THE SIGNIFICANCE AND DISTRIBUTION OF GLAUCOPHANE ROCKS IN TURKEY

G. v. d. KAADEN

Middle East Technical University, Ankara

ABSTRACT. — In this paper the different concepts concerning the genesis of glaucophane rocks are critically discussed. The stability relations of the minerals occurring in the glaucophane rocks are summarized. Their implications on geological-petrological problems are mentioned.

Short descriptions of different types of these rocks and their distribution in Turkey are given. The age relations of the glaucophanitic greenschist facies and the lawsonite-glaucophane facies are evaluated for the different areas of Turkey.

It seems highly probable that the lawsonite-glaucophane facies is not only restricted to alpine geosynclines as was recently stated. All observations in the Mihalıççık - Eskişehir - Bursa area are in favor of a metamorphism in the lawsonite-glaucophane and glaucophanitic-greenschist faciest of Paleozoic age.

The probable reason for the poor development of glaucophane rocks in the alpine geosyncline in Turkey is given.

INTRODUCTION

In the last years a vast amount of publications was written on the significance of the glaucophane schist facies, on chemical, optical and X-ray data of the separate minerals and on stability relations of the critical minerals of these rocks.

As glaucophane rocks are not uncommon in certain areas in Turkey, it seems necessary to make a compilation of our knowledge concerning these rocks in Turkey. Some of these occurrences have been mentioned in publications: Milch (1907), de Wijkerslooth (1941), Schürmann (1956), van der Kaaden and Metz (1954), Blumenthal (1955), van der Kaaden (1959), Çoğulu (1965).

Glaucophane rocks are also mentioned by Ketin (1962, p. 61 and 1963, p. 40) in his explanatory text on the 1:500,000-scale maps of Sinop and Kayseri. Other occurrences are known to exist, which were found by M.T.A. geologists, and of which exist either rock samples and thin sections, or (of the older findings) written reports only, as the older collections got lost. The numbers given refer to the numbers of the rock samples of the M.T.A. or those of the M.E.T.U. collection. Reports on glaucophane rocks in the files of M.T.A. are written by K. Güler, A. Schroder, P. de Wijkerslooth, G. van der Kaaden, G. Müller, F. Ronner, C. Kieft, J. H. Langenberg, K. Markus, G. Elgin, Ö. Öztunalı, and A. Kraeff.

A more detailed description was only possible from material, which was reexamined by the author. Especially the older material is lacking, and the descriptions are rather scanty, giving only the name of the rock, without a description of its components.

At all events, this older material gives an idea about the distribution of glaucophane rocks in Turkey, and they are also marked on the map showing the distribution of these rocks in Turkey and part of the Balkans (PI. I).

The author wishes to express his sincere thanks to Dr. G. Elgin, Chief of the Mineralogical-Petrological Laboratory of M.T.A., for his kind cooperation.

CONCEPTS CONCERNING THE GENESIS OF GLAUCOPHANE ROCKS

Until now two fundamentally different concepts about the genesis of these rocks have arisen.

1. The formation of glaucophane rocks is closely linked to special chemical conditions; i. e. a metasomatic supply of Na, Fe, Mg is required, or a special bulk composition is essential. Special significance is given to the local occurrences of glaucophane schists as aureoles adjacent to serpentinites and to irregular and restricted development of glaucophane schists, apparently surrounded by unmetamorphosed rocks.

This concept is supported, among others, by Taliaferro (1943), Brothers (1954), Schürmann (1951, 1953, 1956).

2. The formation of glaucophane rocks is closely linked to special physical conditions: i. e. certain pressure-temperature conditions must be fulfilled. The formation of these rocks is essentially an isochemical metamorphism; i. e. the composition of the rock remains almost unchanged during the metamorphism.

Already Eskola (1929, 1939), defining the glaucophane schist facies, stressed the fact that the glaucophane schist facies may be formed independently from special chemical conditions or Na-metasomatism.

This concept is supported, among others, by de Roever (1950, 1955 a, *b,* 1956, 1965), Miyashiro and Banno (1958), Ellenberger (1960), van der Plas (1959), Bearth (1959), Bloxham (1960), Coombs (1960), Ernst (1963), Coleman and Lee (1963), Kanissawa (1964), Crawford and Fyfe (1965), Winkler (1965), Ghent (1965).

The second concept, stating that the glaucophanitic metamorphism is in the first place an isochemical process, is supported by the following considerations:

a. Some glaucophane schists have bulk compositions indistinguishable from greenschists and albite-amphibolites. In these rocks at least, glaucophane-crossite must have resulted from physical conditions different from those present during metamorphism of the more common greenschists and albite-amphibolites (Ernst, 1963).

b. Glaucophane rocks have a regional and not a local significance, as is seen from the recent publications from California, Japan, Europe. This is in accordance with the auther's observations from Turkey.

c. Kanissawa (1964) was able to demonstrate from the Kitakami Mountains in Japan, that the basic and ultrabasic rocks, which are located in the same area as the glaucophane rocks; have no direct relation to this metamorphism. The same conclusions are forwarded by Çoğulu (1965) from the region of Mihalıççık (Turkey). Here the metamorphism in the lawsonite-glaucophanc and the glaucophanitic-greenschist facies is definitely later than the emplacement of the ultrabasics or the intrusion and extrusion of diabases and spilitic flows.

d. From the important contributions of Coombs (1960) and Coombs *et al.* (1959) from New Zealand, it became clear that a burial metamorphism exists in the so-called zeolitic facies. This facies shows in its deeper parts transitions to the glaucophane schist facies. Winkler (1965) has compilated modern results and given a classification which is somewhat different from the existing. As this classification is a logical one, and applicable in Turkey, the author will use it in this paper.

1. Zeolitic facies : a. Laumontite-prehnite-quartz facies.
   b. Pumpellyite-prehnite-quartz facies.

2. Glaucophane schist facies . a. Lawsonite-albite facies.
   b. Lawsonite-glaucophane facies (=blueschist facies of Ernst).

3. Glaucophanitic greenschist facies.

The hydrostatic pressure increases from the zeolitic facies (1a) to the glaucophane schist facies (2 b), and the temperature is somewhat higher in the glaucophanitic greenschist facies (3) than in the glaucophane schist facies (2). The glaucophanitic greenschist facies is transitional to the glaucophane schist facies on the one side, and to the lowest-grade greenschist facies of the Barrovian (=Dalradian) type on the other side.

This is supported by observations in Turkey, where the author observed in the Ula-Karabortlen region in the SW of Turkey a gradual change from the glaucophanitic greenschist facies (3) into the lowest-grade chloritoid-bearing greenschist facies of the Barrovian type, and by Çoğulu (1965) from the Mihalıççık area, where he observed a gradual change from the lawsonite-glaucophane facies (2 b) into the glaucophanitic greenschist facies (3). Similar observations are reported by Bearth (1962) from the Western Alps. West of Mihalıççık, a change from the glaucophanitic greenschist facies (3) into the lowest-grade chloritoid-bearing facies of the Dalradian type was observed by the author from the region SW of Söğüt.

Also the mineral stilpnomelane is known in the glaucophanitic greenschist facies in Turkey. Both minerals, chloritoid and slilpnomelane, are stable in the low-grade greenschist facies of the Dalradian type; i.e. the greenschist facies of the high-pressure facies series (Winkler, 1965).

Until now the lawsonite-glaucophane facies (2 b), and the glaucophanitic greenschist facies (3) are established with certainty in Turkey. The existence of the lawsonite-albite facies (2 a) is indicated from the Nallıhan-Sarıyer area (II-8-b-l Coll.no. M.T.A. 21127/914). The glaucophanitic greenschist facies was already known since the beginning of this century (Milch, 1907) from the Elek Dağ east of Kastamonu. Later it was found by de Wijkerslooth (1941) from the area south of Bursa, by Schürmann (1956) from the Eskişehir-Gündüzler area, by van der Kaaden (1954) from the Marmaris-Karabörtlen area, by Blumenthal (1955) from the Bolkar Dağ. Non-printed- reports show that this facies is also known from several other places, which are given on the map. The lawsonite-glaucophane facies was discovered by Schürmann (1956, p. 77) from the Eskişehir area, and by van der Kaaden (1959) from an area southwest of Uludağ. Later it was found by Çoğulu (1965) that this facies is classically developed in the Mihalıççık area. Other findings of this facies are registered on the map.

The pumpellyite-prehnite-quartz facies (1 b) of the zeolitic facies is probably represented in the deeper parts of the eastern Black Sea-coast area. This area (Maucher *et al.,* 1962) consists of a series of submarine basic and acidic lavas and their pyroclastics with insignificant intercalations of sediments, of great thickness, ranging from Jurassic to Eocene. The minerals, prehnite and also pumpellyite, are found here without the formation of lawsonite or glaucophane, but investigations are still lacking.

STABILITY RELATIONS OF MINERALS IN THE GLAUCOPHANE SCHIST FACIES AND IN THE GLAUCOPHANITIC GREENSCHIST FACIES

1. Glaucophane and crossite

These minerals are not diagnostic for the glaucophane schist facies, as they also appear in rocks of the glaucophanitic greenschist facies. This means that the physical conditions cover a rather wide area, as these minerals are stable in both facies. Ernst's (1961) experimental investigations indicate that glaucophane-crossite is stable over a wide range of physical conditions in rocks rich in soda and magnesia, relative to alumina, and deficient in lime. On the other hand, lime schists with glaucophane arc known to exist, and here the physical conditions are more restricted.

Miyashiro and Banno (1958) stress that an appropriate chemical environment should be the contact between albite-bearing country rock and serpentinite. Albite + serpentine = glaucophane + water.

The glaucophane aureoles, which are sometimes observed around serpentine masses, could perhaps be explained this way. In the opinion of the author, here also special physical conditions must be fulfilled, as there are many areas where albite-bearing country rock, or albitites, in contact with serpentine have not reacted under the formation of glaucophane.

Ernst (1963) showed the existence of two polymorphs of synthetic glaucophane. The high-pressure (and low-temperature) form, glaucophane II has a smaller unit cell with volume comparable to those of natural glaucophanes. At 300°C this polymorph is stable at all lithostatic pressures in excess of appr. = 3 kilobar (= 11 km).

The assemblage of glaucophane-crossite *with other minerals* characterizes the lawsonite-glaucophane facies. In this facies it is the combination of glaucophane-crossite with lawsonite, jadeite-quartz, pumpellyite which is characteristic. In California Coleman and Lee (1962), Brown, Fyfe, Turner (1962), McKee (1962) described metamorphic aragonite for the first time from this facies.

In Turkey, glaucophane-crossite, lawsonite, pumpellyite and recently also jadeitic pyroxene (Çoğulu, 1965) are known from this facies, and also stilpnomelane. It is known that biotite never occurs in the lawsonite-glaucophane facies, nor in the glaucophanitic greenschist facies. Its place is taken by chlorite and phengitic mica (Kanehira *et* al., 1960). According to recent investigations of Ernst (1963), muscovife is not present in this facies, which is not in agreement with the observations of van der Plas (1959, p. 473), who states «even the mica of some sodium-pyroxene rocks proved to be muscovite».

2. Lawsonite

Lawsonite occurs in the lawsonite-albite (2 a) and in the lawsonite-glaucophane facies (2 b). Coombs (1960) described this mineral from slightly metamorphosed metagraywackes from New Zealand. This mineral only occurs in the glaucophane schist facies (2) and is one of the critical minerals of rocks belonging to this fades. At higher temperatures in the greenschist facies, lawsonite disappears under the formation of zoisite, and at low temperature and pressure zeolites and other minerals, such as prehnite, may replace lawsonite (Crawford *et, al.,* 1965).

Pistorius *et al.* (1962) were able to produce synthetic lawsonite at pressures above appr. 22 kilobar at 300°C, and zoisite at lower pressures. From this experiment it was shown that lawsonite requires relatively higher pressures at the same temperature than is necessary for epidote minerals.

The extreme pressure necessary for the formation of artificial lawsonite (equivalent to approximately 77 km of lithostatic pressure) is certainly not realized in nature. This pressure is realized below the Mohoroviciç discontinuity. The experiment shows, however, that for the formation of lawsonite in nature very high lithostatic pressures are required.

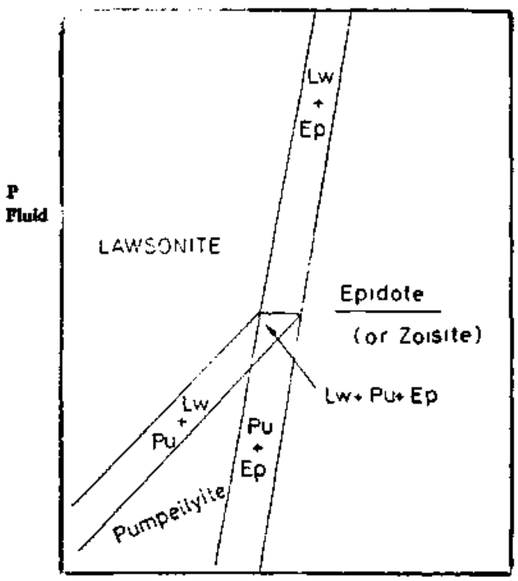
3. Pumpellyite and epidote minerals

Ernst (1963), plotting the stability relations of lawsonite, pumpellyite and epidote (zoisite) on a diagram showing P fluid and temperature, showed that as the composition of these minerals is not identical, two or even three of these minerals may exist stable under some conditions, but their overall fields of stability are certainly dissimilar. Pumpellyite occurs already in the pumpellyite-prehnite-quartz facies (1 b) of the zeolitic facies. It has also been described from rocks of the glaucophane schist facies and from low-grade schists of the glaucophanitic-greenschist facies. Epidote minerals occur abundantly in glaucophane schists in both higher grade rocks of the greenschist as well as in the lower grade rocks of the almandite-amphibolite facies. According to Miyashiro *et al.* (1958), ferric-rich epidote is stable at low temperature and ferric-poor clinozoisite becomes stable with rising temperature. Lawsonite and epidote in general exclude each other, but in accordance with the diagram given by Ernst, exceptions are possible. These exceptions have been reported from California and Japan, and also in Turkey they are known from the Mihalıççık area. Also the associations lawsonite-pumpellyite and pumpellyite-epidote have been reported from Turkey (Fig. la).

