9.78	11.36	9.67	9.08	4.14	7.66	6.83	9.57	8.46
Na_2O	2.68	3.34	2.28	3.31	2.83	5.00	3.21	3.46	3.27	3.28
K_2O	0.17	0.11	0.06	0.28	0.27	0.15	0.54	1.06	0.49	0.55
P_2O_5	0.12	0.15	0.16	0.15	0.11	0.04	0.05	0.08	0.03	0.07
H_2O	0.75	1.36	0.92	0.92	0.73	0.41	1.07	0.57	0.56	0.45
LOI	6.52	3.50	6.92	6.12	3.99	4.13	7.00	4.73	3.97	3.72
Sum	99.70	100.19	100.11	99.59	99.99	99.40	99.90	99.66	99.97	100.48
Trace elements										
Nb	7	8	9	7	7	4	4	6	5	<3
Rb	4	<3	<3	5	5	<3	7	7	5	6
Sr	154	227	149	171	137	79	78	108	141	195
Y	30	39	41	39	29	18	18	23	14	23
Zr	88	108	118	109	75	32	29	59	21	48
Normative components										
Q	2.02	—	3.69	0.81	—	18.56	6.53	—	0.51	—
Or	1.09	0.65	0.36	1.65	1.60	0.93	3.19	6.26	2.90	3.25
Ab	24.53	28.26	19.29	28.01	23.95	44.60	27.16	29.28	27.67	27.75
An	31.04	23.24	30.46	23.74	27.40	19.22	26.10	23.03	29.09	24.64
Mg-Di	13.54	14.12	11.70	12.77	10.01	0.96	6.00	6.03	10.09	9.73
Fe-Di	8.70	5.49	8.76	6.11	3.63	0.82	3.45	2.31	4.67	3.90
En	7.14	4.85	5.96	6.91	14.83	6.07	9.02	7.72	11.31	4.30
Fs	5.26	2.17	5.12	3.79	6.17	5.93	5.95	3.39	6.00	1.98
Fo	—	5.00	—	—	0.96	—	—	7.97	—	11.59
Fa	—	2.46	—	—	0.44	—	—	3.86	—	5.88
Mt	3.48	5.72	3.32	5.16	3.65	1.47	3.22	2.52	2.23	1.57
Il	2.90	3.04	3.25	3.27	2.37	1.34	1.10	1.80	0.91	1.56
Ap	0.31	0.36	0.38	0.36	0.26	0.10	0.12	0.19	0.07	0.17

MG01 - Massive flow, fine-to medium-grained, dark gray.
MG02 - Massive flow, fine-grained, greenish black.
MG03 - Massive flow, fine-grained, dark gray.
MG04 - Massive flow, fine-to medium-grained, medium dark gray.
MG05 - Massive flow, fine-to medium-grained, greenish black.
MG06 - Pillow, devitrified glass, spherulitic, fine-grained, dark greenish gray.
MG07 - Pillow, subdoleritic, medium-grained, greenish gray.
MG08 - Pillow, doleritic, fine-grained, dark greenish gray.
MG09 - Pillow, doleritic, fine-to medium-grained, dark greenish gray.
MG10 - Pillow, doleritic, fine-grained, medium dark gray.

Table 2 - Chemical analyses and CIPW norms af basaltic rock from the Küre area (oxides in weight %, trace elements in ppm)

Oxide	*MG11*	*MG12*	*MG13*	*MG14*	*MG15*	*MG16*	*MG17*	*MG18*	*MG19*	*MG20*
SiO_2	51.23	50.63	49.49	51.61	48.62	50.95	63.05	49.41	47.48	46.97
TiO_2	0.67	1.68	1.02	1.70	0.73	1.78	1.40	1.31	1.47	0.94
Al_2O_3	13.54	14.67	15.82	14.65	14.92	14.73	17.74	15.05	14.84	13.66
Fe_2O_3	1.17	2.70	2.02	1.79	9.74	1.29	5.17	2.83	2.18	1.56
FeO	6.10	8.60	6.26	8.30	8.72	7.68	—	6.37	7.03	8.08
MnO	0.13	0.16	0.13	0.13	0.05	0.14	0.07	0.11	0.20	0.19
MgO	12.82	6.70	6.84	4.72	7.28	3.72	1.94	6.19	4.47	12.27
CaO	6.17	6.32	9.98	7.58	0.68	5.49	4.56	10.30	12.80	8.08
Na_2O	3.26	4.47	2.62	2.47	2.20	5.10	4.33	2.38	2.11	2.70
K_2O	0.04	0.14	0.25	0.13	0.49	0.17	0.12	0.13	0.08	0.30
P_2O_5	0.06	0.15	0.08	0.15	0.05	0.15	0.13	0.10	0.10	0.08
H_2O^-	0.40	0.69	0.44	0.51	0.31	0.64	0.29	1.24	0.71	0.37
LOI	4.74	3.95	4.52	5.89	5.08	7.34	2.71	3.84	6.34	4.47
Sum	100.33	100.86	99.46	99.63	98.88	99.17	98.51	99.26	99.70	99.67
Trace elements										
Nb	4	8	6	8	6	7	6	6	7	7
Rb	<3	<3	5	<3	4	<3	<3	<3	<3	5
Sr	55	173	122	138	46	59	140	150	148	170
Y	18	39	26	36	22	39	32	26	32	22
Zr	34	118	57	111	33	114	96	76	84	55
Normative components										
Q	—	—	2.20	11.61	15.20	1.17	25.76	5.37	4.17	—
Or	0.24	0.83	1.56	0.82	3.08	1.09	0.74	0.81	0.51	1.77
Ab	27.58	37.82	23.46	22.36	19.77	46.96	38.09	21.23	19.11	22.85
An	22.19	19.55	32.45	30.49	3.24	18.28	21.24	31.62	32.94	24.27
C	—	—	—	—	10.25	—	—	—	—	—
Mg-Di	5.11	5.60	10.98	3.23	—	4.33	0.90	12.29	16.50	9.11
Fe-Di	1.31	3.24	4.71	2.68	—	4.22	0.22	5.14	11.70	3.21
En	22.51	10.27	12.93	11.08	19.25	8.08	4.61	10.55	4.26	6.96
Fs	6.61	6.82	6.37	10.55	17.42	9.03	1.29	5.07	3.47	2.81
Fo	4.94	2.68	—	—	—	—	—	—	—	13.58
Fa	1.60	1.96	—	—	—	—	—	—	—	6.05
Mt	1.70	3.92	3.10	2.78	9.48	2.04	3.37	4.33	3.38	2.26
Il	1.27	3.19	2.05	3.45	1.47	3.68	2.76	2.62	2.99	1.79
Ap	0.14	0.36	0.20	0.36	0.13	0.39	0.32	0.25	0.25	0.19
Mg-Sp	—	—	—	—	0.67	0.68	0.65	0.66	0.67	—
Fe-Sp	—	—	—	—	0.06	0.06	0.06	0.06	0.06	—

MG11 - Pillow, variolitic, fine-grained, dark greenish gray.
MG12 - Pillow, doleritic, fine-grained, dark greenish gray.
MG13 - Isolated pillow, doleritic, fine-to medium-grained, dark greenish gray.
MG14 - Isolated pillow, vesicular, microcrystalline, greenish black.
MG15 - Isolated pillow, subdoleritic, microcrystalline, dark greenish gray.
MG16 - Isolated pillow, doleritic-variolitic, fine-grained, greenish gray.
MG17 - Isolated pillow, devitrified glass, spherulitic, greenish black.
MG18 - Isolated pillow, doleritic, fine-to medium-grained, greenish black.
MG19 - Isolated pillow, doleritic, fine-to medium-grained, dark gray.
MG20 - Isolated pillow, subdoleritic, fine-to medium-grained, greenish black.

Table 3 - Chemical analyses and CIPW norms of basaltic rock and related dikes from the Küre area (oxides in weight %, trace elements in ppm)

Oxide	*MG21*	*MG22*	*MG23*	*MG24*	*MG25*	*MC26*	*MG27*	*MG28*	*MG29*	*MG30*
SiO_2	52.02	49.96	57.45	50.83	52.99	51.14	51.51	48.53	45.10	39.64
TiO_2	0.52	1.01	1.36	0.91	1.10	0.60	0.83	0.20	0.28	0.24
Al_2O_3	16.20	14.47	14.59	11.88	16.65	16.02	16.14	17.68	12.38	4.96
Fe_2O_3	2.21	2.56	2.12	2.76	2.47	2.01	2.31	1.03	1.89	2.89
FeO	5.79	5.29	5.75	4.77	3.21	5.54	6.06	4.12	7.03	7.06
MnO	0.13	0.15	0.10	0.10	0.10	0.16	0.13	0.12	0.13	0.15
MgO	8.40	6.84	3.87	4.50	3.92	8.32	7.02	10.39	19.26	30.26
CaO	8.24	10.11	4.00	9.71	10.92	11.22	8.36	12.30	9.54	4.93
Na_2O	2.37	4.29	6.23	2.36	4.62	1.96	3.30	1.73	0.49	0.15
K_2O	0.52	0.04	0.23	0.13	0.25	0.27	0.45	0.33	0.13	0.05
P_2O_5	0.03	0.09	0.12	0.07	0.05	0.03	0.05	0.01	0.01	0.01
H_2O^-	0.47	0.41	0.37	0.39	0.35	0.32	0.47	0.40	0.26	0.28
LOI	3.40	4.88	3.41	11.29	3.60	2.30	2.94	3.34	2.97	7.78
Sum	100.28	100.10	99.60	99.72	100.23	99.88	99.58	100.18	99.47	98.39
Trace elements										
Nb	4	6	7	5	4	<3	4	4	5	4
Rb	5	<3	<3	5	4	5	5	4	<3	<3
Sr	84	145	54	38	133	74	122	131	51	22
Y	16	26	36	19	23	16	23	8	6	5
Zr	17	60	91	53	30	23	44	7	4	7
Normative components										
Q	—	—	5.18	14.03	1.26	3.40	1.60	—	—	—
Or	3.07	0.24	1.42	0.87	1.48	1.60	2.77	1.95	0.80	0.33
Ab	20.05	36.30	55.01	22.69	39.09	16.58	29.04	14.64	4.31	1.41
An	32.03	20.11	11.65	24.36	23.95	34.12	29.01	39.50	32.42	14.07
Mg-Di	5.19	17.95	4.18	16.73	19.15	12.91	7.94	13.98	11.05	8.99
Fe-Di	1.77	5.71	2.55	7.46	4.71	4.25	3.20	3.11	2.23	1.23
En	18.51	0.30	8.12	4.98	0.88	14.74	14.50	11.04	18.25	13.45
Fs	7.25	0.11	5.68	2.54	0.25	5.56	6.70	2.82	4.24	2.10
Fo	—	5.90	—	—	—	—	—	5.86	18.55	46.11
Fa	—	2.37	—	—	—	—	—	1.65	4.74	7.94
Mt	3.20	3.71	3.21	4.20	3.29	2.91	3.48	1.49	2.85	3.85
Il	0.99	1.92	2.70	1.96	2.09	1.14	1.64	0.38	0.55	0.51
Ap	0.07	0.21	0.30	0.19	0.12	0.07	0.12	0.02	0.03	0.03

MG21 - Isolated pillow, doleritic, fine-grained, dark gray.
MG22 - Isolated pillow, vesicular, fine-grained, medium dark gray.
MG23 - Andesine-hornblende cumulate in basalt.
MG24 - Replacement breccia of basaltic rock.
MG25 - Diabase, medium gray.
MG26 - Diabase, medium dark gray.
MG27 - Diabase, dark greenish gray.
MG28 - Diabase, medium bluish gray.
MG29 - High-temperature aureole.
MG30 - Peridotite.

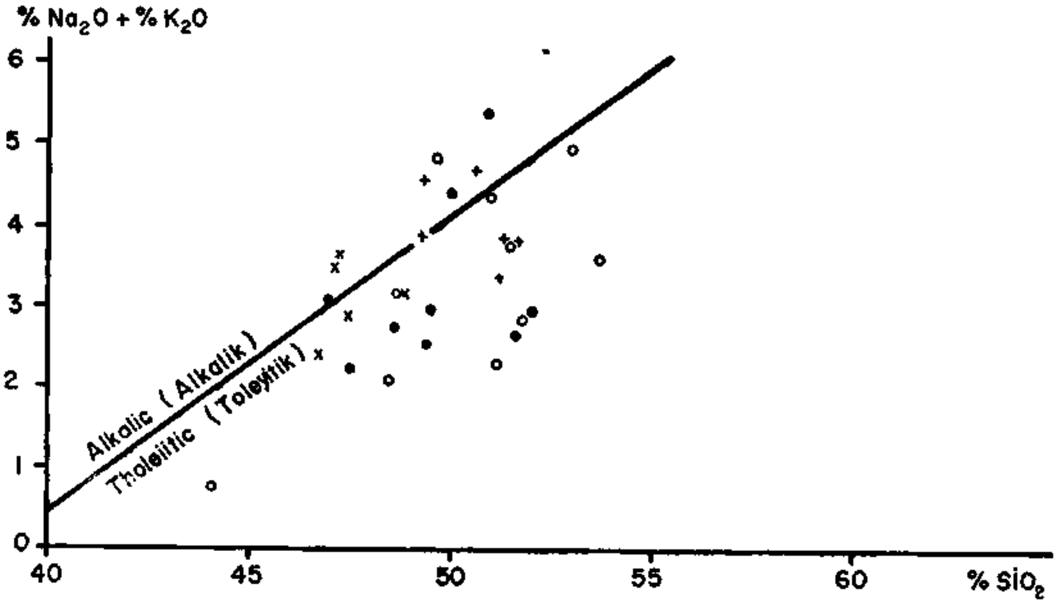

Fig. 2 - Na_2O + K_2O versus SiO_2 diagram of basaltoids from the Küre area using MacDonald and Katsura (1964) dividing line.

DIKE ROCKS

The basaltoid extrusives of the Küre region are intruded by a number of dike rocks, some of which (diabase and quartz diabase) are closely related in time with the extrusives, whilst others (dacite, peridotite, and amphibolitized diabase) are separated from the basalts by a phase of tectonization and the formation of the sulfide ores. Compositionally, all the diabase varieties are abyssal tholeiites and thus similar to the effusives (Fig. 2-9). Also, it appears that the compositions of the dike rocks have not been affected by alteration quite as strongly as those of the extrusives. Nevertheless, there was some uralitization/chloritization and some mobility of total Fe, Mg, and Na.

Diabase

At the southern border of Küre town, at the contact between the basaltoid extrusives and a peridotite, there is a dike of medium-grained, bluish-gray to dark-gray diabase reaching a maximum width of 400 m (Fig. 1). Some of the contacts show a chilled marginal diabase facies. The contact is often difficult to trace. This is to a certain extent due to alteration during the deposition of the ores in the Bakibaba mine area but also to deep weathering, which gives the rocks an earthy consistency.

The main minerals are normally-zoned plagioclase (Ca 60%) and clinopyroxene (Ca 35%). Minor components are magnetite, pyrite, chalcopyrite, ilmenite, and hematite. The ilmenite contains fine-grained inclusions of hematite. The texture of the rock is doleritic to subdoleritic.

Secondary alteration is generally not very extensive but may locally (e.g. along the Karanlık brook) be more through. Plagioclase is altered by chloritization, saussuritization, and serialization. The clinopyroxene has been partially or completely altered to uralite. Four chemical analyses of the diabase are given in Table 3.

