ON PETROLOGY, AGE AND STRUCTURE OF THE MENDERES MIGMATITE COMPLEX (SW-TURKEY)

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ABSTRACT.- The gneisses of the Menderes Massive are migmatites; they are formed by addition of a mobilisate consisting of quartz-feldspar with alcali-surplus to a sedimentary metamorphic series. The interior of the complex displays a very persistent N-S or NNE-SSW lineation and direction of fold-axes; this orogenic phase of N-S direction is of pre-Hercynian age, and can be correlated with similarly directed orogenetic movements in the basement-rocks throughout Western Turkey, the Greek Islands (Cyclades) and S-Bulgaria. Part of this basement consists of migmatitic gneisses as in the Menderes Massive, in other places non-migmatitic meso-catazonal gneisses occur. The phase of dome-like upheaval and migmatization («granitization») is of Hercynian age. The cristalline pre-Hercynian basement rocks acted as rigid masses during later movements; to some extent they underwent alpine block-faulting. Any view of the tectonic history of Turkey, which fails to take in account the pre-Hercynian N-S orogeny, and tries to simplify matters into an east-west structural pattern is necessarily false; the true east-west structure of Turkey starts only with the sinking of the Tethys. in Upper Paleozoic, most probably Permian times.

INTRODUCTION

During 1957, 1958, 1959, 1960 and 1961 the writer spent about 17 months in the Menderes gneissic area (for location, see map Fig. 1), as well as several months in the Kaz-Dağı gneisses and in the gneissic area of Demirci-Gördes, which is a continuation of the Menderes Massive towards the north. Here, as a geologist of the Mineral Research and Exploration Institute of Turkey, he headed a prospect ion team for radioactive minerals. During this time he had occasion to map at a scale 1 : 100,000 the whole of the gneissic area south of the river Menderes (the «Meandros» of the ancient Greek). The area mapped measures about 4000 km^2 and is represented on the map accompanying this paper.

GEOLOGY

The gneisses, seen as a whole, form a large dome-like structure. The presence of many smaller structural units within its borders (domes and anticlines, synclines and basins) makes it preferable to apply the term migmatite complex (see map). T,he complex is surrounded by schists of progressively lower metamorphic grade from the gneissic border outwards. The schistosity (= stratification) of the schists is parallel to the contacts with the gneisses and parallel to the gneissic foliation. The schists, in turn, are surrounded in a very regular way by a marble formation, in which numerous metamorphic bauxite deposits (emeries and diasporites) occur (Onay 1949, see map).