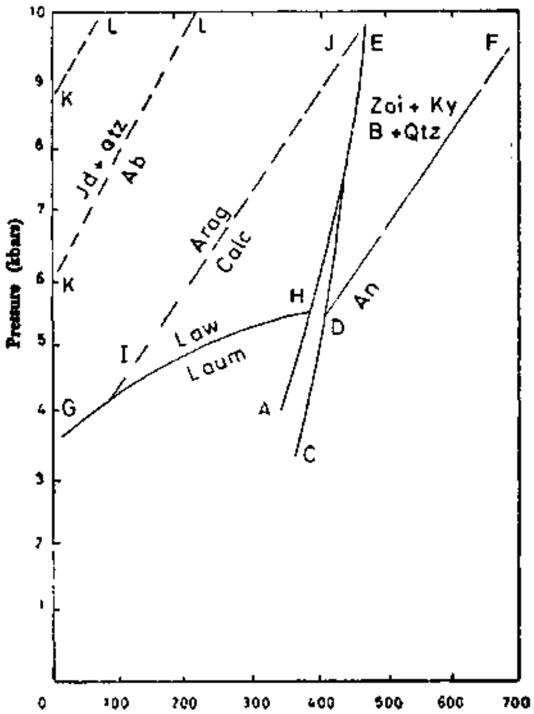
4. Aragonite-calcite

The discovery of aragonite in rocks of the lawsonite-glaucophane facies in California is important. Experiments on the stability relations of calcite-aragonite by Clark (1957) and by Crawford *et al.* (1965) demonstrate that aragonite at 300°C is the stable modification at pressures in excess of 8 kilobar (approximately 26 km of lithostatic pressures). Ernst (1963) and Coleman *et al.* (1962) proved a certain isomorphic replacement of Ca by Sr to a maximum of 1 Mol. % $SrCO_3$ in aragonites of this facies. Winkler and collaborators (1965, p. 150), proved that this isomorphic replacement reduces the equilibrium pressure at constant temperature approximately 1-2 kilobar.

According to Winkler, the pressures during the formation of the lawsonite-glaucophane facies at temperatures of 350°C - 450 °C, were at the order of 7-8 until 8-9 kilobar, corresponding with approximately 25-28 until 28-32 km of lithostatic pressure. If instead of aragonite, calcite belongs to the primary assemblage, then the



Temperature (°C)
(After Ernst, 1963)
Fig. 1a



Temperature (°C)
(After Crawford and Fyfe, 1965)
Fig. 1b

pressures were lower, as can be seen from the experimental equilibrium curves (Fig. \b after Crawford *et al.).* The differences will be probably not very important. Brown *et al.* (1962) stressed the fact, that in order to preserve the dense polymorph aragonite during cooling and unloading, fluids must be expelled from aragonite-bearing rocks. This may be one of the reasons why aragonite until now is only rarely found in other occurrences of this facies. Aragonite has not yet been found in this facies in Turkey.

5. Jadeite

According to Bloxham (1956), jadeite is a product of the reaction: albite = jadeite + quartz. This reaction is favored by a high hydrostatic pressure. Winkler (1965) states that this reaction is more complicated in nature, as a complex mix-crystal of jadeite-bearing pyroxene is formed, instead of pure jadeite. According to experimental investigations at 300 °C (Ernst, 1963, p. 16), jadeite + quartz are stable above 12 kilobar. However, the solid solution with diopside and acmite lowers the pressure necessary to stabilize, a jadeitic pyroxene, and in accordance with the stability relations aragonite-calcite, the pressure necessary for this mix-crystal might be in the order of 8-9 kilobar.

In Turkey, jadeitic pyroxene is mentioned from the Mihalıççık area by Çoğulu (1965).

6. Other minerals

Hematite and sphene are also widespread in rocks of the lawsonite-glaucophane and glaucophanitic greenschist facies. These accessory minerals indicate that glaucophane schists and many greenschists crystallized at low temperatures.

Banno *et al.* (1961) concluded that sphene is characteristic for lower temperatures and rutile for higher grade rocks: sphene+chlorite + quartz=hornblende+rutile-f-water.

GEOLOGICAL - PETROLOGIGAL IMPLICATIONS

Most of the petrologists, dealing with the problems of the glaucophane-schist facies, agree more or less on the physical conditions which must have been active during the formation of this facies. The stability relations of the minerals of the glaucophane-schist facies in combination with experimental evidence suggest strongly that these rocks formed at low temperatures and at relatively elevated pressures. The transitional stage of the glaucophanitic greenschist facies to the low-grade quartz-albite-muscovite-chlorite subfacies of the high-pressure facies series of the Dalradian type, also suggests that here the temperatures were relatively low, but probably somewhat higher than in the lawsonite-glaucophane facies, and the lithostatic pressures also relatively high.

Winkler (1965), after a critical evaluation of the modern literature on this subject, combined with his own experiments, estimated the temperature necessary during the formation of the glaucophane-schist facies at 350°C - 450°C. The stability relations of the system calcitc-aragonite are in favor of lithostatic pressures in between 25-32 km (7-9 kb);

Ernst (1963) stressed the possibility that differential stress may aid in the attainment of the appropriate mean pressure necessary for the production of the high-pressure phases observed in the glaucophane-schist facies. Estimations by Turner and Verhoogen (1960), and Clark (1961) of the effect of this tectonic overpressure are in the order of 1-2 kilobar. In cases where this effect was active, the lithostatic pressures necessary for the formation of these phases would then be in the order of 18-28 km (5-8 kilobar). In California, however, metamorphic aragonite-bearing glaucophane-lawsonite rocks are known, which were certainly not subjected to differential stress during their formation. Glaucophane rocks, schists and related rocks in Turkey show, in general, clear evidence of *pre-metamorphic* granulation, shearing and deformation. Lawsonite of Mihalıççık was formed after the deformation of the rocks. Çoğulu (1965), describes this mineral from diabases, pillow lavas, gabbroic and amphibolitic inclusions in ultrabasics, and lawsonite-glaucophane schists.

His argumentation that the lawsonite-glaucophane facies was promoted by local tectonic overpressure, due to the emplacement of the ultrabasics, seems not entirely convincing.

Another explanation is offered by Ernst (1963, p. 17), «Glaucophane schist terranes are regions of extreme crustal instability, as indicated by their nature and intensely deformed condition, therefore, although the cycle may have been of long duration considering the metamorphic provinces as a whole, it was probably short-lived locally. Reactions proceed very slowly at low temperatures and one might expect pre-existing assemblages to persist metastably, except in regions where cataclastic deformation had *decreased grain size* and thus increased reaction rates. Such shear zones would also be favorable channel-ways for solutions to flux the reactions. This process may in part account for the irregular distribution of glaucophane schists, related rocks, and greenschists in some areas. Furthermore, such zones of weakness would probably localize intrusions of serpentinites.»

If a lithostatic pressure of 8 kilobar is accepted, for the formation of such minerals as aragonite, jadeitic pyroxene and lawsonite, and a temperature of 350°C-450°C, then troughs of depths of almost 30 km must have been formed. The relatively low temperatures at this depth, necessary for the formation of the lawsonite-glaucophane facies, can only be explained by assuming a rapid subsidence of the sediments, and their intercalated lavas and tuffs. Further, during the glaucophanitic metamorphism no heat front must have affected the geothermal gradient. The geothermal gradient must have been less than 20°C/km.

Winkler (1965) points out that the current opinion, concerning the maximum depth of geosynclines, should be reconsidered. In geosynclines, where the lawsonite-glaucophane facies has been developed, depths of the order of 25-32 km must be expected. As the glaucophanitic greenschist facies seems transitional to the lawsonite-glaucophane facies, here also considerable depths are expected.

OCCURRENCES OF GLAUCOPHANE ROCKS IN TURKEY

(Plate I)

I. NORTHERN ANATOLIA

1. Elek Dağ (Province of Kastamonu)

a. Glaucophane schist: glaucophane (length up to 0.5 mm), epidote, chlorite, quartz, albite (muscovite), opaque ore.

   Texture: nematoblastic.

   Location: Kızılkale (after Milch, 1907—collection Leonhard).

b. Glaucophane «eclogite» : reddish-brown garnet (up to 4 mm in diameter), Fe-rich glaucophane (crossite ?), epidote-zoisite, augite as inclusions in garnet (omphacitic ?), chlorite, little quartz and albite, sphene.

   Texture: massive, slightly schistose, porphyroblastic.

   Location : Yılanlı (after Milch, 190-7—collection Leonhard).

Of these rocks the following assays were published (Rosenbusch, 1923, p. 722). (The author calculated from these values, the mol. numbers, the atomic numbers, for the Niggli values, the Köhler-Raaz values, the-positions in the ACF and A'KF diagrams, and the positions in the triangles of Coleman et *al.* (1963), in order to decide about the origin of the rocks in question (Fig. 2 *a/g).]*

	Wt. %	Mol. × 1000	si	al	fm	c	alk
ad a :							
SiO_2	51.01	849	849				
TiO_2	0.25	4					
Al_2O_3	17.54	172		172			
Fe_2O_3	5.78	36					
FeO	7.22	105			177		
MnO	0.031						
MgO	4.51	111			111		
CaO	7.36	131				131	
Na_2O	3.56	57					57
K_2O	0.36	4					4
H_2O	2.77						
P_2O_5	0.23	2					
	100.62		849	172	288	131	61
Density :	3.0567						

al (172) 26
fm (288) 44.5
c (131) 20
alk (61) 9.5
(656) = 100
si (800) = 130
ti = 0.6
al-alk = 16.5 (+)
p = 0.3
qz = 130-(100+4alk) = —8
c/fm = 0.45 (section IV)
mg = 0.38 k=0.07

	Wt. %	Mol. × 1000	si	al	fm	c	alk
ad b :							
SiO_2	48.80	800	800				
TiO_2	1.04	13					
Al_2O_3	15.72	150		150			
Fe_2O_3	5.09	32					
FeO	8.32	116			180		
MgO	7.49	186			186		
CaO	6.38	114				114	
Na_2O	4.53	73					73
K_2O	0.55	6					6
H_2O	2.10						
P_2O_5	0.27	3					
	100.29		800	150	366	114	79
Density :	3.0567						

al (150) 22
fm (366) 51
c (114) 16
alk (79) 11
(709) 100
si (800) = 120
ti = 1.8
p = 0.4
qz = 120—(100+4alk) = —24
c/fm = 0.31 (section VI)
mg = 0.58 k= 0.08
al-alk = 11 (+)

The (a-alk), and c values, plotted in the diagram (alk=7.5-15) of Niggli for the two rocks show that a- falls almost on the border of IV (lime-alumino silicate rocks) and VI (alkali-fm-c-silicate rocks) : and b - well into VI (Fig. 2*a*).

$A = (Al_2O_3) + (Fe_2O_3) — ((Na_2O) + 3(K_2O))$ in case a, as muscovite is present.
$A = (Al_2O_3) + (Fe_2O_3) — ((Na_2O) + (K_2O)$, in case b.
$C = (CaO) — 3.3 (P_2O_5) — (TiO_2)$
$F = (MgO) + (FeO)$
$A' = (Al_2O_3) + (Fe_2O_3) — ((Na_2O) + (K_2O)) — 3/4 (CaO)$, in case a, as epidote is present.
$A' = (Al_2O_3) + (Fe_2O_3) — ((Na_2O) + (K_2O)) — 1/2 (CaO)$, in case b, as garnet + epidote are present.
$K = (K_2O)$
$F = (MgO) + (FeO)$

For the calculation of the ACF and A'KF triangles this gives :

a) $A=(139)$, $C=(120)$, $F=(288)$, $A+C+F=100$, $A=25$, $C=22$, $F=53$
$A'=(49)$, $K=(4)$, $F=(288)$, $A'+K+F=100$, $A'=14$, $K=1$, $F=85$

b) $A=(103)$, $C=(91)$, $F=(366)$, $A+C+F=100$, $A=19$, $C=16$, $F=65$
$A'=(45)$, $K=(6)$, $F=(366)$, $A'+K+F=100$, $A'=11$, $K=1$, $F=88$

The composition points in the ACF and A'KF triangles, come very close to basaltic-andesitic composition, at the border of the graywacke field, as plotted by Winkler (1965) (Fig. *2b).*

Also the atomic percentages for Na, Ca, K, Fe", Fe"', Mg were calculated, in order to plot these values in Na+K, Fe"+Fe"', Mg and K, Na, Ca triangles and compare them with the plots of basalts and glaucophane schists from the Franciscan formation and from other orogenic regions as given by Coleman *et al.* (1963). Also the weight percentages for SiO_2/Na_2O+K_2O, and for the triangle Na_2O+K_2O, $FeO+Fe_2O_3$, MgO were plotted. As seen from Fig. 2cf, the composition points of the rocks of Elek Dağ (Nos. Ia and b), all fall into the compositional field of the glaucophane schists from the Franciscan formation of basaltic origin. Point Ia, falls on the side of the tholeitic series, point Ib just on the side of the alkali series.