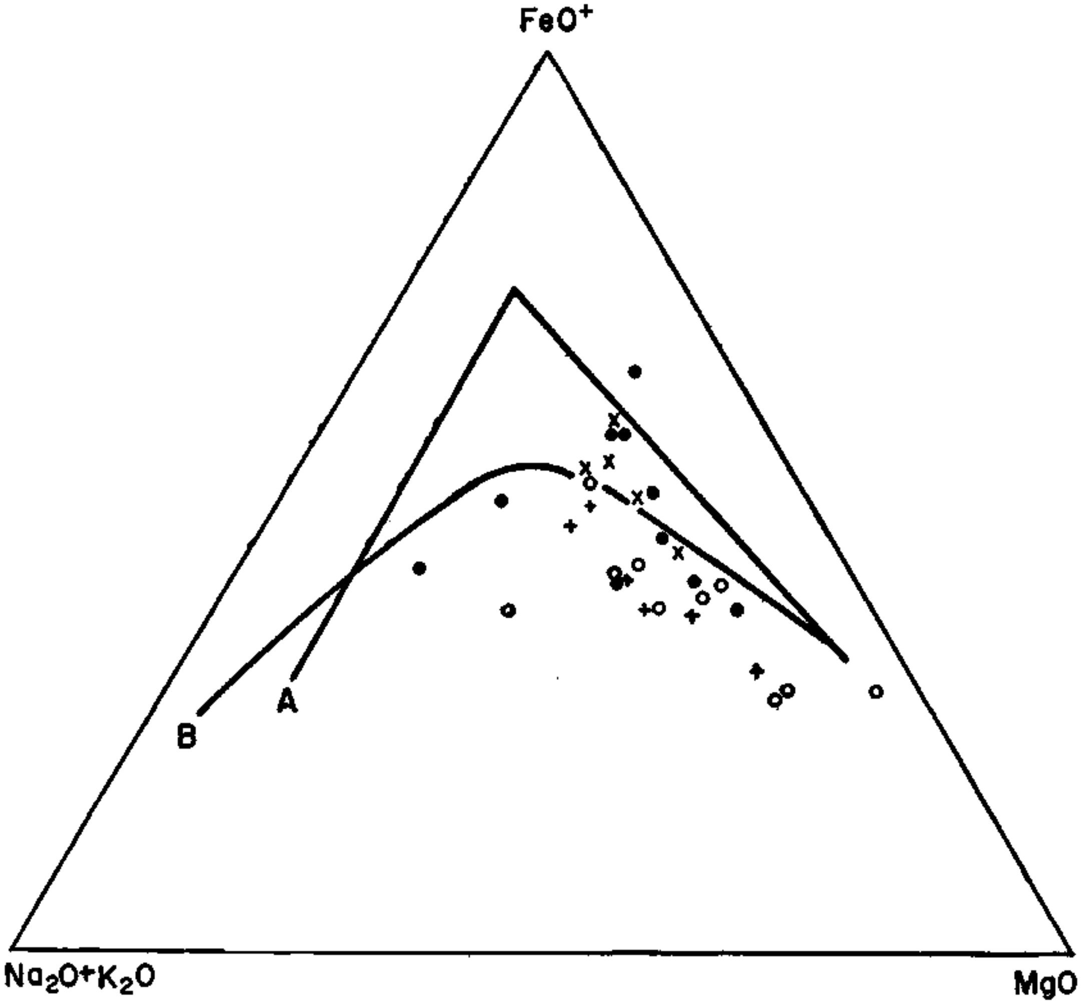

Fig. 3 - $MgO/FeO+/(Na_2O+K_2O)$ diagram for basaltoids from the Küre area. Differentiation trends of tholeiitic (A) and alkaline (B) basalts from MacDonald and Katsura (1964).

Quartz diabase

A medium-grained quartz diabase dike occurs along the highway to Kastamonu, in the SE part of the map (Fig. 1). The width ranges from 50 m to 100 m, but the dike is generally ill-exposed and the contacts are mostly masked by the highway. As a rule, the rock is medium bluish-gray. It differs from the diabase mainly by the occurrence of quartz.

The texture is doleritic or subdoleritic. The rock consists of about 55% pltgioclase, 30 % clinopyroxene and hornblende, and quartz. The plagioclase is usually labradorite, but zoning may be present. It rarely contains tiny specks of clinozpisite and sericite. Clinopyroxene is mostly completely replaced by uralite.

The content of quartz in the rock varies from 2 % to 12 %. It occurs as graphic intergrowths with An-poor feldspar in the marginal zone of plagioclase laths or as clear, interstitial grains. The latter variety associates with chlorite.

In the dike, there are some leucocratic parts, where plagioclase dominates the rock. In these rock varieties, there are also abundant graphic-quartz-plagioclase intergrowths. Two varieties of chlorite are present; one of these is associated with uralitization and has anomalous blue birefringence colors whilst the other forms spherulites and is colorless in thin-section. It associates with quartz and calcite.

Magnetite forms skeletal, reticulated crystals with a network of alteration lamellae of leucoxene. It also occurs as intergrowths with ilmenite plates. Leucoxene is also found in association with uralitization. Some martite forms pseudomorphs after pyrite.

A chemical analysis (MG38) is given in Table 4. The presence of quartz is reflected by a relatively high SiO2 content.

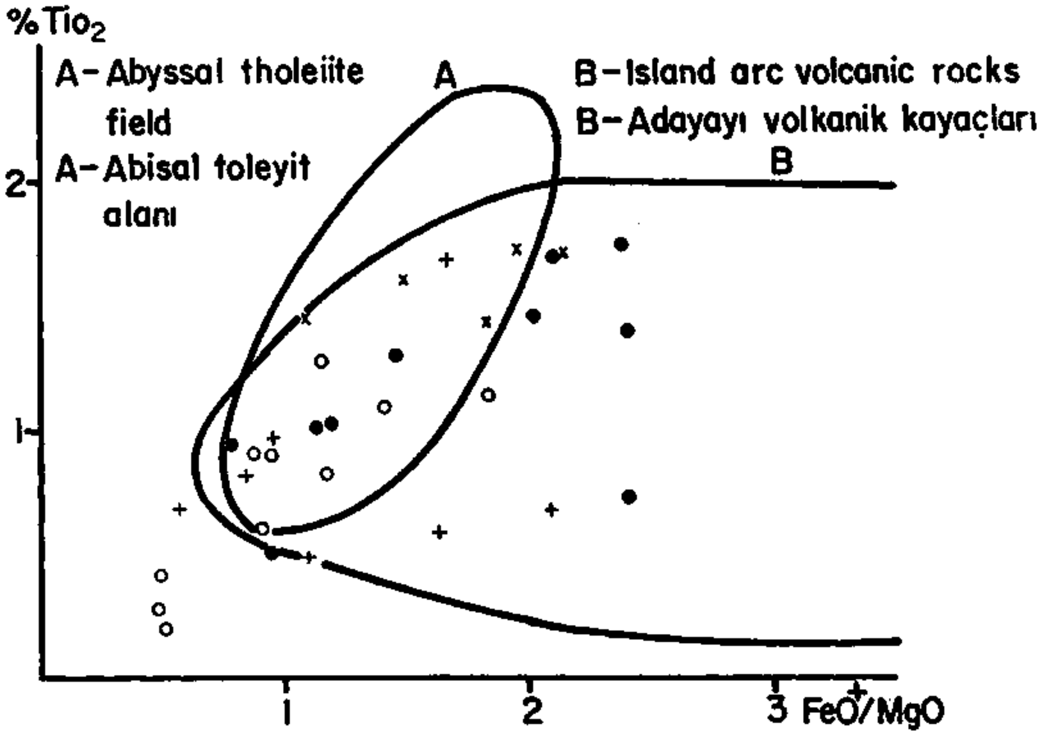

Fig. 4 - Plot of TiO_2 versus FeO+/MgO of basaltoids from the Küre area according to Miyashiro (1975*a*).

Amphibolitized diabase

The youngest rock in the basalt complex is a fine-to coarsely medium-grained, medium to dark-gray or bluish-gray diabase. This diabase forms a dike to the north of Aşıköy mine, at a contact between serpentinite and basalt (Fig. 1). It has a width of about 200 m and can be followed for about 1000 m. In the description of the geological map of the Sinop area (Ketin, 1962), this variety of diabase is called «amphibolite».

The rock consists chiefly of plagioclase and pyroxene and/or hornblende. The texture varies between doleritic in the fine-grained and subdoleritic in the medium-grained varieties. The contacts between the diabase dike and the basalt or serpentinite are seldom distinct and may even be seemingly transitional. Mostly, the coarsely medium-grained diabase variety is found only along the contacts.

Table 4 - Chemical analyses and CIPW norms of serpentinite, metasomatite, diabases and dacite from the Küre area (oxides in weight %, trace elements in ppm)

Oxide	*MG31*	*MG32*	*MG33*	*MG34*	*MG35*	*MG36*	*MG37*	*MG38*	*MG39*
SiO_2	39.62	44.15	44.09	50.94	48.78	51.82	49.64	53.72	66.02
TiO_2	0.06	0.24	0.27	0.90	0.92	1.42	0.28	1.15	0.34
Al_2O_3	0.68	7.04	10.53	16.02	15.03	12.81	15.46	15.95	14.99
Fe_2O_3	5.85	3.20	0.85	2.09	1.93	1.46	2.49	3.89	0.12
FeO	1.65	4.76	5.98	6.18	6.53	4.67	7.09	6.04	2.37
MnO	0.07	0.08	0.14	0.13	0.16	0.12	0.17	0.17	0.07
MgO	37.03	19.15	15.73	8.63	9.56	12.38	8.22	5.28	1.47
CaO	0.09	7.27	10.11	5.90	9.70	10.51	6.26	7.30	3.29
Na_2O	—	0.06	0.42	3.87	2.83	2.21	4.72	3.22	2.22
K_2O	0.03	0.03	0.31	0.45	0.27	0.57	0.11	0.34	2.72
P_2O_5	—	0.01	0.01	0.07	0.07	0.01	0.08	0.11	0.14
H_2O^-	0.84	0.15	0.23	0.49	0.21	0.39	0.46	0.45	0.53
LOI	12.30	12.47	11.10	4.15	4.07	2.58	3.97	2.39	5.52
Sum	98.23	98.60	99.77	99.81	100.05	99.95	99.94	100.01	99.81
Trace elements									
Nb	<3	4	<3	5	5	4	6	6	9
Rb	<3	<3	14	4	<3	4	<3	6	120
Sr	<3	29	53	150	155	117	103	117	117
Y	<3	7	8	25	26	12	27	32	11
Zr	<3	6	9	53	47	14	67	72	110
Normative components									
Q	—	—	—	—	—	—	—	9.01	32.25
Or	0.21	0.21	1.83	2.66	1.60	3.45	0.68	2.01	17.14
Ab	—	0.59	3.55	32.75	23.95	19.15	41.51	27.25	20.04
An	0.53	21.92	25.93	25.01	27.51	23.91	21.49	28.06	16.43
C	—	—	—	—	—	—	—	—	2.93
Mg-Di	—	13.59	15.72	2.28	12.13	19.56	5.95	4.16	—
Fe-Di	—	2.22	3.53	0.78	4.08	3.82	2.32	1.87	—
En	35.79	46.56	20.71	16.32	9.46	19.28	3.70	11.22	3.91
Fs	3.52	8.70	5.34	6.36	3.65	4.32	1.66	5.77	4.08
Fo	50.52	1.82	7.83	2.88	6.12	2.25	10.39	—	—
Fa	5.48	0.38	2.22	1.24	2.60	0.56	5.12	—	—
Mt	3.03	3.46	1.23	3.03	2.70	2.17	3.75	5.38	0.19
Il	0.13	0.53	0.51	1.71	1.75	0.82	2.53	2.18	0.69
Ap	—	0.03	0.02	0.17	0.17	0.02	0.20	0.26	0.35
Mg-Sp	0.74	—	—	—	—	0.64	0.65	—	—
Fe-Sp	0.07	—	—	—	—	0.06	0.06	—	—

MG31 - Serpentinite.
MG32 - Low-temperature metasomatite.
MG33 - Amphibolitized diabase, medium-grained, medium bluish gray. From the contact with the metasomatite at the west end of the dike.
MG34 - Amphibolitized diabase, fine-to medium-grained, greenish black.
MG35 - Amphibolitized diabase, fine-grained, medium dark gray.
MG36 - Amphibolitized diabase, medium-grained, medium bluish gray.
MG37 - Amphibolitized diabase, fine-to medium-grained, dark greenish gray. From the contact with the serpentinite at the east end of the dike.
MG38 - Quartz diabase, fine-to medium-grained, dark greenish gray.
MG39 - Dacite.

In thin-section, two kinds of plagioclase have been observed. One of these appears to be labradorite, the other andesine, but the plagiodases are generally very ill-preserved, cloudy and not easy to investigate.

In a medium-grained rock from the west end of the dike (MG 33), the cloudy central plagioclases are surrounded by rims of albitic plagiockse, chlorite, and sericite. An associated amphibole appears to have been formed during a deuteric or late magmatic stage. In contrast, in a medium-grained rock from the east end of the dike (MG36), the amphiboles are clearly uralitization products'of pyroxene and still exhibit relic diallage features. This uralite has a lower relief than the amphibole in MG33. In fine-grained rock varieties (MG34 and MG35), uralites form pseudomorphs after clinopyroxene.

Titanite and leucoxene are very abundant being found particularly along the dike contacts. Titanite often occurs in association with chlorite and quartz, which appear to be alteration products of titaniferous clinopyroxene. Ilmenite has undergone almost complete alteration to leucoxene, that is often intergrown with minute grains of ilmenite and hematite. There are some pyrite grains rimmed by martite and containing minute inclusions of chalcopyrite. Other accessories are epidote and calcite.

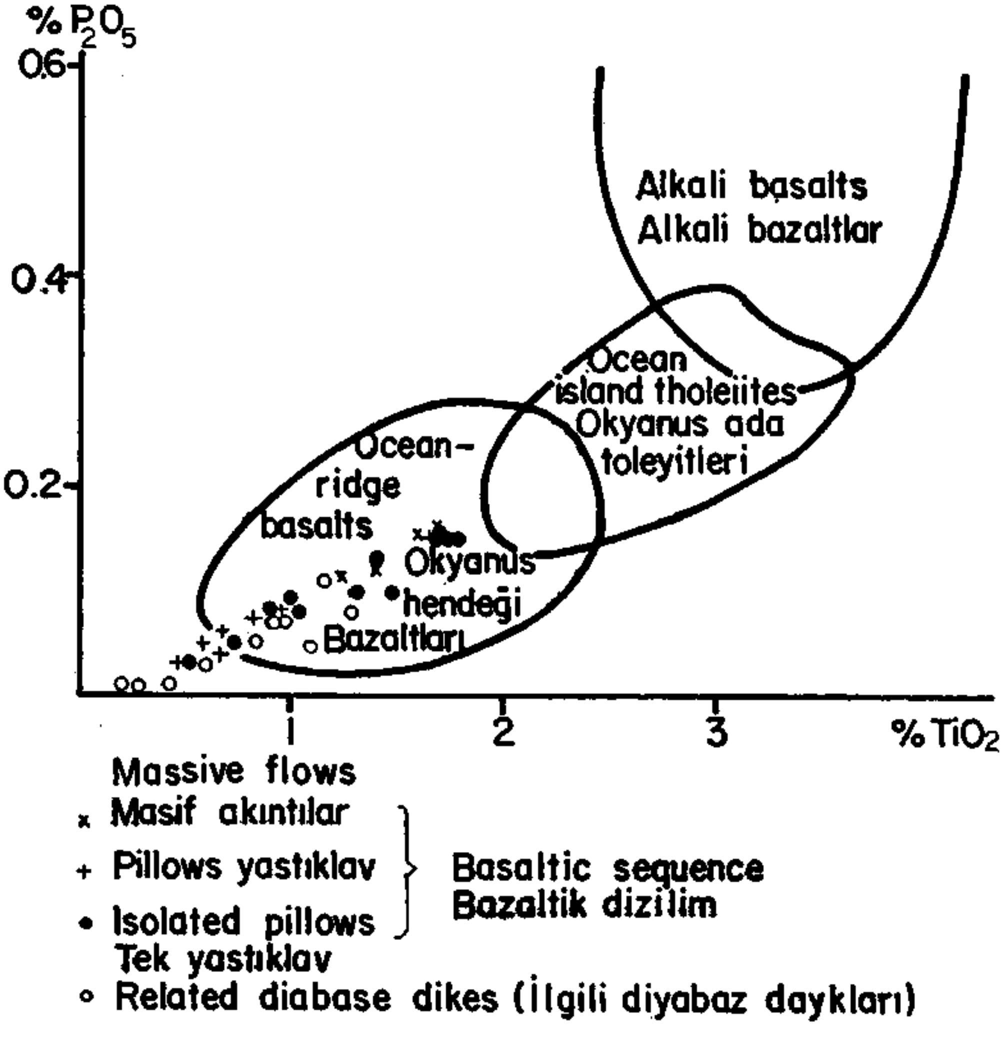

Fig. 5 - Plot of P_2O_5 versus TiO_2 of basaltoids from the Küre area according to Ridley et al., (1974).

