MIGMATITES IN THE GÖRDES AREA

Mehmet AYAN

Mineral Research and Exploration Institute of Turkey

SUMMARY. — The metamorphic rocks of the studied area were examined with respect to their grade of metamorphism and were thus mapped as separate metamorphic facies series. Development of migmatites and granitization phenomenon were also studied in addition to the petrochemistry of the metamorphic series of rocks. In this context, it is explained that the metamorphic rocks of the region are of para-origin, and that migmatization took place under severe conditions of high-grade metamorphism followed by the formation of an anatectic granitic magma. The granitic rocks of the region were, therefore, formed by palingenesis processes and their emplacement occurred during the Variscan orogeny, while the pegmatoids were produced as a result of metamorphic differentiation. The Alpine orogenic movements affected the region as a whole.

LOCATION

The area mapped constitutes an essential part of the quadrangles of İzmir $K20_1$, b_1, b_2,b_3 and b_4 and is found located between the longitudes of Ig and li and the latitudes of 20-21, as indicated on the 1:200,000-scale regional geographical map. It is bordered in the east by the Demirci-Borlu-Salihli highway running in a northeasterly direction about 5 km east of Gördes. Köprübaşı (Araplı village) marks the southern boundary, while the Gördes-Demirci highway borders the northern part of the studied area. As a whole it covers an area of 330 km^2 (Location map).

LITHOSTRATIGRAPHY AND PETROGRAPHY

The rocks of the area are considered under two groups: the metamorphic series and the sedimentary formations. Since a great deal of attention was centered on the more detailed study of the metamorphic series, the Neogene formations consisting of sedimentary rocks were only dealt with in general.

The metamorphic rocks constitute a large part of the lithologic units of the area. They are banded gneisses and muscovite-almandine-quartz schists of the greenschist facies and almandine-muscovite-biotite gneisses and the layer migmatites of the metatexis group belonging to the almandine-amphibolite schist facies.

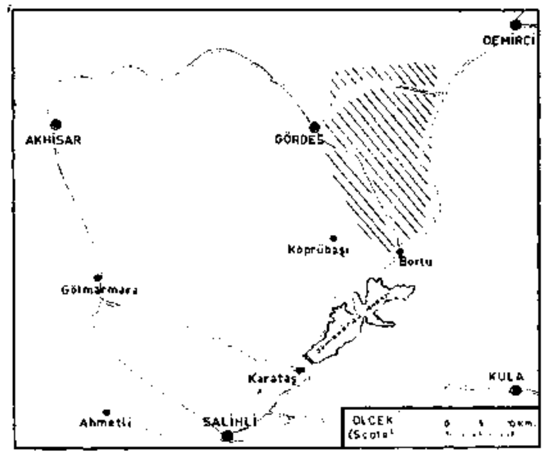
Although some lens-like bodies of the epidote-amphibolite schists occur within the biotite gneisses of the almandine-amphibolite schist facies, they are not of mappable dimensions.

METAMORPHIC FORMATIONS

1. Quartz-albite-almandine-muscovite schist (banded gneisses)

The metamorphic rocks, called the banded gneisses, extend along a zone 1-3 km in width and 15 km in length, in the direction of SSW-NNE, parallel to the axis of the Comakhdagi anticline. This zone dips 40-50°SE and covers the southeastern part of the area, The muscovite and tourmaline crystals exhibit a somewhat discontinuous lineation on the schistosity surfaces and give the rocks a banded appearance, because of which these facies series were named the «banded gneisses».

These gneisses—which contain, in order of abundance, muscovite, quartz, plagioclase (albite-oligoclase, 5-15 % An), orthoclase, biotite, garnet (almandine), tourmaline and zircon, apatite, magnetite; minor amounts of cerussite and chlorite as alteration products—correspond to the upper gneiss zone in the Jung and Roques classification.



Location map of the studied area.

Following Turner and Verhoogen's classification of metamorphic facies series, these rocks are considered to belong to the quartz-albite-epidote-almandine subfacies of the greenschist of regional metamorphism. They are composed of the following mineral assemblage: muscovite-biotite-almandine-quartz-albite. Although the rock contains two micas—muscovite and biotite—the former is found more abundantly while the latter is comparatively rare. Strong deformation is a characteristic feature of these series of rocks. Apart from the main SW-NE schistosity, they display a second schistosity in the direction of N-S. Quartz crystals are observed to have been flattened and elongated, while muscovite displays a plaited structure. The rock has a heterogenous granular texture though quartz and feldspar are, on occasions, developed in porphyroblasts. Development of «eyes» is observed initiating on the «C» surfaces perpendicular to the schistosity. Under the microscope the rocks display the effects of cataclasis. The texture is mainly heterogranolepidoblastic but cataclastic texture is also common.

Tourmaline is often macroscopically visible on the schistosity planes of the rock. It appears in the form of needles measuring 1-2 cm in length. Tourmaline crystals, which have a dark color, display a strong pleochroism (brown) under the microscope. They are observed as large automorphic crystals which are, on occasions, poikilitic with quartz inclusions.

2. Muscovite-almandine-quartz schists

Geologists who have previously worked in this area named these rocks as quartzites. Quartzite is in general a rock consisting chiefly of quartz crystals. When quartzites contain some aluminous material, muscovite-quartz schists are produced from them as a result of metamorphism. These schists contain abundant muscovite crystals and are described as muscovite-almandine-quartz schists. They are found in the southern part of the studied area, particularly near the Tozludamları, Kıranşeyh and Araplı villages. Muscovite crystals encountered in the rocks of these areas have a regular preferred orientation and occur as small uniform plates with straight edges. Garnet is less abundant. However, the amount of garnet increases approaching the Araplı village and these schists are observed as alternating intercalations within the kyanite-almandine-muscovite-biotite schists (biotite gneiss) near the village of Deliler. They have a cataclastic texture. Development of feldspathization is common. The same situation is also observed near Kurttutan in the east. Here, the amount of muscovite increases in the muscovite quartz schists and they show pre- and syndeformative signs. Quartz blastesis sometimes show augen-gneiss-like patterns in the center of the warped muscovites.

These schists encircle the biotite gneiss and migmatites on the western and eastern flanks of the Çomaklıdağı anticline, where they have the same dips, but in the southern part they dip southwards. They overlie the biotite gneisses and migmatites and underlie the banded gneisses. It is possible to accept this rock as muscovite-almandine-quartz schist in the quartz-albite-epidote-almandine subfacies of Turner's greenschist facies, because it contains almandine.

The rock consists mostly of quartz; it contains also muscovite, garnet (almandine) and tourmaline, zircon, monazite, magnetite, rutile (as accessory minerals).

3. Disthene-almandine-rnuscovite-biotite gneiss

In the classification of Turner-Verhoogen these gneisses, occurring in the disthene-almandine-muscovite-biotite subfacies of the almandine-amphibolite facies, took place in the katazone of Grubenmann-Niggli, but according to the Jung-Roques classification they occur in the inferior gneiss group. Because these rocks contain excessive biotite and recessive muscovite they are sometimes named «biotite gneisses».

These gneisses occur in large areas on the flank of the Çomaklıdağı anticline looking towards Gördes, in the western parts of the studied area. These blackish-dark green gneisses contain abundant garnet crystals, as found on the way from Gördes to Borlu, near Gördes, around Deliler village.

The gneisses trending in a SW-NE direction and showing a general schistosity in the same direction, have an approximate dip of 60-70° towards NW. They generally contain numerous pegrnatoids and quartz veins both parallel and comformable with the schistosity and marbleized, crystallized limestone bands—conformable again—together with intercalations of muscovite-almandine-quartz schist.

Pegmatoid veins increase towards east and are found in a complex form as pegmatoid masses and enclaves. They pass into layer migmatites in the central parts. This transition is not clear but indefinite and gradual.

In the southern part of the area toward Tozludamları village, the schistosity turns to the east. At the entrance of Kurttutan village, at the beginning of Kasar-Araplı road and around Kıranşeyh in the east, the biotite gneisses are sometimes overlain by muscovite-almandine-quartz schists and banded gneisses. They are also found in the form of intercalations and sometimes within the banded gneisses, particularly near Mestanh and Beynamaz villages, where they are strongly affected by tectonic movements. Taylor and Egger described them as mica schists, which according to them is a normal situation, while the presence of the banded gneisses overlying them should be considered as uncommon. For this reason they reported that an overthrust or a recumbent folding took place in the area. These gneisses are composed of quartz, plagioclase (albite-oligoclase, 5-25 % An), orthoclase, biotite, almandine, kyanite, muscovite and, as accessory minerals, zircon, apatite, rutile, magnetite and rarely tourmaline.

Kyanite is more abundant particularly in the vicinity of Deliler, Kaşıkçı and Mestanlı villages. It is of medium size and pocurs as coarse xenomorphic crystals. These crystals are elongated in the direction of schistosity arid have wavy edges. They contain abundant quartz and some magnetite inclusions. They have a slight poikilitic texture.

Muscovite is rare and occurs in the narrow zones encircling the porphyroblasts of the feldspar. Sericite also occurs as a secondary mineral. Chlorite is found as an alteration mineral.

4. Amphibolites

Amphibolites are seen as small lenses measuring about 1-3 m within the biotite gneisses between the Divanegoban and Kılavuzlar villages and in the southern parts of the Benlieli village. They are blackish in color, schistosity is seen no more and the rock became rather hard and compact, The rock is composed of hornblende-plagioclase (25-40 % An), almandine, quartz and magnetite. Quartz is less abundant and occurs as small xenomorphic crystals. Hornblende shows strong pleochroism, greenish in color. The rock contains numerous magnetite inclusions which are intimately admixed with plagioclases. The texture is diablastic.

Specimens taken from the enclaves of amphibolite bodies show an assemblage of epidote, actinolite, diopside, plagioclase, quartz, magnetite and ilmenite.

5. Layered migmatites

Migmatites crop out in the central part of the mapped area. Their contact with muscovite-quartz schists, pegmatoids and granites is more readily recognizable than the contact between migmatites and biotite gneisses, which is gradual and indeterminable. It is also difficult to distinguish the contact between migmatites and pegmatoids because of numerous large xenoliths in the massive pegmatoids.

Study of the map shows that migmatites contain veins of pegmatoids in the western and central parts, and massive pegmatoids in the eastern part of the area. In many places migmatites are not readily distinguishable from biotite gneisses. Migmatites are composed of rocks with a pegmatitic character and of biotite gneisses. The migmatitic appearance is more evident going from west to east and from south to the central and northern parts of the area.

For these rocks the term «migmatite» is used on the basis of their macroscopic appearance. Pegmatitic parts of the migmatites are leucocratic and form irregular thin bands which follow the schistosity surfaces in a parallel but discontinuous fashion. Because of this appearance these rocks are called «layer migmatites».

Migmatites which occur in the area, correspond to the metatexite group according to the Menhert classification, while according to the Jung-Roques classification they may be considered as homogenous migmatites of an embrechite facies. Migmatites of the «metatexite» group are composed of a *paleosome*—kyanite-almandine-muscovite-biotite gneisses of the studied area—and of a *neosome*, a rock produced by the process of melting and recrystallization, with a pegmatitic, aplitic, or granitic character.

Microscopic examinations have shown that transition from biotite gneisses to layered migmatites is marked by a large growth of the feldspar crystals and an increase in their proportion. The biotite plates become thinner and tend to segregate in a semi-circular fashion in the middle of which an early porphyroblastic development of the feldspar is particularly observed. This gives the rock a somewhat «eyed» appearance.

Going towards the central parts of the area, it may be observed that these «eyes» join one another and the rocks show a more granular texture.

The dominant schistosity of the original rock is always recognized in the layered migmatites. The «paleosome» portion of the layered migmatites is composed of biotite gneiss, while the «neosome» portion contains a pegmatoid (metatect) and a melanosome restite. The mineral content of the rock is as follows: plagioclase, quartz, orthoclase, biotite, muscovite, almandine and some kyanite. Accessory minerals are zircon, apatite, and magnetite.

Pegmatoid of the «neosome» forms the leucosome part of the migmatite. It is composed entirely of feldspar and quartz. Quartz content has a percentage of 30, while that of feldspar is about 65-70. A considerably basic oligoclase (25-30 % An) and andesine form about 90 % of the total feldspar. Potassium-bearing feldspar is only represented by orthoclase which constitutes about 5-10 % of the leucosome, Some muscovite may also be found in the «neosome» part of the migmatite.

The restite generally consists of aggregates of biotite, dark reddish in color. Cleavage planes of the biotite are slightly traceable and the mineral resembles the «meroxene» type containing 25-50 % Fe. In comparison with common biotites, the biotites of this type show less or practically no pleochroism. Some of the biotites, however, exibit normal pleochroism. Biotite is anhedral and commonly occurs as large (1-4 mm) and elongated plates with irregular edges apparently corroded by quartz and feldspar.

Although biotites are marginally chloritized and generally arranged along the direction of schistosity, they display a syndeformative nature. Biotite contains as inclusions abundant zircon and magnetite and occasionally garnet. The texture is heteroblastic.

6. Pegmatoids

Pegmatites are considered as derivatives of initial granitic magmas. They generally occur near granites, both within granites and in the surrounding crystalline rocks. The pegmatites formed through migmatization, anatexis and granitization are called «pseudopegmatites» or «pegmatoids».