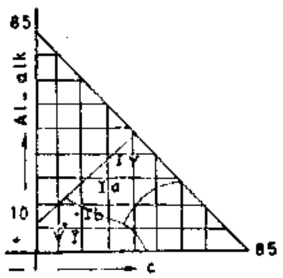


Fig. 2a
IV. = lime alumino
VI. = alkali -fm-c silicate rocks.
(After Niggli, 1948, p. 27)

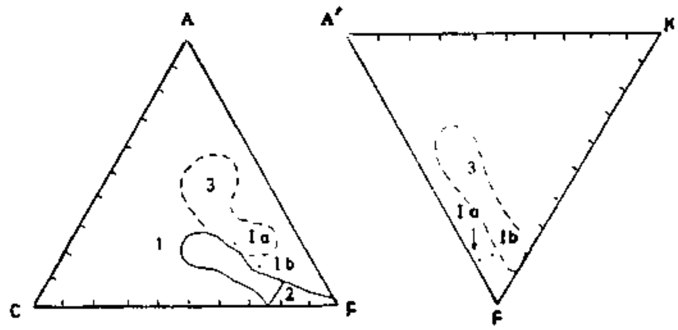
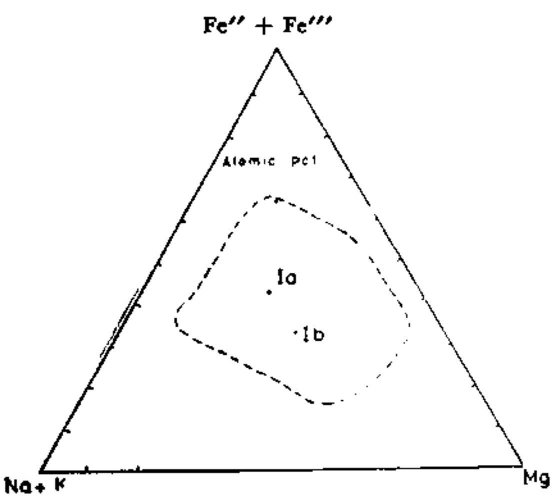
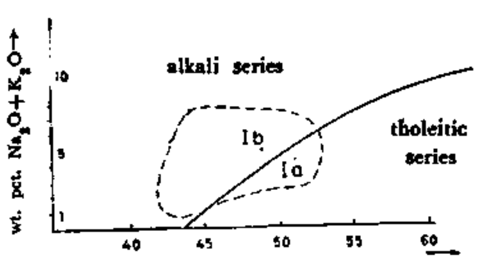


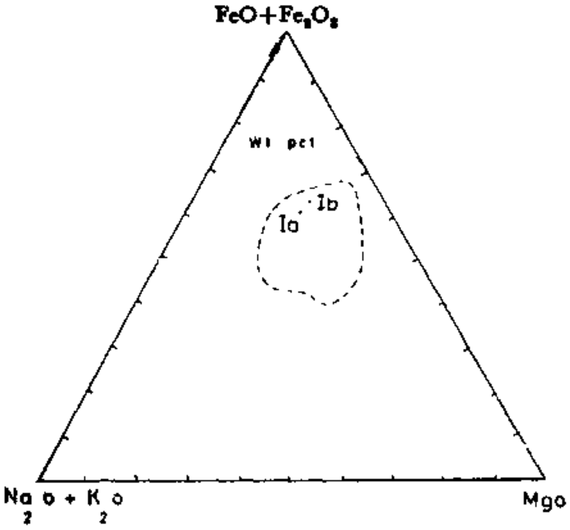
Fig. 2b
1. basaltic and andesitic rocks
2. ultrabasic rocks
3. greywackes
(After Winkler, 1965)



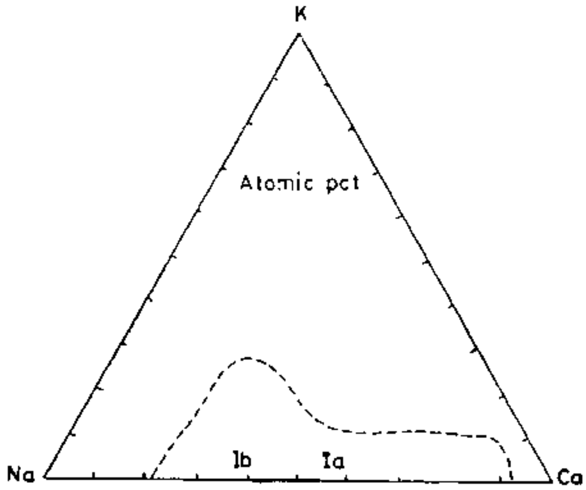
Glaucophane schists from Franciscan formation and world
(After Coleman et al. 1963)
Fig. 2c



Glaucophane schists from Franciscan formation
Fig. 2d



Glaucophane schists from Franciscan formation
(After Coleman et al., 1963)
Fig. 2e



Glaucophane schists from Franciscan formation and world
(After Coleman et al., 1963)
Fig. 2f

For the Köhler *et al.* (1951) values, the atomic numbers are calculated.

a)

Wt. %	*Atomic numbers*	
SiO_2 = 51.01	849	
Al_2O_3 = 17.54	344	
TiO_2 = 0.25	4	
Fe_2O_3 = 5.78	72	292 + 12.5 = 304.5 = fm
FeO = 7.22	105	
MgO = 4.51	111	
CaO = 7.36	131	—5/3p, = 124. minus 12.5 = 111. 5 = c
Na_2O = 3.56	114	122 = alk
K_2O = 0.36	8	
P_2O_5 = 0.23	4	

(al /alk+2c)

al—(alk+2c)=—25, as there is a deficiency in Al_2O_3, and anorthite uses for each Ca, 2 Al, 12.5 Ca have to be taken with fm.

si' = 3 alk + 2c+ fm = 1003.5

qz= 849 — 1003.5 = —(154.5) =22 (—)

F= alk + c (223.5) =33

fm = (304.5) =45

(682.5) 100

F—fm = —12

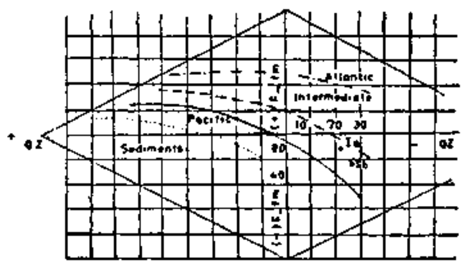


Fig. 2g

b)

Wt.	%	Atomic number	
SiO_2	= 48.80	800	
Al_2O_3	= 15.72	300	
TiO_2	= 1.04	13	
Fe_2O_3	= 5.09	64	379 + 33 = 412=fm
FeO	= 8.32	116	
MgO	= 7.49	186	
CaO	= 6.38	114	—5/3 p=104, minus 33=71=c
Na_2O	= 4.53	146	158=alk
K_2O	= 0.55	12	
P_2O_5	= 0.27		

(al (alk+2c)

al—(alk+2c)=—66, as there is a deficiency in Al_2O_3, and anorthite uses for each Ca, 2 Al, 33 Ca have to be taken with fm.

si' = 3 alk + 2c + fm = 1028
qz = 800 — 1028 = — (228) = 26 (—)
F = alk + c = (229) = 26
fm = (412) = 48
(869) = 100
F—fm = —22

The values for qz and F—fm plotted in the diagram of Köhler *et al.* for I a-b, show that the rocks are in between the Mediterranean, intermediate suite (Fig. 2 *g)* and the Pacific suite.

2. Mehmerler - İnebolu (Province of Kastamonu)

Glaucophane-epidote-bearing hornblende-chlorite schist—Coll. M.T.A. 8812/1388.

Description : Schroder — Collected by Blumenthal.

3. Ulutepe (District and province of Kastamonu)

Chlorite-glaucophane-epidote-calcite schist—Coll. M.T.A. 8815/1388.

Description : Schroder — Collected by Blumenthal.

4. Daday (Province of Kastamonu)

Garnet-bearing glaucophane-epidote-albite schist—Coll. M.T.A. 17928/618;

Description : v.d. Kaaden.

5. Kupsan - Alaca (Province of Çorum)

Albite-bearing muscovite-epidote-calcite-glaucpphane schist—Coll. M.T.A. 17071/503.

Description : Müller — Collected by Yücel.

II. WEST-CENTRAL, ANATOLIA

1. Çan-Doğalca (Province of Çanakkale)

Stilpnomelane-bearing albite-quartz-glaucophane rock — Coll. M.T.A. 45309/4516.

More or less parallel-orientated long prismatic crystals of 0.1-0.5 mm length located in a groundmass of extremely . fine-grained quartz and untwinned albi Also some stilpnomelane is present.

Description: v. d. Kaaden.

2. Erdek-Çakıl-Küçük P. T. (Province of Balıkesir)

Glaucophane-garnet-bearing muscovite quartzite—Coll. M.T.A. 23739.

Description: Kieft and de Wijkerslooth.

3. Kapsut-Sarnıç (Province of Balıkesir)

Lawsonite-glaucophane schist (with little pumpellyite) —Coll. M.T.A. 34660/3599.

Description: v.d. Kaaden.

4. The area around Uludağ (Province of Bursa) (Fig. 3)

Glaucophane «eclogite» — Coll. M.T.A. 16230.

Description: v. d. Kaaden—Collected by Danışman (exact location unknown).

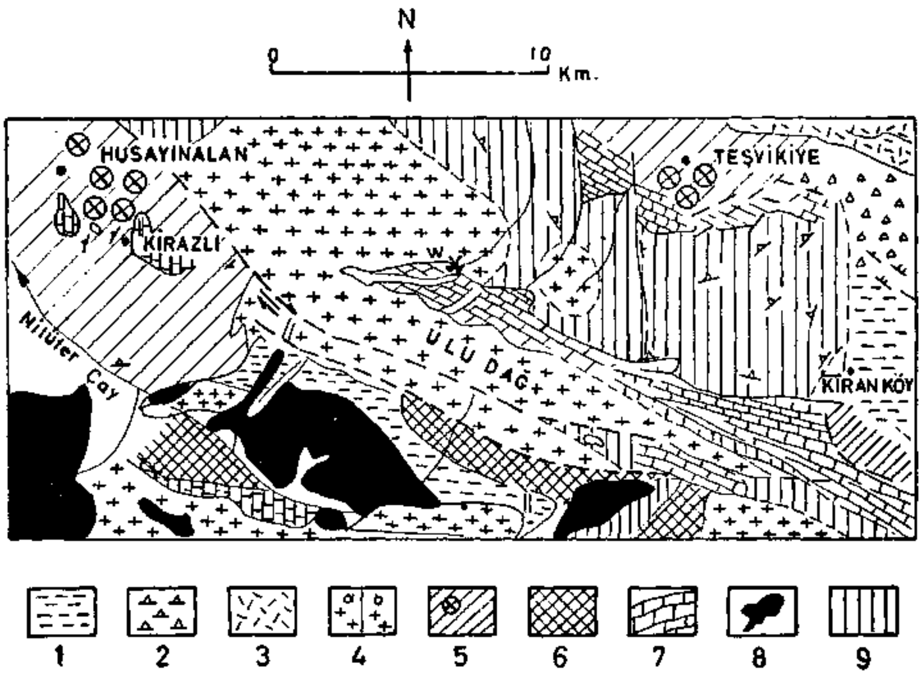


Fig. 3

1 - Neogene; 2 - Pleistocene debris; 3 - Tertiary volcanics; 4a - Paleozoic granodiorites; 4b - Sheared granodiorites; 5 - Glaucophane-bearing greenschists; 6 - Contact-metamorphosed early Paleozoic formations; 7 - Marbles; 8 - Serpentinized ultrabasics; 9 - Gneisses.

(After v.d. Kaaden, 1959)

The medium-grained rock consists of crossite (X= yellowish, Y= bluish, Z = blue, 2V (—), small axial angle, axial-plane perpendicular to (010). Elongation length slow, Z/c=18°, long prismatic. Length 4-8 mm, length : width = 3:1) as essential constituent. Idioblastic crystals of garnet (in thin section, rosa-colored, partly replaced by chlorite, size appr. 3 mm in diameter), epidote and quartz pseudomorphoses after plagioclase are widespread. Zoisite, rare. Ilmenite rare.

Southwest of Uludağ-Hüseyin Alanı: Wijkerslooth (1941, p. 27) mentions glaucophane schists and epidote-glaucophane schists from this location. The age of the metamorphism is considered by him as Paleozoic. G. v. d, Kaaden (1959) mentions between Hüseyin Alanı and Kirazlı Köy, glaucophane-epidote schists, chlorite-epidote-glaucophane schists and glaucophane-bearing-epidote schists. It was shown here that the contact-metamorphism of a a late Paleozoic granite, destroyed pre-existing glaucophane. This confirms the opinion held by P. de Wijkerslooth, that the glaucophanization is of Paleozoic age. It also confirms Schürmann (1956, p. 85), that the granitic-granodioritic intrusions in the west of Turkey destroyed the glaucophane rocks in the contact aureoles.

Teşvikiye Köy: G. v. d. Kaaden (1959b, p. 28) mentions glaucophane-epidote schists intercalated in a strongly disturbed zone of lenses of olivine-gabbro, picrite, olivine diabases and graywackes.

NW of Tiraz Köy and Bileylikyayla Dere: G. v. d. Kaaden (1959b, p. 28) mentions from a narrow zone of schists, between strongly disturbed serpentinized peridotitic rocks and black schistose limestones, epidote-glaucophane and quartz-rich chlorite-lawsonite-glaucophane schists.