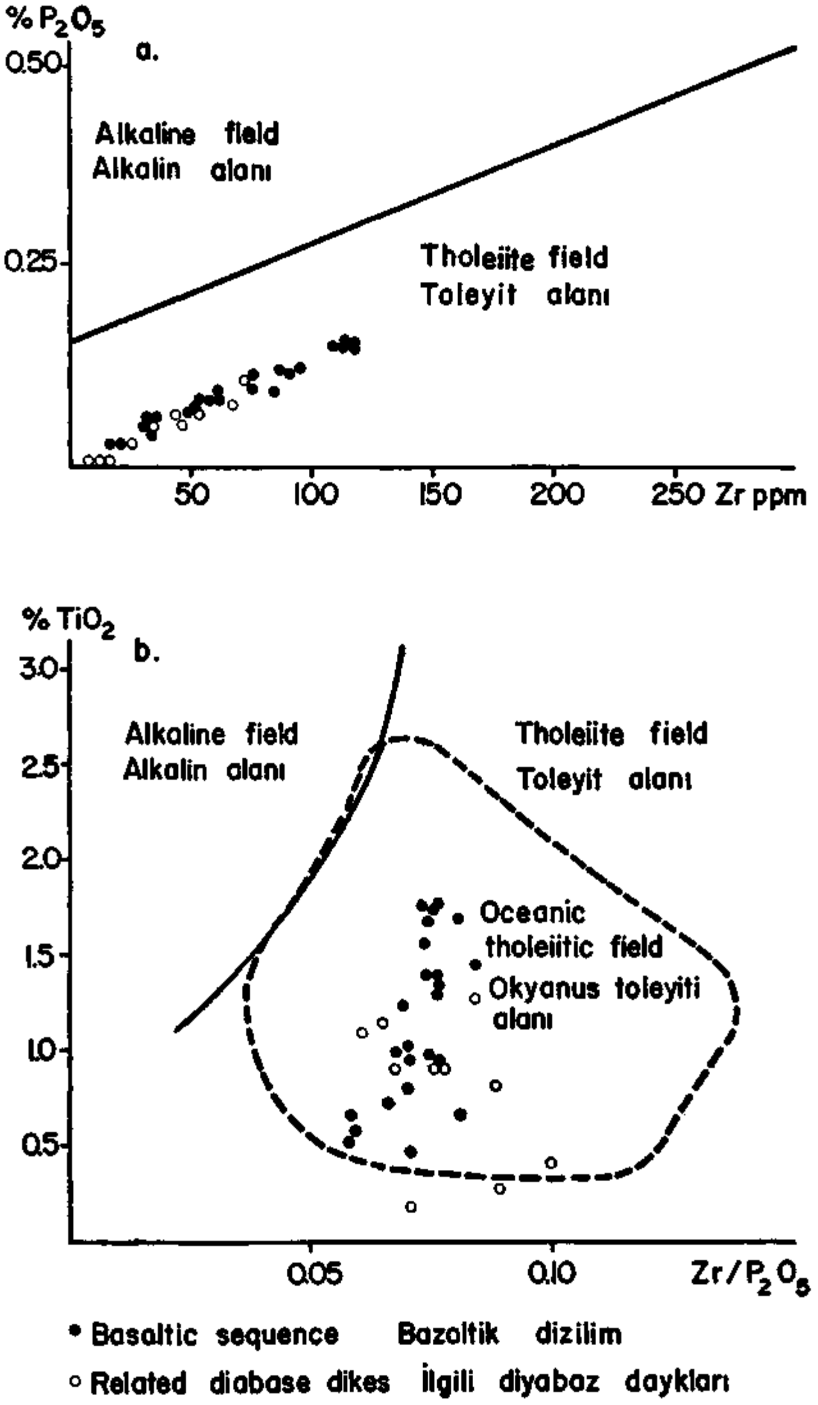

Fig. 6 - Discrimination diagrams of basaltoids from the Küre area for alkaline and tholeiitic magmas (Floyd and Winchester, 1975).

The chemical analyses, MG33 through MG37 (Table 4) represent samples taken along the strike of the dike from the west to the east. Sample MG33, from the contact with the metasomatite is characterized by an apparent enrichment of magnesium and calcium, which is probably due to a considerable loss of sodium, aluminium, and silica. In contrast, sample MG34 appears to have been enriched in sodium. Sample MG37 has slightly deviating contents of total iron, but in general the composition of the amphibolitized diabase is clearly similar to that of the previously described diabase.

Peridotite

The next youngest intrusive rock in the area is a dark gray, coarse-grained, olivine-rich dike-rock, which also contains some clinopyroxene, orthopyroxene, plagioclase, hornblende, and opaques. The dike curves from the southern edge of Küre town to the Karanlık brook whence it could not be followed any farther (Fig. 1). Its width ranges from about 1 m to 50 m. At the contacts with the diabase dike and the basaltic extrusives, the peridotite is surrounded by a high-temperature alteration aureole.

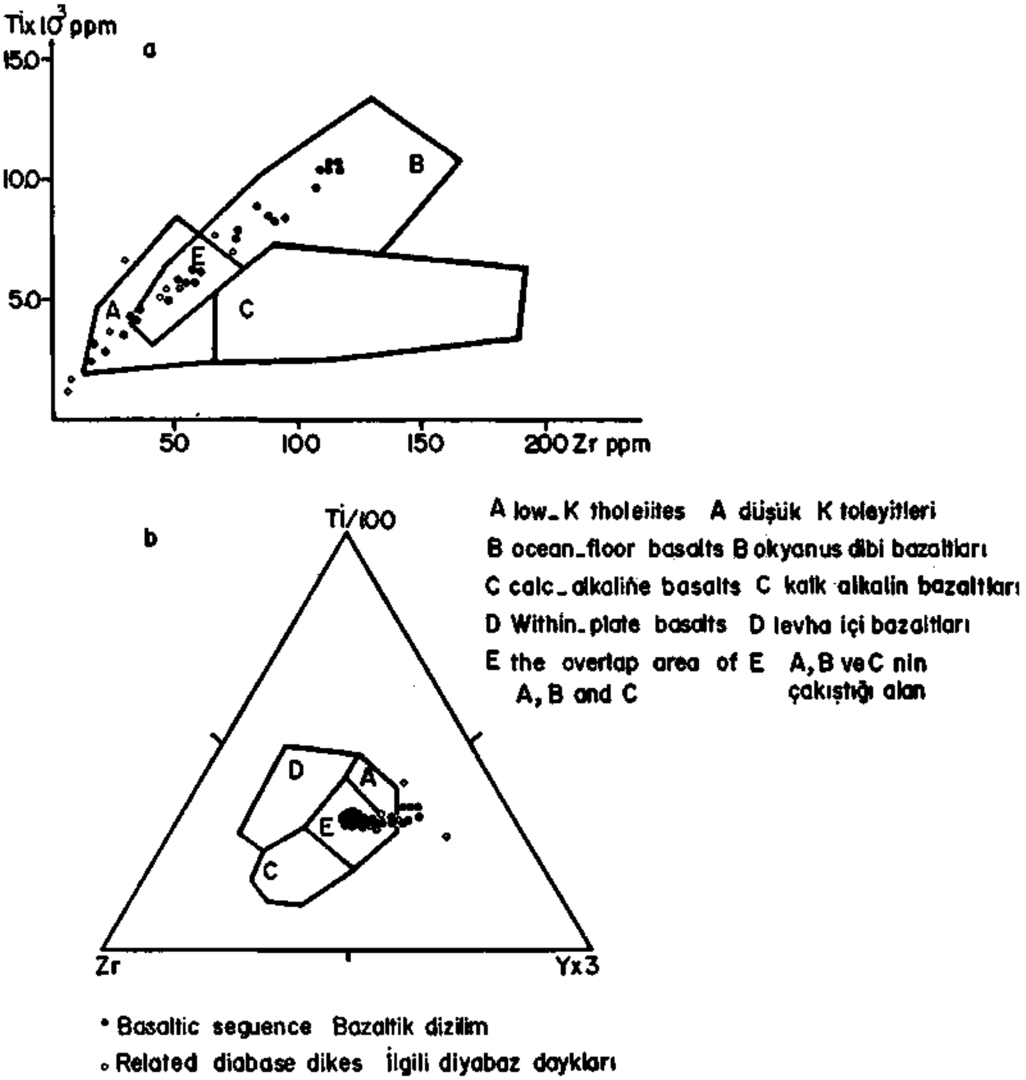

Fig. 7 - Plot of the basaltoids from the Küre area in the discriminant diagrams of Pearce and Cann (1973).

The texture of the peridotite is generally characterized by the development of alteration fabrics. The pyroxenes form up to 10 mm large poikilitic plates enclosing several olivine grains. The olivine usually appears to have been euhedral, but during the initial stage of alteration it was surrounded by serpentine rims. In some cases, the olivine has undergone almost complete serpentinization into pseudomorphs carrying magnetite or opaque dust along original cracks.

Clinopyroxene is more abundant than orthopyroxene. Uralitization has usually only affected the clinopyroxene, whilst orthopyroxene tended to alter into serpentine. The two pyroxenes form exsolution intergrowths, which often enclose magnetite grains.

Amphibole occurs in varying amounts both as a primary and a secondary phase. The primary amphibole is a brown hornblende forming large poikilitic plates that contain inclusions of olivine and have higher refringence and birefringence than common hornblendes.

Also the plagioclase contains inclusions of olivine and pyroxene. This has commonly been altered to clinozoisite accompanied by a little sericite.

The opaques are dominated by chrome spinel and ilmenite. Other accessory minerals are magnetite, pyrite, pyrrhotite, and chalcopyrite.

The chemical composition of the peridotite is shown in Table 3.

A point-count analysis rendered the following mineral composition: olivine 45 %, pyroxene 39 %, opaques 7 %, plagioclase 5 % (incl. 3 % clinozoisite), and amphibole 4 %.

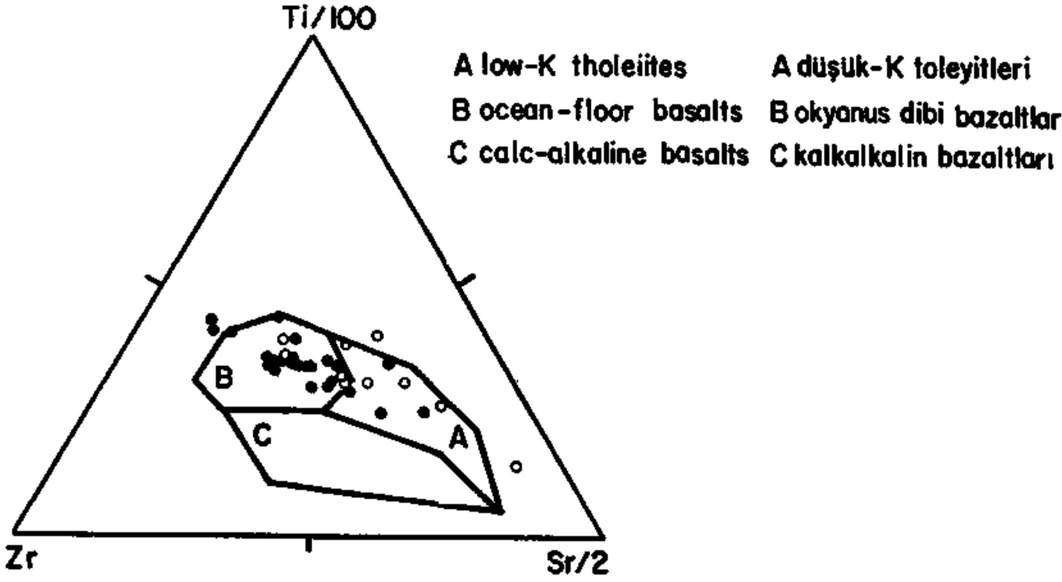

Fig. 8 - Plot of the basaltoids from the Küre area in the discriminant diagrams of Pearce and Cann (1973).

The presence of plagioclase and the predominance of clinopyroxene over orthopyroxene classify the rock as a high-temperature peridotite (Coleman, 1977).

High-temperature aureole. — Along the contact of the peridotite with the diabase and the basaltic rock to the south of Küre town, there is a dark gray, coarse-grained, narrow reaction zone. This zone has a width ranging from about 10 cm to 120 cm and in some places is developed as a sequence of lenses. It is probably an alteration aureole along the periphery of the peridotite and was formed by the heat of that rock.

The principal minerals in the peridotite aureole are plagioclase, pyroxene, and olivine. Hypersthene forms large-grain fabrics poikilitically enclosing bytownite, olivine, and clinopyroxene. At the borders between hypersthene or olivine and bytownite, uralite is developed as long irregular fibres. The bytownite has been partly altered to fine-grained aggregates of clinozoisite with some sericite along the original cleavages. In the larger laths of bytownite there occur some inclusions of clinopyroxene. A brownish iddingsite forms pseudomorphs after olivine, but otherwise the olivine is little altered. Opaques, chlorite, and primary hornblende are accessories. The opaque minerals occur both as schiller inclusions in pyroxene and as grains and dust along the cracks of olivine.

A point-count analysis gives the following mineral composition: plagioclase 42% (incl. 4% clinozoisite), pyroxene 35 % (incl. 5 % uralite), olivine 21 % (incl. 3 % iddingsite, chlorite, and serpentine), opaques 1 %, and hornblende 1 %.

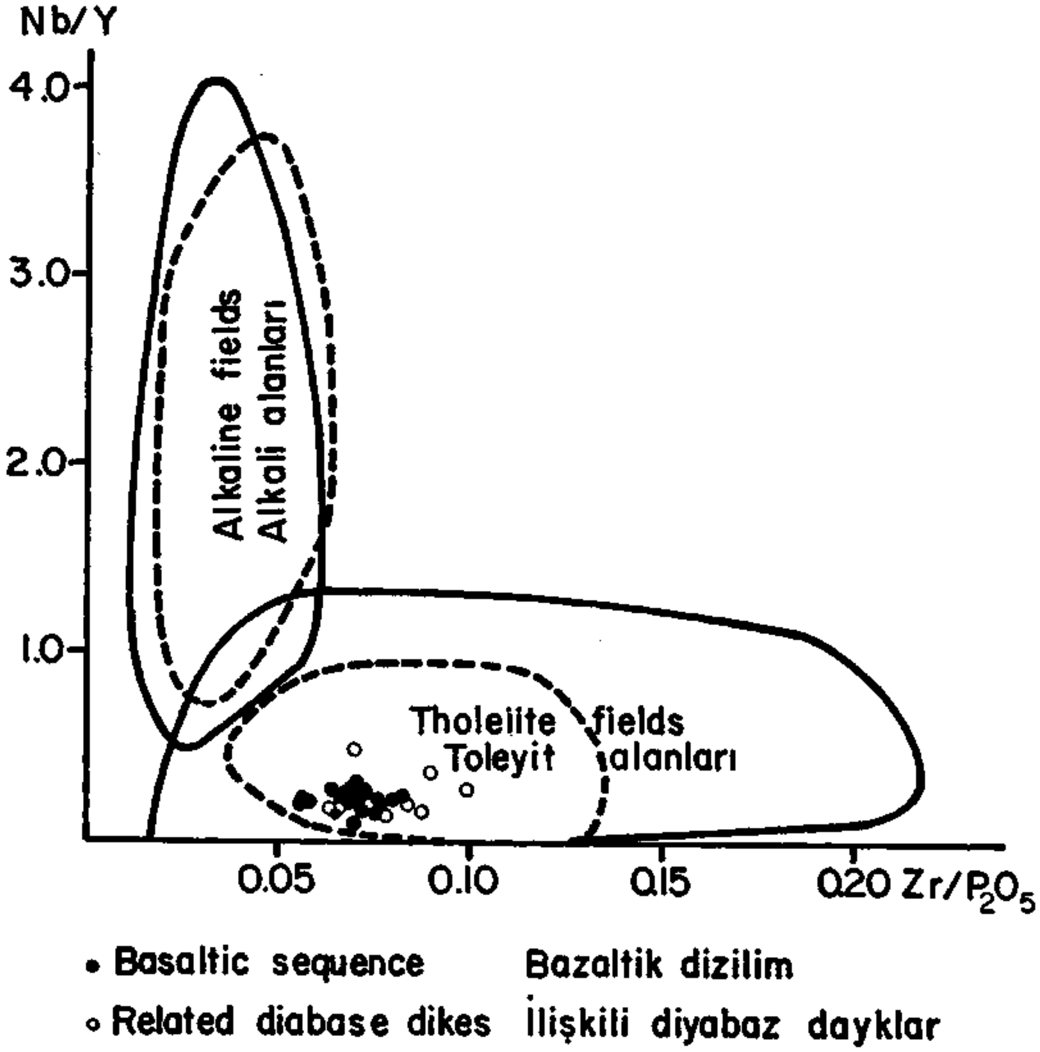

Fig. 9 - Plot of Nb/Y versus Zr/P_2O_5 of basaltoids the Küre area in the discriminant diagram for alkaline and tholeiitic magmas (Floyd and Winchester, 1975). Broken lines: oceanic rocks, unbroken lines: continental rocks.