The pegmatoids found in the studied area show three different kinds of deposition: as veins, lenses and masses. They developed in three different places in the area:

1. The vein-type pegmatoids are generally found on the basal line of the marble and muscovite-quartz schist bands, extending along the western flank of the Çomaklıdağı anticline; they are conformable and parallel to the axis of the anticline and to the general schistosity of biotite gneisses in the SW-NE direction. Though their thickness differs between 0.20-4.5 m, the average thickness is 1-1.5 m, while the length is between a few decameters and 600-800 m. These vein-type pegmatoids are widespread in a zone extending from Deliler towards Kaşıkçı and Devlethan villages in the north.

2. The widening veins or thin-lensed pegmatoids, occurring unconformably to the general schistosity, are developed in the central part of the Çomaklıdağı anticline, east of Kaşıkçı village, Kadayıfçı Çeşmesi, in the vicinity of Çekirdeksiz, and around Kovancı and Kayranokçular villages. This type of pegmatoids are thicker but their lengths are less.

3. Pegmatoids found as masses are observed in the eastern parts of the Çomaklıdağı anticline. They developed between Kurttutan and Bayramşah villages and at the north of Huriler village, which is situated in the middle part of the area, and on the Atalan Plateau they extend over large areas. The vein type is not observed in this kind of pegmatoids. They are mostly found mixed with the biotite gneisses. Because these rocks are scattered irregularly as large xenolites within the pegmatoid masses, they cannot be mapped in any scale.

Pegmatoids that show thin veins are kaolinized due to alteration. Generally pegmatoids that contain quartz, feldspar, muscovite, and, in lesser amounts, biotite, tourmaline, kyanite, rutile and apatite do not show any zonation.

However, zoned pegmatoids are encountered between Borlu and Gördes. In this locality, towards the marginal sides of the zone, some tourmaline and quartz bands are observed but the central part contains massive, common pegmatite components.

7. Granites

Granites are found in the northern part of the area, around Benlieli, Divaneçoban and Kilavuzlar villages. Their extension is more limited in eomparison with the other rocks encountered in this area. These fine-grained and leucocratic granites showing two-mica calco-alcaline character have definite contacts with biotite gneisses and layered migmatites but they do not show halos of contact metamorphism. Granites with dome structure have generally uplifted the biotite gneisses in the shape of a dome.

The granites, in places partly converted into pegmatitic granites, were exposed to a strong deformation. The granites found near a fountain by the road to Kılavuzlar village have a schistosity in a N-S direction and contain garnets. As we go towards the west, the garnets are seen no more, but a slight chloritization is observed. Granites contain quartz, plagioclase (20-25 % An), orthoclase, biotite, muscovite, garnet, zircon, apatite, monazite, chlorite. The texture is granitic; however, some samples show porphyric and cataclastic textures.

8. Marble bands

Marble bands are found within muscovite-quartz schist intercalations in the biotite gneisses seen on the western flank of the Çomaklıdağı anticline. These perfectly crystallized, hard, conchoidal fractured, dark-gray marbles extend for a few kilometers in a SW-NE direction from Deliler to Kaşıkçı and Sögeler villages; they are seen as a band or a succession of bands 4-5 m wide. South of Deliler village, these bands turn in a SE direction towards Tozludamlar. They are parallel to the general schistosity and structure and lie comformably within the biotite gneisses with a dip of 60°-70°W. These marbles are composed completely of calcite crystals and contain some diopside.

SEDIMENTARY FORMATIONS

9. Mesozoic-Permian crystalline limestones

These formations, composed of a well-crystallized dolomitic limestone, are found in the north of Ragıllar village, which is in the eastern part of the region, jn the vicinity of Kaletepe; they cover an area less than one square kilometer. These crystalline limestones sometimes overlie a breccia or are found directly overlying the banded limestones with a distinct angular unconformity. They are bright gray, white or light brown in color and are sometimes intensively marmorized. They lost their stratified character and are faulted and fractured. Occasionally the presence of supergene phosphate having a few cm thickness is observed. It fills the cavities and small depressions in these limestones. This proves that the amount of phosphorus here is above normal. Local enrichments contaning about 5 % P2O5 are observed in the same limestones occurring in the west of Gördes.

Although no positive age determination can be made, these crystalline limestones show a resemblance to the crystallized limestones in the vicinity of Gördes; thus, keeping in mind the regional geologic situation, a Mesozoic-Permian age can be tentatively attributed to these formations which occupy a restricted area of some 100-150 m in thickness in the studied region.

10. Tertiary

Tertiary is represented in our area by sedimentary series of Neogene age which are of continental and lacustrine character. Neogene sediments are divided into two parts as fluviatile-continental sediments at the bottom and lacustrine sediments at the top. It is possible to divide the lacustrine sediments again into two parts: 1) marl, clayey sandy marl and siltstone and 2) lacustrine limestones.

A. Fluviatile-continental series. — These series are widespread in the eastern part of the studied area. The clastic series surrounding banded gneisses is generally composed of conglomerates with coarse gravels, poorly consolidated sandstones and sandy siltstones. In places, it contains large gneiss blocks (1-3 m in diameter). These formations in some places include also white-colored, slightly kaolinized bands that have a tuffitic and silty appearance.

Though the series is well-bedded in general, the parts with different lithology show lateral transition and irregular bands and lenses. The pebbles are well-sorted. Pebbly conglomerates and sandstones are composed of gneiss elements and quartz fragments. Sandstones are not well-cemented. These sediments of typical clastic facies indicate the presence of a bed of an ancient river. Their thickness is not important near the crystalline massif, but increases going eastwards about 100 m and continues further to the east; outside of our area it reaches some 200-259 m.

Generally the border with gneisses is disconformable. Although the strata are usually horizontal, they have sometimes a dip towards SE. These fluviatile, continental formations are estimated to be of Lower Miocene age. In many places near the crystalline massif, secondary uranium mineralizations are observed.

B. Lacustrine formations. — Lacustrine formations occur around Akçaalan and Yerdere villages, in the eastern part of the studied area; they are represented by a lower series composed of marl greenish in color, clayey sand and siltstone belonging to the Upper Miocene. White lacustrine limestones overlie this series.

1. Marl, clayey sandy marl and mudstones: The decrease of the fluvial activity and the beginning of lacustrine conditions produced marls, greenish in color, clayey and sandy marl, calcareous sandstone, chert and tuffaceous levels. These levels grade into the white lacustrine limestones in the upper parts, where they surround the limestones like a belt; the color of these bands is greenish or bluish-gray. These formations have a thickness of 50 to 100 m and show a regular and horizontal stratification.

2. Lacustrine limestones: Lacustrine limestones, overlying the uppermost Neogene series, are dull in appearance and light-yellowish, white, gray in color, as observed around Ak9aalan and Yerdere villages. In some parts of the limestones silicification, siliceous nodules, oolites and pisolites are encountered. Within the studied area it is 50-80 m in thickness. These lacustrine limestones belong to the Upper Miocene and occur as regular and horizontal beds. Angular disconformity is seen near their contacts with the banded gneisses.

Table-1

Chemical analyses of the samples

Sample no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
SiO_2	72.36	66.92	71.64	58.44	65.36	61.60	68.42	86.20	61.62	69.24	59.64	62.48
Al_2O_3	14.41	17.67	11.88	15.60	23.40	18.48	22.00	6.47	17.80	20.05	15.51	18.51
Fe_2O_3	1.50	1.00	0.70	3.57	0.50	3.00	0.40	0.30	0.90	0.60	3.40	1.45
FeO	1.70	1.25	0.88	5.00	0.80	5.02	0.65	0.55	1.05	0.65	4.05	1.80
MnO	0.10	0.07	0.05	0.16	0.05	0.13	0.04	0.06	0.08	0.07	0.18	0.06
MgO	0.50	1.50	0.95	1.75	0.20	1.65	0.10	0.05	0.40	0.05	1.60	0.48
CaO	0.25	1.15	0.60	1.00	0.49	1.50	0.60	0.23	1.00	0.72	1.10	0.98
Na_2O	0.76	4.40	3.50	3.40	0.73	3.10	4.00	0.23	3.00	3.00	2.30	2.70
K_2O	3.22	2.62	3.87	4.60	2.80	3.67	2.23	1.43	2.70	2.55	4.13	3.10
TiO_2	0.63	0.32	0.20	1.03	0.37	0.99	0.27	0.24	0.25	0.18	0.92	0.44
P_2O_5	0.17	trace	0.34	0.25	trace	0.34	trace	trace	0.17	0.17	trace	0.25
P.F.	2.00	0.39	0.58	1.25	1.27	1.22	0.86	0.75	0.42	0.50	0.72	1.10
H_2O	—	—	—	—	—	—	—	—	—	—	—	—
CO_2	—	—	—	—	—	—	—	—	—	—	—	—
Total:	97.60	97.29	95.19	96.05	95.97	100.70	99.57	96.51	88.89	97.78	93.55	93.35

Sample locations: 1 - Dis-Alm-Mus-Bi gneiss, north of Deliler village; 2 - Granites from Divaneçoban village; 3 - Banded gneiss from Yerdere village; 4 - Layered migmatite from Yeniköy; 5 - Mus-Alm-quartz schist from north of Deliler village; 6 - Dis-Alm-Mus-Bi gneiss from Deliler village; 7 - Granite from Kılavuzlar village; 8 - Mus-Al-quartz schist from Kurttutan village; 9 - Granite, between Divaneçoban-Kılavuzlar villages; 10 - Granite, near Kılavuzlar village; 11 - Layered migmatite from Benlieli village; 12 - Banded gneiss from Beynamaz village.

ROCK CHEMISTRY (PETROCHEMISTRY)

The chemical composition of rocks is important in their classification and in the interpretation of geological events. Petrochemical analyses formed an important part of our studies and also were used to explain various problems of metamorphism, in the classification of rocks and in determining the origin of crystalline schists.

In the laboratories of the M.T.A. Institute rock analyses were carried out in addition to trace analyses of 36 samples for Pb, Cu, Ni, Ti, Zn, Co, Sb, Mo. Four different methods of petrochemical calculations were employed. The results were plotted on graphs and their interpretation was carried out accordingly. For the metamorphic rocks Niggli, Osann, Eskola and H. de la Roche methods were employed.

It can be seen from the Niggli variation parameters diagram (Fig. 1) that the Si value is very high only in the muscovite-quartz schist (sample no. 8) while in all other specimens it is between the values of 223 and 488. Among these the minimum Si amount is found in the layered migmatite specimens no. 11 and 4, then in the granite specimens no. 2, 7, 9, 10, respectively. Kyanite-almandine-muscovite-biotite gneiss (specimen no. 6) falls near the migmatites, while another specimen takes place beyond the granites. On the contrary, banded gneisses fall away from the migmatites and lie near and beyond the granites.

The Al parameter shows a tendency to increase from migmatites to biotite-gneisses, granites, banded gneisses and muscovite quartz schists with some occasional decreases.

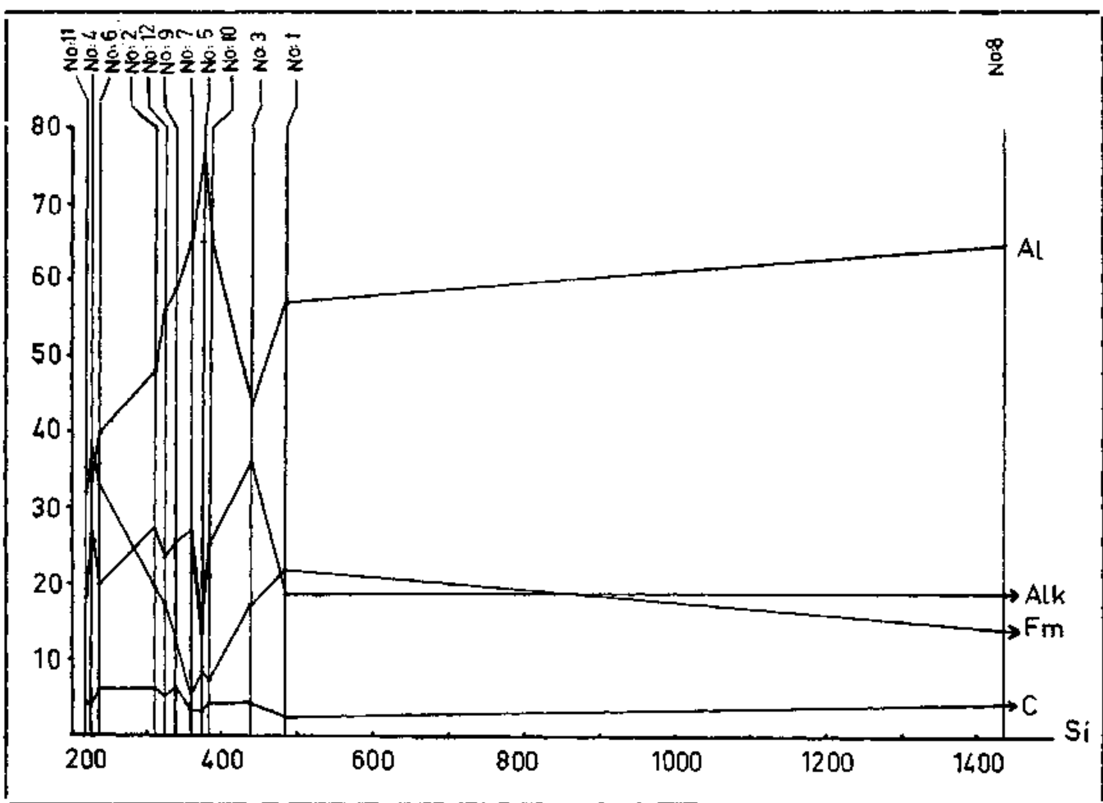


Fig. 1 - Digram of the variation of Niggli parameters.