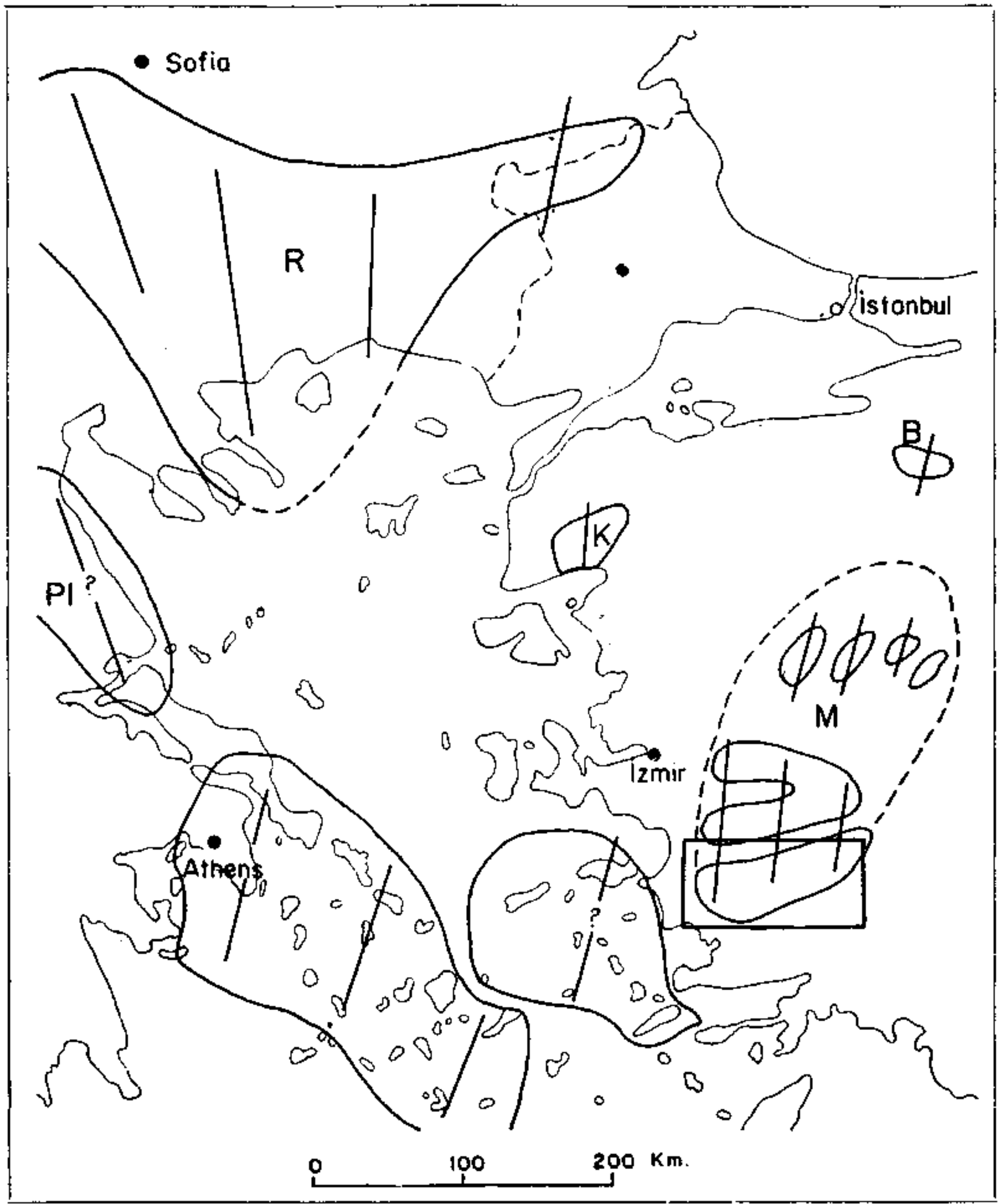


Fig. 1 - Distribution of several important pre-Hercynian massives in Western Turkey, Greece and Bulgaria

Straight heavy lines indicate the mean direction of the tectonic axes in these massiyes.

R - Rhodope Massive; Pl - Pelagonic Massive; C - Cyclades Massive; K - Kaz-Dağı Massive; B - Gneissic massive SE of Bursa; M - Menderes Massive, partly covered by Neogene formations. Southern part of Menderes Massive represented on map accompanying this paper

Within the migmatite complex the structure is no longer concentric, dom -like, but shows a very persistent N-S lineation, which is also the direction of the axes of smaller and larger folds as for example the mica-schist-syncline extending from Koçarlı to S of Mersinbeleni, 25 km long (see map, and also Photo No. 1 and 2). This persistent N-S or NNE-SSW trend of lineations and fold-axes has also been observed by the author at other places where the old basement emerges from below Upper Paleozoic or still younger formations.

Apart from the fossiliferous Permo-Carboniferous from Göktepe no fossiliferous Paleozoic or Mesozoic formations have been found surrounding the Menderes migmatite complex. In the Göktepe formation samples taken by Onay yielded :

Lithostrotion indet.
Lonsdaleia floriformis McCoy
Lilhostrotion irreg. Phill.
Fusiella or *Fusulinella*

A Viseen Sup. age seems indicated.