A chemical analysis (MG29) is given in Table 3. It indicates that the chemical alterations in the reaction zone include enrichment in calcium and an apparent removal of alkalis. Thus it appears that the zone has undergone considerable calcium metasomatism. There is also relative enrichment of magnesium, aluminum, and iron and a corresponding depletion in silica. It can be assumed that magnesium and iron have immigrated from the peridotite whilst aluminum came from the basaltic rock. The loss of silica and alkalis aided in this enrichment of Fe, Mg, and Ca and produced a silica-undersaturated composition.

Mineralogically, the peridotite aureole is characterized by Ca-plagioclase, pyroxene, and olivine, which indicates relatively high temperatures at the peridotite contact. Challis (1965) has described high-temperature peridotite aureoles from New Zeeland whilst Coleman (1977) has shown that the narrow, high-temperature amphibolite aureoles around peridotites usually contain brown hornblende, clinopyroxene, garnet, and Ca-plagioclase. In the present case, the absence of garnet may well be a function of low pressure which may also explain the scarcity of amphibole. Similar, metasomatized «gabbroic rocks» (aureoles of lenses?) have been reported from several contacts of ultrabasic complexes in Turkey (Kaaden, 1970).

Dacite

As is seen in the map (Fig. 1), the investigated area is cut by three large dacite intrusions near Aşıköy and by smaller intrusions in the subgraywacke area. The intrusions at Aşıköy form dikes that are exposed vertically down to a depth of about 600 m. They often contain fragments of the subgraywackes, black shales and basalts through which the dacite lava passed. In the Aşıköy mine the dacite is the wall rock of the massive sulfide ore.

The dacite is light gray, porphyritic, and contains about 7 % former high-quartz phenocrysts, 18 % plagioclase phenocrysts,and 14 % chlorite flakes. Because the rock tends to cleave along the preferred orientation of chlorite flakes it forms plain surfaces when broken.

Kovenko (1944) described the rock as a «white albitic dike», wherein the microscopic examination of the plagioclases showed pure albite and andesine.

The quartz phenocrysts usually have corroded borders with irregular tongues of matrix projecting into the grains. Otherwise, they are euhedral, pyramidal, ca 2 mm large, and contain inclusions of calcite and chlorite. The quartz in the phenocrysts is now low-quartz. The plagioclase phenocrysts are partly altered to fine-grained calcite and albite. The six-sided, 3 mm large, chlorite flakes contain fine-grained interlayers of taeniolite which show distinct twinning. Most probably, these chlorite-taeniolite flakes replaced original biotite.

The groundmass of the dacite is microcrystalline and consists mainly of quartz and feldspars. Fine-grained calcite aggregates and fine, flaky chlorite are subordinate constituents.

The chemical composition of the dacite is shown in Table 4. The rock is extremely high in LOI, which is. due to the presence of large amounts of calcite. In spite of the presence of 14 % chlorite, it is rather low in Fe, Mg, and Al.

METABASIC ROCKS

Serpentinite

A well-exposed, grayish brown serpentine mass occurs to the NW of Aşıköy (Fig. 1). The contact between the serpentinite and the metasomatized contact rock, described in the next section, is not well-defined and transitional. Two small serpentinite slabs, that have been dislocated during alteration of previously existing rock, occur to the east of the serpentinite mass in the black shale and to the north of Bakibaba peak basalt (Fig. 1).

The serpentinization has been so intense as to alter completely the primary olivine and pyroxene. Texturally, however, pseudomorphosed olivines in similarly altered poikilitic pyroxenes could be recognized. This suggests that the rock was derived from a peridotite. An X-ray diffraction analysis showed clino-chrysotile with insignificant quantities of magnetite and chlorite.

Some minute, 1-2 mm thick veinlets of chrysotile show as cross-fibre textures. Magnetite grains and magnetite dust are distributed in the serpentine masses. They mostly occur along the borders and in the fractures of former olivine grains and rarely also as schiller inclusions in former pyroxene. Accessories are chrome spinel, magnesite, and garnet. In thin-section, the color of the garnet grains is yellowish brown. A chlorite identified by X-ray analysis could not be clearly recognized in the thin-sections. The chrome spinel! has been strongly altered to serpentine and shows corrosion effects.

The chemical composition of serpentinite is shown in Table 4. A comparison with the analysis of peridotite in the same table shows that the serpentinized mass is clearly a peridotite derivate.

Low-temperature metasomatite

At the contact between the serpentinite and the amphibolitized diabase, there is a zone of metasomatic rock reaching a maximum width of about 70 m (Fig. 1). Due to the diffuse contacts with the serpentinite and the amphibolitized diabase, the precise extent of the metasomatite is difficult to assess, but its localization suggests that the rock is a product of reaction metasomatism on a local scale. The rock is greenish black. It is made up principally of flaky aggregates of chlorite, fine fibres of emerald-green amphibole, and fine-grained aggregates of calcite. These minerals could not be clearly recognized optically and their identification therefore relies on X-ray diffraction. Accessory phases are chrome spinel, quartz, hematite, and magnetite. Hematite as well as magnetite either form rims around spiriel or occur as minute grains and needles distributed throughout the matrix. The chrome spinel is identical with that of the serpentinite. Therefore, it seems reasonable to suppose that the metasomatic rock described here as well as the serpentinite have been produced at the expense of the same parent rock. From the field contexts and the compositions it appears probable that this rock was an ultramafite. The alteration may have occurred in conjunction with a tectonic event.

A chemical analysis of the metasomatic rock is shown in Table 4. The extremely large amount of LOI is due to the presence of calcite. It is worth mentioning that the oxidation state of iron is lower in the metasomatic rock than-in the serpentinite.

The metasomatism appears to have implied enrichment in Ca, Al, and Si and a migration of Mg in the reaction zone. There had been no introduction of alkalis. The increase in Ca, Al, and Si has produced the described mineral assemblage containing chlorite, hornblende, and calcite. There are no traces of hydrogarnet which is a predominant phase in rodingites (Coleman, 1967; Gianelli et al., 1972). Chlorite and nephrite, however, are common along serpentinite contacts (Coleman, 1977).

SEDIMENTARY ROCKS

More than the half of the investigated area is occupied by sedimentary rocks. These rocks can be divided into two genetic groups, namely -the eugeosynclinal deposits and the non-eugeosynclinal sequences.

The eugeosynclinal deposits comprise subgraywacke and black shale and cover large areas in the SW and SE part of the map. The subgraywacke is the oldest among the rocks occurring in the Küre area. It is overlain by the black shale which is less resistant to erosion than most of the subgraywacke. In a transitional zone, the subgraywacke is interbedded with and passes into the black shale. In other areas, the black shale is so dominant that it could be mapped out as a unit of its own. The subgraywacke-black shale area is very strongly deformed by several phases of folding. One of these tectonic events, that resulted in the isoclinal folding of the graywacke-black shale unit, took place probably before the extrusion of the basaltic effusives.

The non-eugeosynclinal sequences are made up of conglomerates covered by mudstone that is followed by limestone. These rock types occur in the southern part and along the eastern limit of the mapped area. Because of soil cover, the contact relationships of the occurrences could not be studied in detail. The limestone is the youngest rock in the area. It contains Late Jurassic fossils.

Subgraywacke

Approximately one third of the Küre area is occupied by a medium dark-gray to light brownish-gray, fine -to medium-grained subgraywacke (Fig. 1). This subgraywacke is very strongly folded. It is difficult to make way-up determinations in this folded deposit which is particularly true of areas where the frequency of joints and fractures is high. The stratigraphic thickness of the rock cannot be determined exactly on account of its unresolved internal structure, but a rough estimate suggests an approximate minimum of 400 m.

As a rule, the subgraywacke-black shale unit dips almost vertically at the contact toward the basaltic sequence. In some places, black shale interbeds were observed in the zone of the graywacke close to the overlying shale. These interbeds vary from some centimetres to some metres in thickness.

The mineral and rock fragments in the graywacke are angular to subrounded and are interbedded in a matrix of sericite, chlorite, and limonite. Generally the sericite and chlorite flakes are deformed and molded against the grains of quartz and feldspar. Both K-feldspar and plagioclase are present. Most of the rock fragments are of volcanic (andesite?) origin. The opaque minerals are subordinate quantities of hematite, chrome spinel, ilmenite and pyrite with martite rims.

The color variation of the subgraywacke depends on the amounts of limonitic substance. A rather limonite-rich, light brownish-gray, feldspar poor, poorly sorted sandstone dipping almost vertically occurs in the Bakibaba mine area. In the gallery at the 920 m level, the contact zone between the subgraywacke and the black shale is marked by interbedding of the two lithologies. This transition belt is between 1 and 5. m wide.

The following point-count analyses describe the mineral composition of some subgraywackes (vol. %):

Mineral	*Medium dark-gray*	*Greenish gray*	*Light oliv-gray*	*Light brownish-gray*	*Average*
Quartz	**40**	**46**	**52**	**72**	**53**
Feldspars	**7**	**9**	**10**	**2**	**7**
Mica+chlorite	**25**	**22**	**17**	**8**	**18**
Rock-fragments	**22**	**17**	**15**	**6**	**15**
Limonitic substances	**2**	**1**	**2**	**9**	**3**
Chert	**3**	**4**	**3**	**1**	**3**
Opaque minerals	**1**	**1**	**1**	**2**	**1**

According to Pettijohn's definition (1949), subgraywackes contain 15-85 % quartz, 0-15 % feldspar, 5 % rock-fragments, and 15-75 % matrix. The term «subgraywacke» is based on the low content of feldspar in this rock.

Black shale

A very fine-grained, unfossiliferous shale overlies the subgraywacke (Fig. 1). In unweathered exposures the color of the shale is black, but it becomes medium dark-gray on weathered surfaces. The thickness of the black shale can be estimated as being approximately 300 m. Within the Bakibaba mine area, the black shales as a rule dip vertically. Movements along faults have resulted in a multitude of slickensides.

Locally, a secondary cleavage is developed at a small angle to the bedding. In thin-sections, the black color of the shale tends to reflect the quantity of bituminous matter, which is present as minute discrete granules.

X-ray diffraction shows that the shale is composed of illite, quartz, chlorite, siderite, and muscovite. Siderite occurs both in fissures and as a very fine-grained impregnating dust througout the rock groundmass, which usually contains some small grains of quartz. Other opaque accessories include chalcopyrite, pyrite, chrome spinel, ilmenite, and hematite.

A laminated, medium gray, consolidated shale horizon that occurs in the Aşıköy mine is probably much younger than the black shale. It can even be younger than the massive sulfide deposits of Küre. Also this shale is strongly faulted, which results in numerous slickensides. Its laminae range between 0.1 and 1 mm in thickness and are due to a rythmic alternation of coarser and finer particles. A 2 mm thick layer of sulfides contains pyrite, marcasite, chalcopyrite, and fine-grained covellite. Presumably, the sulfide elements were derived secondarily from the massive sulfide ores and are precipitated as synsedimentary layers.

Nikitin (1926) has a short note stating that the age of the black shale is Zechstein. Ketin (1962) has more precisely attributed it to Lias. However, on the basis of the minor content of bituminous matter in the black shale in the Küre area, a correlation appears conceivable with the black, very fine-grained Westphalian-Permian shales of the Amasra coalfield (Tokay, 1962), which is situated 110 km to the west of Küre. Furthermore, the graywacke-black shale unit of the Söğütözü area, only 10 km to the west of the Küre area, is described even by Ketin (1962) as being Permian in age. As far as fossils are concerned, Kovenko (1944) has found an ill-preserved ammonite, *Arietites latisulcatus,* in a pit in medium gray shale in Küre town. This specimen was assigned to the Sinemurian (Middle Lias) by Stchepinsky of the MTA. However, in the opinion of the present writer, the very small shale outcrop in Küre town, is probably equivalent to the laminated, presumably much younger, medium gray shale type found in the Aşıköy mine area. As the fossil was found in a pit ,it is also conceivable that the ill-preserved ammonite specimen may have been transported to the Küre area from somewhere else.

Conglomerate

Conglomerate beds occur beneath the limestone south of Turanlar, where the road leaves the subgraywacke-black shale unit, and also along the eastern edge of the map area, northeast of Küre town (Fig. 1). In the southern part of the mapped area, the conglomerate is of an intraformational type, whilst in the northeast a polymict conglomerate is found.

The intraformational conglomerate has an apparent thickness of about 120 m and is made up of subrounded pebbles and subangular to subrounded cobbles. The average size of the cobbles is between 15 and 20 cm, but a large boulder of subgraywacke was found to reach 1m in diameter. Normally, the coarse fractions of the conglomerate consist of about 90 % limestone, the rest being graywacke and black shale. The matrix is made up of cryptocrystalline calcite, in which no distinct fragments of limestone can be recognized. In a medium gray, fossiliferous cobble of limestone there can under the microscope be seen remnants of corals, foraminifera, coralline red algae, and peloids. The longest diameter of the ellipsoidal peloids is about 3 mm. They are composed of calcite crystals about 0.1 mm in size.

From its texture and composition it appears that the intraformational conglomerate is of a very local origin. The limestone fragments have undergone very little if any transportation and are only slightly worn. The fragmentation of the limestone must consequently have taken place within the basin of deposition semicontemporaneously with the sedimentation of the conglomerate.

The upper limit of this conglomerate is seldom distinct. It grades successively into mudstone. However, both the upper and the lower contacts are mostly covered by landslides and observations are therefore few.

The polymict conglomerate reaches a thickness of about 50 m. As different from the intraformational conglomerate, this rock carries well-rounded pebbles and cobbles of plutonics, volcanics, graywacke, shale, and limestone. These cobbles are embedded in a matrix of arkosic detritus and limy to limonitic cement. Most of the cobbles of volcanic rocks belong to types which do not occur in the investigated area. The average diameter of the cobbles is about 15 cm.

The polymict conglomerate appears to be a product of an eugeosynclinal environment, where there had probably been rapid deposition in a deep marine trough. Another polymict conglomerate occurring between Küre and Devrekani has been described by Ketin (1962) as a «transgressive basal conglomerate overlying unconformably the black shale. Similarly to its counterpart in the Küre area, this conglomerate consists of fragments of granite, basalt, diabase, black shale, graywacke, and limestone.

Mudstone

A mudstone occurs to the south of Turanlar, where it forms a wedge between the intraformational conglomerate and the limestone. Where observable, the apparent thickness is about 150 m. The color of the mudstone varies from light gray to pale red and the predominant grain-size fractions from clayey to silty in spite of their color, the red mudstone varieties are not particularly iron-rich. The beds rich in clay fraction break along shaly partings or conchoidal fractures. The rock softens very easily when wetted. Compositionally, micaceous mudstones and marls are predominant. However, as the lower contact of the massive limestone unit is approached, they grade into limy shale. The contact toward the overlying limestone is generally characterized by transitional rocks.