The Alk parameter decreases inversely in proportion to that of the Al. The decrease is gradual from the migmatites to biotite-gneiss, granite, banded gneiss and muscovite-quartz schist. The Fm parameter shows a slight parallelism to that of Si and Al while the C parameter is parallel to that of alcaline.

K/Mg variation diagram (Fig. 2) shows an increase in the K parameter towards the banded gneiss, biotite gneiss and migmatites from the granite which has the lowest value. As the ratio of Mg is considered, the points representing the specimens of granite, migmatite, biotite gneiss and banded gneiss within the zone bordered with a dotted line, converge and show a similarity from the K/Mg point of view.

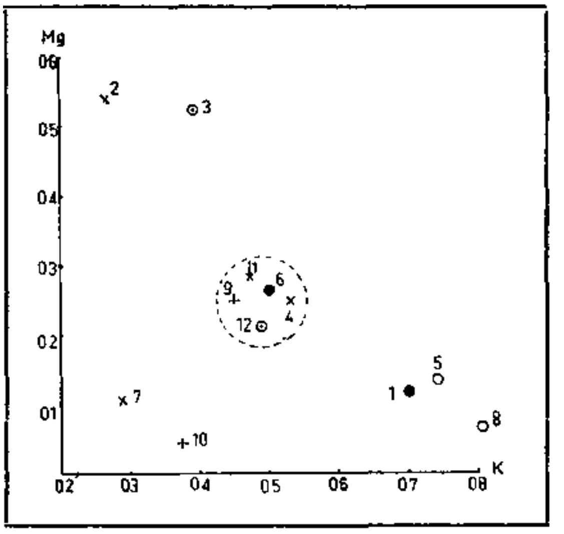


Fig. 2 - Variation diagram of Niggli K/Mg.

+ granite; ● disthene alm. mus. biotite gneiss; × layered migmatite; ⊙ banded gneiss; ○ muscovite-quartz schist.

The weight diagram of K_2O/Na_2O in Fig. 3 has been drawn according to the percentage of the specimens. In the distribution of the points representing the rocks on this diagram, an arrangement according to the enrichment is observed.

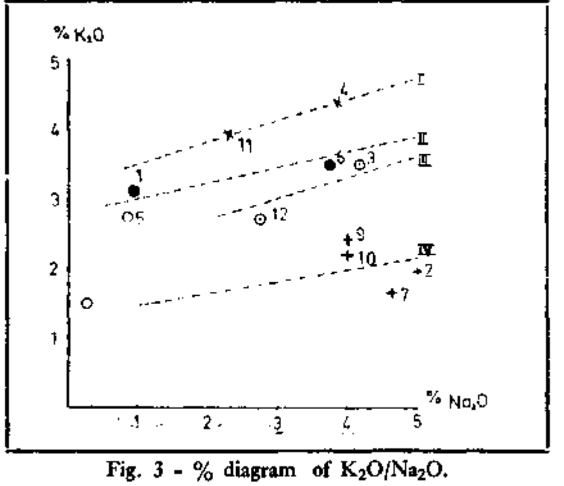


Fig. 3 - % diagram of K_2O/Na_2O.

These points are placed on four lines which are more or less parallel to each other. Line IV is the line showing the lowest K_2O/Na_2O ratio. Also the calco-alcaline granites are present on this line. As we follow Up the lines, we see that the line no. III, consisting of banded gneisses; no. II, consisting of biotitic gneisses; and at the top no. I, consisting of migmatites, show an enrichment from the point of view of K content in the migmatites. The decrease of K content in the calco-alcaline granites is due to the differentiation of this element at the pneumatolytic stage during granitization and accumulation in pegmatoids which are closer to it. Also this phenomenon, including K enrichment during the migmatization stage, is confirmed by the microscopic study and the field observations carried out in the pegmatitic leuchosome in migmatites or K-feldspar blastesis.

As is seen in Fig. 4, among the points representing the rocks on the Osann's diagram, no. 8 and no. 5 muscovite-quartz schists are completely para-, no. 7 and no. 10 granites are para-, and no. 9 and no. 2 are the ortho-para-boundaries. From the banded gneisses specimens (no. 3 and no. 12), biotitic gneisses (no. 6 and no. 1), migmatites (no. 4 and no. 11) occur on the boundaries of the ortho-, para-zone and exactly para-ortho-zones, respectively.

In the C-Al-Alk diagram (Fig. 5) all points are in the para-metamorphic zone. Those lying nearest to the ortho-zone are banded gneiss no. 3, migmatite no. 1 and no. 11, and granite no. 2.

As is seen in the Osann's diagrams that ate Applied just to have an idea about the origins of the rock varieties in the area, the presence of granites and migmatites is normal but the existence of biotite gneisses at this boundary (Fig. 4) contradicts with the field observations. The settlement of banded gneisses (specimen no. 3) at the ortho-zone, no. 2 at para-zone (as seen in Fig. 5) and no. 3 again near to the ortho-zone did not eliminate the doubts on the origin of this type of rock. In the C, Al-Alk Osann's diagram, all points have settled in the para-zone except migmatites and granites that are the closest rocks to the ortho-zone.

When Osann's C, Al-Alk diagram is applied to acidic and neutral rocks the results are good but when it is applied to basic rocks the results are wrong. For instance, when a metamorphic lime-stone is represented in this diagram it witl appear in an area nearest to the C spot, that is, it will take place within the ortho-zone in spite of the fact that it is certainly of a para-origin.

Muscovite-almandine-quartz schists, specimens no. 5 and no. 8, projected on the Eskola's quartz-albite-epidote-almandine subfacies of the greenschist facies (as seen in Fig. 6) take place within alumina-rich clay zone in the ACF diagram and appear in pyrophyllite-muscovite-chloritoid area after metamorphism. The sample no. 8 is at the border of the muscovite-chlorite-almandine ternary diagram and all of the three samples approach towards the muscovite area. Banded gneiss no. 3 is within the muscovite-microcline-biotite area. Its paragenesis is conformable with the microscopic observations but it is distanced from the almandine area. The slight difference may have resulted from the lack of necessary correction in the A parameter of the muscovite.

In the ACF diagram ofthekyanite-almandine-muscovite subfacies of the almandine-amphibolite facies (as seen, in Fig. 7), the biotite gneiss no. 1 is between alumina-rich clay zone and the clay zone with a 35 % carbonate content; the biotite gneiss sample no. 6 is within the marl area containing 35 % carbonate. Migmatite sample no. 11 also takes place in the same zone, with the migmatite sample no. 4 in the marl area. Granites are also shown in the same diagram. The granites are aligned in an order between the clay zone and the graywacke zone.

In the A'KF diagram the biotite gneiss no. 1 gives exactly the same paragenesis as observed under the microscope. Sample no. 6 approaches to almandine and biotite because of its excessive biotite content. Migmatite no. 11 is within the muscovite-biotite-microcline area. Since kyanite (disthene) content decreases because of the decomposition and K-feldspar formation increases in migmatites, it is reasonable to find them at the border of the muscovite-almandine-biotite triangle closer to the microcline area. Thus it is seen that the Eskola diagrams can give information about the types of sediments that originated from the metamorphic rocks and show also which mineral paragenesis resemble in which facies and subfacies due to metamorphism.

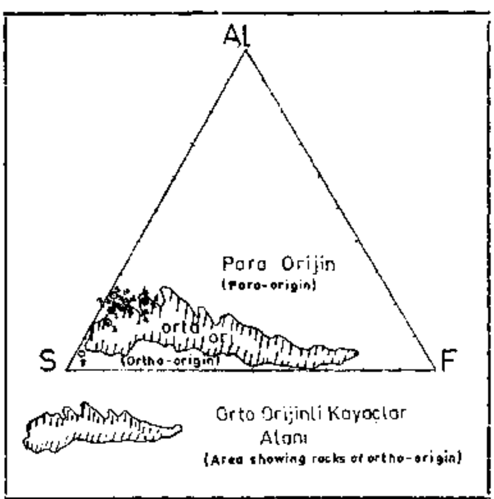


Fig. 4 - Osann's Al-S-F diagram.

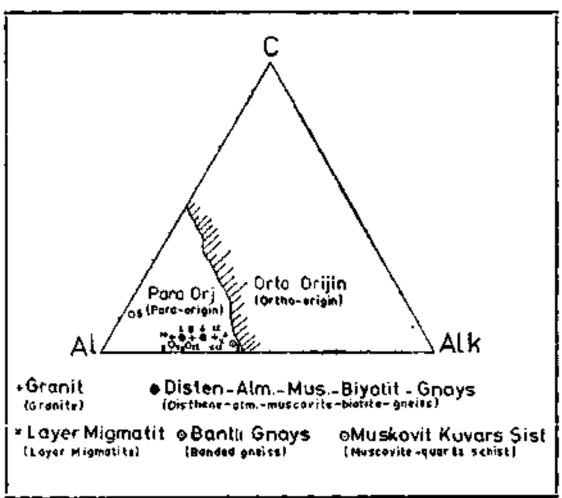


Fig. 5 - Osann's C-Al-Alk diagram.

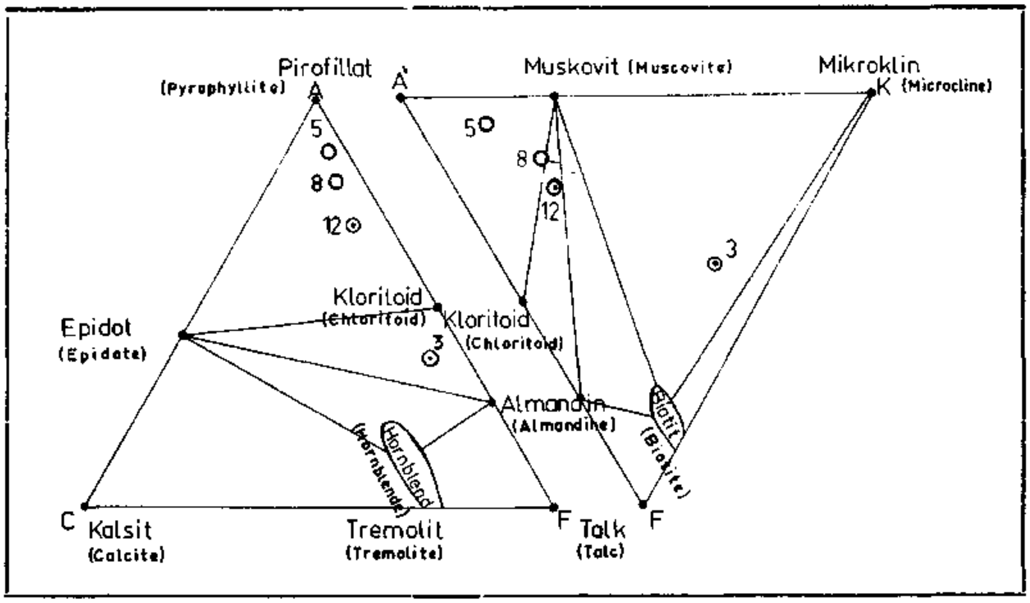


Fig. 6 - Eskola diagrams for the greenschist facies.

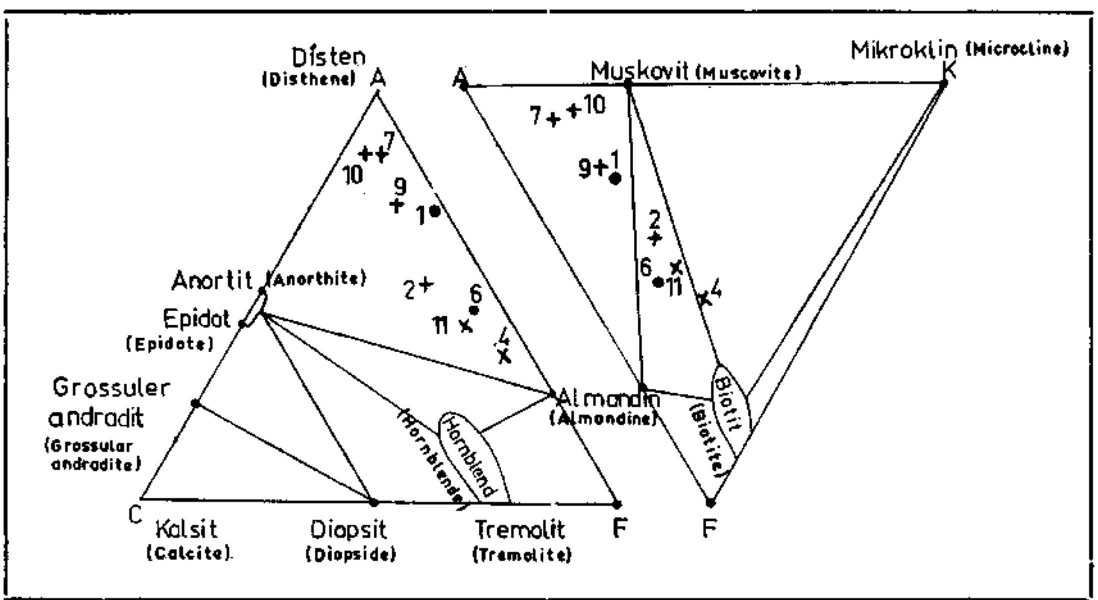


Fig. 7 - Eskola diagrams for the almandine-amphibolite facies.