From this Göktepe formation, but presumably from higher levels, samples taken by v. d. Kaaden and Metz yielded :

Stylidophyllum rolzi (Yabe & Hayasaka)

which seems to indicate an under-Permian age.

Mrs. Kırağlı kindly undertook the determination of some corals sampled by us from the same formation and found :

Waagenophyllum indicum (Waagen & Wentzel)

which is probably of still somewhat younger age than *Stylidophyllum volzi.* Apart from the *Waagenophyllum indicum* our samples contained some badly preserved Crinoids and Fusulinids.

Ideally,, the Menderes Massive and Paleozoic surroundings consist of the following formations (from top to bottom) :

Table 1 — Rock-sequence in the Menderes Massive

1. Permo-Carboniferous (= Göktepe formation)	200 m	bituminous crystalline limestones, intercalated in schists and quartzites.
2. Devonian (?) (= Menteşe formation)	1000 m	marbles, with intercalations of metamorphosed bauxites (emeries and diasporites).
3. Silurian (?) (= Graphitschiefer-series)	1000 m [1] (locally more)	sericite-chlorite schists, amphibolites, quartzites, graphitic schists with or without chloritoid.
4.	0-250 m	biotite-garnet schists, often graphitic.
5.		transition zone between schists and gneisses.
6.		leucocratic gneisses with tourmaline and muscovite.
7. Cambrian and pre-Cambrian (?)	several km.	coarse-grained (augen-) gneisses, with two micas.
8.		fine-grained, biotite-rich gneisses, sometimes interbedded with amphibolites, gabbroid rocks and «residual cipolins».
9.		graphitic garnet-mica-schists.
10.		gneisses.

[1] There might be some correlation between sedimentary furies and thickness of this formation, being thickest where uniform graphitic schists, with local limestone intercalations predominate, and thinnest, where quartzites become prominent.

It should perhaps be mentioned, that the stratigraphical sequence as given in Table 1 has only a schematic value; especially the tectonic position of formations «8» and «9» is not always clear. According to Onay it seems improbable that Carboniferous sediments ever covered the gneissic massive; the marbles of probably Devonian age (the so-called Menteşe formation) have been the youngest formation to form a continuous cover over the Menderes Massive.

In this section we will treat some general relationships between orogeny, metamorphism and migmatization in the Menderes Massive including its surrounding non-migmatized Paleozoic mantle, bearing in mind that the Permo-Carboniferous Göktepe formation is still weakly metamorphosed (chloritoid—v. d. Kaaden & Metz, 1954), but that Mesozoic formations in Western Turkey are non-metamorphic. The following observations are significant. In the graphitic (Silurian ?) schists, chloritoid is often present; nearer to the gneissic border and strictly parallel to it a zone of mica-schists with porphyroblastic garnet is developed. Only where sehist-synclines enter the gneissic massive kyanite and staurolite have been found in addition to garnet. The relation between gneissic border and zone of «porphyroblastic metamorphism» is so close that one can without hesitation accept that *the formation of gneiss, the doming of the complex and this type of metamorphism are causally related and took place at the same time.* The same relationship holds for the «corundum metamorphism», a concentric zone of emery deposits following the gneissic border at some distance, as shown oh the map. A general contemporaneity of «porphyroblastic metamorphism» and the formation of corundum and diaspore can be postulated, and even extended towards the chloritoid, although the latter, when it occurs in emeries, often seems to be of somewhat later origin (Onay).

First conclusion : The metamorphism of the Paleozoic rocks, as far as regards corundum, diaspore and garnet (and associated porphyroblastic kyanite and staurolite) is contemporaneous with the formation of the migmatitic gneisses and the doming of the complex. With regard to chloritoid, the situation seems less clear; but part of it may have formed at the same time.