Both the upper and the lower contacts of the mudstone are usually unexposed. The representation given in the map is therefore based upon strike/dip observations in mudstone in the roadcuts above Turanlar.

Limestone

Limestone occurs close to the eastern edge of the mapped area, northeast of Küre town, and in the southern part of the map area (Fig. 1). in these localities, it is overlying the polymict conglomerate and the mudstone respectively. The limfestone unit forms marked cliffs, locally more than

60 m high. The base of these cliffs is covered by talus slopes which containing large blocks and almost everywhere cover the lower contacts of the limestone unit.

Texturally, the limestone is cryptocrystalline. It has most probably been formed by chemical precipitation. Because the limestone is pure, massive, and hard, the local population calls it «marble». The color is medium light-gray to very light-gray and becomes lighter towards the top of the unit. A successive decrease of the contents of microfossils is observed when proceeding from the basal contact upwards in the southern occurrence area. The limestone is generally poor in macrofossils. Thin-sections of a medium light-gray fossiliferous specimen from the bottom parts of the formation in the southern occurrence area showed fragments of corals, foraminifera, coralline red algae, peloids and also fragment of a pelecypod. The fossils in the limestone appear to be similar to those found in the cobbles of limestone occurring in the intraformational conglomerate. Consequently, no great span of time appears to separate these two rocks.

In a limestone specimen collected by the CENTO group (Sancan, 1968) in the Küre area, Erol Öngüç of the MTA identified the foraminifera *Pseudocydammina* sp., *Trocholina* sp., *Verneuilina* sp., and Miliolidae indicating a Late Jurassic age. Late Jurassic fossils were also found by Kovenko (1944) in the Küre area. One of them, *Stilosmilia michelini,* was assigned by M. Alloiteau of the MTA to the Kimmeridgian or Portlandian.

Mustafa Topal of the KBİ has found 3.48 % SiO_2 in the limestone, but no traces of quartz could be observed in the thin-sections. It is thus probably disseminated throughout the rock matrix. Some silica also occurs in clay minerals. However, these are are not conspicious in the thin-sections.

ALTERED WALL-ROCKS AROUND THE ORES

The completely altered wall-rocks of the massive sulf ide deposits differ substantially from the regional, but generally weaker alteration throughout the basaltic formation. The intense alteration around the ores has only affected the igneous rocks. Neither the black shale nor the subgraywacke were involved, although both of these act as host rocks to the massive ores. In addition to the mentioned rocks, in the Aşıköy mine there also occurs dacite that is younger than the sulfide ores. In the Bakibaba mine area, the altered wall-rocks outcrop over an area of more than 0.5 km^2. Mostly they have an earthy consistency, which makes it impossible to examine the rocks in normal thin-sections. Thus we find that the formation of altered wall-rocks was followed by a partly very deep weathering. These relationships are seen particularly well in the southern part of the Bakibaba mine area. Normally, the earthy character of the altered rock tends to become less pronounced with depth. At a greater distance from the deposits, there appear relic textures and structures which clearly indicate an ultimate basaltic origin of the rocks in the alteration belt around the ores. In some cases, there even occur remains of pillows and pillow breccias. These are particularly common in the upper parts of the alteration aureoles.

The types of alteration in the wall-rock include chloritization, replacement brecciation, silicification, uralitization, argillic alteration, calcitization, sideritization, and albitization. The alteration zones in the wall-rock around the ore deposits are not proportional to the size of the ore bodies. They vary in extent from ore body to ore body. However, the height of the column of rock affected by hydrothermal alteration is presumably several kilometres. However, with the exception of extensive chloritization, all occurrences of the other alteration varieties are situated close to the ore bodies, where they are developed in the shape of small, short, sporadic belts and lenses. Because most of them are transitional, the contacts of these different alteration-rock belts could not be traced precisely through the altered wall-rock.

Microscopic and chemical investigations (samples MG40, MG41, MG42, and MG43) show that the altered parts of the basaltic sequence have suffered extensive compositional changes. The original minerals have been replaced by new mineral assemblages where chlorite, quartz, clay minerals, and sometimes uralite are particularly important.

Chloritic alteration

Descriptions of drilling cores from the Küre mine area, made by mine geologists of Etibank, mention the occurrence of pale green wall-rocks called "friable chloritized diabases" and white rocks designated as "friable kaolinitized diabases". X-ray diffraction analyses of both these types of altered rocks show only chlorite and no traces of kaolinite. However, there is a quantitative difference between the two rocks in so far as the contents of quartz are higher in the white-colored rock type and the contents of chlorite correspondingly lower. In most exposures, the white rock is the predominant kind of alteration product. This is probably due to the easier weathering and leaching of chlorite minerals as compared to quartz.

The contents of chlorite in the chloritized alteration rocks range between 20 and 95 %. The rocks with the highest chlorite contents are commonly associated with regionally developed faults. Other chlorite-rich rock varieties occur as aureoles around the pyrite deposits. In addition, in the Bakibaba mine, large masses of chlorite rock form a kind of roots beneath the bodies of massive pyrite ore.

The color of the chlorites in the chloritic alteration rock is pale green, white, or black. They are generally non-pleochroic and sometimes almost isotropic. There is most probably a range of chlorite compositions, which is suggested by large variations in interference colors related systematically to the distance from the occurrences of massive ore. In nearly pure chlorite rock, the chlorite forms finely fibrous, reticulated aggregates, spherulites, and intervening, irregularly fibrous masses. There are intimate intergrowths with quartz and still more commonly with uralite and calcite. Sometimes, siderite is an abundant constituent in the chlorite rock. It mostly forms fracture fillings. Epidote may be found in accessory amounts. Some hydrogrossular occurs together with fine-grained quartz in fractures in the rock.

The development of chlorite as a predominant alteration mineral involves a substantial enrichment of the rock in total iron, magnesium, and aluminum. The chemical compositions of the two principal types of chlorite are shown in Table 5. The amounts of total Fe and Al are inversely proportional. The contents of total Fe as Fe_2O_3 vary from 18 % in the white chlorite (MG42) to 25.8 % in the pale green mineral (MG41). In contrast, the content of $A1_2O_3$ is 16.6 % in the pale green and 21.6 % in the white chlorite. The white chlorite is also somewhat richer in SiO_2.

Silicification

Next to chlorite, quartz is the most common mineral in the altered wall-rocks. The silicification is an obvious result of the alteration associated with the ores. Silicification occurs in rocks representing a range of chemical compositions and associates with chloritization, carbonatization, albitization, argillic alteration, and uralitization. Macrocrystalline quartz is an abundant constituent of the disseminated ores, where it commonly occurs together with chlorite and siderite. With the exception of veins in complex replacement breccias, "which may be almost wholly composed of quartz, the amount of quartz does not exceed 5 %.

The quartz of the altered wall-rocks is often impregnated by both siderite and iron oxides. In massive pyrite ores, the low total amounts of gangue minerals are frequently made up exclusively of quartz. That quartz is found as infillings between the pyrite grains.

Table 5 - Chemical analyses and CIPW norms of metasomatically altered basaltic rock from the Bakibaba mine (oxides in weight %, trace elements in ppm)

Oxide	*MG40*	*MG41*	*MG42*	*MG43*	*MG44*	*MG45*	*MG46*
SiO_2	45.38	30.60	34.98	45.51	49.36	94.79	50.88
TiO_2	1.64	1.40	1.14	0.80	1.04	0.06	1.15
Al_2O_3	13.70	16.59	21.61	15.43	14.46	0.08	14.91
Fe_2O_3	1.58	25.79	1.30	3.02	4.04	3.13	2.64
FeO	17.22	—	15.03	7.22	3.86	—	6.37
MnO	0.03	0.07	0.12	0.10	0.14	—	0.14
MgO	9.59	12.89	12.23	12.47	6.84	0.09	6.40
CaO	0.30	0.11	0.20	3.82	6.70	0.08	7.98
Na_2O	—	—	0.04	0.39	5.02	—	3.23
K_2O	0.03	0.04	0.24	0.19	0.08	0.03	0.27
P_2O_5	0.13	0.03	0.04	0.02	0.07	0.01	0.11
H_2O^-	0.24	0.37	1.40	1.52	0.59	0.07	0.62
LOI	9.62	9.66	10.69	8.02	7.18	1.00	5.10
Sum	99.45	97.56	99.03	98.52	99.37	99.34	99.80
Trace elements							
Nb	9	9	6	5	5		6
Rb	<3	5	<3	<3	<3		4
Sr	<3	<3	4	15	94		130
Y	36	27	36	20	22		28
Zr	107	84	62	37	57		70
Normative components							
Q	20.04	7.33	18.80	12.53	—	95.30	4.87
Or	0.20	0.27	1.63	1.26	0.52	0.18	1.62
Ab	—	—	0.39	3.71	46.37	—	28.91
An	0.71	0.40	0.84	21.15	18.21	0.13	24.27
C	14.88	—	—	8.64	—	—	0.43
Mg-Di	—	—	—	—	11.24	0.02	8.63
Fe-Di	—	—	—	—	2.79	0.16	4.24
En	26.45	26.10	20.35	34.91	3.69	0.22	9.19
Fs	30.64	25.60	16.62	11.47	1.05	1.69	5.45
Fo	—	—	—	—	6.80	—	2.19
Fa	—	—	—	—	2.14	—	1.03
Mt	2.54	8.52	2.17	4.57	4.87	2.17	3.46
Il	3.45	3.04	2.49	1.71	2.16	0.12	2.27
Ap	0.34	0.08	0.11	0.05	0.18	0.02	0.26
Mg-Sp	0.70	14.99	20.81	—	—	—	0.14
Fe-Sp	0.06	13.67	15.79	—	—	—	0.01

MG40 - Chloritized basaltic rock, dark greenish gray.
MG41 - Pale green chloritic rock.
MG42 - White chloritic rock.
MG43 - Uralitic rock, greenish gray.
MG44 - Complex replacement breccia.
MG45 - Jasper.
MG46 - Average of 24 analyses of basaltic rock from the Küre area.

Replacement brecciation

Replacement breccias occur as indistinctly delimited occurrences throughout the wall-rock alteration aureoles of the Bakibaba and Aşıköy mines. They replace the basaltic rocks close to the sulfide deposits and, although representing a part of the intensely altered wall-rock, have from a technical point of view also been included among the disseminated ores by the mine geologists. The replacement breccias commonly occur in the upper parts of the wall-rock alteration aureoles. Their contacts with other rock components of the alteration belts and the sulfide ores are always transitional. The replacement breccias have been formed by chemical replacement processes. They contain «breccia» inclusions of various compositions, ranging from about 1 to 10 cm in size. These inclusions are usually made up of very fine -to fine-grained minerals. Chlorite-jasper, pyrite-chert, and complex replacement breccias have been distinguished.

Chlorite-jasper replacement breccia. — In the upper parts of the altered wall-rock in the Bakibaba mine, there are some occurrences of jasper «fragments» embedded in a matrix of chlorite, disseminated pyrite, and sporadic chalcopyrite. The size of the jasper inclusions reaches 10 cm. Chlorite-jasper breccias have not been observed in the gallery at the 920 m level, not even in places where there is intense chloritization of the wall-rock. In the gallery at the 1130 m level, the chlorite-jasper replacement breccia reaches an apparent maximum width of 170 m and is squeezed-in between the massive ore and the black shale (Fig. 10). Usually, the «fragments» of jasper in the chlorite masses vary widely in quantity, which applies to the replacement breccias proper as well as to the altered wall-rock sequence as a whole. However, in most places jasper or microcrystalline quartz is a quantitatively subordinate constituent. The occurrences of chlorite-jasper replacement breccias are diffusely delimited, the distribution of silica in the altered wall-rock being in general rather irregular.

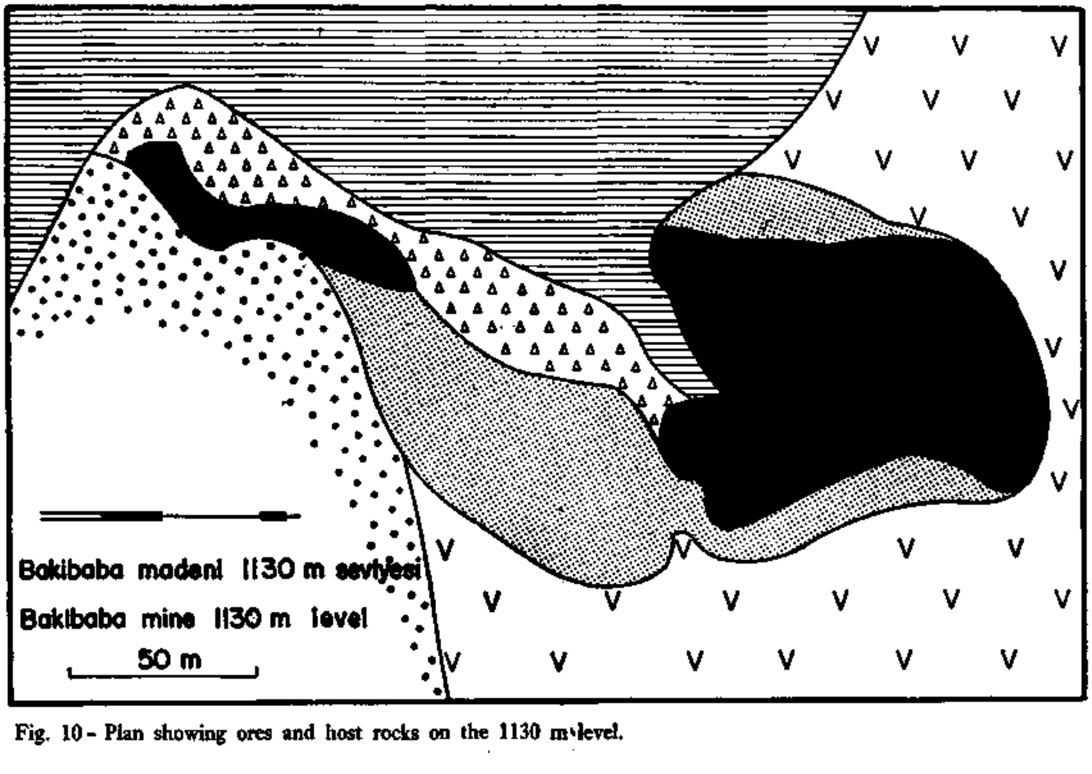

Fig. 10 - Plan showing ores and host rocks on the 1130 m level.

The jasper inclusions are red in color. Their occurrence is related directly to the incidence of hematite in the rock. The jasper is usually microcrystalline or very fine-grained. Megaquartz is developed along some fractures that appear to belong to a later phase of rock development. Hematite generally forms fine-grained, dusty disseminations pigmenting the silica. Rarely it also occurs in the shape of bands.

Amongst the sulfides of the chlorite-jasper replacement breccias, some larger, euhedral pyrite grains are usually developed in the jasper patches whilst chalcopyrite and anhedral pyrite are distributed as irregular aggregates throughout the fibrous chlorite masses. Cracks are often filled with quartz and occasionally also siderite.

The chemical composition of a jasper fragment (MG45) is shown in Table 5.

Pyrite-chert replacement breccia. — The described chlorite-jasper replacement breccia in the Bakibaba mine is similar to a pyrite-chert replacement breccia that extends over a large area in the vicinity of the massive pyrite ores in the Aşıköy mine. Its-incidence decreasing gradually with depth. Locally, this replacement breccia contains considerable amounts of large, discrete pyrite euhedrons, which are irregularly developed throughout the breccia rock. The chert fragments reach 50 mm in size and are embedded in a matrix of microcrystalline quartz with minor quantities of chalcopyrite and chlorite. Chalcopyrite often also occurs as inclusions in large, euhedral pyrites and in some cases fills the interstices between pyrite grains. Covellite occurs as rims or replaces completely the chalcopyrite masses.