In the H. de la Roche diagram, given in Fig. 8, three different parameters are represented and each rock sample is marked on the same vertical line twice, as a circle and as a cross. The spots representing the cross-marked samples in the upper right corner of the diagram are divided into two groups. This division is made according to the functions of ferromagnesian and alcaline elements. The upper group includes granites, banded gneisses and muscovite-quartz schists. In this group K enrichment shows an increase from left to right. The closeness of muscovite-quartz schists (samples no. 8 and no. 5) to the quartz point, is the result of their resemblance to meta-quartzites and the K content depends on muscovite. The lower group, rich in ferromagnesians, includes biotite gneisses and migmatites. This can be taken as a chemical evidence to explain the fact that paleosome is a biotite gneiss and the layered migmatites are derived from it.

In the center of the diagram, where the samples are expressed by circles, there are groups made of spot accumulations. Granites and banded gneisses are concentrated here. One biotite gneiss is included into the group while the granite sample no. 2 is excluded because of its difference. (In fact it is necessary to analyze a great deal of samples in order to obtain more sensitive conclusions and make a good interpretation.)

Migmatites and biotite gneisses no. 1 are excluded from this group. It is remarkable that our granite samples diverge from the area fixed for the initial magmatic granites, towards the left and upwards, in spite of the areas where magmatic rocks, shown in the diagram, are present. The calco-alcaline granite should normally move away in the direction of granodiorite.

Studies on trace elements

The presence of some elements in rocks as traces is directly related to their petrogenetic formations. Many trace elements concentrate in secondary minerals, found in lesser amounts in the rocks, or they occur in crystal systems of some minerals, such as hornblende, biotite, muscovite, plagioclase, etc. The rock types of some trace elements and the affinity between them and oligo-elements forming the rocks is closely related to the rock origins and formations.

In the recent years, trace elements were used in the interpretation of many geological problems. For instance they were used succesfully in separation of lacustrine and marine sediments; in determining the origins of serpentines and graphites; in determining the similarity between the origins of rocks formed through metamorphism; in determining the massifs that pegmatite veins belong to.

36 specimens taken from different rocks in the studied area were analysed for 8 elements by the optical spectrographic and colorimetric methods. Those elements are Cu, Ni, Pb, Zn, Ti, Co, Sb, Mo.

Only one pegmatite and one muscovite-quartz schist sample taken from the Deliler area and a cataclastic muscovite-quartz schist and banded gneiss samples taken from the vicinity of Kurttutan contain uranium in trace form. (Pb, Zn contents are also high in these samples.) Cr, V, Be, As, Cd, La could not be seen in the spectrum analyses.

Results of the analyses on the ppm basis are given in Table 2. When they are examined together, it can be seen that Cu, Ni, Pb and Zn contents are almost the same, both in muscovite-quartz schist and banded gneisses, excluding the cataclastic specimens. Muscovite-quartz schists contain more Ti. Likewise, the Cu, Pb and Zn percentages are almost the same in the biotite-gneisses, with only slight differences, but the amount of Ni and Ti increases. Titanium content increases up to 2 % in the amphibolite samples. Compared with the rocks cited above, the Cu content decreases in

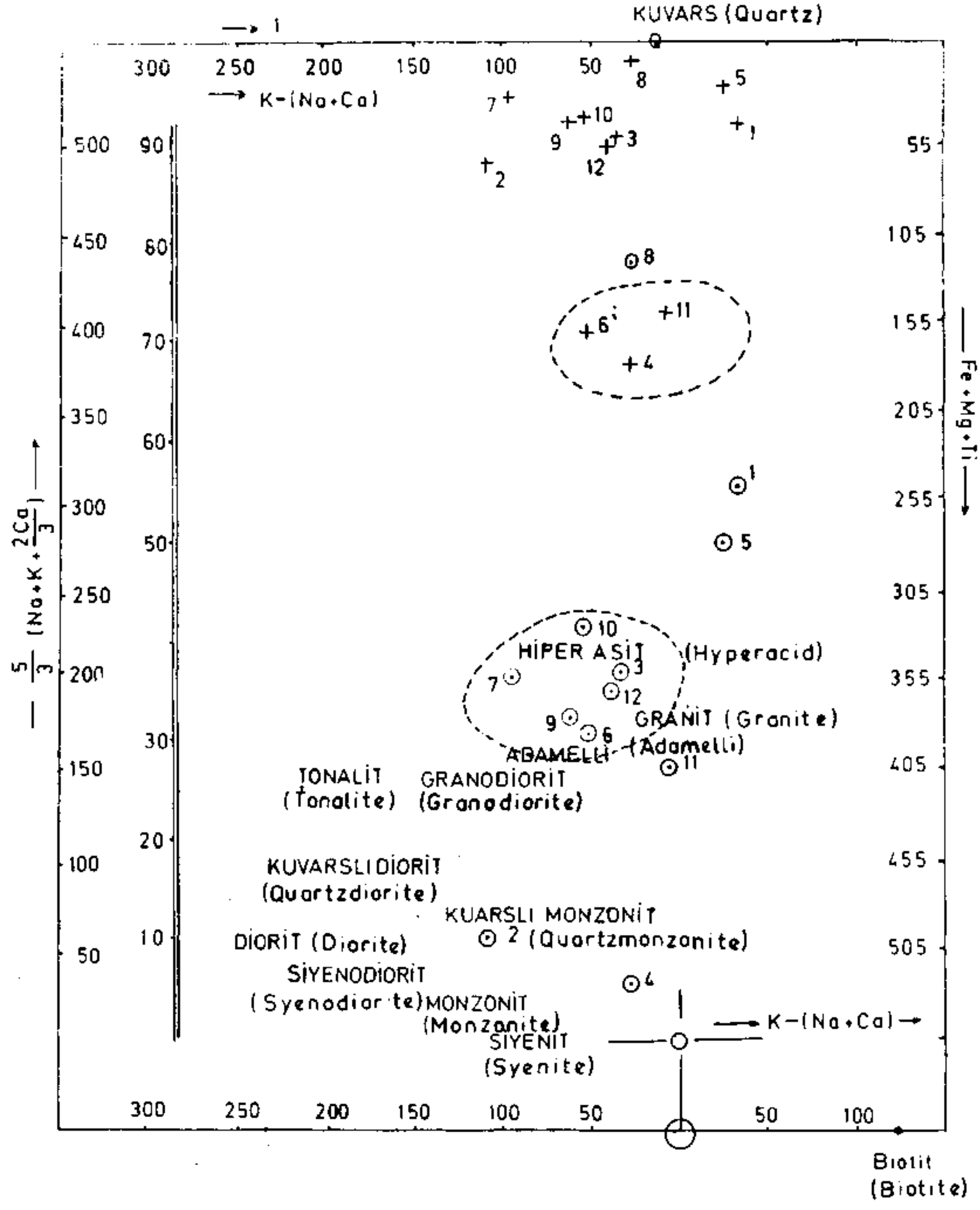


Fig. 8 - Diagram of H. de la Roche.

migmatites, while Ni and Ti content increases; the Pb and Zn contents also show a slight increase. On the other hand, the Cu and Pb contents increase, while Ni and Ti contents decrease in the granites. The same case can be seen in pegmatoids.

Finally the study of the trace elements shows us that muscovite-quartz schists, banded gneisses and biotite gneisses are similar in trace element content; migmatites show a difference and they are partly close to biotite gneisses; granites and pegmatoids are similar to each other, while they differ from other types of rocks. Thus it can be seen that there is a difference between the formations of two groups; namely the muscovite-quartz, banded gneiss and biotite-gneiss on the one hand and the migmatites, granites and pegmatoids on the other hand. The contents of some elements show an increase or decrease by means of «apport-depart» form throughout the metatexis and anatexis phases.

Table - 2

Trace element analyses (in ppm)

Sample	*No.*	*Cu*	*Ni*	*Pb*	*Zn*	*Ti*	*Co*	*Sb*	*Mo*
Muscovite - quartz schist	1	40	18	45	80	3600	10	1	2
	2	90	36	75	160	9400			
Banded gneiss	3	20	28	120	90	200	5	2	3
	4	80	20	75	60	100	10	1	3
	5	980	46	3700	3400	200	15	5	6
	6	110	30	25	160	100	20	2	2
	7	60	16	65	80	100	15	2	2
	8	80	15	75	80	200	10	2	5
Dis. alm. mus. bio. gneiss	9	95	62	100	130	200	5	1	4
	10	50	15	108	120	700	15	1	2
	11	60	45	125	120	640	5	1	3
Amphibolite	12	40	24	100	120	20 000	10	1	2
Layered migmatite	13	85	96	90	250	200	55	1	3
	14	40	72	105	200	850	10	1	3
	15	40	52	135	200	100	10	1	4
	16	40	50	55	170	400	15	1	1
	17	50	44	195	120	400	10	2	2
	18	80	62	84	140	400	10	1	4
	19	50	54	45	140	700	15	2	3
Granite	20	90	15	145	90	40	10	2	2
	21	50	15	108	90	40	10	3	2
	22	50	15	100	80	40	10	1	2
	23	90	30	145	160	40	10	1	2
	24	50	15	150	80	40	10	1	2
	25	550	38	65	120	40	15	2	3
	26	80	15	100	80	40	15	1	2
Pegmatoid	27	60	24	105	160	200	10	2	4
	28	40	16	85	60	40	5	3	2
	29	30	18	65	60	100	10	1	2
	30	50	24	100	40	—	15	1	3
	31	40	15	95	40	—	10	1	3
	32	90	22	95	80	200	5	1	2
	33	70	16	120	60	—	10	1	1
	34	60	26	65	80	400	10	1	2
	35	40	22	100	150	200	20	2	3
Marble	36	40	18	120	40	40	10	3	2

METAMORPHISM-MIGMATIZATION-GRANITIZATION

Metamorphites of the studied area have progressed in metamorphism. They are formed under high pressure, in a state of lower geothermal gradient and show a Barrovian type of metamorphism. According to the Winkler heat-pressure and depth diagram, the greenschist facies takes place between 400-540°C, after the pressure of 3 kbar (from the depth of 10-12 km). Amphibolite facies takes place between 540-680°C at 15 km depth.

Quartz-albite-almandine-muscovite schists (banded gneiss) and muscovite-almandine-quartz schists are represented in the quartz-albite-epidote-almandine subfacies of the greenschist facies. Almandine is first seen in this subfacies and its presence is continuous in the facies representing higher-grade metamorphism. The muscovite-almandine-quartz schists that underlie the banded gneisses, existing in the studied area, were defined as quartzites by the previous researchers. The muscovite amount in these formations increases from north to east. Almandine is found abundantly. The existence of almandine proves the fact that these rocks have been subjected to high pressure and temperature. The original rock is quartzite containing lesser amounts of clay. Albite is seen in banded gneisses. Excessive muscovite is present with smaller amounts of biotite and chlorite. Here iron is found first in the chlorite, and with increasing metamorphism,

Fe, Mg-Al chlorite + quartz——> almandine + Mg chlorite almandine

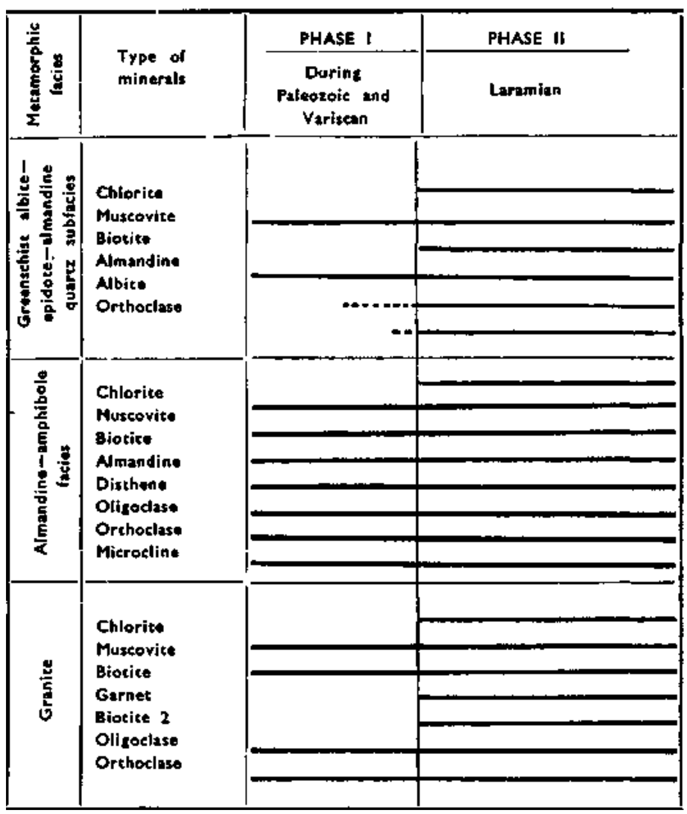
is produced as shown in the reaction.