The N-S directed tectonic structure which is very much in evidence in the Menderes Massive (lineations in the micas and fold-axes) seems to arrive not much higher in the series than the limit schists-gneisses; it does not affect rocks of formation «2» (marbles, probably Devonian). This formation, on the other hand, is very clearly affected by the doming, so we arrive at our second conclusion:

The N-S orogeny and structure precedes the doming.

In an earlier report (Schuiling, 1959) we have called the N-S tectonics paracrystalline; this hypothesis must be specified as follows: it is paracrystalline with regard to the micas, but precrystalline with regard to the feldspathic eyes, which formed later, during migmatization and doming.

It seems worthwhile to mention that in the Kaz-Dağı Massive (the «Mons Ida» of Antiquity), we arrived at comparable conclusions (Schuiling, 1959): here a N-S directed tectonic movement is paracrystalline with regard to all minerals (as these gneisses were not subjected to migmatization), but pre-crystal-

Photo 1 - Small-scale fold in transition zone of schists and gneisses, north of Selimiye. Direction of fold-axis N-S

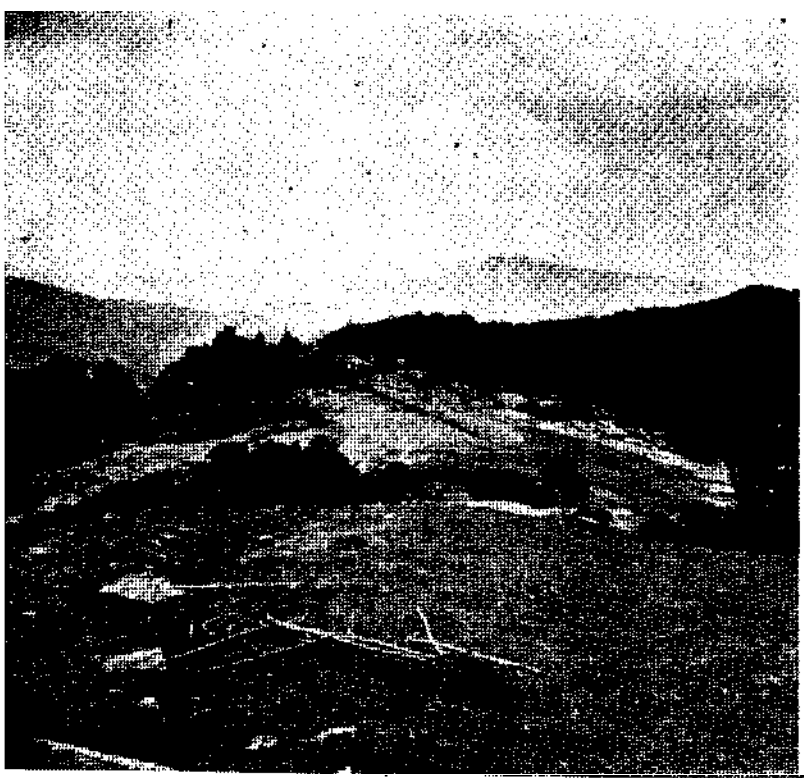


Photo 2 - Labranda anticline, with N-S axis, in the gneisses. Looking south towards Milâs