5. The area around Tavşanlı-Domaniç

The area Tavşanlı-Ovacık (Province of Kütahya): Glaucophane rock —Coll. M.T.A. 18645/668. This rock occurs in a border zone of a peridotite-serpentine complex, in the neighborhood of a thrust zone, which trends the peridotites from the limestones (Paleozoic ?). In this strongly disturbed zone, besides glaucophane rocks, fragments of red chert, silicified limestones and marbles are found.

Description: v. d. Kaaden—Collected by Holzer.

Tavşanlı-Kızılçukur (Provinceof Kütahya): Epidote-glaucophane schist— Coll. M.T.A. 19755/751.

Description: Ronner.

Domaniç-Kocalar Yurdu (Province of Bursa) : Glaucophane-stilpnomelane-bearing quartz-albite-epidote-schist — Coll. M.T.A. 33131.

Description: v.d. Kaaden.

6. The area Kütahya-İnönü-Seyitgazi

Kütahya (exact location unknown): Calcite-rich glaucophane-bearing chlorite-oligo-albite-actinolite schist (composition of prassinite)—Coll. M.T.A. 19533/730.

Description: Ronner — Collected by Colin.

Kütahya-Çekürler: Crossite-glaucophane-chlorite schist—Coll. M.T.A. 19534/730.

Description : Ronner.

Kütahya - Toprak - Yakuplar : Glaucophane (crossite)-calcite-white mica-quartz schist —Coll. M.T.A. 33141.

Description: de Wijkerslooth.

Kütahya-Yerlikören : Glaucophane-epidote-albite schist—Coll. M.T.A. 32407/ 3197.

Description : de Wijkerslooth.

Kütahya-Andız Sırtı.: Glaucophanized (crossitized) porphyritic basic rock — Coll. M.T.A. 33075;

Description: de Wijkerslooth.

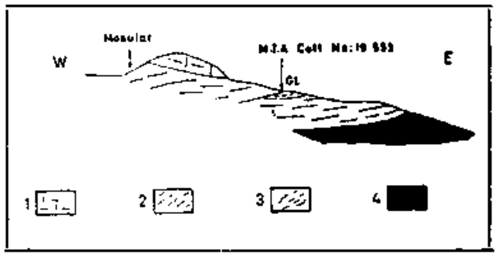


Fig. 4a - Seyitgazi Area
1 - Marble (Carboniferous); 2 - Paleozoic schists (Devonian?); 3 - Gl. (Glaucophane schists); 4 - Serpentinized ultrabasics.
(After Kupfahl)

Seyitgazi-Mosular (Province of Eskişehir): Glaucophane-clinozoisite schist—Coll. M.T.A. 19553/729.

Description: Ronner — Collected by Kupfahl (Fig 4a).

İnönü-Yörükalan (Province of Bilecik): Epidote-glaucophane schist—Coll. M.T.A. 33110.

Description: Markus.

7. The area Yenişehir-Bilecik-Bozüyük-Söğüt-Eskişehir-Mihalıççık

Yenişehir-Mahmudiye Mah. (Province of Bursa): Glaucophane schist—Coll. M.T.A. 38299/4006.

Description: Elgin.

Yenişehir-Subaşı (Province of Bursa) : Glaucophane-bearing actinolite-chlorite-albite-epidote schist (with little quartz, calcite, albite with «snowball» textures)—Coll. M.T.A. 38306/4006.

Description: v.d. Kaaden.

Bozüyük-Darıdere (Province of Bilecik) : Galcite-bearing-muscovite-glaucophane-crossite schist—Coll. M.T.A. 33085.

Description: Markus.

Bozüyük-Çokçalar (Province of Bilecik) : Calcite-bearing muscovite-glaucophane-crossite schist—Coll. M.T.A. 33086.

Description: Markus.

Bozüyük-Ketenli (Province of Bilecik) : Albite-epidote-glaucophane schist — Coll. M.T.A. 33087 and 33088.

Description : Markus.

Bozüyük-Yeşil Çukur (Province of Bilecik) : Glaucophane-bearing albite-epidote schist —Coll. M.T.A. 33089.

Söğüt-Çamurlu (Province of Bilecik) : Glaucophane-epidote-muscovite schist — Coll. M.T.A. 18855/676.

Description : v.d. Kaaden—Collected by Weingart.

In the same Paleozoic metamorphic formation, in the neighborhood of Dudaş Köy not far from Söğüt, the author found a series of actinolite-chlorite-albite schists, which are locally *chloritoid-bearing,* with subordinate graphitic schist, phyllites and arkoses.

Karatepe Köy (Province of Eskişehir) : Quartz-epidote-glaucophane schist — Coll. M.T.A. 44111/4386.

Description: Kraeff.

İkipınar : Quartz chlorite-bearing hematite-magnetite-glaucophane-crossite schist— Coll. M.T.A. 19556.

Description: Ronner —Collected by Kupfahl.

Alpu-Başviran (Province of Eskişehir) : Chlorite-prehnite-glaucophane schist — Coll. M.T.A. 1884/686.

Description: v. d. Kaaden—Collected by Weingart.

Taşköprü-Bondağı (Province of Eskişehir) : Crossite-bearing epidote rock —Coll. M.T.A, 37049/3904.

Description: Markus.

Note: Schurmann (1956, p. 76/77) describes from an area NE of Eskişehir, between Gökdere and Gündüzler, glaucophane-bearing epidote and albite amphibolites, glaucophane-bearing garnet-amphibole-mica-schist, lawsonite-glaucophanite, mica glaucophanite, garnet-glaucophanite, epidote glaucophanite.

8. Mihalıççık area (Province of Eskişehir)

Mihalıççık-Karageyikli:, Glaucophane-bearing epidote-albite schist —Coll. M.T.A. 18893/681.

Description: v. d. Kaaden—Collected by Weingart.

Mihalıççık surroundings (Fig. *4b/c.):* Albite-epidote-glaucophane-calcite schist—Coll. M.T.A. 17148/531.

Albite-glaucophane-epidote schist (with subordinate calcite, magnetite, sericite) — Coll. M.T.A. 17036/485.

Description: Müller—Collected by Weingart.

Pumpellyite-bearing crossite-lawsonite rock—Coll. M.E.T.U. 1064/a.b.

Lawsonitized gabbrqic rock —Coll. M.E.T.U. 1127/1072 ş.

Lawionite-bearing glaucophane rock —Coll. M.E.T.U. 1110.

Albite-quartz-bearing crossite-glaucophane rock (with little calcite). Sphene is a very common mineral in these rocks—Coll. M.E.T.U. 1067.

Description: v. d. Kaaden.

Note: The rocks, of the Mihalıççık area are described in detail by Çoğulu (1966, in print). He considers the age of the metamorphism as Paleozoic in this area.

Mihalıççık-Tatarcık : Glaucophane-bearing epidote-tremolite-chlorite schist — Coll. M.T.A. 18557/661.

Description: v. d. Kaaden—Collected by Weingart.

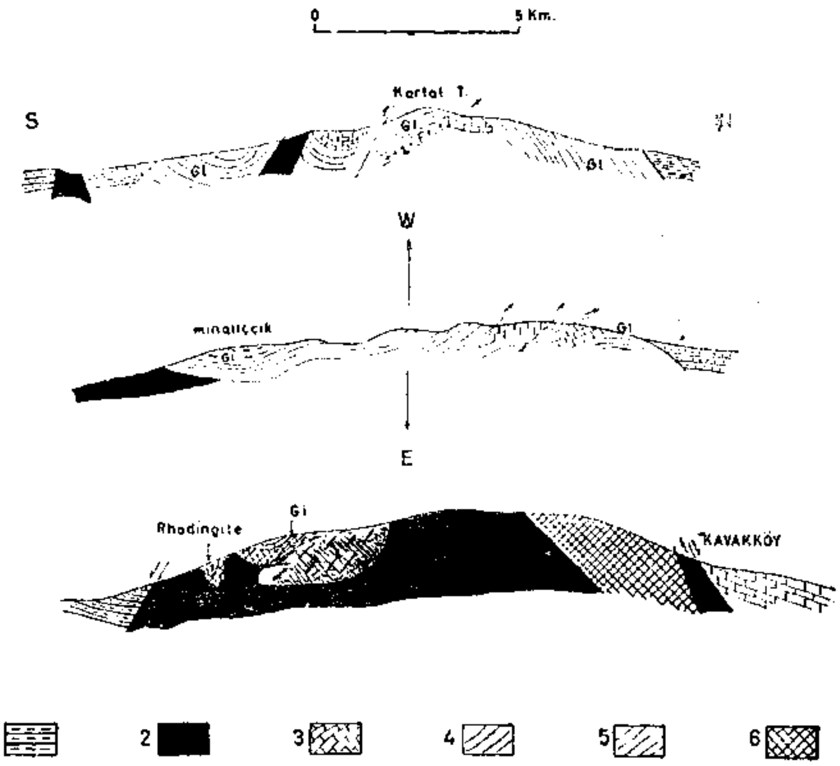


Fig. 4b - Mihalıççık Area

1 - Neogene formations; 2 - Serpentinized ultrabasics; 3 - Marbles; 4 - Glaucophane rocks; 5 - Sericite-quartzite schists; 6 - Epidote-albite schists.

(After Weingart)

Mihalıççık-Belen : Glaucophanc-epidote-mica-schist—Coll. M.T.A. 18606/664.
Description: v. d. Kaaden—Collected by Weingart.

Mihalıççık-Yağaşlar : Glaucophane-tremolite schist —Coll. M.T.A. 18608/664.
Description: v. d. Kaaden—Collected by Weingart.

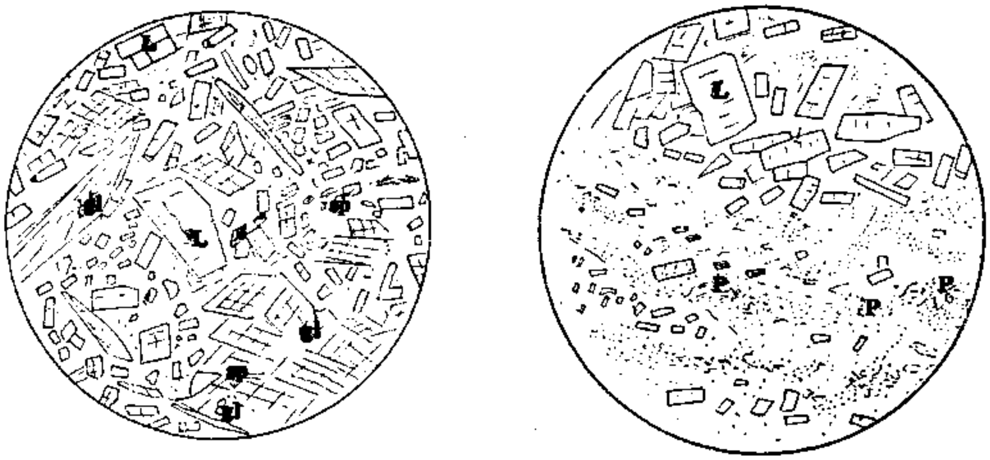
Mihalıççık-Beşpınar : Albite-epidote-glaucophane schist—Coll. M.T A. 18627/666.
Description: de Wijkerslooth.

Mihalıççık-Aktaşlık Tepe : Albite-glaucophane-actinolite-chlorite schist (albite porphyroblasts, sphene) — Coll. M.T.A. 21651.
Description: Kieft—Collected by Jasenko.

Mihalıççık-Beylipınar-İkipınar : Zoisite-bearing chlorite-crossite-glaucophanc schist — Coll. M.T.A. 19556/729.
Description: Ronner—-Collected by Kupfahl.

Mihalıççık-Sekören: Muscovite-stilpnomelane-albite-quartzite—Coll. M.T.A. 23113.
Description: dc Wijkerslooth.

Mihalıççık-Kavak-Güreşköy : Glaucophane schist —Coll. M.T.A. 5846/606.
Description: Schroder — Collected by de Wijkerslooth.



M.E.T.U. coll. no. 1664/a, × 100 **M.E.T.U. coll. no. 1072/a, × 100**

Fig. 4c

L - *lawsonite;* gl - *glaucophane;* sp - *sphene;* P - *granulated clinopyroxene in shear zones.*

Mihalıççık - Çat Yayla : Glaucophane-bearing epidote-chlorite-schist—Coll. M.T.A. 5841/599.

Description: Schroder— Collected by Ziegler.

Mihalıççık-Lütfiye : Quartz-epidote-glaucophane rock —Coll. M.T.A. 8783/1356.

Description: Schroder—Collected by de Wijkerslooth.

9. The area Nallıhan-Ayaş (Province of Ankara)

Nallıhan-Kayapınar-Nallıdere: Epidote-bearing actinolite-crossite-albite schist (sphene, apatite) — Coll. M.T.A. 20990/907.

Description: Kieft — Collected by Rondot.

Nallıhan-Sarıyar - (dam site) : Glaucophane-bearing actinolite-lawsonite schist (glaucophane replaces actinolite, some quartz, calcite, sericite, ilmenite, leucoxene) — Coll. M.T.A. 21126/914.

Lawsonite-scricite-chlorite-quartz-albite schist (sphene, apatite) — Coll. M.T.A. 21127/914.

Description: de Wijkerslooth—Collected by Jasenko.

Glaucophane schist —Coll. M.T.A. 20991/907.

Description: de Wijkerslooth —Collected by Rondot.

Stilpnomelane-bearing quartz-sericite schist (porphyroclasts of quartz)—Coll. M.T.A. 22791/1052.

Description: v. d. Kaaden.

Pumpellyite-albite schist—Coll. M.T.A (porphyroblasts of albite in very fine-grained matrix).

Description: de Wijkerslooth and v. d. Kaaden.

Lawsonite-pumpellyite rock—Coll. M.T.A. 22799.
Description: de Wijkerslooth.