The paragenesis of banded gneisses included in this facies shows the same paragenesis with the «muscovite + biotite + almandine + quartz + chlorite ip albite ip epidote» subfacies of the Turner-Verhoogen classification, and is produced by high-grade metamorphism of clayey sediments. Muscovite-almandine-quartz schists, however, are produced by the metamorphism of quartzites containing a little clay and they have a similar paragenesis with the «muscovite-chloritoid-epidote» subfacies of the Turner classification.

The biotite-gneisses, that are widespread in our area, are included in the almandine-amphibolite facies. Since these biotite-gneisses contain kyanite (disthene) that indicates high pressure, they are included in the «kyanite-almandine-muscovite» subfacies. If the original rock is a clayey sediment, the most common paragenesis in this subfacies is as follows:

Table - 3

Differences between the metamorphic zones, phases and the time



1) Muscovite+kyanite+almandine+quartz+plagioclase+epidote

2) Muscovite+biotite+kyanite+almandine+quartz+plagioclase+epidote

The biotite gneisses have the same paragenesis with the Barrovian 2 paragenesis derived from the clayey sediments.

The metamorphic rocks of almandine-amphibolite facies are produced at 540-700°C. Minimum 4000 bars of water vapor pressure and 680-690°C temperature is necessary for the complete disintegration and disappearance of muscovite found with biotite and quartz. Pressure, together with the increase of temperature, plays an important role here. If the temperature does not change but the pressure increases, kyanite and sillimanite are formed; if the pressure is low, instead of kyanite, andalusite is produced; and in case of lower pressure, cordierite is formed.

Mehnert (1968) describes migmatite as: (Megascopically composite rock consisting of two or more petrographically different parts, one is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic, or generally plutonitic appearance».

Generally migmatization begins after the sillimanite-almandine-orthoclase subfacies, which is the highest-grade metamorphism of the amphibolite facies. Muscovite, found in the previous facies, decomposes and disappears in this facies. As a result of decomposition due to the increase of temperature, orthoclase and sillimanite are formed and an amount of water is liberated.

1 muscovite + 1 quartz——> 1 orthoclase + 1 sillimanite + H2O

The orthoclase formed by disintegration of mure vite in the kyanite (disthene) zone and the plagioclase and quartz within the gneiss begin to melt under the effect of liberated water and causing a partial anatexis migmatization begins.

The sillimanite-almandine-orthoclase subfacies was not encountered in the studied area. The highest grade of the metamorphism present is, disthene-almandine-muscovite subfacies.

According to Winkler (1967), due to an increase in pressure in the disthene (kyanite) subfacies, a higher temperature is obtained in some parts, and thus migmatites can be formed. According to the kyanite-sillimanite stability phase curve found by Althaus (1967), by the increase of pressure while the kyanite is kept, the temperature increases and the parts of metamorphic rocks in the kyanite subfacies isograde, which are subjected to high temperature, can be easily migmatized.

The layered migmatites existing in the area have been formed by partial anatexis of the kyanite-almandine-muscovite-biotite gneiss. They are more distinct in the central and northeastern parts of the area and they locally gain an agmatitic and nebulitic appearance.

In the regions of high-grade metamorphism, by the beginning of anatexis, the amount of solution and consequently the amount of liberated water extends and the pressure in the fluid phase also increases. Generally, the high-grade metamorphism regions, being at the same time orogenic regions, there is a close relationship between metamorphism and orogenesis.

By the effect of the pressure that the fluid and solution phase exerts outward and oriented pressure due to orogenic events, the anetectic solution ascends upwards. This ascension is generally dome-shaped and according to the degree of ascension it can form contacts with the overlying metamorphic schist series in the area between the amphibolite facies of the higher-grade metamorphites and even in the subfacies of the greenschist facies. In case of an excessive increase in pressure, the anatectic solution in granite composition behaves like an intrusive granite and it can be injected upwards by ascending.

This kind of ascension is present in the studied area and its migmatitic front is formed at the contact of layered migmatites with the gneisses in the disthene-almandine-muscovite-biotite subfacies. Later on the anatectic-granitic solution, found in the deeper levels, produced granites with two micas and pegmatoids existing in central parts during its ascension.

It is impossible to accept the suggestion that the enormous granitic complexes surrounded by metamorphites, as seen in many parts of the world, are formed by the fractional crystallization of a gabbroic magma. For this reason some hypotheses regarding granitization were advanced by several researchers.

Recent experiments carried out on the rocks that were transformed into gneisses from clays, clayey schists and graywackes by the metamorphism have established that granitic, granodioritic and sometimes tonalitic magmas are formed by the anatexis processes of these gneisses.

At 800°C the anatectic magma of granitic or granodioritic composition either cools down and crystallizes in the deeper levels where it has been formed, or becomes intrusive by ascending through metamorphic series. These granites form a distinct contact with the metamorphic rocks they touch. However, according to the pressure and temperature conditions of the metamorphic environment in which they are embodied, or according to the degree of ascension, they either show many signs of contact metamorphism or none at all. This situation is observed also in the granites with two micas occurring in the studied area.

Pegmatoids

The pegmatoids existing in the area are formed by injection, by the decrease of temperature and pressure due to the rise of anatectic magma, formed as a result of anatexis, and by the excessive volatile elements that are the result of the crystallization of granites which caused the magma to be more viscous in the amphibolite schists of the kyanite-almandine-muscovite-biotite gneiss subfacies.

These pegmatoids, showing vein- and massive-type bedding, are poor in mineral paragenesis. Generally they contain micr6cline, orthoclase, quartz, muscovite and tourmaline. They also contain some biotite; in some places kyanite and rutile as metamorphic minerals; and zircon, monazite, apatite and fluorite as accesssory minerals. For this reason they show resemblance to the mineral contents of wall rocks. Generally they are not zoned, except in one place around Atalan Plateau, where a K-feldspar zone is seen outside, and a quartz zone inside.

According to Ş. Birand (1953), two beryl crystals were found in these pegmatoids; however, no beryl was encountered during several prospection studies made in this locality. Trace element analyses have been carried out on the specimens taken from these pegmatoids. Spectral analyses made on a rutile crystal revealed 0.10 %-Ta_2O_5 and 0.24 % Ni_2O_5, but Sn was not observed. These percentages are too low for a rutile crystal coming from a plutonic pegmatite. In addition, the trace elements are concentrated in the mica flakes; a number of muscovite specimens have been analyzed, but Be, Nb, Ta, Mo and Sn have not been found even in little amounts. This situation comprises another clue that the pegmatoids present in the area are of metamorphic origin.

Since there are no plutonic magmatites in the vicinity, the mineral contents of pegmatoids being relatively the same as the wall rocks, their systematic distribution and their mineral paragenesis being also very simple; and the content of trace elements compared with the content of pegmatites that are the result of plutonic differentiation, the pegmatoids of the area are called «pseudo-pegmatite» or «migmatite pegmatoid» or pegmatoid which is formed by the injection of pegmatitic solutions, separated from anatectic magma which has a granite composition. The anatectic magma has been formed as a result of ultrametamorphism atid anatexis.

GEOLOGIC INTERPRETATIONS

The metamorphites present in our area show inner metamorphic belt characteristics and they are para-metamorphic rocks derived from sediments. The criteria proving that these are para-origined metamorphites is as follows:

1. In the western parts of the studied area, near Deliler and Sögeler villages, the metamorphic limestone beds are parallel and conformable with the general stratification and structure and they occur near the muscovite-quartz schist zone on the upper parts of the schists displaying an amphibolite facies.

2. These marble layers have regular contacts with schists. They are dark gray in color and contain small amounts of diopside.

3. Quartz found in the biotite gneisses and muscovite-quartz schists are generally aggregates formed by smaller crystals.

4. Amphibolites containing hornblende, actinolite and rich in calcium, do not form regular series but appear as lenses and small pockets.

5. Most of the points representing rock samples of the studied area shown in the petrochemical triangle diagram of Osann took place in the para-metamorphic area.

6. In the trace element analyses, excluding the layer migmatites, trace elements do not show great variations.

Para-metamorphic rocks of the studied area were formed by the metamorphism of the graywacke-type lithological units and of the shale and clayey pelitic sediments which were deposited in a pre-Paleozoic geosyncline within the region where the present Menderes massif is situated now.

Metamorphic facies are also closely related to the geological age. Generally, regional metamorphism occurring under low and medium pressures can be encountered in all periods from Precambrian to Mesozoic. But the high pressure in kyanite and similar sub-facies—that is the regional metamorphism in great depths—commonly took place in Paleozoic and older ages (Miyashiro, 1961).

Granites and migmatites, accepted as the oldest rocks of the studied area, are pelitic and graywacke-type sediments that were deposited on a sialic basement in a pre-Paleozoic geosyncline. They were probably formed as follows:

In Precambrian the thickness of the deposited sediments increased and with the excessive temperature of about 200°C the diagenesis began. Later on, during continuous sedimentation, the temperature and pressure were also continuously augmented; between 200°-400°C a zeolitic facies was formed. In low pressure of 3 kbar or in 8-10-km depth, prehnite-laumontite-quartz; and in deeper parts, at high pressure, lawsonite-albite facies was developed. The present-day knowledge does not enable us to determine the subfacies isograde in which this metamorphic period had ceased. It is also necessary to draw attention to the probable continuation of metamorphism by the new sediments besides a discontinuation.

However, up to date, there has not been any detailed observations that should confirm or contradict these suggestions. As the deposition continued, the thickness of sediments became 20-25 km, the pressure reached up to 7-8 kbar, and 54G°-680°C, respectively. According to these conditions, the lowermost greenschist facies was probably transformed into an almandine-amphibolite facies, and the zeolitic facies, overlying it, turned into greenschist facies. Then zeolitic facies developed in the uppermost younger sediments.

With the increase of temperature up to 700°-720°C, partial fusion (anatexis) began in the lowermost gneisses of the kyanite-almandine-muscovite-biotite subfacies. This process developed as follows:

First, the growth of blastic feldspar (meta-blastesis) took place. Then, by partial fusion, leucocratic metatect was separated from the restites (metatexis). Following that, restites were mixed with the melted material and finally nebulitic medium (diatexis) has developed. By the increase of temperature of up to 800°C, 80 % of the original rock was melted. This percentage reaches up to 90%, when the rock is graywacke (Scheumann, 1973; Didier & Roques, 1960).

During this phase, restites that were in a solid state in the solution also separated. Thus, a palingene anatectic magma with a homogenous granitic composition originated. During the Variscan orogenesis phase, this magma reached up to the biotite-gneiss level. During the rise of palingene magma, the liquefaction of gases was reduced due to the decrease of pressure. Therefore the amount of gases and vapor and the pressure increased and thus the magma became more viscous. This higher pressure caused the formation of migmatitic pegmatoids which occur as a mass containing biotite gneiss and migmatitic inclusions in the core of the kyanite-biotite-gneisses. But the migmatitic pegmatoids are in the form of veins in the outer parts of the same rocks.

The original material of the area consisting of granites and migmatites was deposited in Precambrian; kyanite-almandine-muscovite-biotite gneiss were formed in Cambrian; and the banded gneiss and muscovite-quartz schist originated in Cambrian-Silurian. The metamorphism of these rocks developed in the greenschist and garnet-amphibolite facies, respectively. Thus the migmatization process had been completed, at the latest, in Hercynian. Then palingenesis occurred. The deposition of calco-alcaline granites with two micas took places during the Variscan orogenic phase. These granites are dome-shaped and generally have conformable contacts with the overlying rocks. Their localization is syntectonic. A certain amount of solution found in migmatites, formed by partial fusion resulting from the anatexis process, moves (about a few centimeters or meters) as pegmatitic mobilizates in this phase, including water vapor and volatile elements. Migmatites increase in volume and move upwards due to a local pneumatogenic phase.

In the migmatites of the studied area a polymigmatization occurred, caused especially by the appearance of migmatite pegmatoids. Thus, migmatites became dome-shaped and separated by stretching the biotite-gneisses from the muscovite-quartz schists which represent the overlying strata. Migmatites in the central part took a new structural form of the biotite-gneisses and muscovite-quartz schist, dipping again in an E-W direction.

Granites observed in the studied area are intrusive in character. Contacts with the adjacent rocks are distinct, but there are not any thermal metamorphism halos at the contacts. This situation is the result of the intrusion of anatectic magma; having a temperature of about 800°C it penetrated into the amphibolite schist facies of deeper layers, instead of rising upwards. Thus this process is due to the minor difference in temperature between the magma and the amphibolite schists. Study of some thin sections revealed that these calco-alcaline granites with two micas show a porphyritic texture. This indicates a rapid cooling. In the K-feldspars at least a slight perthitization and myrmekitization is seen; and in the plagioclases sometimes a zoned structure can be observed. This distinct character of intrusive granites, that crystallized from a magma, occurs as metasomatic granitization by ion transformation in solid form in the granites of the area. Although the ratio of the long edges of apatite and zircon crystals to the short edges is connected with the granitization type, this criteria is not definite. But it is an important point of view. The ratio of elongation of apatite crystals in the plutonic granites is 5/1; in the palingene granites it is 2-3/1; and in the pegmatoid migmatites the crystals are almost xenomorphic in shape. The ratio of elongation in the zircon crystals is 3-2/1 in the granites which crystallized from plutonic magma. This ratio is about 2/1 or even 1.5/1 in the granites of sedimentary origin. Though the length/width ratios of the metamorphites and granites having sedimentary origin in the studied area were riot measured and counted statistically, the microscope analyses show that both apatite and zircon crystals have nearly the same lengths as widths; that is the ratio in question is very small.