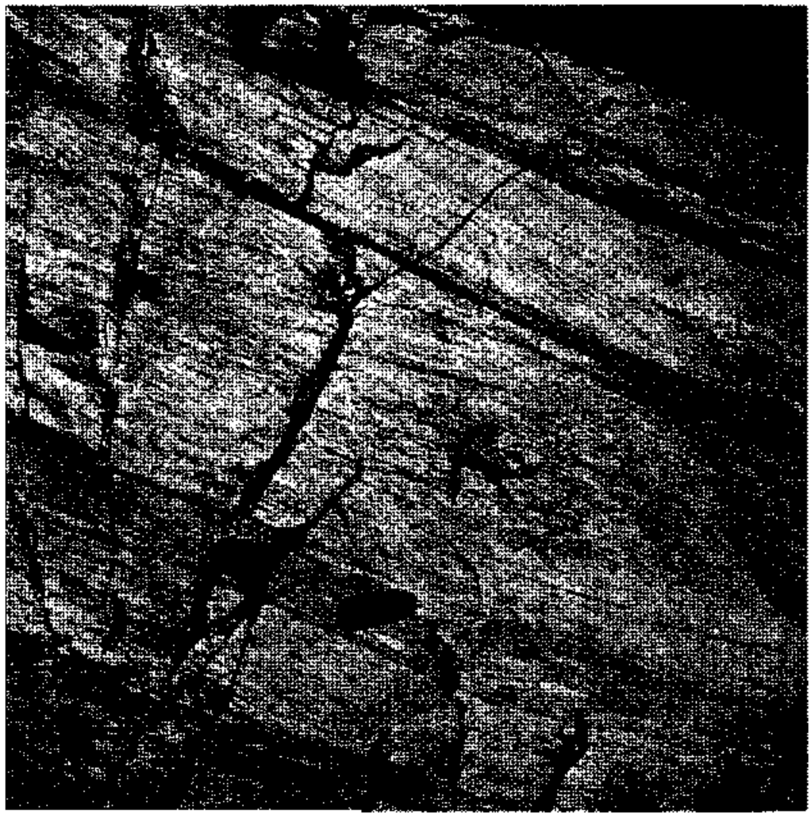


Photo 3 - Sedimentary structures (current bedding) remain intact in the gneisses

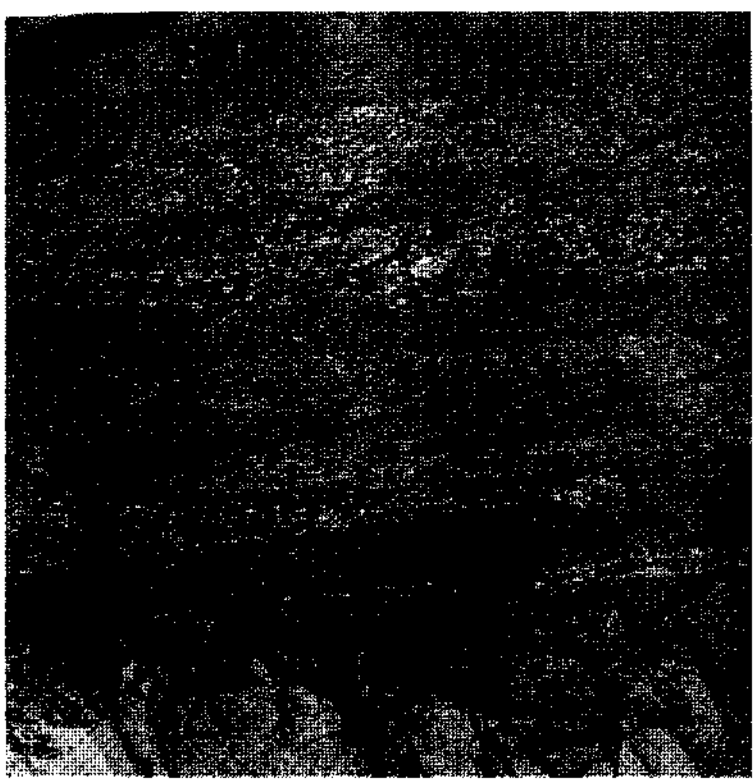


Photo 4 - Migmatization proceeds along schistosity (=ancient stratification) planes, giving rise to an alternation of migmatized and non-migmatized bands