Lawsonite-bearing quartz-albite-sericite-chlorite schist—Coll. M.T.A. 22790/1052.
Description: de Wijkerslooth.

Ayaş-Sorgun : Glaucophane-epidote-muscovite-albite rock (chlorite, calcite, sphene, opaque ore) — Coll. M.T.A. 21135/914.

Glaucophane-epidote-calcite-albite schist (muscovite, chlorite, opaque ore, sphene) — Coll. M.T.A. 21137/914.
Description: de Wijkerslooth — Collected by Jasenko.

10. Ankara-Çubuk area (Province of Ankara) (Fig. 5)

Çubuk-Durhasan : Epidote-glaucophane-bearing chlorite schist — Coll. M.T.A. 6158/678;
Description : Schroder — Collected by Ziegler;

Çubuk-Kaptıboğazı: Epidote-bearing glaucophane-calcite schist — Coll. M.T.A. 17019. This sample is taken from a Liassic conglomerate, where it occurs as a reworked pebble, proving the pre-Liassic age of the glaucophane metamorphism in this area.
Description : Müller — Collected by Erol.

Çubuk-Durhasan : Glaucophane-bearing chlorite-calcite schist (albite, quartz, opaque ore)—Coll. M.T.A. 16496/399.
Description : Müller — Collected by Erol.

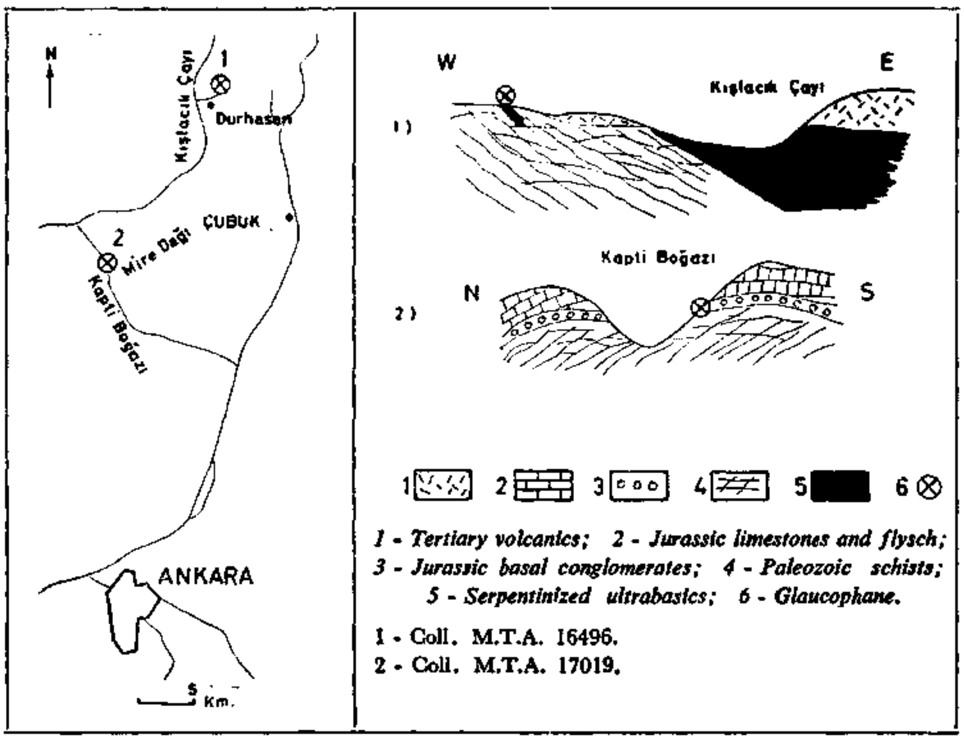


Fig. 5

The sample was taken from a series of quartz sericite phyllites, schistose hematite-quartzites, actinolite rock, near a contact with serpentinites.

Çubuk-Tuğla : Calcite-chlorite-epidote-glaucophane schist (quartz) — Coll. M.T.A. 41172/4208.

Description : Elgin — Collected : by Tokay.

Çubuk-Kuruçay-Bahadarin Tepe : Pumpellyite-albite-crossite schist (calcite, sphene) — Coll. M.E.T.U. Regional Akıman 18.

Description : v.d. Kaaden —- Collected by Akıman.

Note: Other findings are reported by Prof. Dr. M. Tokay from west of Başdedeler Tepe-Kösrelik-Bağlum (oral communication).

III. SOUTH-CENTRAL ANATOLIA

1. The area around Kenya (Province of Konya)

Ilgın : Glaucophane-bearing porphyry — Coll. M.T.A. 20547/887.

Description: Kieft — Collected by Agalede.

Sille : Glaucophane-bearing porphyry — Coll. M.T.A. 20541/887.

Zivarik-Magdos : Glaucophane-sericite-quartzite—Coll. M.T.A. 4012/335.

Description : Schroder — Collected by Ziegler.

Zivarik-Akçasar: Epidote-pumpellyite-bearing glaucophane schist (sphene, fibrous glaucophane) — Coll. M.T.A. 34308/34309-3502.

Albite-epidote-glaucophane schist—34311/3502 (sphene, glaucophane fibrous) — 34312/3502.

Description : Markus & v. d. Kaaden — Collected by Niehoff.

Kadınhanı-Ladik-Avılva Sırtları : Glaucophane-bearing quartz-diabase — Coll. M.T.A. 18815.

Description: v. d. Kaaden.

Karadağ : Epidote-bearing glaucophane-garnct-muscovite quartzite (minerals garnet, glaucophane, epidote are arranged in parallel bands) — Coll. M.T.A. 20157.

Epidote-garnet-bearing calcite-quartzite — Coll. M.T.A. 20158.

Description : Kieft — Collected by Agalede.

Note: Devonian porphyrites in the neighborhood of Sızma, with idioblastic phenocrysts of perthite after sanidine, are full of stilpnomelane (Karatepe).

2. The area Ulukışla-Bolkar Dağları (Province of Niğde) (Fig. 6)

UIukışla-Kızıltepe-Bolkar Dağları: Glaucophane-quartzite — Coll. M.T.A. 11839/2089.

Glaucophane-niica-quartzite — Coll. M.T.A. 11840/2089.

Albite-glaucophane-quartzite — Coll. M.T.A. 11833/2084.

Glaucophane-actinolite-epidote-albite rock—Coll. M.T.A. 11837/2084.

Glaucophane-quartzite — Coll. M.T.A. 11824/2082;

Glaucophane-cpidote-albite rock —Coll. M.T.A. 11827/2082.
Description : de Wijkerslooth — Collected by Blumenthal.

Glaucophane-calcite schist *(Orosoğlu Taşı)*.

Glaucophane-actinolite-albite-schist *(Karataş)*.

Glaucophanite *(Kızıltepe)* — Coll. M.T.A. 11660.
Description: Güler & v.d. Kaaden — Collected by Blumenthal (1954).

Actinolite-glaucophane schist — Coll. M.T.A. 16102/171.
Glaucophane replaces actinolite, length glaucophane 0.1-0.5 mm, X=yellow-colorless, Y=violet, Z=sky blue.) (albite, quartz, sericite).

Chlorite-albite-epidote-glaucophane rock *(Kızıltepe)* (actinolite, transitional to glaucophane, quartz, sphene)—Coll. M.T.A. 16105/171. -

Muscovite-glaucophane-quartzite *(Kızıltepe Yayla)* Blumenthal (1955) (crossite is also present, sphene, opaque ore) —Coll. M.T.A. 16108/171.

Glaucophane quartzite *(Kızıltepe)* —Blumenthal (1955) (carbonate, muscovite, sphene)— Coll. M.T.A. 16109/171.

Epidote-crossite-albite rock *(Madenköy)* — Blumenthal (1955) — Coll. M.T.A. 16028/126.

Garnet-bearing hematite-quartzite *(Göğru Yayla)* —Coll. M.T.A. 16049/162.

[(Crossite axial plane perpendicular (010), 2V (—) small, length fast and length slow is observed], garnet pale yellow-rosa).

Epidote-bearing albite-glaucophane rock *(Karagedik-Sivrihöyük)* Blumenthal (1955) — Coll. M.T.A. 16135.

Glaucophane-bearing albite-epidote rock *(Aydede Başı)* (chlorite, albite) — Blumenthal (1955)—Coll. M.T.A. 16136. *(Karataş Yayla)* — Blumenthal (1954).

Epidote-actinolite-glaucophanc-crossite-albite schist — Coll. M.T.A. 15812/146.

Glaucophane-crossite-albite-calcite schist — Coll. M.T.A. 15809.
Description: v.d. Kaaden — Collected by Blumenthal (1955).

Garnet-bearing albite-glaucophane-crossite schist (calcite, pumpellyite, white mica) — Coll. M.T.A. 43413/4304.
Glaucophane-bearing lime schist — Coll. M.T.A. 43419/4304.
Description : Elgin.

Ulukışla-Saçkaya: Glaucophanized diorite — Coll. M.T.A. 11843/2091.
Description : de Wijkerslooth — Collected by Blumenthal.

İvriz-Kövcelik Tepe-Ereğli (Province of Konya)
Riebeckite-bearing albite diabase — Coll. M.T.A. 15797. (sphene, chlorite, riebeckitc X = dark blue green, Y = yellowish, Z = green-gray, almost parallel extinction.
Description: v.d, Kaaden — Collected by Blumenthal (1954).

The area Bünyan-Pınarbaşı (Province of Kayseri)

Bünyan-Akkışla-Kalulu : Pumpellyite-bearing crossite-albite schist — Coll. M.T.A. 26087/1682).
(chlorite, sphene).
Description: Langenberg & v.d. Kaaden — Collected by Lebküchner.

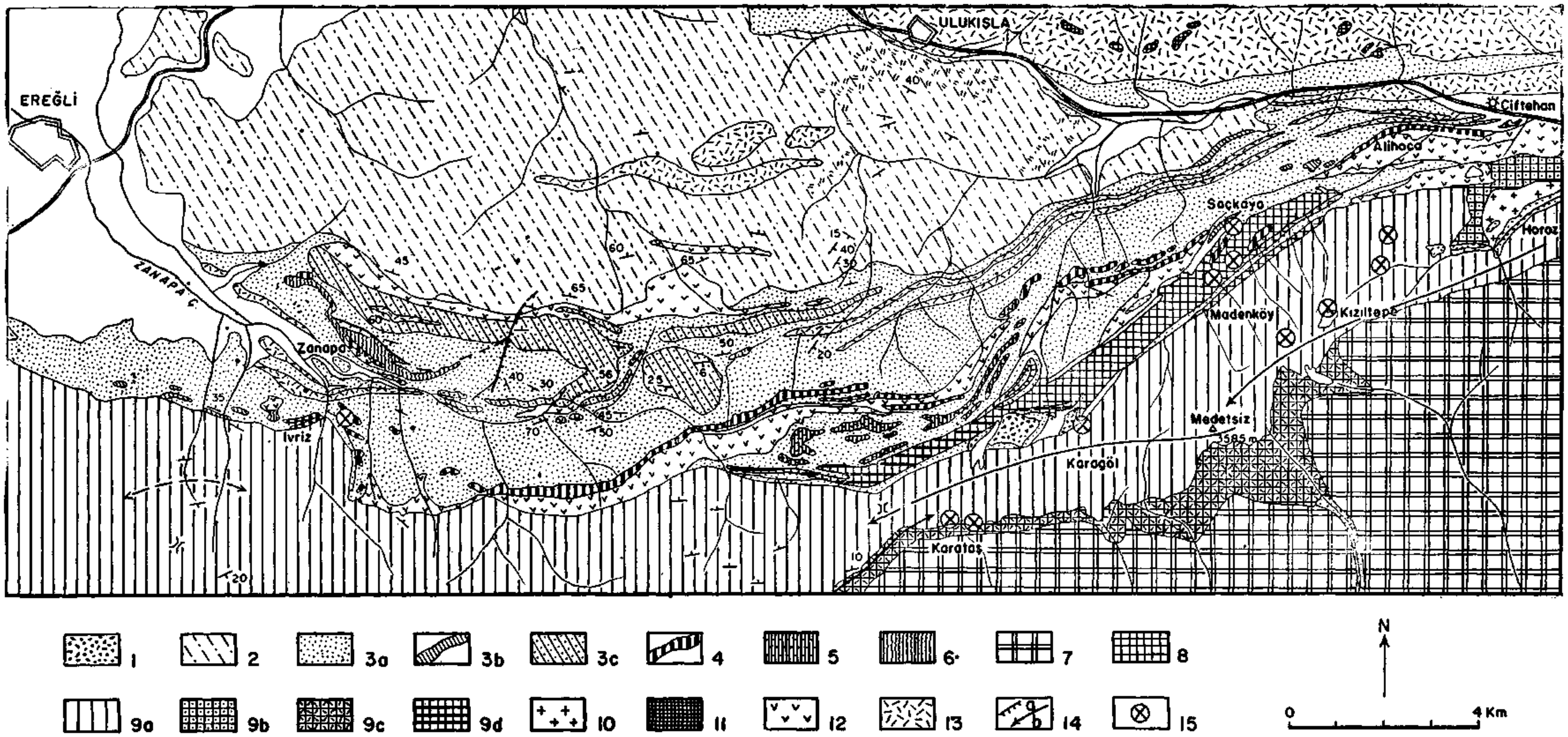


Fig. 6 - The Area Ulukışla - Bolkardağları

1 - Pleistocene debris; 2 - Oligocene formations; 3a - Eocene sediments; 3b - Nummulitic limestones and breccias; 3c - Cungli limestones (probably basal Eocene); 4 - Basmakcı limestone (Paleocene); 5 - Cretaceous limestones; 6 - Lower chert and schist formation (early Mesozoic - late Paleozoic); 7 - Permian limestones; 8 - Paleozoic schists with marble intercalations; 9a - Bolkardağ marble; 9b - Northern phyllite and marble zone; 9c - Southern phyllite and marble zone; 9d - Local larger marble intercalations; 10 - Granite and larger stocks of quartz porphyries; 11 - Syenite; 12 - Ophiolitica (ultrabasics, gabbroic rocks, diabases, spilites, etc.); 13 - Andesites and related rocks; 14 - Faults, anticlinal axes; 15 - Glaucophane rocks.