During the development of the initial metamorphism, observed in our area, metamorphites acquired a schistosity of a NNE-SSW direction. The rocks of this area, affected by the Alpine orogenesis, were exposed to a second metamorphism. However, this is a retrograde metamorphism.

The rocks observed in our area belong to a Laramian phase of the Alpine orogenesis. They were affected by a thrust coming from the south. Under the effect of this thrust a second schistosity (S_2) was formed, which is very apparent in the banded gneisses, while towards the eastern limit of the granites it can be clearly but locally observed. This schistosity, having a strike in an almost N-S direction, makes an angle about 15°-25° with the S1. (İzdar, 1969, accepts that the Bozdağ overthrust in the Ödemiş district was produced by a force coming from a SE direction during the Laramian phase.)

Because of their strong schistosity the granites of the area acquired a granitic gneiss form on their eastern border, near the Kılavuzlarköyü fountain, in a zone about 5-6 m wide. They contain abundant autometamorphic garnet crystals. These crystals must have been deformed if they had been originated before the Alpine orogenesis. These garnet crystals having regular crystal shapes are post-deformative. Granite, showing a granite-gneiss appearance, which can be seen in a narrow zone near the Kılavuzlar Köyü fountain, acquired its schistosity under the effects of the Laramian phase. Under the effect of this second metamorphism, the presence of biotite in the banded gneisses, a neoformative biotite and chlorite appeared in the western part of this granitic zone, which indicates that a regressive metamorphism took place here. All varieties ofthe rocks found in the area were metamorphosed by the effect ofthe Alpine orogenesis. Mica flakes in the migmatites and kyanite-biotite gneisses display irregular ruptures and breaks; feldspars and quartz always show undulatory extinction. In places, cataclasis can be observed. The same cataclastic texture is encountered also in the granites. Excessive amount of quartz in the muscovite-quartz schists indicates to a strong deformation. Cataclastic texture developed especially in the east, where banded gneisses are abundant.

This cataclastic texture is a general feature of the banded gneisses, and in some cases it shows a similarity to fluidal texture. Due to this deformation, muscovite crystals concentrate in the banded gneisses and give a banded appearance to the rock. In rare cases neoformative biotite along with a certain degree of albitization can be observed. In addition, development of K-feldspars is also encountered, giving the rock a typical banded appearance and a slightly augen structure. The banded gneisses that show the beginning of an augen structure reached the stage of migmatization by blastesis during early metamorphism. However, it is possible that following the Alpine orogenic movements these gneisses might have acquired a cataclastic structure and probably were influenced by a regressive metamorphism. It is also possible to think that the Alpine deformation and the ensuing cataclasis have brought about the banded texture of the muscovite-almandine-quartz schists and the growth of feldspars. The latter suggestion is more suitable to our field and microscopic observations. According to Egger (1960), these gneisses are of an ortho-origin. He suggests also that an overthrust mirks the contact between the gneisses and the pegmatoids and migmatites, the gneisses being thrusted over the mica schists. Taylor (1962) suggests, however, that these gneisses and mica schists form an upthrust near Mestanlı village. We think that these researchers accepted the biotite-gneisses rich in kyanite as mica schists. The biotite-gneisses around Mestanh Dere have been uplifted by a reverse fault and in the vicinity of Kınık these beds have been thrusted over the banded gneisses. The fact that the rocks overlying the banded gneisses represent a lower grade of metamorphism (mica schists), and furthermore the fact that the banded gneisses overlie the biotite gneisses containing kyanite along the fault line, have led the previous researchers to point out to the possibility that there may have been an overthrust or an upthrust relationship between these two types of rock. We think that there has been a K-concentration in the environment, due to pegmatoids that have been formed during the Variscan orogenic phase. The muscovite-almandine-quartz schists were displaced and fractured by swelling and by the development of migmatization. Thus, these cracks and gaps enabled the circulation of pneumatolitic volatile elements. The tourmalines, seen in pegmatoids, occur also as large crystals in banded gneisses.

In general, there are many examples regarding the beginning of granitization by metasomatic process which is the result of the influence of K-mobilizates on quartzites and the existence of pegmatoids (Quirke & Collins, 1930). There is a similar K-addition to the muscovite-quartz schists of the area from the pegmatoids of the west; the feldspatization processes began within these schists. This addition took place in the Variscan and probably continued till the Laramian phase and the growth of feldspar developed. Scotford (1969) accepted also that the augen gneisses occurring in the southern parts of the Menderes massif originated in the greenschists facies by means of K-metasomatism. During Laramian phase, forces coming from the south affected a zone, 3-5 km in width, in the eastern part of the area, by the K-metasomatism process. The muscovite-quartz schists were deformed and acquired a cataclastic texture; the muscovites have concentrated and oriented, giving a banded appearance to the rock. It is known that the dynamometamorphism easily dislocates the mobile elements in the rock. Thus, it is evident that ion transformation is speeded up in such rocks by friction, cracking and smashing. This process increased the metasomatic activity. Previous researchers did not mention any proofs to show that banded gneisses are of an ortho-origin.

Dora (1969) and Öztunalı (1967), who studied the metamorphites of Simav and Eğrigöz occurring in the northern pdrts of the Gördes region, suggested that the migmatization and granitization of the area are due to an early Alpine orogenesis. But the following reasons contradict their suggestion:

Dora (1969) declared in his studies about the granite massif of Karakoca (Eğrigöz) that the origin of anatectic granite is autochthonous *(in situ).* The anatectic granite, shown as biotite granite on the geologic map, has clear contacts with the chlorite schists and limestones in the eastern part of the area. In that case, the granite that comes into contact with these rocks of low metamorphic grade should rise upward. Furthermore, since such an anatexis process with the given isograd is not possible under the chlorite schists, the anatexis should have occurred much earlier; the overlying strata should be eroded; the greenschists should be deposited over these rocks; and the whole should be metamorphosed again in the greenschist facies. As the beginning of mica schist series are accepted as Silurian (İzdar, 1969), the anatexis and migmatization process should have taken place much earlier than the Alpine phase. Furthermore, the porphyric texture, obtained in the eastern and western borders of the same biotite-granite, is a proof to the displacement of anatectic solution to a colder environment; thus marginal zones crystallized rapidly. There is no gradual transition of granites into gneisses here. There is no mention of the augen gneisses of Kireçdere, in the two-mica gneiss area, shown arqund Dolaylı village, which is in the NE of the area situated in the Koca9ay Valley. According to the new concept these augen gneisses should be included in the migmatite group. The feldspar blasthesis observed in these augen gneisses is well developed and in many places the pegmatoid mobilizates are divided as thin bantis.

Chlorite schists are in contact with these augen gneisses where blasthesis—which is the beginning of an anatectic phase—was developed. Since the granites are old in origin, the blasthesis, beginning of anatexis, should also have occurred before the sedimentation of the original material of the chlorite schists. The granite-gneisses are in contact with the chlorite schists on the western side of the Koca9ay Valley, which is a depression and a fault zone. It is rather difficult to explain how these granite gneisses, accepted as migmatites, formed contacts as *in situ* during the early Alpine phase. Furthermore, it is probable that the granite-gneisses , found along the Kocaçay Valley, have been formed during the Alpine erogenic phase by forces coming from the south with a resulting schistosity of these rocks, as is the case of the granite-gneisses observed in the vicinity of Gordes-Kilavuzlar.

The local and regional data, supporting the theory that the anatectic and granitization processes took place in the studied area before the Alpine phase are as follows:

1. The Gördes migmatite region has the characteristics of an inner metamorphic belt. The rocks are generally of para-origin in this type of metamorphic complex where palingenetic granite intrusions are present.

2. The rocks of the almandine-amphibolite facies, recrystallized in great depths where high-pressure index minerals are found, are generally of Paleozoic or older ages (Miyashiro, 1961). The kyanite-almandine-muscovite-biotite gneisses, found in the studied area, carry these properties.

3. The metamorphic rocks of the area are included in the category of rocks of high-grade metamorphism. These are of the quartz-albite-epidote-almandine subfacies of the greenschist facies and of the kyanite-almandine subfacies of the almandine-amphibolite facies. The rocks of lower metamorphism, which should have been present in the upper levels, have been removed by erosion. Among the metamorphic rocks of the area those showing the lowest degree of metamorphism are found in the outer zone and show a concentric structure. Banded gneisses, muscovite-almandine, quartz schist, kyanite-almandine-muscovite-biotite gneiss, layered migmatites, pegmatoids and granites take place towards the inner parts. This structure is observed generally in the Paleozoic and older migmatitic complexes. (As seen in the metamorphic complexes of Highlands, Scotland; Norway; Appalachians; Pyrenees; Montagne Noire, France; Bohemia and Black Forest.)

4. The age determination by total lead isotope method applied by G. Durand (1962) to the pitchblende samples taken from the uraniferous pegmatoid formations in the southern part of the Menderes massif, in the vicinity of Dikmen village (Muğla, Milas), has shown 268 + 60 million years. The pegmatoids found in the Gördes metamorphic complex caused the formation of secondary uranium mineralizations in the south of our area. These pegmatoids are considered to be uraniferous and resemble those found in the vicinity of Dikmen village and were probably formed in the same epoch. This age of 268 + 60 million years is synchronous with the Variscan orogeny phase.

5. According to Brinkmann (1967), the crystallization of the Menderes massif has ended during the Liassic as the main phase. The Upper Cretaceous limestones in the neighborhood of Milas-Muğla overlie the marble schists of the Menderes massif with a slight disconformity. Here, marble gravels and phyllite fragments are observed in the basal conglomerates. M. Akartuna (1962) has observed the same situation around Izmir. In that case, according to the presence of the unmetamorphosed phyllites at the beginning of Upper Cretaceous, the metamorphism of mica schists and nucleus augen gneisses reach much older ages.

The crystallization of the Gördes metamorphic complex began in the Precambrian and continued during the Paleozoic; the anatexis and migmatization took place, at the latest, during the Hercynian. The palingenetic granitic increase and the migmatitic swelling occurred in the Variscan phase.

The Variscan folding process in Anatolia started at the beginning of Carboniferous and ended during the transition period from Permian to Triassic. The Tethys sea originated as the result of the transgressions coming from the east. The Permian-Mesozoic crystalline limestones of this area have been deposited during this period. Later on, at the beginning of Triassic, the central part of the lithologic sequence—which was probably much older—emerged above sea level and, thus, a gap took place in the stratigraphic column.

During the Upper Cretaceous the massif was again partially submerged by the sea. In the Tertiary period, due to the Alpine orogenic movements, the complex gradually emerged and the low-grade metamorphites, occurring in the upper parts of the massif in the developing lacustrine basins, eroded forming the sediments that were deposited in these basins. Finally, after the Miocene epoch, the massif had totally emerged, which contributed to the development of the continental Neogene formations in this area, while the uplifting of the metamorphic complex continued.

The lacustrine Neogene sediments, observed between the Gördes-Deliler and the Araplı-Kiranseyh villages, give a definite proof of the uplifting processes in the central part of this area. Depression basins were formed in the Tertiary period, during the Alpine, Savian and Rhodanian phases; Demirci Çayı is bordering the eastern and Gördes Çayı the western parts of the area. The formation of the Gediz graben in the south and the Küçük Menderes depression basin took place probably during the same phase.

The Gördes metamorphic complex is still rising. Continuation of a regional uplifting of the area, which is bordered by the Simav-Sındırgı graben in the north, and by the Gediz graben in the south, is confirmed by frequent earthquakes and the presence of abundant hot-water springs in the neighborhood of Gediz, Simav, Demirci, Gördes, Salihli and Alaşehir.

CONCLUSION

According to the study, based on the data obtained by the field, microscope and laboratory observations, it may be concluded that the Gördes metamorphic complex has been deposited on the sialic basement of a geosyncline that existed in the Precambrian time. The sediments that were formed by the deposition of clayey pelitic material and the graywackes have been metamorphosed and recrystallized at great depths under high temperatures and great pressures. The metamorphism and recrystallization processes have started at the end of Precambrian and the beginning of Paleozoic and continued during the entire Paleozoic era. The migmatization and anatexis were formed during the Hercynian, at the latest; uplifting of the palingenetic granites took place during the Variscan orogenic phase.

Later on the doming of the complex began, and during the Laramian phase of the Alpine orogenesis a second metamorphism took place. As a result of this diaphthoretic metamorphism and deformations, a local schistosity has been developed in two-mica calco-alcaline granites, and post-deformative garnet crystals have been formed. The eastern part of the area, where the banded gneisses occur, was affected by the forces coming from the south, and the muscovite-almandine-quartz schists that were subjected to the K-metasomatism processes by the introduction of pegmatoids, were deformed and this cataclastic structure has given a banded appearance to the gneisses.