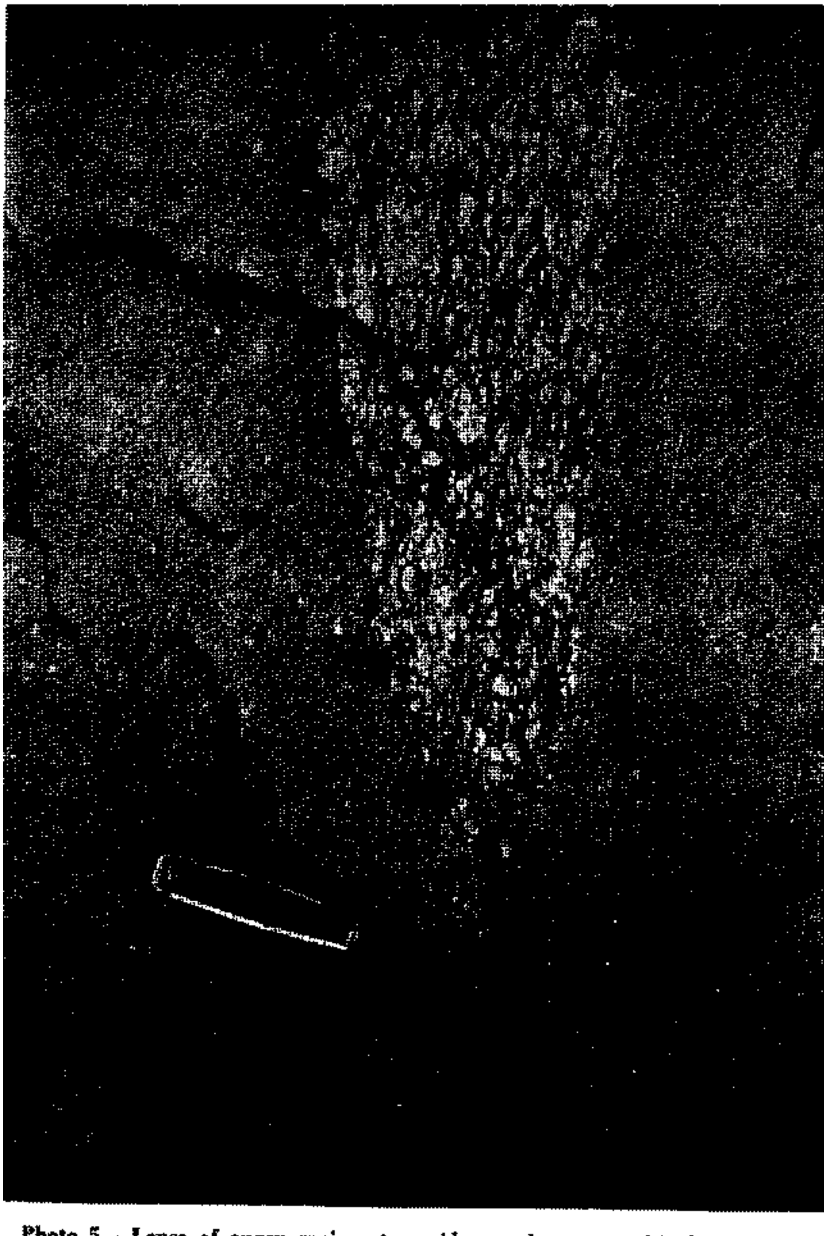


Photo 5 - Lense of augen-gneiss stops sideways in a quartzitic formation line with regard to small quart.zo-feldspathic exsudations, which might represent an underdeveloped analexitic phase. This anatexitic phase is probably contemporaneous with the intrusion of granocliorilic batholiths in Upper-Paleozoic times surrounding the old gneissic core of the Kaz-Dağı Massive.

There is ample evidence, that sedimentation in the upper parts of formation «3» (Silurian ?) and in formation «2» (Devonian ?) was not of a quiet geosynclinaltype,butshowsevidenceofstrongoscilations,orevenemergence above sea-level. We cite as examples:

1. The presence of metamorphosed «placers» rich in zircons and ilmenites (the latter largely transformed into brookite), near Bafa and Kısır. These indicate a littoral, or even fluviatile environment of deposition.
2. Numerous intercalations of quartzites in the mica-schists, possibly indicative of shallow-water deposition.
3. The presence, in some of these quartzites, of cross-bedding and slumping, extremely well preserved (in biotitc-grade metamorphism) near Kızılca. These indicate the presence of a delta.
4. The metamorphosed bauxites (now emeries and diasporites) show that there have been temporary emergences above sea-level.