Glaucophane-bearing actinolite-chlorite-albite schist—Coll. M.T.A. 21634/954.
Description : Kieft —- Collected by Lebküchner.

Bünyan-Süksün : Glaucophanite — Coll. M.T.A. 20429/847.

Glaucophanized effusive rock — Coll. M.T.A. 20430/847.
Description : Kieft — Collected by Lebküchner.

Pınarbaşı-Kaynar-Kavak : Pumpellyite-glaucophane-lawsonite rock — Coll. M.T.A. 26099/1682.
Description : Langenberg — Collected by Lebküchner.

IV. SOUTHWEST ANATOLIA (PROVINCE OF MUĞLA) (Fig. 7)

1. Datça Peninsula-Alavar Mahallesi

Glaucophanized volcanic rock—v.d. Kaaden *et al.* (1954 p .117)—Coll. no. 408. The very dense, compact, bluish-colored rock consists of aggregates and clusters of tiny needles of glaucophane. These needles are often radially arranged in a micro-crystalline groundmass in which albite and chlorite can be recognized. The schlieren texture in the groundmass (bands of different shades) resembles closely a flow texture of former volcanic glass. The needles of glaucophane are deformed in a post-crystalline stage.

This rock is collected from a zone of disturbance of schists, Mesozoic limestones, and flysch sediments, along a tectonic contact with ultrabasics.

Marmaris-Çetibeliköy-Marmaris-Aralık : Glaucophanized spilite—Coll. M.T.A. 21881. Tiny needles of criss-cross orientated glaucophane are located in a groundmass of albite. Pseudomorphs of chlorite after pyroxene are recognizable. Glaucophane=length: width = 1 : 10. Transitions to crossite are seen. Glaucophane X = yellowish, Y = violet, Z = sky blue; crossite X = yellowish, Y = blue, Z = violet.
Marmaris-Aktaş Tepe : Glaucophanized spilite—Coll. M.T.A. 21884.

(Crossite is replaced by glaucophane, little chlorite, epidote).

Çilekli Tepe: v.d. Kaaden *et al.* (1954, p. 117). Glaucophanized «Schalstein» = tuff. The hard, slightly schistose rock consists of numerous angular fragments of clinopyroxene (0.1-0.5 mm) in an extremely fine-grained matrix of albite and chlorite, with needles of actinolite, which are replaced by glaucophane;

Marmaris-Çilekli Tepe : Chlorite-albite-glaucophane schist —Coll. M.T.A. 21887.

The fine-grained schistose rock consists of sodium hornblende (thin needles), which is transitional to glaucophane and actinolite. Glaucophane X = yellowish, Y= violet, Z = blue, length fast (albite, chlorite, both extremely fine-grained).

Çetibeliköy-north of Altın Sivrisi Tepe : Glaucophane schist —Coll. M.T.A. 22158. Thin fibrous glaucophane (up to 0.1 mm length) is located in a cryptocrystalline matrix, with still smaller fibres of glaucophane and fine-grained albite.

Description : v.d. Kaaden — Collected by v.d. Kaaden.

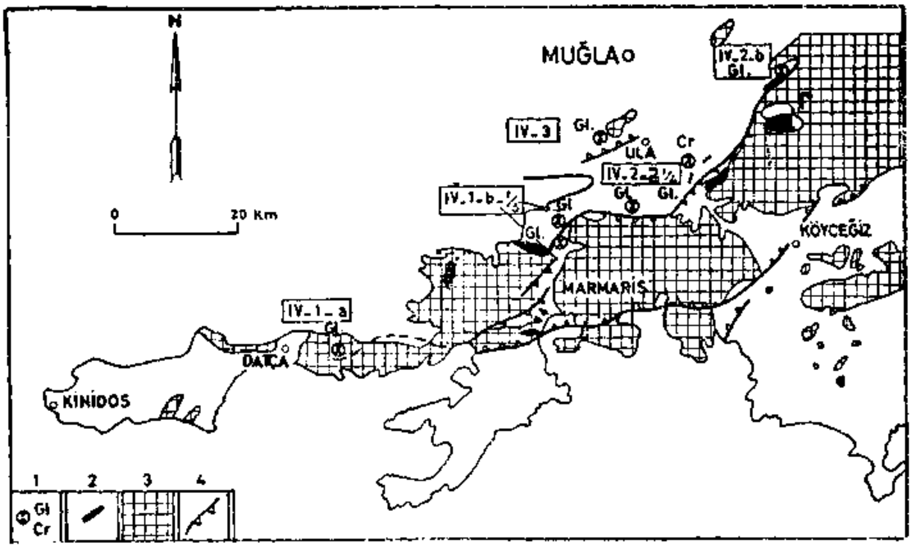


Fig. 7

1 - Gl. = Glaucophane, Cr. = Crossite; 2 - Amphibolites; 3 - Ultrabasics; 4 - Uphtrust zone (hachures on tectonic hanging wall).

Z. Gökova-Karabörtlen

Miyen-Tepe ; Southern plane of Gökova.

Glaucophanized chert — Coll. M.T.A. 22141.

East of Ortaburun : Glaucophanized radiolarian chert — Coll. M.T.A. 22144.

The rock is recrystallized, but pseudomorphs of chalcedony after radiolaria are still preserved. Along shear-zones, fibres of glaucophane (0.05 mm).

These rocks are located in the schist formation of Karabörtlen-Çetibeliköy, which is rich in radiolarian cherts, close to the contact with peridotites.

Karabörtlen-Kışla : Glaucophanized amphibolite —v.d. Kaaden *et al.* (1954, p. 118). Blue-green amphibole is largely replaced along the borders by glaucophane. Quartz occurs as poikilitic inclusions in amphibole (apatite, stilpnomelane).

Glaucophane-bearing amphibole quartzite—Coll. M.T.A. 22146.

North of Karabörtlen : Stilpnomelane-bearing crossitite—Coll. M.T.A. 21784. — Coll. M.T.A. 21790.

The rock is taken from a metamorphosed basic dike rock, intercalated in a series of semi-phyllites.

All transitions are present from quartz-chlorite schist to albite-amphibolites, crossite - bearing amphibolites, and compact stilpnomelane-bearing crossitite.

The rocks were subjected to pre-crystalline deformation and are fine-grained; they were also post-crystalline deformed (sphene, apatite, magnetite, sodium pyroxene).

Çakmak Mahallesi : Glaucophane-bearing garnet-amphibole-quartzite — Coll. M.T.A. 19774/79/601x.

The banded rock consists of quartz-rich and amphibole-rich bands. Quartz shows mosaic texture and is anomalous. In the quartz-rich parts idiomorphic garnets

(0.1-0.3 mm) are concentrated. The amphibole is glaucophanized along its borders.

Subordinate : rutile, apatite, opaque ore.

Description : v.d. Kaaden — Collected by v.d. Kaaden.

3. Ula-Kyllandos

v.d. Kaaden *et al* (1954, p. 99).

In the imbricated zone of Ula, Mesozoic rocks, strongly disturbed serpentinized peridotites, and crystalline schists are mixed. From this zone a glaucophanized chert became known.

The rock consists of a strongly strained, almost mylonitized quartz mosaic. Intergrown with quartz are very small, radially arranged, fibres of glaucophane. Idioblastic albite is formed after the deformations.

Note : Near these rocks chloritoid-bearing schists are common.

Description : v.d. Kaaden — Collected by v.d. Kaaden.

Note : Rosenbusch (1923) mentions glaucophane rocks from the area of Izmir, but no later findings in this area became known to the author.

See also Oebbeke : «Ueber das Vorkommen des Glaukophan. Ztschr. Krystallographie und Mineralogie», 12 Bd. 1887, p. 205, who mentions glaucophane from «Eski İzmir» (Old Smyrna).

AGE RELATIONS OF THE GLAUCOPHANITIC GREENSCHIST FACIES AND THE LAWSONITE-GLAUCOPHANE FACIES FOR THE DIFFERENT AREAS OF TURKEY

(Plate I)

I. NORTHERN ANATOLIA

The age of the metamorphism is probably Cretaceous or at all events it seems to be a post-Paleozoic metamorphism. Only the glaucophanitic greenschist facies is represented. The samples, known to us, represent metamorphosed basic rocks or basic pyroclastics.

Although, certainly Paleozoic metamorphic series are represented in the area, Ketin (1962, p. 62) states: «On the other hand, the metamorphic series contain a rather important amount of greenschists, serpentine schists, red radiolarite-schists, slightly metamorphosed schists, diabases and even red limestones. All these belong to ophiolitic formations of Cretaceous age (mostly Upper Cretaceous) and contain red limestones and crystallized Globotruncana (Rosalina). Such formations occur as large outcrops between the metamorphic series at massifs of Daday, Ilgaz, Amasya and Tokat,» and (p. 61) : *«The Ilgaz Mountains massif...* Large volumes of serpentine-gabbro masses, diabase beds, red radiolarite schists with glaucophane and mica-schist are also present.» and further (p. 61): *«Mountain chains south of Çorum-Mecitözü:* The metamorphic series in these mountains and the crystalline mass of Deveci Mountains display similar geological and lithological characteristics. Here too, the dominating rocks are the greenschists, ophiolitic intercalations, sericite-chlorite schists, quartzitic phyllites, marbles and semi-marbles.» and on page 62: «Interfingerhig between the ophiolitic formations and metamorphic schists can be seen at various localities along the Kastamonu-Tosya, Ilgaz - Tosya, Tosya-Kargı and Kargı-Durağan highways.»

The samples discussed come from the above-mentioned areas.

According to Ketin (1962, p. 63), *Globotruncana* aff. l*innei* d'Orb. was also found, more or less crystallized, in red limestones cropping out together with serpentines and radiolarites included in the metamorphic series, between Ilgaz and Tosya.

The geosynclinal phase in this region lasted, according to Ketin, till the Maestrichtian period. The metamorphic rocks are covered by sandy limestones deposited by a Maestrichtian-Paleocene transgression.

II. WEST-CENTRAL ANATOLIA

The age of the metamorphism in the glaucophanitic greenschist facies and the lawsonite-glaucophane facies is considered by the author for this part of Turkey as Paleozoic for the following reasons :

1. The epi-metamorphic formations, including glaucophane rocks, are in several places covered by non-metamorphic conglomerates of Middle-Upper Triassic and Liassic age. This was observed:

a. *In the Edremit region* (by v.d. Kaaden) : here Middle Triassic conglomerates are on top of Paleozoic granites. The conglomerates contain pebbles of metamorphic formations. In the same area Middle Permian limestones are in discordant position on top of the metamorphic series (G.v.d. Kaaden, 1959b, p. 20, 21.) Similar observations are made from the Balya area by Bittner (1890), Neumayr (1887) and Aygen (1956).

b. *Near Çan* (by v.d. Kaaden, 1959b, p. 22), where fossiliferous Liassic formations rest on top of the epi-metamorphic series.

c. *From Söğüt* (by v.d. Kaaden, Kupfahl and Niehoff — non-printed M.T.A. reports), where Liassic conglomerates rest on top of Paleozoic granites, which are intrusive in the cpi-metamorphic glaucophane-bearing formations.

d. *From north of the Uludağ* (by Erk, 1942), where Upper Triassic conglomerates contain pebbles of metamorphic schists.

e. *Near Çubuk,* where Erol (1953) found Liassic conglomerates containing pebbles of glaucophane rock on top of ultrabasics near Kaptıboğazı.

f. *Between Yakacık Köy and Sirkeli north of Ankara,* Paleozoic schist, including glaucophane schist, are overlain by Permian limestones and dolomites and Liassic beds, starting with a basal conglomerate. This conglomerate also contains *pebbles of glaucophane rocks* (oral communication by Prof. Dr. Melih Tokay).

2. Late Paleozoic granitic-granodioritic intrusions, are intruded in the epi-metamorphic formations in several places. In one place v.d. Kaaden (1959, p. 28) could prove that the glaucophane metamorphism was destroyed by the contact-metamorphism in the aureoles. The Paleozoic age of these intrusions is proved by pebbles of granites and granodiorites in Middle Triassic conglomerates near Edremit and in Liassic conglomerates near Söğüt and in Middle Permian formations, north of Uludağ (Erk, 1942, p.47), at Dişkaya Dağ.

3. Ketin (1963, p. 39-40) states: «In the northwestern corner of the map, the extension of the Paleozoic massif of Ankara continues along the road... In this part of the area are observed mostly epizonal metamorphic schists, chlorite-sericitic-calcareous schists, phyllites and graywackes with schists in the form of thin layers and semi-marbles. Towards the west, however, mica-schists, glaucophane schists and, in general, green schists predominate.» And : «The age of this formation, which is named in the Ankara section as the «Dikmen series», is not definitely determined (O. Erol, 1956). On the other hand, fossiliferous (Fusulinidae) and sandy limestone formations belonging to the Permo-Carboniferous overly this series both at Dikmen and near Lalabel Station. Hence, the metamorphic series is older than Pcrmo-Carboniferous. The Visean conglomerates, observed by Chaput (1936) at Ludumu, also rest on this series.»