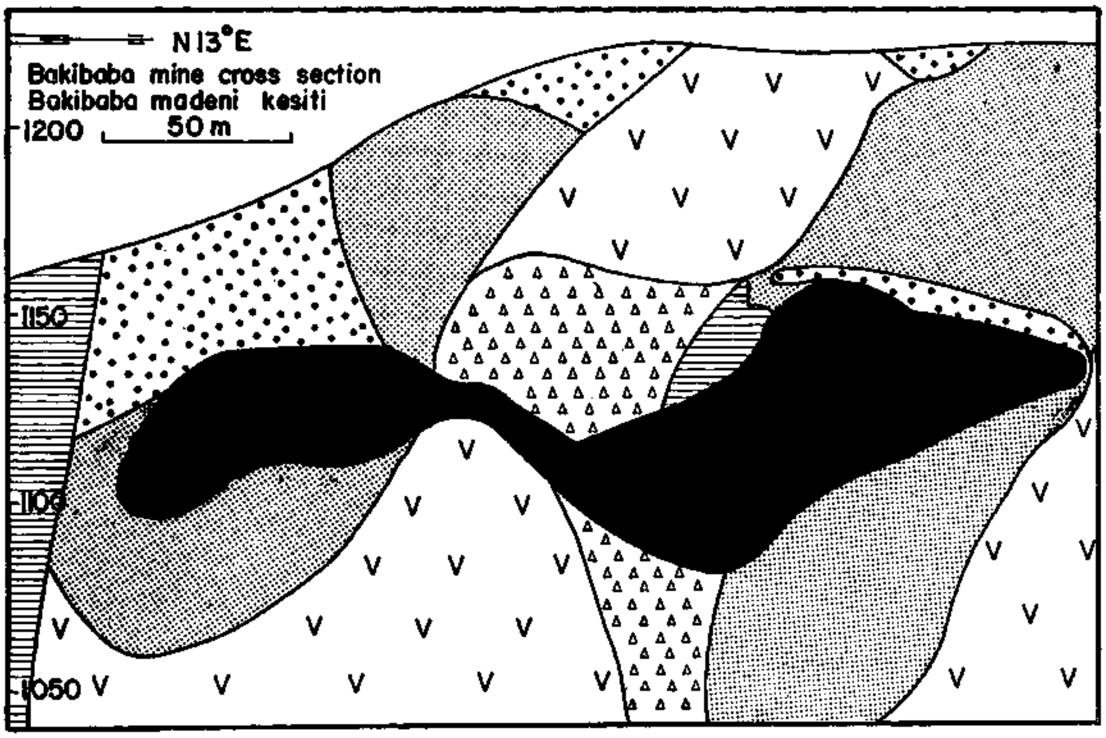

Fig. 11 - Vertical cross-section showing ores and host rocks.

Complex replacement breccias. — Complex replacement breccias differ from the chlorite-jasper and pyrite-chert replacement breccias principally by having larger variations in mineral composition and being characterized by the total absence sulfide minerals. They are found sporadically as small occurrences throughout the altered rock sequence. Most observations have been made in drill cores, particularly those from the «root zone» between the two large ore bodies in the Bakibaba mine. The complex replacement breccias are not strictly delimited or regular in shape. Rather, these rocks can be considered an integral part of the throughly altered wall-rock complex in the Bakibaba area.

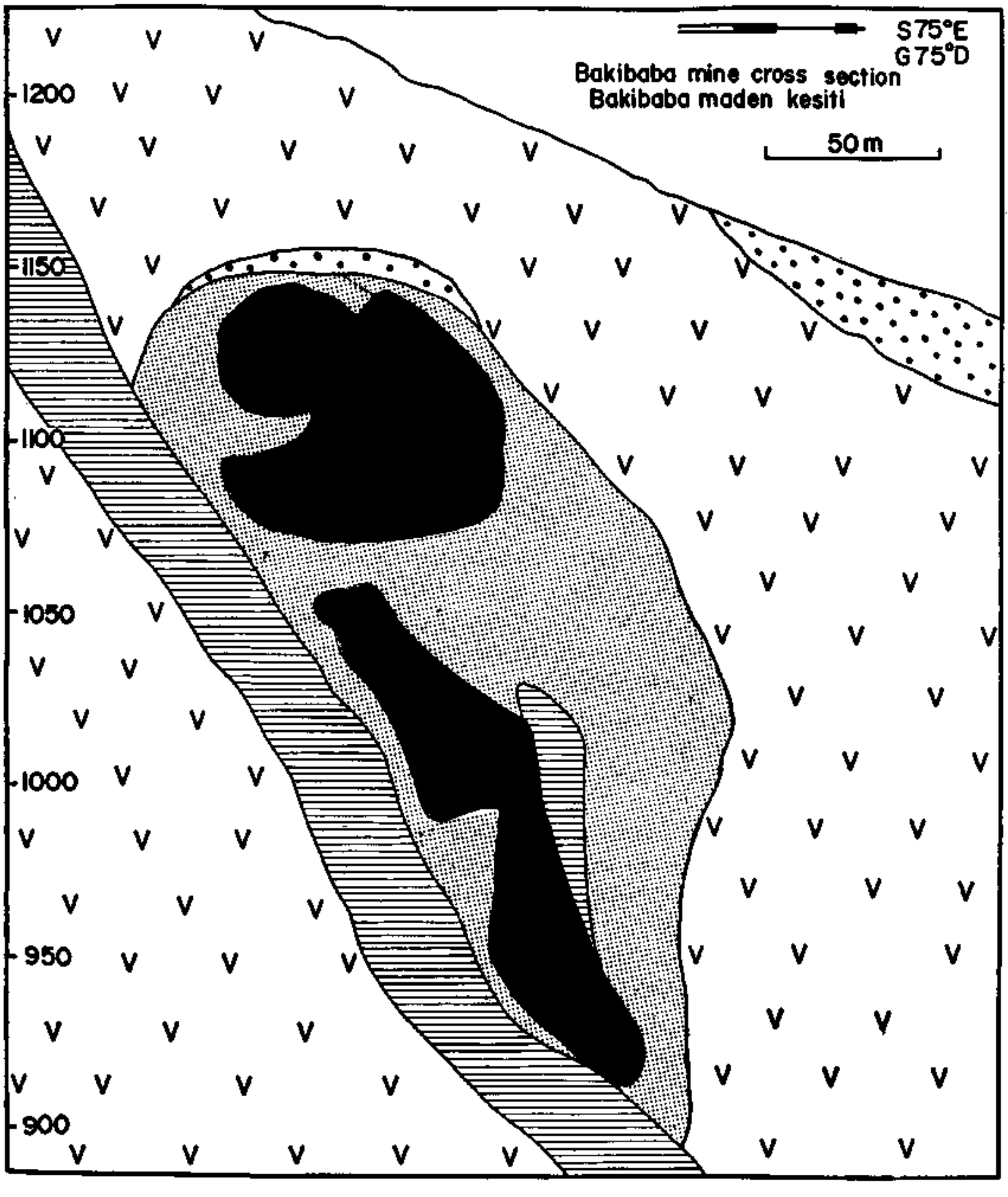

Fig. 12 - Vertical cross-section showing ores and host rocks.

According to the distribution and quantities of various component minerals, the complex replacement breccias can be subdivided into the following types: albite (30-35%)-chlorite (25-30 %)-calcite (20-30 %), albite (40-50 %)-calcite (20-20 %)-iron oxides (5-10 %), albite (25-30 %)-epidote (20-30 %)-calcite (20-25 %), albite (25-30 %)-chlorite (10-20 %)-iron oxides (10-15 %), and collophan (10-80 %)-calcite (5-60 %)-chlorite (5-15 %) breccias. The contents of quartz do not exceed 5 %. All of the microcrystalline to fine-grained aggregates of the principal minerals of the replacement breccias form separate «fragments», usually approximately 2 cm across, but rarely reaching sizes up to 5 cm. In general, the chlorite masses and the isotropic, cryptocrystalline masses of collophan are fragmented into larger pieces, albite variolites and calcite masses forming smaller «fragments». Epidote usually occurs in the shape of ca 0.8 mm long acicular crystals between which, normally, calcite and chlorite form the matrix. The usual cement between the replacement «fragments» is formed of a dust of iron oxides in a calcite and/or chlorite matrix.

The chemical composition of an albite-chlorite-calcite complex replacement breccia (MG44) is shown in Table 5. It is obvious that there is no great chemical differences between this sample and the average composition of the rocks of the basaltic sequence (MG46). The chemical composition the complex breccia also agrees with that ofthe already mentioned replacement breccia (MG24).

Argillic alteration

Sheets of clay minerals are developed at the contacts between the massive pyrite deposits and their host rocks or disseminated ores. Argillic alteration follows closely all the individual ore bodies every depth level of the Bakibaba mine (Fig. 13). Most borders of these clay belts against the massive ores and the black shales are extremely sharp. Rarely, the clay belts pass gradually into the other varieties of altered wall-rock and/or disseminated ores. They are commonly characterized by the absence of sulfide minerals, but the gradual contacts with the disseminated ores in the Aşıköy mine frequently contain euhedral pyrite grains.

The width of the clay zones in the Bakibaba mine varies between 0.5 m and 8 m. The colors of the clay belts are as follows: at the contacts with black shale medium gray, at the contacts with disseminated ores white, and at the contacts with altered basaltic rock light gray to pale red. An X-ray diffraction study of a white-colored clay belt showed kaolinite, quartz, and chlorite. Kaolinite usually continues into the sideritic alteration rock described in the next section, but its contents decrease with increasing distance from the massive ore bodies.

Siderite occurrences

Siderite is found in the shape offine-grained, fibrous aggregates and usually occurs as impregnation masses lacking well-defined margins. Sideritic rocks composed of dominant siderite masses associated with microcrystalline quartz and occasionally with kaolinite are a common matrix of the disseminated ores. As a rule, the presence of siderite in an altered wall-rock of the ores is signalled by light gray rock colors. The siderite contents decrease when proceeding from the disseminated ores to the inner zone ofaltered wall-rock envelops. Most siderite is enriched at the immediate contacts of disseminated ores against kaolinite rims. However, also within the normal chloritic rocks, siderite is present in subordinate amounts.

Uralitization

A relatively soft, greenish gray uralite rock is found in the upper parts of the outer zones of altered wall-rock. It appears to be typical of an outlying zone of alteration. The contacts of

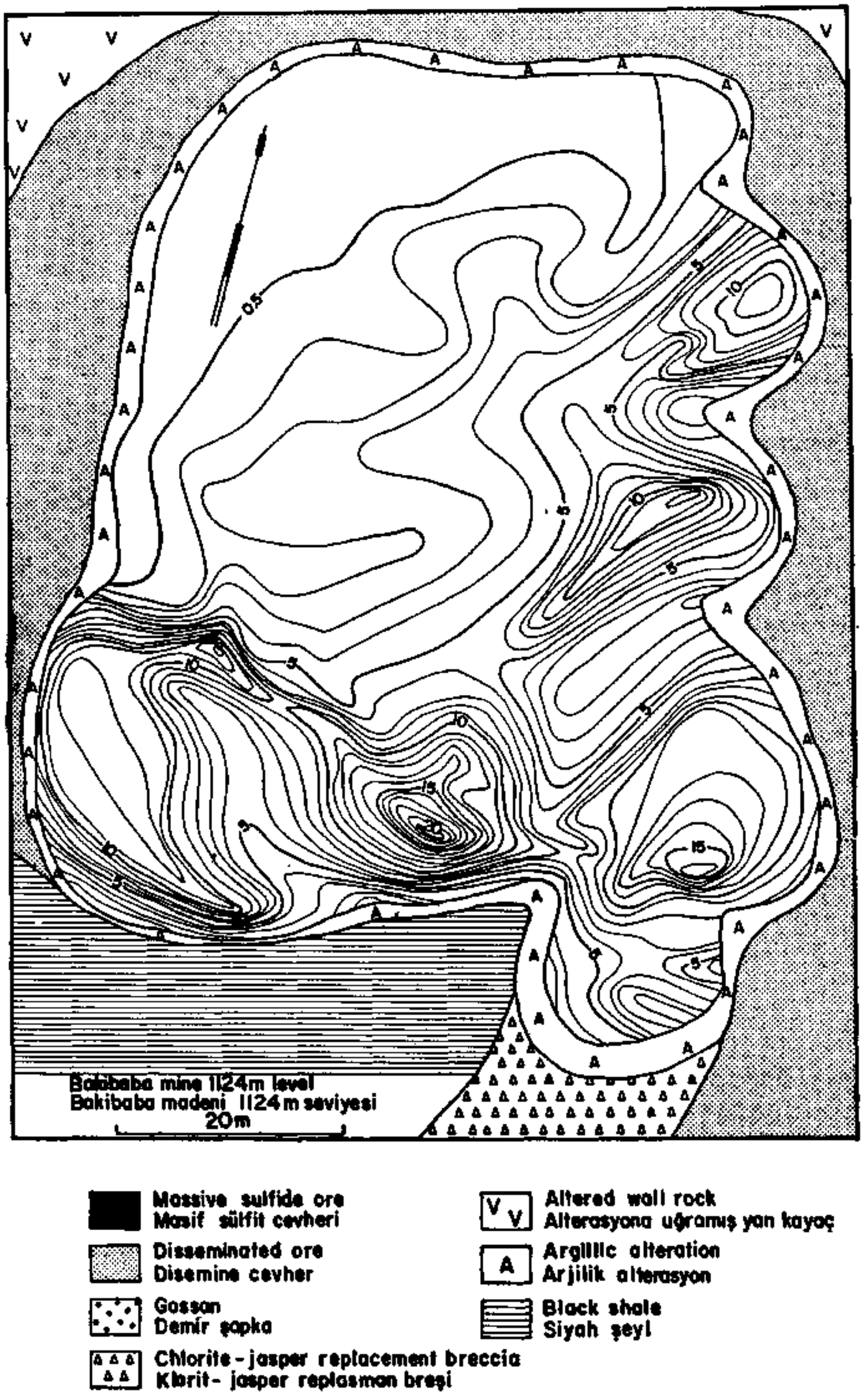

Fig. 13 - Distribution of Cu-percent in massive ore on the 1124 m level.

this belt are not distinct. In the Bakibaba mine, the ucalitic rock usually dissipates almost imperceptibly into the chloritic variety of alteration rock. The uralitic rock consists of predominant uralite, chlorite, and quartz. There are no preserved primary, structures or traces of the minerals from which the uralite was formed. As a rule, the uralite grains have the shape of fibrous aggregates. In thin-sections, they appear almost colorless or exhibit very weak pleochroism. The fibrous aggregates of uralite form diffuse intergrowths with chlorite and quartz. Long fibres of uralite commonly penetrate the quartz grains. In some cases, there areamygdules filled by weakly birefringent chlorite, chabazite, and/or quartz. The uralitic rocks also carry chrome spinel unaffected by the hydrothermal alteration of the wall-rock. This feature indicates that the uralitic rocks have been derived from the preexisting, clinopyroxene-rich rocks of the basaltic sequence, in which the same chrome spinel is a common accessory. Leucoxene is sometimes found in association with the chlorite of the uralitic rock.

The chemical composition of the uralitic rock is shown in Table 5.

Calcite occurrences

In the alteration rocks intimately associated with the massive pyrite deposits there are minor concentrations of calcite. Calcitization may be intense in the complex replacement breccias. In other instances, calcite is a common, but subordinate alteration product of the plagioclase laths in the basaltic rocks. The distribution of calcite suggests that it is not necessarily related to the formation of the ores but may be part of the regionally developed alteration of the rocks of the basaltic sequence.

Albitization

Albite is normally not very common in intensely chloritized rock. It is totally absent from the disseminated ores but occurs together with chlorite and calcite in other rocks usually situated in the outer zones of the alteration aureole surrounding the ores. As a rule, albite is always present in rocks with a preserved primary basaltic texture. In a particular instance, there is intense albitization in a variety of the complex replacement breccia described in a previous section.

THE ORIGIN OF METASOMATIC ROCKS AND MINERALS

To judge from their pattern of occurrence, the formation of the replacement breccias and the related mineral assemblages of altered rocks of the chloritic, quartzitic, uralitic, and argillic kinds was semicontemporaneous with the formation of the sulfide ores. The hydrothermal alteration and metasomatism appear to be results of the action of ore-bearing solutions. The extensive, through chloritic alteration of the basaltic sequence is particularly marked in the upper parts of the wall-rock alteration aureoles. It is therefore suggested that in the pillow breccias and tuffaceous chloritic masses, which are common in the upper parts of the basaltic sequence, a high primary porosity permitted an especially effective circulation of the hydrothermal solutions. In the soft, tuffaceous rocks there was of course initially a higher content of chlorite than in the massive or pillowy lavas. The chlorite masses derived from tuffes can be recognized by their paucity in chrome spinel.