The continuously rising massif has emerged from the sea at the beginning of Triassic, but during the Upper Cretaceous it had been again partly subjected to transgression. Following this period, the massif was again uplifted and the Neogene lacustrine sediments have been deposited. Today this metamorphic complex is still rising.

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P L A T E S

PLATE - I

Photo 1 - S1 and S_2 schistosity orientations of the muscbvite flakes within the banded gneisses and a tourmaline crystal L.N. X 125.

Photo 2 - Disthene crystals in biotite gneisses. L.N. x 125.

PLATE - II

Photo 1 - Rotation of syndeformative garnet crystal in biotite gneisses. L.N. x 125.

Photo 2 - Rutile (upper right corner) and almandine crystals in biotite gneisses. L.N. x 125.

PLATE - III

Photo 1 - Pegmatoid leucosome (light-colored, feldspar and quartz) and biotite restites in metatexis of the layered migmatite sample. L.N. x 125.

Photo 2 - Pre-deformative biotite flakes in deformed migmatite sample and in the center feldspar blasts having an augen appearance. L.N. x 125.

PLATE - IV

Photo 1 - Zoned plagioclase (at the right) in calco-alkaline granite sample, in the center orthoclase and quartz crystals. L.P. x 125.

Photo 2 - Graphic texture in a pegmatoid sample. L.P. X 400.

PLATE - V

Photo 1 - Pegmatoid metatect in neosome and a light-colored leucosome together with the biotite restites seen as black spots in a layered migmatite sample.

Photo 2 - Oriented migmatite sample showing ptygmatic folds.

PLATE - VI

Photo 1 - Migmatite-granite contact. Migmatite enclaves are seen within granite (at the right). The emplacement of granite is post-migmatitic.

Photo 2 - Granite-migmatite contact; it is distinct and is vertical to the schistosity.

PLATE - VII

Photo 1 - Muscovite bands and tourmaline crystals in banded gneisses.

Photo 2 - A paleosome (dark-colored part) and a neosome (in the form of bands of light-colored pegmatoid mobilizats) are seen in a layered migmatite sample.

PLATE - VIII

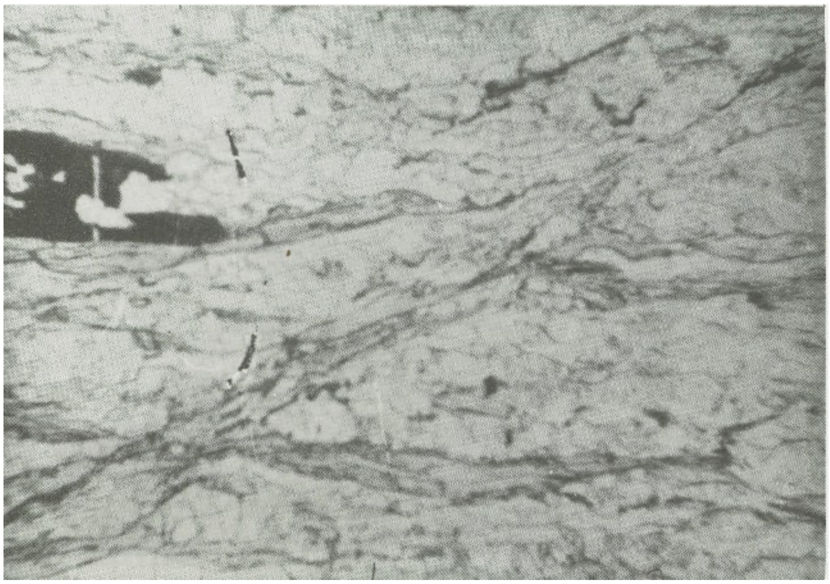
Photo 1 - The contact between a migmatite (with an agmatitic structure) and a pegmatoid.

Photo 2 - The leucocratic metatect in migmatites from the vicinity of Benlieli village.

PLATE - IX

Photo 1 - The pegmatoid injected into migmatite and its contact.

Photo 2 - The dome-shaped granite found in the biotite gneisses near Kılavuzlar village.



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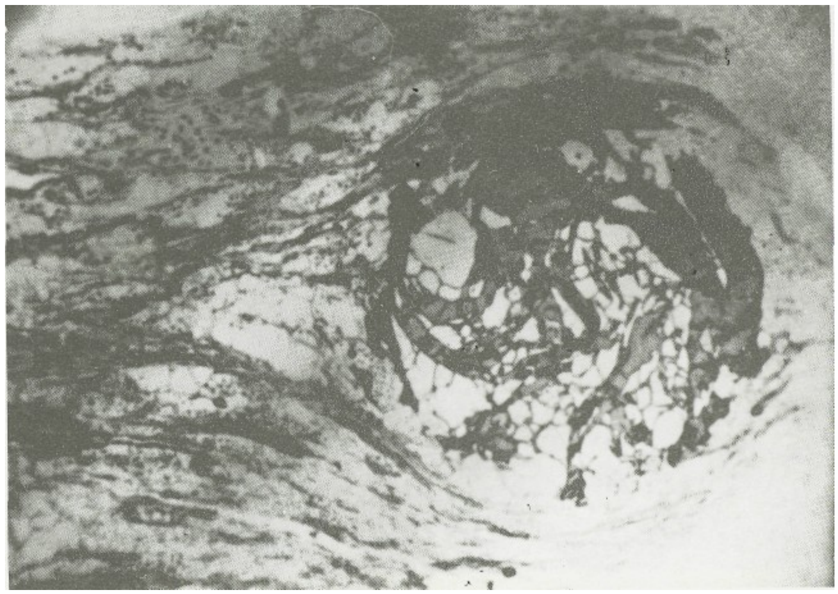

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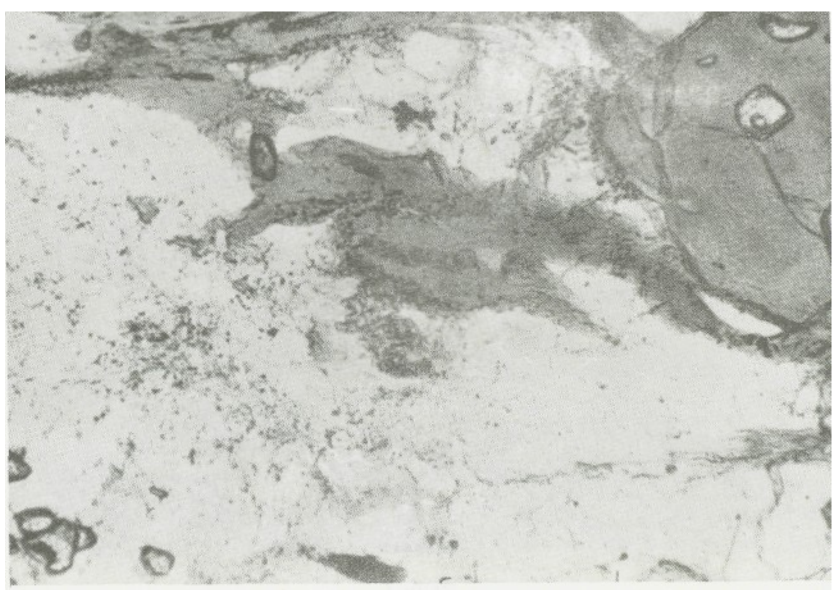

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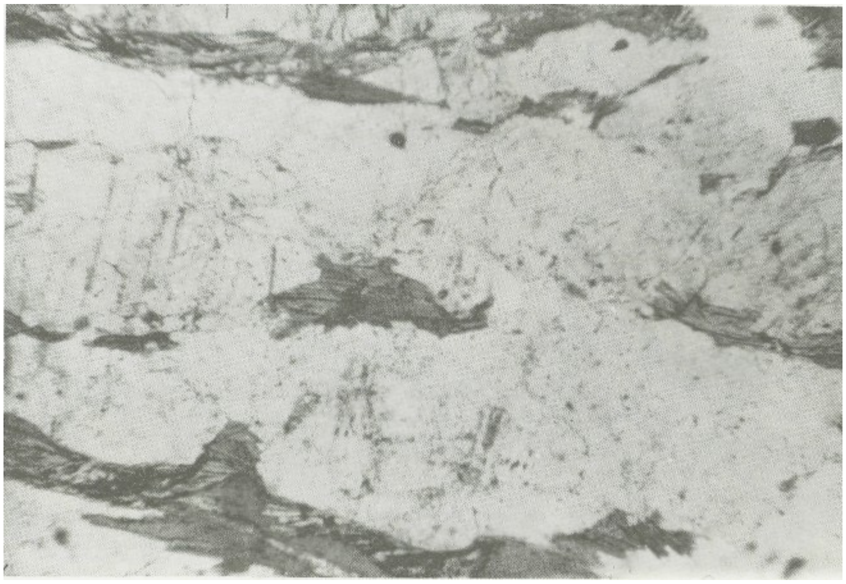

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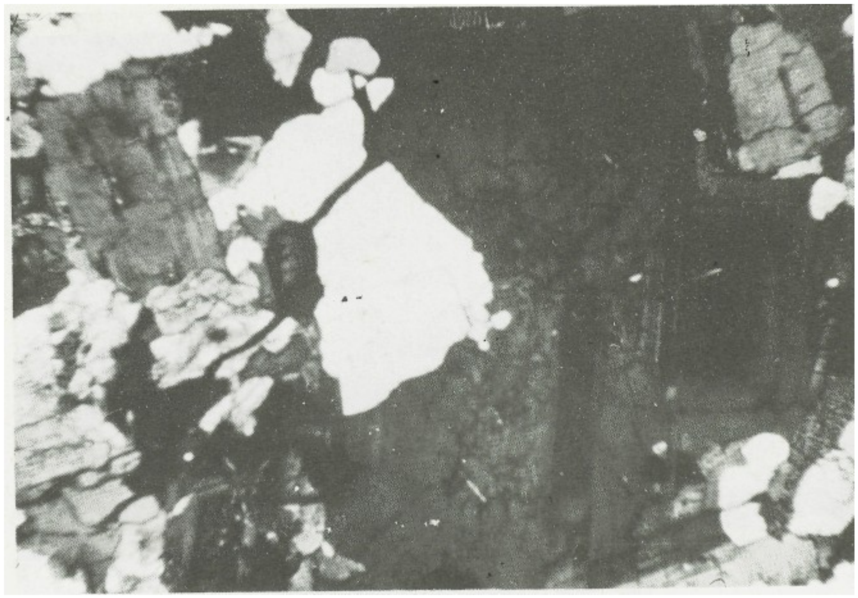

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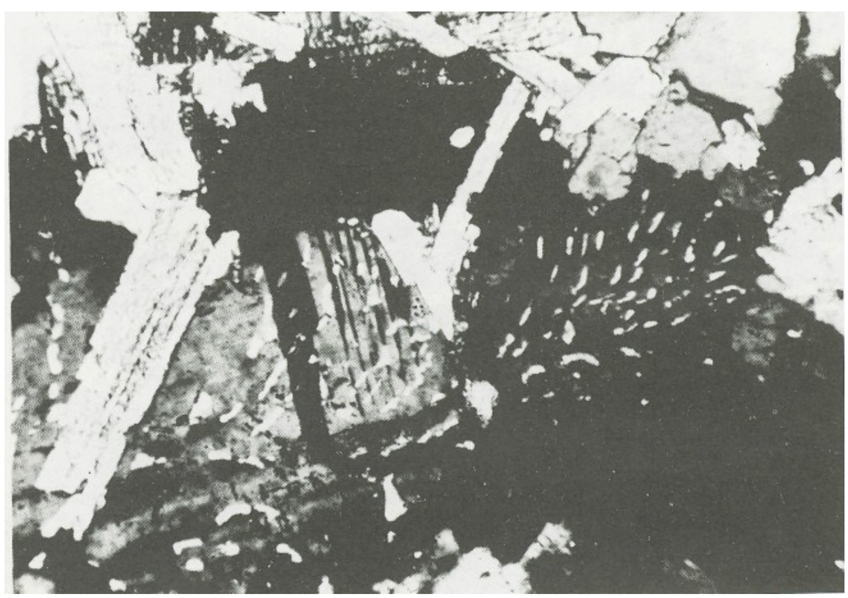

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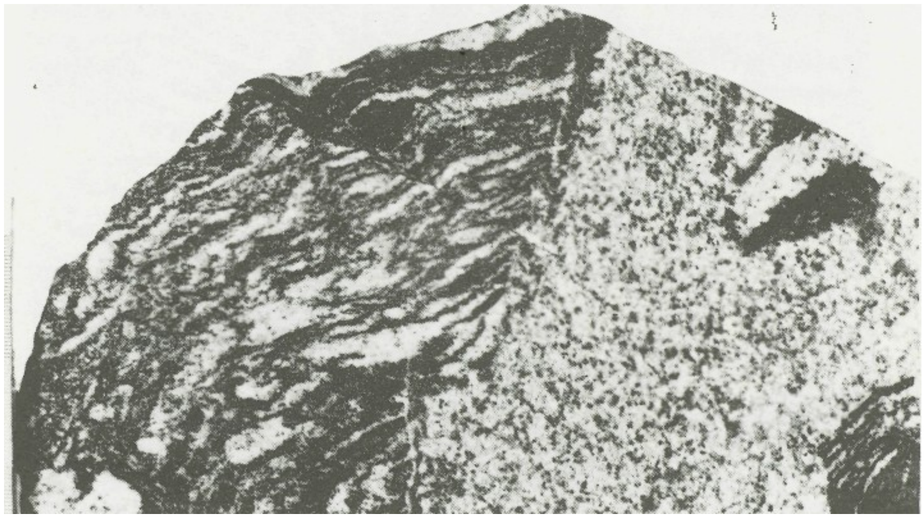