From these examples it should be clear that there have been *rather strong oscillations of the sea-level,* from which we conclude to orogenetic movements. These may possibly be correlated with the N-S directed orogeny affecting the massive [2].

Let us now resume the picture, which the Menderes Massive offers to the understanding observer :

The gneisses form a dome-like structure, a migmatite complex, surrounded by concentric zones of successively lower metamorphic grade, surrounded concentrically too by a marble formation with intercalated bauxites (now metamorphosed to emeries and diasporites). Internally the gneisses display a very persistent N-S lineation. *Doming was later than N-S tectonics* and *contemporaneous with migmatization of the gneisses and metamorphism of their mantle.* It occurred later than Devonian and earlier than Mesozoic; largely speaking, it is a *hercynian phenomenon*.

Metamorphism and migmatization

Rather often, the augen-gneisses of the Menderes Massive have been regarded as orthogneisses. This interpretation we cannot accept, for the following reasons :

1. The regular banding (foliation) of the gneisses is parallel with the stratification of the schists and intercalated marbles and quartzites, at the contact of the schists and the gneisses.

2. There exist stratiform, concordant intercalation of layers of different composition in the gneisses, even showing sometimes relict sedimentary structures like current bedding (see Photo 3).
3. In a typical sample of an augen-gneiss the rounding index of the zircons was 92.0, strongly indicative of a clastic sedimentary origin of the host-rock (Schuiling, 1958).
4. In the transition zone between schists and gneisses, a regular alternation of schist- and gneissbands has often been observed, a situation highly unusual in intrusive contacts.
5. Graphite has been found in the gneisses, though it is admittedly rare.

So the possibility that the gneisses represent a tectonized magmatic granite seems remote. In order to present our view on the origin of the Menderes Massive it is necessary to make a short digression into theoretical petrology combining an argumentation of Palm (1958, see also Schuiling, 1960) with experimental facts as found by Winkler & Platen and Tuttle & Bowen.

Anatexis, the ultimate process in migmatite areas, is the melting of sediments, which often underwent previous feldspathization. It is only logical to suppose, that during the rise in temperature, leading towards this magmatic stage, hydrothermal and pegmatitic conditions arise, in reversed sequence to the situation well known and generally accepted at the end of a magmatic intrusion. In a complete ultrametamorphic cycle we can thus distinguish :

1. a pre-anatexitic hydrothermal phase (quartz-exsudations),
2. a pre-anatexitic pegmatitic and pncumatolytic phase (migmatization),
3. a palingenetic magmatic phase (anatexis),
4. a post-anatexitic pegmatitic and pneumatolytic phase (discordant pegmatites and quartz-tourmaline veins),
5. a post-anatexitic hydrothermal phase (quartz veins and hydrothermal mineralizations).

It will be clear that within one layer the phases follow another, but that at different levels different phases may exist at the same time. There is a *significant difference betiween the pre-anatexitic phases on the one hand and the post-anatexitic phases on the other.* The pre-anatexitic phases manifest themselves as impregnations or as concordant lenses and veinlets (see Photo 4 and 5); the post-anatexitic phases are discordant and distinct. This difference must be attributed in our opinion to the fact that the pre-anatexitic phases have welded together, during their crystallization, the walls of pre-existing channelways, pores and schistosity planes, whereas the post-anatexitic phases had to use fractures and joints during their emplacement. As the gneisses have formerly been sediments (see above) we must, account for their present, granitoid composition as compared with their ancient sedimentary composition. This difference consists mineralogically in an addition of quartz-feldspar with alcali-surplus, or chemically an addition of Si-Na-K. Logically speaking, a subtraction of all the other elements would give the same result; as some of these elements are notably refractory, and as doming indicates an increase of volume, we will consider only the first possibility.