Compared to the chemical composition of the average basaltic rock (MG46), the metasomatic alteration products of the ore wall-rock (MG40-MG43) have suffered substantial to almost complete losses of CaO and Na_2O and extensive losses of SiO_2. Total Fe, MgO and $A1_2O_3$ increase somewhat. TiO_2 appears to have been essentially immobile during the wall-rock alteration. Chloritized basaltic rocks from the outermost parts of the alteration aureoles around the massive ores show less chemical change than similar rocks from the inner parts of the aureoles. The two chloritic rocks from the vicinity of the massive ores (MG41 and MG42) thus show definitively higher contents of total Fe and Al_2O_3 and lower contents of SiO_2 than the two analyzed rocks from the outer part of the alteration aureoles (MG40 and MG43). Schwartz (1955) states that there exist ore bodies, where chlorite is geometrically so closely related to the ores that it can be used as an ore indicator. In contrast, e.g. a study of wall-rock alteration at Boliden (Nilsson, 1968) shows that the central zone of altered rock contain less MgO and total Fe and more $A1_2O_3$, SiO_2, TiO_2, and K_2O than the unaltered rocks. In the Boliden case, chloritic rocks occupy the outer zone of altered rock. In Küre, the chlorite contents increase with increased degrees of hydrothermal alteration. Except for the narrow envelopes of argillic rocks, there appears to have been no destruction and leaching of chlorite. The highest chlorite contents are therefore found in the vicinity of the massive ores.

The $MgO/(MgO+FeO^{tot})$ ratios of the Küre rocks are as follows: average basaltic rock (22 analyses)=0.42, chloritic rock (MG41 and MG42)=0.39, chloritized basaltic rock (MG40) =0.34, uralitic rock (MG43)=0.56. From this comparison it is clear that there has been no involvement of magnesia metasomatism in the production of the alteration aureoles around the Küre ores.

ORE DEPOSITS

The ore deposits of the Küre area comprise both massive and disseminated sulfides. The ores generally associate with faults along the black shale-basalt contacts where they always occur within the basaltic sequence. The disseminated ores replace the altered basaltic rock around the massive ore bodies. The aureoles of disseminated ore have varying extents that are not proportional to the sizes of the associated massive ores. The contacts between the two ore types are sharp only where there occur argillic rims. Otherwise, the transitions are gradual. As a rule, the sulfide content of the disseminated ores decreases away from the massive ore bodies. There are no distinct borders between disseminated ores and normal basalts and the indicated limits are therefore a matter of convention.

Massive sulfide deposits

Bakibaba, Aşıköy, and Kızılsu are the three large occurrences of massive ore hitherto discovered in the area. The Aşıköy deposit is the largest, having an area of about 170x300 m. It has been traced to a depth of 900 m. Together with a smaller ore it is mined by the Etibank Company. In Bakibaba, an occurrence investigated by KBİ, two ore bodies are under exploitation. The smaller one has a size of about 30x80x 170 m whilst the larger is very irregular. East of Bakibaba peak, this writer found a new ore body in a minor fault system in the basaltic rocks near the black shale contact. This ore probably extends from the point of exposure to the black shale contact approximately 150 m away. Owing to inaccessibility, the ore body in Kızılsu has not been surveyed in detail. Its size is largely unknown, but data from a drill hole indicate ore in a zone 50 m in thickness. Hitherto, the geological investigation of ore deposits has been concentrated on the Bakibaba ores. Much less is known about the geology of the Aşıköy mine.

All the mentioned occurrences have a similar geological setting. Usually, they form bun-like or loaf-shaped bodies within the upper parts of the basaltic sequence near its contacts to the isoclinally folded subgraywacke-black shale unit. Almost all of the recently discovered ore bodies seem to be closely related to faults along these contacts. No brecciations, drag-fold structures or other signs of deformation were observed in the parts of the ores adjoining the faults. The oblong ore-bodies were deposited in effusives along the contacts, cbncordantly with the limits of the folded sub-graywacke-black shale rock unit. Only the basaltic rocks have been hydrothermally altered by extensive chloritization along the faults and fracture zones. In Aşıköy, the alteration mostly resulted in hard wall-rock, whereas the Bakibaba area largely comprises soft, chloritic masses.

The contacts between the massive sulfide deposits and the black shale and argillic rims are extremely sharp. The massive ore bodies consist almost exclusively of sulfides (90-100%) with only a minor gangue of quartz or, more rarely, chlorite. The sulfide minerals chiefly comprise pyrite. In addition, there are varying amounts of chalcopyrite, bornite, covellite, sphalerite, digenite, marcasite, tennantite, carrollite, and traces of idaite and galena. Most of the copper minerals are concentrated in the cores of the bodies or close to the contacts with the black shale (Fig. 13). Bornite, covellite, and digenite are enriched particularly in the upper levels. Consequently, the concentration of copper varies considerably in the upper parts but is rather constant in the lower parts of the ore bodies. This is a feature common to all the massive ores.

The average grade of copper is 6 % at Bakibaba and 3 % at Aşıköy. In the former area, the ore bodies are subdivided into different zones according to their Cu-content, i.e. Zone I has 12-24 % Zone II 6-12 %, Zone III 2-6 %, and Zone IV 0.5-2 % of Cu. Due to its relatively low Cu-content, Zone IV is only mined for sulphur. It is characterized by porous pyrite of varying grain-size. In contrast, the hard ores are as a rule very rich in copper, which usually ranges from 6 to 24 %. Besides chalcopyrite, these ores usually also carry hypogene bornite, covellite, and digenite. There are frequently, small, extremely enriched parts of the ore that carry between 35 and 75 % Cu and consist essentially of chalcopyrite and/or digenite. For the sake of simplicity, the following terms will be used in the text: 24-75 % Cu: extremely high-grade ore, 12-24 % Cu: high-grade ore, 6-12 % Cu: copper-rich ore, 3-6 % Cu: moderate-grade ore, and 1-3 % Cu copper-poor ore.

Mineralogy of the massive sulfide ores. — Pyrite is the dominant or sole sulfide both in the hard and porous ores. Brecciated, colloform and framboidal textures are common especially in the most copper-rich zones that occuring particularly at the contacts with the black shale and in the inner parts of the ore bodies. Coarse and porous, euhedral to anhedral grains are typical of the copper-poor parts of the ore, where chalcopyrite is the only copper mineral. It occurs both as fracture fillings and an interstitial matrix between the pyrite grains. The cracks in brecciated pyrite, as well as in colloform and framboidal pyrites, are commonly filled by chalcopyrite, bornite, covellite, and sphalerite. The colloform bands are commonly composed of alternating layers of sphalerite, pyrite and chalcopyrite.

Most of the sulfide matrix in the copper-rich zones is made up of fragmented framboidal and fine-grained pyrite. Here, the contacts between the pyrite aggregates and the associated Cu-phases are always ragged and irregular. Sometimes, successive envelopes of pyrite, chalcopyrite, and sphalerite surround a pyrite nucleus or a chalcopyrite rosette, which is the case especially in zones **of** high-grade copper ore. Minute inclusions of chalcopyrite, sphalerite, bornite, and marcasite are frequently found in the large pyrite crystals. Often, the pyrite crystals are fractured and replaced by chalcopyrite. In the extremely high-grade ores, pyrite occurs only as an accessory phase or is altogether absent. The pyrite sometimes exhibits a weakly to distinctly anisotropic behavoir, which is presumably due to lattice distortions caused by impurities.

Chalcopyrite is second in abundance among the sulfide minerals. The Cu-rich parts of the ores usually consist of pyrite grains with interstitial chalcopyrite masses sometimes substituted by bornite, covellite, and digenite. Quartz is also a common interstitial phase. Chalcopyrite varies extremely in abundance, ranging from about 1.5 % in pyritic ores to about 99 % in particularly Cu-rich zones. Generally, but with minor exceptions due to the presence of bornite and covellite, its abundance is proportional to the total copper content. Small pyrite anhedrons are common in the chalcopyrite masses of the high-grade copper zones. Initial stages of chalcopyrite replacement by masses of digenite and/or covellite are common and are characterized by diffuse grain borders. Digenite and/or covellite are penetrating the chalcopyrite along fractures and grain borders, and also follow its cleavage directions. Sometimes, only corroded relic patches of chalcopyrite are left in the digenite masses. Large twin lamellae are common in the massive chalcopyrite ores.

Bornite is a major constituent in some high-grade ores occurring particularly in the upper parts of the ore bodies. However, it has been detected as far down as the gallery at the 920 m level where it occurs in chalcopyrite masses. Bornite varies widely in abundance but is as a rule absent from ores carrying colloform and framboidal pyrites. It is usually associated with other Cu-phases and sphalerite. In the brecciated pyrites, it always occurs interstitially. The mineral is intergrown intimately with chalcopyrite and covellite and frequently contains lamellae of chalcopyrite indicating changing environmental conditions (e.g. retrograte reactions). Exsolution intergrowths of laminae of chalcopyrite along the crystallographic planes of bornite are common in the high-grade ores. In some cases, the bornite masses are veined by wide zones of digenite and/or covellite. In the copper-rich ores particularly the margins of bornite grains are often irregularly replaced by covellite that has ragged and diffuse contacts with its host crystals. Where bornite is the major Cu-phase, minute inclusions of bornite also occur in large pyrite grains.

Covellite is common in copper-rich and high-grade ores in the upper levels of the ore bodies. It differs from bornite by occurring also in the colloform pyrites. Its distribution is not proportional to the Cu-grade pf the ores. In copper poor zones, this mineral usually partly or wholly replaces the minor masses of chalcoyprite. Normally, large masses of fine-grained intimately intergrown covellite, chalcopyrite, and bornite occupy the interstices of brecciated pyrites. Covellite sometimes also replaces chalcopyrite. In these cases it forms rims along fractures and along chalcopyrite-pyrite and chalcopyrite-quartz contacts. It also occurs as fracture fillings in bornite and rims large inclusions of bornite in chalcopyrite. Where quartz is present covellite sometimes occupies the interstices in it. Rarely, it occurs together with chalcopyrite and sphalerite as alternate layers in colloform pyrites. The contacts between covellite and the other sulfides are usually irregular and diffuse.

Sphalerite is commonly enriched in copper rich ores. Its mode of occurrence is similar to that of the Cu-phases. However, sporadically minor sphalerite veins also occur in copper poor-ores, where chalcopyrite may be present as small spherical particles in an apparently random arrangement referred to as emulsion texture (Stanton, 1972). Sphalerite forms anhedral crystals of ragged and irregular shapes. They are commonly intimately intergrown with the chalcopyrites, bornites, and covellite that form a matrix in brecciated pyrites. Only rarely does sphalerite occur together.with chalcopyrite as layers in colloform pyrites. Where sphalerite is frequent, it often contains minute inclusions of chalcopyrite, bornite, and pyrite. Locally, trace amounts of sphalerite occur as inclusions in pyrite. Isolated islands in bornite are common in the zones of massive ore bodies that are adjacent to the disseminated ores.

Digenite is mostly developed as films along fractures and rims around chalcopyrites where these are in contact with pyrite and quartz .In the same occurrences, it is commonly intergrown with covellite. In veins, in bornite masses, it also sometimes forms intergrowths with covellite. Particularly where quartz is more common than chalcopyrite, idigenite may partly or wholly replace the minor quantities of chalcopyrite present as a cementation material mostly in the outer zones of the ore bodies. Zones of pure digenite, carrying 76 % Cu, appear to have been formed at the expense of chalcopyrite, which is indicated by relic, strongly corroded chalcopyrite patches.

Marcasite is concentrated in zones transitional between the massive and disseminated ores. It occurs as lath-shaped, euhedral to subhedral crystals consisting of coarse twin lamellae. Marcasite has been developed as intimate intergrowths with pyrite either in veins in the moderate-grade copper ores also carrying chalcopyrite, covellite, and quartz or in the spheroidal and brecciated pyrites of the copper-poor ores. In both cases, it frequently forms fine lamellae.

Tennantite generally coexists with the chalcopyrite, bornite, covellite, sphalerite, carrollite, and galena ofthe copper-rich ores. Its grains are more or less ragged or irregularly developed and commonly have sharp margins toward their host minerals. They occur in relatively small quantities in the major sulfide masses. Where galena is present, tennantite is generally intergrown with it.

Carrollite has the same mode of occurrence as tennantite and is as a rule found in bornite-rich ores. It is usually present in subordinate quantities and shows relatively well-defined margins toward its host minerals. Euhedral to anhedral grains of various sizes are enclosed in and/or intergrown with chalcopyrite and bornite. Anhedral carrollite intergrown with chalcopyrite often forms the matrix in brecciated pyrites. Commonly, large grains of carrollite contain numerous blebs and minute inclusions of chalcopyrite.

Idaite appears in zones of copper enrichment, where it forms tabular, probably hypogene crystals. It only occurs as an accessory phase, being mostly enclosed in covellite masses. In some cases, the mineral is intimately intergrown with chalcopyrite, sphalerite, and bornite.

Galena is only found in trace amounts, occurring especially in the Cu-rich ores. It may form fine-grained intergrowths with tennantite and to some extent also with chalcopyrite, bornite, sphalerite, and covellite. However, the most common type of occurrence are strongly corroded inclusions in covellite, which indicates replacement.

Chrome spinel was found as an accessory in copper-poor ores carrying brecciated pyrite. Its crystal habits are euhedral and appear to be unaffected by the hydrothermal, ore-carrying solutions. The chrome spinel of the ores is identical with that found in the basaltic rocks and their alteration products. The reflectance of spinel from the massive ores ranges from about 10.5% to 12.0%. This value agrees satisfactorily with that of the basalt spinels .The spinels mostly occur in the gangue, but cubic inclusion in pyrite are also common. The characteristics of the spinels show that this mineral is a relic of the original high-temperature basalt paragenesis that is unrelated to the low-temperature mineral association of the hydrothermal ores.

Disseminated ores

The ore minerals of the lower-grade, disseminated ores chiefly consist of pyrite with minor amounts of iron oxides. The total absence of iron oxides from the massive ores constitutes one of the major differences between the two ore types. From an economic point of view, the disseminated ores are of little or no importance. The disseminated ores occur with varying frequencies throughout the altered basaltic rocks. Their limits against both the massive sulfide ores and the hydrothermally altered wall-rock are arbitrary and have not been drawn according to strict delimination criteria. The disseminated pyrite ores generally continue into the uninvestigated rocks below the deepest mining levels. They are restricted to the basalts and do not occur in the black shale sequence. Pyrite is the predominant sulfide with usually minor but locally high chalcopyrite contents. The pyrite content decreases gradually with increased zonal distance from the massive ore bodies. However, minor concentrations of massive ore are common in the disseminated ore zones. Iron oxides, specularite and magnetite, occur generally as intimately dispersed accumulations in these small, massive ores.

As mentioned previously the pyrite-chert replacement breccia in the Aşıköy mine and the essentially equivalent Bakibaba chlorite-jasper replacement breccia can be considered to be a kind of disseminated ore. At least there is no great difference in the mode of occurrence beween the disseminated pyrites and the pyritic replacement breccias. In zones adjacent to massive ores, where replacement by pyrite is extensive, the discrete, euhedral to subhedral, irregularly distributed pyrite grains are commonly embedded in a matrix of dominant quartz, chlorite, and in places siderite with varying quantities of kaolinite. The large, anhedral pyrite grains frequently contain minute inclusions of chlorite, quartz, sphalerite, and chalcopyrite.

Chalcopyrite is abundant in chloritic rocks. It occurs as intergrowths with pyrite and sphalerite. When present in subordinate quantities only, as is the case e.g. in quartz dominant matrices, this mineral is mostly replaced by covellite and/or digenite growing from the contacts with the adjoining quartz and pyrite grains.