The glaucophane-lawsonite metamorphism in the Mihalıççık area is proved to be somewhat younger than the emplacement of the ultrabasics in that area. Lawsonite is described by Çoğulu (1965) from metadiabases, pillow lavas, glaucophane schists, retrograde metamorphosed gabbroic inclusions in the ultrabasics, and from amphibolites. Also the minerals pumpellyite, jadeitic pyroxene, and stilpnomelane are widespread. Fragments of eclogites, tectonically transported from depth, retrogradically metamorphosed in the lawsonite-glaucophane facies, as well as rhodingites, are also reported by him.

A strong deformation and granulation, prior to the metamorphism is proved from this area.

From other areas, but also from the Mihalıççık area, it is established without doubt, that the intrusion of the Late Paleozoic granites and granodiorites is younger than the emplacement of the ultrabasic rocks in that area, as these granites arc intrusive in the ultrabasics in several places.

Combining the observed and reported facts of the area of West-Central Anatolia, the author is certain that there existed in this part of Turkey an early Paleozoic Variscan geosyncline filled with basic volcanic rocks, tuffs, graywackes, radiolarian cherts, with some limestone intercalations, in which at an initial stage, ultrabasics were emplaced, perhaps coinciding with strong local deformative forces. The geosyncline became now deep enough (the temperature remained relatively low) to create the P.T. conditions necessary for the formation of the lawsonite-glaucophane facies. Where the thermal gradient was steeper in neighboring parts of the geosyncline, the glaucophanitic-greenschist facies developed or the chlorite facies of the Dalradian type with chloritoid. Much later, probably during Upper Carboniferous - early Permian, time, late tectonic intrusions of granites-granodiorites. in already metamorphosed and folded series, destroyed the glaucophane metamorphism in their aureoles. Middle Permian, Triassic and Liassic conglomerates prove the subsequent period of upheaval and erosion.

Also the presence of the mineral chloritoid in certain parts of the area, as near Söğüt, Sivrihisar, south of Uludağ, are in strong support for a deep geosyncline, under relatively low temperatures.

III. SOUTH-CENTRAL ANATOLIA

Here the age of the metamorphism is more difficult to establish.

1. The area around Kenya

The glaucophane rocks are located in Paleozoic formations. Only the glaucophanitic greenschist facies is developed here. Basic and less so psammitic rocks are represented. Devonian porphyritic flows at Kara Tepe, near Sızma, are slightly metamorphosed and contain in certain places abundant newly formed stilpnomelane and also in the neighborhood of Karadağ, Zivarik, Ilgın, Ladik, the glaucophane rocks are located in Paleozoic formations showing geosynclinal facies. It is possible, but not proved, that the glaucophane metamorphism of these rocks belongs to the metamorphism of the southeastern continuation of the Variscan geosyncline, described above. This is supported by the fact, that the Alpine geosyncline is located to the south and that the area under consideration reacted more or less cratogenic during the Alpine diastrophism. Discontinuous Mesozoic formations are in carbonate facies and poorly developed. The presence of stilpnomelane is also in favor of low temperatures and high confining pressures.

2. Ulukışla-Bolkar Dağları (Fig. 6)

Blumenthal (1955) in describing the glaucophane rocks of this area, attributes these rocks to metasomatic «contact» phenomena during the emplacement of the ultrabasics. Although his interpretation seems doubtful, it seems highly probable that the time of emplacement was more or less simultaneous with P.T. conditions, favorable for the development of the glaucophanitic greenschist facies. Basic and less so psammitic-pelitic rocks are represented.

The time of emplacement of the ultrabasics is not certain, but Blumenthal is in favor of an Alpine emplacement. At all events, the emplacement is pre-Tertiary, as already pebbles of ultrabasics are found in Paleocene formations. The Bolkar Dağları are upthrown and overturned to the north and represent the northern flank of the Toros Dağları in this area. The Bolkar Dağları consist of strongly recrystallized limestones of great thickness within its upper part schistose semi-phyllitic formations. The age is considered as Triassic to Permian (Wippern, 1964, p. 77). Glaucophane rocks occur; (1) along the summit region as a row of isolated outcrops in the semi-crystalline limestones, in the close vicinity of lenses of ultrabasics, or tremolite schists, and (2) as a row of occurrences directly north of the upthrust zone, in a mixed zone of low-grade metamorphic schists, lenses of serpentine, vertically inclined lenses of Cretaceous limestones, etc.

It seems highly probable, but not proved, that the age of the glaucophanitic metamorphism in the Bolkar Dağları area was of Alpine age. As all the glaucophane occurrences are in tectonic contacts, it may be possible that they represent older rocks, which were tectonically transported from depth, together with the emplacement of the ultrabasics, during Alpine diastrophism.

3. The Bünyan-Pınarbaşı area

In this area, consisting of slightly metamorphic Paleozoic formations, the lawsonite-glaucophane and the glaucophanitic-greenschist facies are developed. Only basic rocks are represented. Also here as in the Konya area, the region is located north of the Toros Range, and behaved more or less cratogenic during the Alpine diastrophism. It seems possible, but not proved, that the glaucophanization and lawsonitization is of Variscan age. Perhaps we have here the eastern continuation of the Variscan geosyncline, discussed above, extending over the Konya area. The shape of this old geosyncline suggests that in its eastern part it was bounded by an old cratogenic block in the north.

The presence of the mineral lawsonite is in favor of relatively low temperature and high confining pressures in this part of the geosyncline.

IV. SOUTHWEST ANATOLIA (Fig. 7)

According to v.d. Kaaden (1959 a, p. 3/4) the metamorphism in the glaucophanitic greenschist facies in the Datça - Marmaris - Çetibeliköy - Gökova - Karabörtlen - Ula area of Muğla is older than the pure dynamic metamorphism which accompanied the overthrust movement of early Tertiary age. It is younger than the amphibolites, radiolarian cherts, spilitic rocks and phyllitic schists. It might be somewhat later than the first emplacement of the ultrabasic rocks. Close to the glaucophane occurrences of Ula (v.d. Kaaden *et al.,* 1954, p. 99) the greenschist facies contains chloritoid, and all the emery deposits of Greece and Turkey contain this mineral in more or less degree. In the upper part of the Lower Permian at Gök Tepe, consisting of fetid fossiliferous limestones with quartzite intercalations, the quartzitcs are full of newly formed chloritoid (v.d. Kaaden *et al.,* 1954, p. 103). According to recent investigations by Wippern (1964, p. 77),Triassic formations arc still involved in the metamorphism. The metamorphism of the glaucophanitic greenschist facies might be somewhat older than the granitization of the Menderes crystalline, which raised the geothermal gradient in its aureoles, and is estimated by Wippern (1964, p. 77) as early Jurassic. Wippern (1964, p. 80) estimates the initial magmatism in the area at late Permian early Mesozoic. At all events the ultrabasic rocks of the Marmaris - Fethiye area seem to be pre-Middle Cretaceous (v.d. Kaaden, 1959 a, p. 2), as Middle Cretaceous rests on top of ultrabasics in the area SE of Dalyan Later the ultrabasics were involved in strong Alpine movements and upthrusted on younger formations, but no metamorphism was involved here.

It seems highly probable that the glaucophanization of this area belongs to an early stage of the Alpine orogenetic cycle. The glaucophanitic greenschist facies extends to the west, over the Greek archipelago into the Greek mainland, as can be seen on the map on which the glaucophane occurrences, known to the author, are compiled. Also here the metamorphism is considered as Alpine. The glaucophane occurrence mentioned by Rosenbusch probably also belongs here. This arc of glaucophane occurrences in the southwest of Turkey, with its prolongation into Greece, has, in the opinion of the author, no connection with the glaucophane occurrences which can be traced from the West - Central - Anatolian zone of Variscan age to the west along Salonika - Greece, to the Skoplje-Raduscha area in Yougoslavia.

The glaucophane rocks of the Datça-Marmaris-Karabörtlen area, occur as isolated occurrences, mostly located along the northern zone of disturbance, which is upthrown on Paleozoic formations and has much in common with the Bolkardağ area. The southern zone of disturbance, where the ultrabasics are upthrown to the south on top of Cretaceous formations, does not contain glaucophane occurrences. Spilitic rocks, basic dike rocks, amphibolites, and radiolauan cherts are represented among the glaucophane rocks of this area. It is possible that locally tectonic overpressure was active during the formation of the glaucophane rocks. It is also certain that some of these occurrences are tectonically transported. The glaucophanized radiolarian cherts suggest that, locally at least, metasomatic processes were involved. The coexisting of glaucophane and chloritoid is in favor of relatively low temperatures and high confining pressures in this part of the geosyncline.

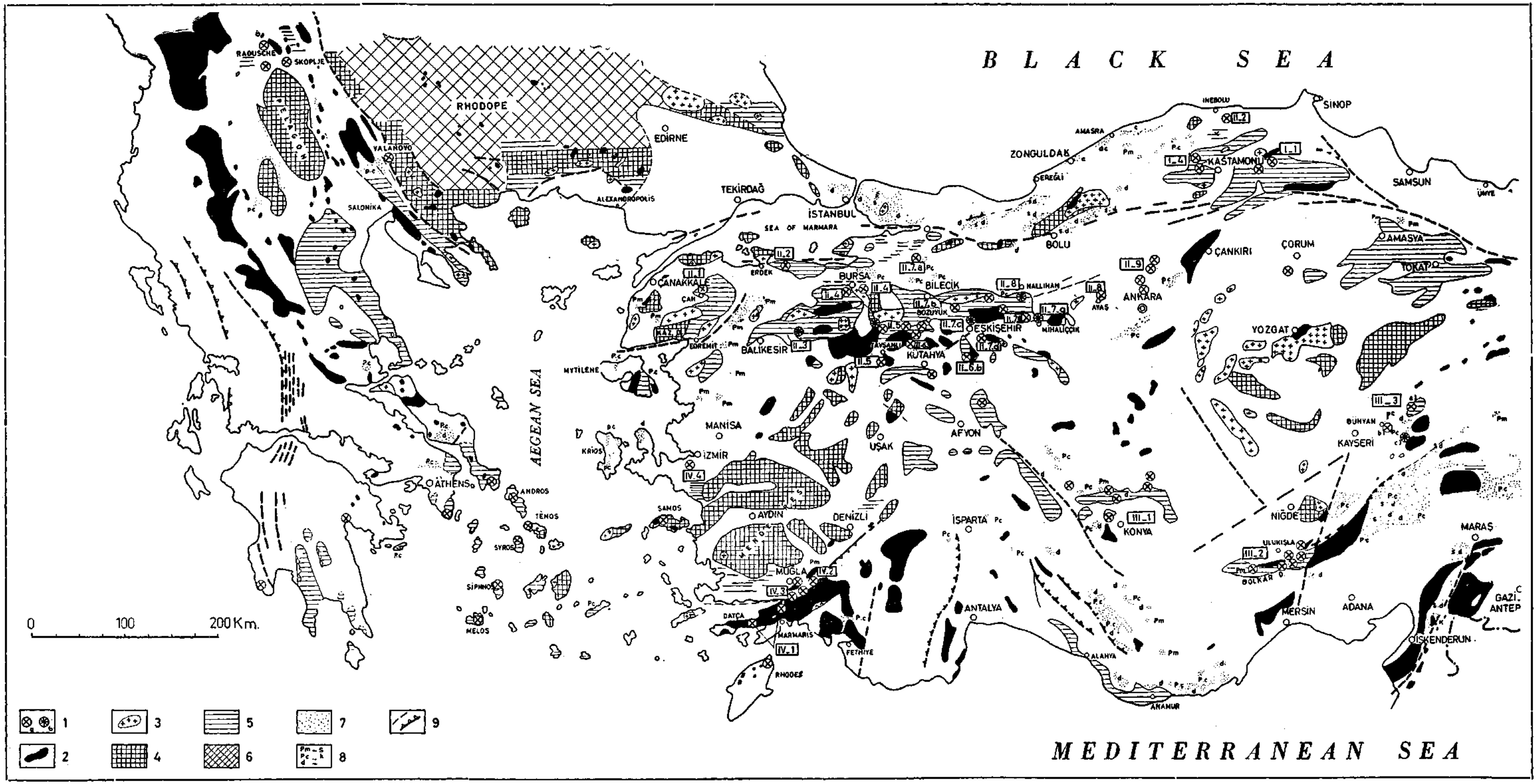
CONCLUSIONS

It was shown that in Turkey exist at least four separate areas with glaucophane rocks. 7. *Northern Anatolia:* Here the age of the metamorphism is considered as Alpine (Cretaceous ?). Only rocks in the glaucophanitic greenschist facies are represented. //. *West-Central Anatolia:* Here the age of the metamorphism is considered as Variscan (early Paleozoic). Rocks in the lawsonite-glaucophane and in the glaucophanitic greenschist facies are represented. III. *South-Central Anatolia:* The metamorphism in the Konya and Bünyan-Pınarbaşı area is considered as Variscan (early Paleozoic), the metamorphism in the Bolkardağ area as early Alpine, but proof is lacking. In the Konya and Bolkardağ areas only the glaucophanitic grcenschist facies, in the Biinyan-Pınarbaşı area the glaucophanitic greenschist facies and the lawsonite-glaucophane facies are represented. *IV. Southwest Anatolia:* The metamorphism of this area is considered as early Alpine. Only the glaucophanitic greenschist facies is represented.

It is shown that two different areas of glaucophane rocks can be followed into Greece and the Balkans. *A northern one* south of the Istranca massif, containing the district II of West-Central Anatolia with perhaps Konya and Bünyan-Pınarbaşı areas of district III along Salonika in Greece, to Skoplje-Raduscha in the Balkans, and *a southern one,* following the northern side of the Toros Range, from the Bolkardağ in the east, with a large interruption to the Karabörtlen-Ula-Marmaris-Datça area in the west into Greece over the Greek archipelago.