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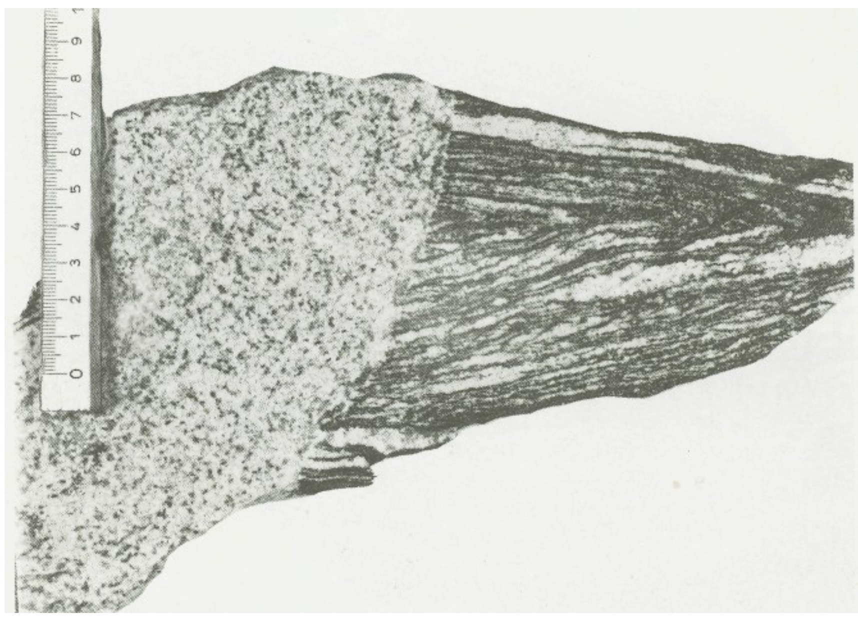

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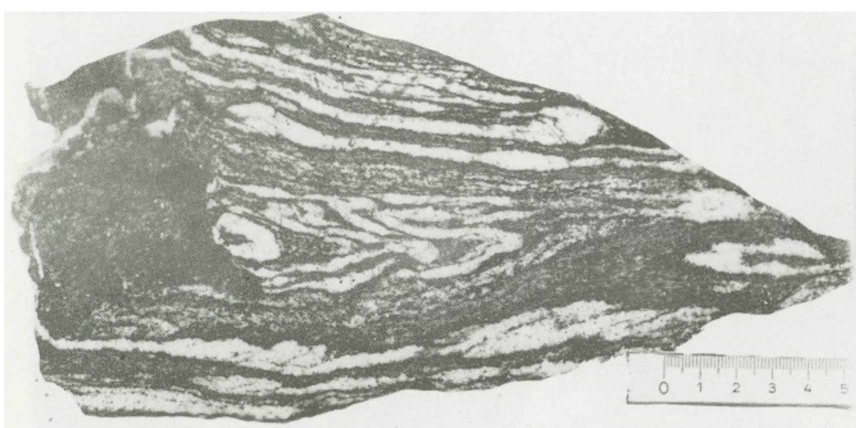

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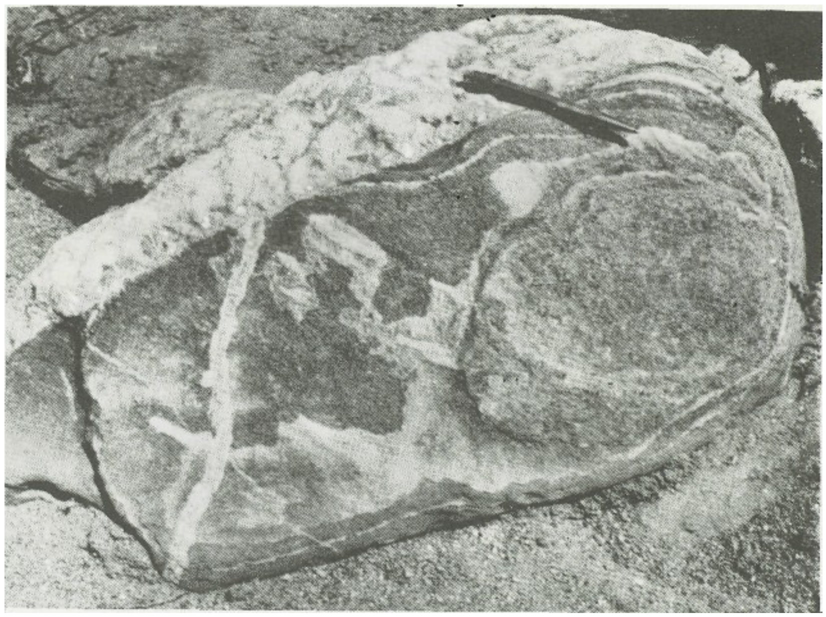

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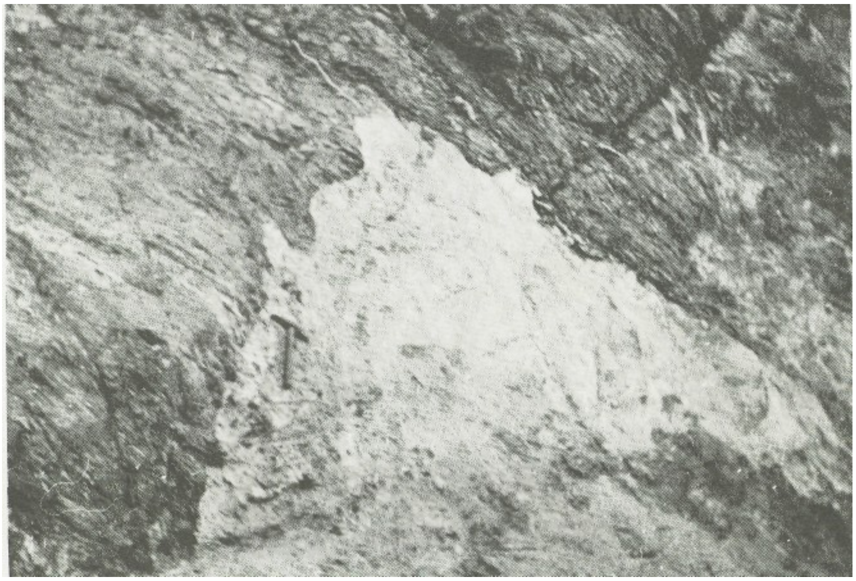

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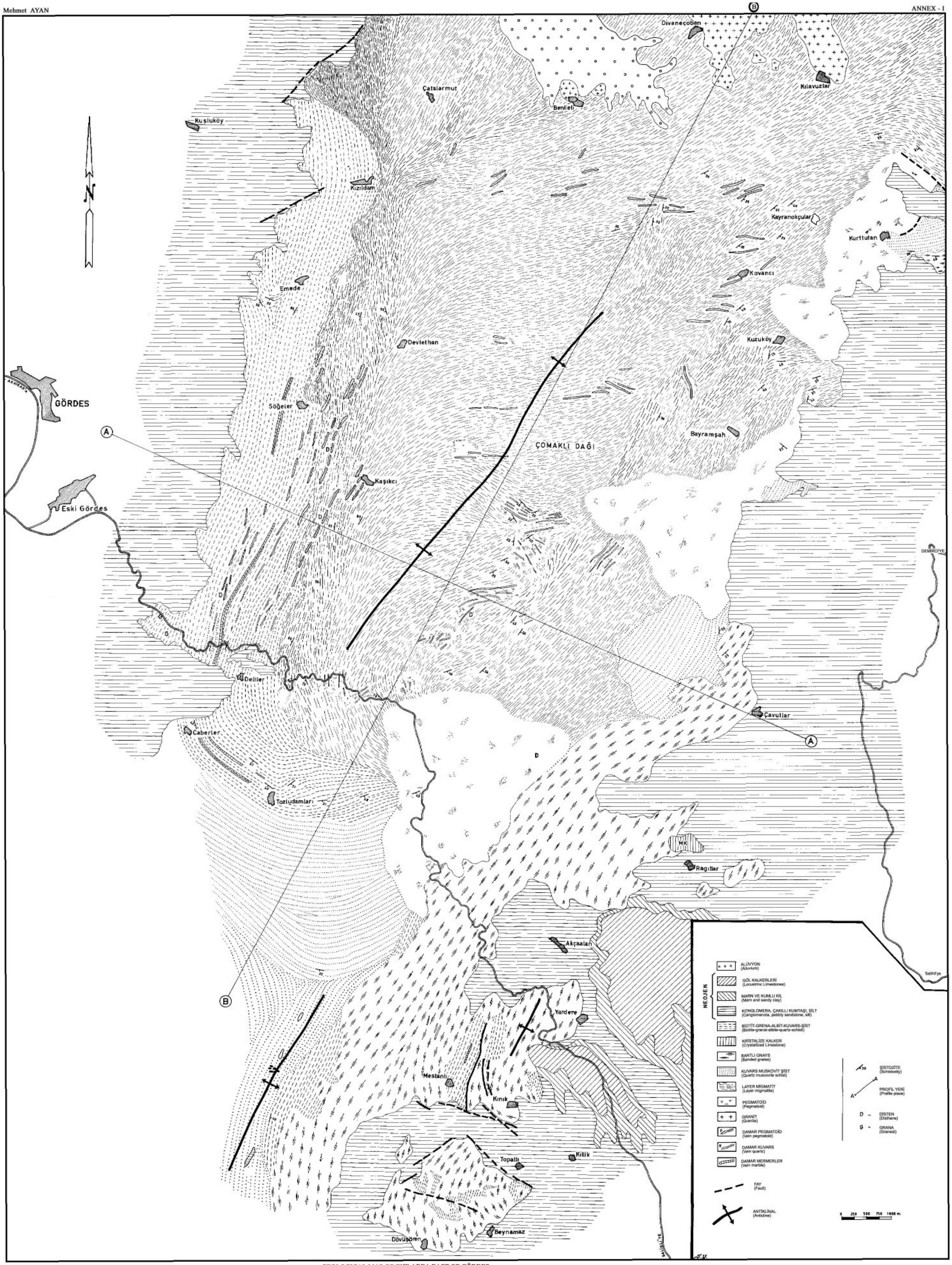
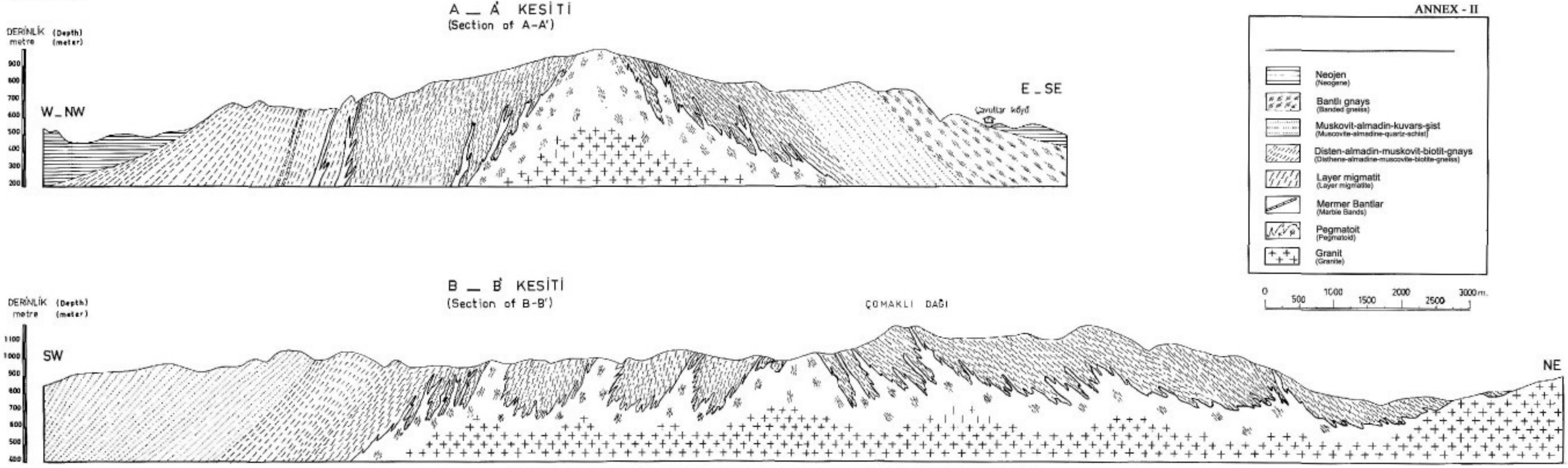


GEOLOGICAL MAP OF THE AREA EAST OF GÖRDES

ANNEX - II



GEOLOGICAL SECTIONS OF THE METAMORPHIC COMPLEX IN THE VICINTY OF GOREDES

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