Small accumulations of specularite and magnetite with various quantities of sulfide minerals have been reported by mine geologists from several drilling holes through the massive ore bodies. However, specularite lenses have sporadically also been found beneath the gossan formation, in zones adjoining the massive ores. The specularite needles are irregularly developed and seem to be somewhat deformed. They often penetrate the larger, euhedral pyrite crystals. In places where the interstitial matrix around the specularites is dominated by chlorite, the pyrite grains seem to be replaced by chalcopyrite and siderite that form mutually interpenetrating growths. When quartz is the main matrix mineral, it is penetrated by specularite needles and chalcopyrite is either entirely absent or forms large lamellae with pyrite. In the specularitic ores, the magnetite is only found as needles that also penetrate pyrite crystals. Sometimes, specularite coexisting with chalcopyrite is abundant in nearly pure chloritic rock.

In contrast to specularite, magnetite as a rule occurs in the deeper zones of the disseminated ores. Since there exist remains of hematite that form inclusions in the magnetite grains, magnetite seems to form pseudomorphs after specularite. The lath-like or neddle-shaped magnetite crystals are irregularly arranged, deformed, and partly broken. In the magnetitic ores, there have been found some euhedral pyrite grains of up to 5 mm size, which are usually penetrated by magnetite needles. A black chlorite variety and some chalcedony form most of the matrix in the magnetite-bearing rocks. Fine-grained quartz commonly occupies the interstices between magnetite needles. The determinations of Vickers hardness and reflectivity for Küre magnetites will be reported in a separate paper.

Marcasite is an abundant disseminated mineral occurring locally in the vicinity of the massive ores. It forms lath-shaped or coarsely lamellar intergrowths with pyrite.

The chrome spinel of the disseminated ores is unaffected by the replacement processes. It is common in zones of disseminated sulfides but is absent from occurrences of disseminated iron oxides, where it has probably been completely aftered to chlorite. This suggestion finds support in the sluggish reaction rates of oxides as compared to sulfides.

Gossan

The original extent of the gossan occurrences in the Bakibaba area was larger than at present. Much of it has been removed in the course of mining, operations and the growth of Küre town. As a rule, the gossan is autochthonous. Nevertheless, a few small gossan bodies on hillsides have presumably been dislocated by sliding. The sizes of the gossans are not necessarily proportional to those of the primary ore bodies. Normally, however, all gossans in the mine areas can be directly correlated with ore deposits and general do not extend beyond the limits of the ore bodies on which they form superficial covers. The thicknesses of the limonitic gossan rocks vary from about 1 to 120 m. The gossans may include some small, isolated, pyritic ore bodies.

The two most common varieties of gossan in the Bakibaba area are grayish red, heavy, massive limonite and light red, light, slaggy, porous limonite. Both varieties are usually very hard and exhibit local breccia structures. The breccia fragments, which reach 5 cm in size, consist either of earthy limonite plus locally some goethite, or of fine-grained quartz. They are embedded in a limonitic matrix with some accessory quartz. X-ray diffraction does not show any crystalline substances except quartz and some hematite indicated by very diffuse basal reflections. However, in the earthy yellow fragments, goethite is definitely present.

Table 6 - Semiquantitative analyses of massive sulfide ores, disseminated ores and gossans from the Bakibaba mine (oxides in weight %, elements in ppm)

	High grade copper ore	*Low grade copper ore*	*Disseminated ore*	*Gossan*
SiO_2	1.92	5.13	38.50	19.50
TiO_2	0.02	0.02	0.77	0.44
Al_2O_3	0.19	<0.19	6.80	1.40
Fe_2O_3	45.95	46.78	29.65	69.10
MnO	<0.01	<0.01	0.03	0.01
CaO	<0.14	<0.14	<0.14	<0.10
MgO	<0.17	<0.17	3.28	0.01
Na_2O	<0.10	<0.10	<0.10	<0.10
K_2O	<0.12	<0.12	<0.12	0.10
H_2O^+	0.70	0.50	3.10	6.90
H_2O^-	0.20	0.10	0.20	0.10
P_2O_5	0.15	0.15	0.14	0.23
CO_2	0.02	<0.01	1.30	0.14
F	<0.01	<0.01	0.01	<0.01
S	38.40	38.50	16.40	0.27
BaO	0.17	0.12	0.03	0.02
Cu	> 13000	> 13000	7150	1900
Pb	415	139	23	13
Zn	> 4188	> 3997	411	58
Mo	14	22	<10	<10
Ni	30	27	43	<10
Cr	8	7	165	162
Co	> 600	> 600	> 600	42
As	909	702	88	<50
Ag	> 100	17	<3	<3
V	69	34	304	230
Sr	24	22	13	26
Sn	243	122	7	<5
Be	<3	<3	<3	<3
Bi	14	10	<5	<5
W	125	192	60	<50

The limonitic matrix mostly consists of irregular masses and colloform types. Only rarely are there microboitryoidal textures. Where the colloform limonite predominates, the rock is massive and very hard. In thin-section, this limonite is black to brown whereas the earthy type is yellow. In reflected light, the massive limonite is seen to belong to two varieties: a light gray clearly colloform type with a reflectance of about 12. 0% (Güner, in press) and a Vickers hardness of about 400, and a light bluish-gray, semicolloform type usually enveloping the colloform limonite or occurring as irregular masses. The latter type has a reflectance of about 19.5 % and a Vickers hardness of about 300.

Quartz is the only major crystalline constituent in the massive gossans. Its contents vary between 1 and 15 %. It is mostly developed as breccia fragments and rarely as grains distributed evenly throughout the limonitic rock. The formation of quartz thus appears to be contemporaneous with the limonitization of the pyrite.

The light red, earthy gossan variety as a rule consists of limonite and altered basaltic rock. The preservation of some bodies of pyrite in the limonitic rocks appears to be due to the formation of enveloping, massive, colloform limonites which prevented further oxidation.

Generally the contacts between massive pyritic ores and gossans are very sharp. The deep oxidation of porous pyritic ores to form hard, massive limonites has protected the underlying pyrite deposits from destruction. The zones of deep oxidation are often manifested by colloform limonite and are almost without brecciation structures.

Conclusions regarding the origin of the ore deposits

Nikitin (1926), who partly investigated the gallery at the 894 m level (caved-in adit) in the ore body near the Zemberekler brook, just beneath the slaughterhouse, concluded that the sulfide mineralization was introduced in connection with the «diorite» (diabase) intrusions. In contrast, Kovenko (1944) argues that the dynamometamorphism of «diabase» (basaltic rock) took place before the formation of the ores. He thought that the Küre deposits were related to the metasomatism of «dia base». Ketin (1962) summarized the views of Kovenko as follows: «The ore developed as a result of metamorphism and is related to the diorite and diabase intrusions intersecting Liassic flysch deposits». Having investigated the Aşıköy ore body, the CENTO group (Sancan, 1968) arrived at still another conclusion that was based on the study of the structures seen in the field. It says cautiously that neither the «mafic volcanic rocks» (basaltic sequence) nor the dacite can be reasonable sources of the ore fluids.

In the opinion of the present writer, the wide extent of the sulfide mineralization and the associated extensive alteration of the basaltic rocks indicate that neither the solutions nor the copper were derived locally. It is therefore suggested that the ores are relatively far-transported and that the major faults dominating the area provided zones of weakness in the basaltic rocks and paths for a pulsative upward migration of hydrothermal ore solutions. However, all deposits are not necessarily characterized by faults. Several ore bodies in the Bakibaba mine area, e.g. the extensively mined gallery at the 894 m level, were obviously developed in zones of weakness in the basaltic sequence that more or less closely follows the contact with the black shales. Even so, the ore fluids have probably made their way upwards mostly along the weak zones. The major fault system running in a N-S direction is considered to have played an important role as a provider of channelways for the ascending ore solutions.

The massive structures of the sulfide emplacements and their sharp, characteristically sinusoidal contacts with the black shales indicate that the ores were formed from hydrothermal fluids rich in Fe, Cu, and S. Rest magmas may have been the source of the fluids. The alteration induced by the hydrothermal ore solutions has only affected the basaltic sequence. Because of the impermeability of the black shales, it is most probable that the circulation of hydrothermal ore solutions through these rocks was impossible. The thoroughly chloritized zones in the basaltic rocks always associate with significant pyrite mineralizations.

The minute inclusions of gangue represented by secondary quartz and chlorite in the pyrite grains of the massive and disseminated ores suggests a replacement of the basaltic rocks by the ores. The colloform and framboidal structures of pyrite indicate that the massisve ores were formed at a relatively low temperature. Chrome spinel is preserved in the massive sulfide ores whereas it is totally absent in zones of iron oxides. It is suggested that this is due to a total alteration during the oxidation process.

REGIONAL SYNTHESIS: STRUCTURES AND AGE RELATIONS

The CENTO group (Sarıcan, 1968) has studied the tectonics of the Küre area. However, because their evidence is considered insufficient by this writer and their characterization of field relationships is dubious, much of their structural conclusions are not employed in the present discussion. Particularly, much of the tectonic pattern that they ascribed to the basaltic rocks was found to be invalid during the peresent study. Other structural characterizations of the remaining lithological units were found more usable.

The major, N-S running faults in the basaltic sequence are mostly masked by intense chloritization. In contrast, minor faults probably related to the N-S faults, but striking in east-westerly and other directions, are more or less distinct. Nevertheless, the major N-S faults can commonly be recognized along the basalt-black shale contacts, where they have left alteration imprints on the basaltic rocks.

Some independent evidence is provided by a paleomagnetic study of the basalts, dike rocks, massive sulfide ores, and the peridotite (Güner, in press). The paleomagnetic study reinforces and confirms the geological evidence suggesting that many of the principal rock units differ widely in age. The oldest rocks in the area are the eugeosynclinal accumulations, the subgraywackes and black shales. As mentioned previously, the age of the latter is assumed to be Permian. The tectonic features of the subgraywacke-black shale unit and its contacts with the basalt complex indicate that the deformation of the eugeosynclinal rocks commenced during a phase of intense isoclinal folding associated with the extrusion of the submarine basalt flows and the emplacement of the semicontemporaneous quartz diabase and diabase dikes. During the Permian-Jurassic phases, the orogenic movements in northern Anatolia are known to have been violent (Ketin, 1962). According to the CENTO group (Sarıcan, 1968), the basalts were extruded in two major volcanic pulses clearly separated in time. The eastern basalts were considered to be older than the western ones. This age difference is not confirmed by the paleomagnetic study. The paleomagnetic determinations also suggest than the quartz diabase and the diabase are approximately coeval with the basalts. The magnetic pole positions of these three rocks are rather similar. However, the faulting and the accompanying sulfide mineralization are considered to be substantially younger. As to the upper age limit, Kovenko (1944) stated that the sulfide mineralizations at Küre took place long before the Middle Jurassic. From observations in the Aşıköy mine, the dacite dikes are distinctly younger than the sulfide ores. However, the dacites have an extremely low magnetic susceptibility and their virtual geomagnetic poles are therefore very unreliable. The paleomagnetic study therefore offers no good dating of these post-mineralization intrusions. However, the paleomagnetic investigation confirms that the amphibolitized diabase is the youngest igneous rock in the area. The development of serpentinite may have taken place after the intrusion of the amphibolitized diabase. A new stage of thrust faulting probably occurred during the same time. Unfortunately, the intrusion age of the serpentinized ultramafic rock is not known. There may be age equivalence with other ultramafic rocks in Anatolia, which are known to be Mesozoic (Brinkmann, 1972). As to the late sediments, fossil finds in massive limestone indicate that these rocks are Late Jurassic. In connection with a subsequent faulting of the non-eugeosynclinal sequences, there appears to thave been a weak, late folding of the eugeosynclinal deposits. During the same event, probably at the end of the Jurassic, the Kike area was elevated above sea level whilst its surroundings remained under water. This is indicated by the nature and distribution of the Cretaceous formation around the Küre area. It has been noted (Ketin, 1962) that Kimmeridgian movements of the Alpine orogeny characterize this part of the Pontides.

The regional structural features indicate that the Küre area, situated in the western part of the Pontic Ranges, was characterized by mobile-belt behavior prior to the sedimentation of the eugeosynclinal subgraywacke. According to Ketin (1977), evidence of the earliest known pre-Alpine movements can be seen in this part of the Pontids. In addition, the occurrence of Early Alpine orogenic events, such as the Late Kimmerian and Austrian phases, has been noted in the central and northern parts of the Pontic Ranges, especially in the areas between Kastamonu and Abana (Ketin, 1977), approximately 15 km east of Küre.

On the basis of this discussion, the age relations of the different units and structures can be summarized as follows:

Youngest : Uplift of the Küre area above sea level

Folding of eugeosynclinal accumulations

Faulting of non-eugeosynclinal sediments

Late Jurassic : *Formation of massive limestone*

Sedimentation of mudstone

Formation of the conglomerates

Thrust faulting of the different units

Development of metasomatic rock

Serpentinization

Intrusion of amphibolitized diabase

Intrusion of peridotite

Intrusion of dacite

Formation of the sulfide ores from hydrothermal solutions

Development of major faults and thrust faulting

Intrusion of diabase

Intrusion of quartz diabase

Extrusion of the rocks of the basalt complex

Isoclinal folding of the eugeosynclinal accumulations

Permian (?) : *Sedimentation of black shale*

Oldest : *Sedimentation of subgraywacke*

SUMMARY

This paper deals with the geology and massive sulfide deposits of the Küre area, which is situated approximately 50 km to the north of Kastamonu and 20 km from the Black Sea coast in the Pontides, northern Turkey.

Sedimentary rocks occupy more than the half of the investigated area. These formations comprise eugeosynclinal deposits of subgraywacke and black shale, and non-eugeosynclinal sequences of conglomerates, mudstone and limestone. Among the rocks occurring in the Küre area, subgraywacke is the oldest (Permian?) and Late Jurassic limestone the youngest component. The subgraywacke-black shale unit appears to have been folded isoclinally before the extrusion of the effusives.

A large body of rocks belonging to a submarine basaltic sequence of possible Permian-Triassic age associates with the eugeosynclinal accumulations. Several generations of related dikes of various compositions occur among the basaltic rocks. Massive and pillowed flows generally occur in the lower parts of the basalt succession. Upwards, they are succeeded by pillow breccias and tuffaceous chloritic masses. In the zone transitional towards the breccias of isolated pillows, the content of matrix increases gradually. The pillows simultaneously become more diversiform and ill-sorted, broken pillows and pieces of lava commonly occupying the top of the basalt succession. The basaltoids and the related diabase dikes have tholeiitic, ocean-floor basaltic chemical compositions.

The Bakibaba, Aşıköy and Kızılsu cupriferous pyrite deposits of the Küre area have many features in common. All consist chiefly of sulfides replacing the basaltic rock. The largest ore body (Aşıköy mine) has an area of about 170x300 m and has been traced to a depth of 900 m. The massive ores contain more than 90 % by volume of sulfide minerals. The contents of chalcopyrite vary from 1.5 to 99 %. Disseminated ores contain less sulfides and little or no chalcopyrite or iron oxides. In the Bakibaba mine, the massive ores have an average grade of 6 % copper. In the Aşıköy mine the copper grade is 3 %. Textural studies show the presence of brecciated, colloform, and framboidal pyrites but, besides unaffected chrome spinels, almost no other evidence of a replacement of the preexisting silicate minerals by sulfides.

Almost all ore bodies lie close to the black shale-basalt contact. Their localization has been controlled by major faults that offered pathways for the upward migration of ore-bearing solutions along zones of weakness in the basaltic sequence. The introduction of the ores probably occurred in a pulsatory manner. The ascending ore solutions caused extensive hydrothermal alteration in the basalt complex but did riot affect the sedimentary rocks. Hydrothermal alteration resulted in the formation of replacement breccias and various other rock types rich in chlorite, quartz, and uralite. During the metasomatism, large amounts of alkalis, Si, Mg, and Fe were liberated from the mineralized areas and presumably redeposited in other, higher parts of the column of altered wall-rock. Some chloritic rocks show large additions of total FeO, MgO, and Al_2O_3, but continuing removal of much Na_2O, CaO and some SiO_2.

The gossans, which in some places have slid down from higher topographical levels, seem generally to be restricted to the immediate surface of the massive or disseminated ores. They have obviously been formed by oxidation of the sulfides.

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