The northern one is considered by the author as Variscan, the southern one as early Alpine. A continuation of the glaucophane metamorphism of Alpine age (Cretaceous?) of Norhern Anatolia, to the west, to be expected north of the Istranca massif is not known to the author. As pointed out recently by de Roever (1965), glaucophane metamorphism in pre-Alpine metamorphic areas seems to be extremely rare, and until now, the lawsonite-glaucophane facies has not been proved from pre-Alpine metamorphic areas. On the other hand, Kanissawa (1964) described a glaucophanitic greenschist facies of pre-Devonian age from the Matai district in the Kitakami Mountains in Japan, from a series of basaltic rocks, tuffs and pelitic sediments. Alpine formed glaucophane rocks are however also known from other areas in Japan. Other old Paleozoic areas with glaucophanitic metamorphism are known from Anglesey (Scotland), İle-de-Croix (France), European Urals and Queensland (East Australia). These areas are not studied in detail, but until now no lawsonite became known from them.

As it seems however highly probable that the lawsonite-glaucophane facies in West-Central Anatolia is of early Paleozoic age, the rule that lawsonite is restricted to Alpine metamorphism, as stated by de Roever (1965) and Winkler (1965. p. 151) has its exceptions.



MAP SHOWING DISTRIBUTION OF GLAUCOPHANE AND LAWSONITE ROCKS IN TURKEY - GREECE AND PART OF YOUGOSLAVIA

[Compiled after geological maps of Greece and Turkey 1 : 500 000 , annex VIII of Hiessleitner (1951/2), fig. V of v.d. Plas (1959), Archives of M.T.A. literature referred in text, and own observations.]

1 - X = glaucophane rocks; ⊗ = lawsonite rocks; 2 - Ultrabasic rocks and gabbroic inclusions; 3 - Pre-Tertiary granites and granodiorites (in Turkey mainly pre-Mesozoic); 4 - High-grade metamorphic complexes; 5 - Low-grade metamorphic complexes; 6 - Rhodope crystalline complex (not differentiated); 7 - Non-metamorphic Paleozoic formations; pm = Permian, p.c. = Permo-Carboniferous, c = Carboniferous, d = Devonian, s = Silurian, k = Cambrian 8 - Non-metamorphic Mesozoic and Tertiary formations (including extrusive rocks of that age); 9 - Major fault and thrust zones (hachures on tectonic hanging wall).

After the glaucophane rocks were destroyed in the aureoles of the late-tectonic batholiths of West-Central Anatolia, the remaining parts outside the sphere of influence of the batholiths were protected, and the area reacted cratogenic during the Alpine orogenesis, which in these parts was not very impressive.

In the Alps, the orogenetic movements were much stronger than in this part of Turkey, and this may be one of the reasons that lawsonite was able to survive in the West-Central part of Anatolia under these special conditions. In the Toros Range the glaucophanitic greenschist facies is only locally and sporadically developed. Here the age is probably early Alpine as stated previously. Another glaucophane occurrence became known from the east of Turkey, in the south of the Bitlis massif in a zone of Upper Cretaceous - early Tertiary geosynclinal spilites, diabases and sediments at Kulp (glaucophane quartzite schist— M.T.A. coll. 11668, Description: Güler). In between this finding and the occurrences of the Bolkardağ no other glaucophane rocks became known from the Toros Range and its near surroundings until now. One of the reasons might be that the Toros geosyncline was never very deep in most of its parts and the P.T. conditions required for the formation of the lawsonite-glaucophane or the glaucophanitic greenschist facies were not reached.

Manuscript received May 16, 1966

REFERENCES

AYGEN, T. (1956) : Etude geologique de la region de Balya. *M.T.A. Publ.,* ser. D, no. 11, Ankara.

BANNO, S. & KANEHIRA, K. (1961) : Sulfide and oxide minerals in schist of the Sanbagawa and central Abukuma metamorphic terranes. *Jap. J. Geol. and Geogr.,* 32, 331-48.

BEARTH, P. (1959) : Ueber Eklogite, Glaucophanschiefer und metamorphe Pillowlaven. *Schweiz. min. petrogr. Mitt.,* 39, 267-86.

———(1962) : Versuch einer Gliederung alpinometamorpher Serien der Westalpen. *Ibid.* 42, 127-137.

———(1963) : Chloritoid und Paragonit aus der Ophiolit-Zone von Zermatt-Saas. *Ibid.* 43, 269-286.

BITTNER, A. (1890) : Brachiopoden der Alpinen Trias. *Abh. d. K. K. geol. Reichsanstalt,* Band 14, Wien.

BLOXHAM, T. W. (1956) : Jadeite-bearing metagraywackes in California. *Am. Min.,* 41, 488-96.

———(1960): Jadeite rocks and glaucophane schists from Angel Island, San Francisco Bay, California. *Am. J. Sci.,* 258, 555-73.

BLUMENTHAL, M. M. (1955) : Geologie des hohen Bolkardağ, seiner nördlichen Randgebiete und westlichen Auslaufer. *M.T.A. Publ.,* ser. D, no. 7, Ankara.

BROTHERS, R. N. (1954) : Glaucophane schist from North Berkeley Hills, California. *Amer. J. Sci.,* 252, 614-26.

BROWN, W. H.; FYFE, W. S. & TURNER, F. J. (1962) : Aragonite in California, glaucophane schists and the kinetics of the aragonite-calcite transformations. J. *Petrology,* 3, 556-82,

CHAPUT, E. (1936) : Voyages deludes geologiques et geomorphologiques en Turquie. Paris.

CLARK, S. P. (1957) : A note on calcite-aragonite equilibrium. *Amer. Min.,* 42, 564-66.

———(1961) : A rcdetermination of equilibrium relations between kyanite and sillimanite. *Am. J. Sci.,* 259, 641-50.

COLEMAN, R. G. & LEE, D. E. (1963) : Glaucophane-bearing metamorphic rock types of the Cazadero Area, California. *J. Petrology,* 4, 260-301.

ÇOĞULU, E. (1965) : Remarques sur les schistes a glaucophane et lawsonite de la region de Mihalıççık (Turquie). *Arch. Sciences, Soc. Phys. Hist Nat. Geneve,* 18, 126-31.

COOMBS, D. S. (1953) : The pumpellyite mineral scries. *Min. Mag,,* 30, 113-35.

———(1960): Lawsonite metagraywackes in New Zealand. *Amer. Min.,* 45, 454-5.

———; ELLIS, A. J.; FYFE, W. S. & TAYLOR, A". H. (1959) : The zeolite fades, with comments on the interpretation of hydrothermal synthese. *Univ. of Otago, Dept. of Geol.,* Publ. no. 250, New Zealand.

CRAWFORD, W. A. & FYFE, W. S. (1965) : Lawsonite equilibria. *Am. J. Sci.,* 263, 262-270.

ELLENBERGER, F. (1960) : Sur une paragenese ephemere a lawsonite et glaucophane dans le metamorphisme alpin en Haute-Maurienne (Savoie). *Bull. Soc. Geol France, 7.* serie 2, 190-94.

EROL, O. (1954) : *M.T.A. Rep. no.* 2026 (unpublished), Ankara.

———(1956) : A study of the geology and geomorphology of the region SE of Ankara in Elmadağı and its surroundings. *M.T.A. Publ.,* ser. D, no. 9. Ankara.

ERK, S. (1942) : Etude geologique de la region entre Gemlik et Bursa (Turquie). *M.T.A. Publ.,* ser. B, no. 9, Ankara.

ERNST, W. G. (1963) : Petrogenesis of glaucophane schist. *J. Petrology,* 4, 1-30.

ESKOLA, P. (1929) : Om Mineralfacies. *Geol. Fören. Stockholm, Förh.* 51, 157-71.

———(1939) : Die Entstehung der Gesteine (Barth-Correns, Eskola), Berlin.

GHENT, D. E. (1965) : Glaucophane-schist facies metamorphism in the Black Butte Area, Northern Coast Ranges, California. *Amer. J. Sci.,* 263, 385-400.

HIESSLEITNER, G. (1951/1952): Serpentin- und Chromerz Geologie der Balkanhalbinsel und eines Teiles von Kleinasien. Sonderband 1, 2, *Jahrbuch d. geol. Bundesanstalt,* p. 449, Wien.

KAADEN, G. v. d. & METZ, K. (1954) : Beitrage zur Geologie des Raumes zwischen Datça-Muğla-Dalaman gay (SW Anatolien). *Bull. Geol Soc. of Turkey,* vol. 71-171, Ankara.

———(1959a) : On relationship between the composition of chromites and their tectonic-magmatic position in peridotite bodies in the SW of Turkey. *M.T.A. Bull.* no. 52, 1-15, Ankara.

———(1959b) : Age relations of magmatic activity and of metamorphic processes in the northwestern part of Anatolia-Turkey. *M.T.A. Bull.* no. 52, 15-34, Ankara.

KANEHIRA, K. & BANNO, S. (1960) : Ferriphengite and aegirine jadeite in a crystalline schist of the limori District, Kii Peninsula. J. *Geol. Soc. Jap.,* 66, 654-9.

KANNISAWA, S. (1964) : Metamorphic rocks of the southwestern part of the Kitakami mountainland, Japan. *Sci. Report Tohuku Univ.,* third series, IX, 155-98.

KETİN, İ. (1962) : Explanatory text of the geological map of Turkey, 1:500,000- Sinop. *M.T.A. Publ,* pp. 60-63, Ankara.

———(1963) : Explanatory text of the geological map of Turkey, 1-.500,000- Kayseri. *M.T.A. Publ,* pp. 39-40, Ankara.

KÖHLER, A. & RAAZ, F. (1951) : Ueber eine neue Berechnung und graphische Darstellung von Gesteinsanalysen, *Neues J. Min. Mit.,* 247-63.

MAUCHER, A.; SCHULTZE-WESTRUM, H. & ZANKL, H. (1962) : Geologische Lagerstattenkundliche Untersuchungen im Ostpontischen Gebirge. *Bayr. Akad. Wiss.,* Neue Folge. 109.

MILCH, L (1907) : Ueber Glaukophan und Glaukophangesteine vom Elek Dağ (nordliches Kleinasien) mit Beitragen zur Kenntnis der chemischen Beziehungen basischer Glaukophangesteine. *Neues Jb. Min. Geol und Pal,* Festband (1907), 348-96.

MIYASHIRO, A. & BANNO, S. (1958) : Nature of glaucophanitic metamorphism. *Amer. J. Sci.,* 256, 97 110.

McKEE, B. (1962) : Aragonite in the Franciscan rocks of the Pacheco Pass area, California. *Amer. Min.,* 47, 379 87.

NEUMAYER, M. (1887) : Über Trias und Kohlenkalkversteinerungen aus dem westlichcn Kleinasien. *Anz. d. Kais. Akad. d. Wiss.*, Wien.

NIGGLI, P. (1948) : Gesteine und Minerallagerstatten. Bd. I, p. 27, Basel.

PISTORIUS, G.W.F.T.; KENNEDY, G.G. & SOURIRAJAN, S. (1962) : Some relations between the phases anorthite, zoisite, lawsonite at high temperatures and pressures. *Amer. J. Sci.*, 44-56.

PLAS, L. van der (1959) : Petrology of the northern Adula region, Switzerland. *Leid. geol. Meded.* 24, 418-598.

ROEVER, P. W. de (1950) : Preliminary notes on glaucophane-bearing and other crystalline schists from southeast Celebes, and on the origin of glaucophane-bearing rocks. *Proc. Kon, Ned. Ak.* Wet. 53, 1455-65.

———(1955a) : Some remarks concerning the origin of glaucophane in the North Berkeley Hills, California. *Amer. J. Sci.*, 253, 240-4.

———(1955b) : Genesis of jadeite by low-grade metamorphism. *Amer. J. Sci.*, 253, 283-98.

———(1956) : Some additional data on the crystalline schists of the Rumbia and Mendoka Mountains, south-east Celebes. *Ver. Kon. Ned. Geol. Mynb. Gen.*, 16, 385-93.

———(1965) : On the cause of the preferential distribution of certain metamorphic minerals in orogenic belts of different age. *Geologische Rundschau*, 54, 933-44.

ROSENBUSH, H. & OSANN, B. (1923) : Elemente der Gesteinslehre. Stuttgart.

SCHURMANN, H.M.E. (1951) : Beitrage zur Glaucophanfrage (1). *N. Jb. Min. Mon.*, 49-68.

———(1953) : Beitrage zur Glaucophanfrage (2). *N. J. Min. Abh.*, 85, 303-394.

———(1956) : Beitrage zur Glaukophanfrage (3). *Ibid.* 89, 41-85.

TALIAFERRO, N. L. (1943) : Fransiscan-Knoxville problem. *Amer. Assoc. Petrol. Geol. Bull.*, 27, 109-219.

TURNER, F. J. & VERHOGEN, J. (1960) : Igneous and metamorphic petrology. *McGraw-Hill*, New York, p. 459.

WINKLER, H.G.F. (1965) : Die Genese der metamorphen Gesteine. *Springer Verlag*, Berlin.

WIPPERN, J. (1964) : Die Stellung des Menderes Massivs in der alpidischen Gebirgsbildung. *M.T.A. Bull.* no. 62, 83-90.

WIJKERSLOOTH, P. de (1941) : Einiges über den Magmatismus des jüngeren Palaeozoikums (des Varistikums) in Raum west-Zentral Anatoliens. *M.T.A. Mecm.*, no. 4/25., p. 542.

GEOLOGICAL MAPS OF TURKEY AND GREECE - 1 : 500,000.