As pegmatites approximately fulfill our conditions, we might already accept as possible the migration of our postulated «quartz-feldspar with additional alcali» - liquid (which we will henceforward call the «mobilisate» (Mehnert, 1959), without additional experimental proof of its possible existence and mobility at sub-magmatic temperatures. These low temperatures we must postulate on account of the persistence of pre-migmatic tectonical and sedimentary structures like lineations, folding, banding and current bedding, and the rather low-grade metamorphism in the contacts of the gneisses, which make magmatic temperatures with accompanying melting phenomena unlikely. Experimental proof, however, of the existence of mobile liquids of just this composition at submagmatic temperatures has been forthcoming through the experimental work of Bowen and Tuttle, who demonstrated that «residual solutions developed during the crystallization of hydrous granitic magmas may exhibit a continuous gradation from hydrous silicate liquids to hydrothermal solution. Evidence for the gradation is based on experimental data on portions of the system K_2O-Na_2O-Al_2O_3-SiO_2-H_2O. It is concluded that continuous gradations from magma to hydrothermal solution will obtain in hydrous liquids if the alkali to alumina ratio is such that crystallization results in concentration of alkali-silicates in the residual liquids. This restriction may not apply to a complex system such as a granite magma in which many volatiles in addition to water are concentrated. Such a system concentrating lithia, carbon dioxide, sulfur, chlorine, fluorine and many other materials may exhibit a continuous gradation even when alumina is present in excess of that amount required to combine with the alkalies to form feldspar».

So it seems natural to invoke a process, which we call *migmatization*, whenever one encounters positive structures (domes or domed complexes) of granitoid gneisses, which still display characteristics of sedimentary origin. Migmatization, in our genetic terminology, is the addition of a mobile phase at submagmatic temperatures (estimated at between 500 and 650° C.) to a sedimentary series, changing it into migmatitic gneisses of approximately granitic composition. The mobile phase we call mobilisate; it consists of a watery melt of quartz-feldspar composition, enriched in alkalies and generally containing volatile elements (B, F, P_2O_5, UO_3). As addition of material takes place, an increase of volume accompanies the migmatization, which contributes to doming and swelling of the migmatites. The most mobile elements are carried farthest and are deposited as a leucocratic crust just below the front of migmatization; here real tourmaline «fronts» can be found (comparable with the formation of greisen on top of some granites), as well as unusual concentrations of uranium («radioaktive Fronten», see Borchert, 1961).

Metamorphic facies in the Menderes Massive

When, in the following, we will make some tentative statements regarding metamorphic facies in this large area, it should be borne in mind, that the appr. 100 rockslides we studied, clearly are an insufficient base for determining the metamorphic associations, let alone their zonal arrangement. On the other hand this restriction does not apply to metamorphic zones which were recognizable and mappable in the field, e.g. emery-bearing marbles, chloritoid-schists, garnetiferous schists and 2 mica augen-gneisses.

We hardly need to enter into the paragenesis of the diasporites and emeries, which were treated at length by Onay. Essentially they are composed of corundum, diaspore, chloritoid, margarite and ore, while kyanite and muscovite may be present.

In the mica-schists of probably Silurian age, which surround the gneissic massive, the following associations have been found :

chloritoid-muscovite-paragonite (dct. by X-ray analysis)-quartz,
albite-muscovite-quartz.

As we have seen that kyanite is already a stable phase in the emeries, we may infer that

kyanite-muscovite-chloritoid-quartz

would be a stable association too. As biotite is not found in these rocks, partly because the chemical composition of the schists does not permit its crystallization, but in the outer zones mainly because its stability field is not yet reached, we may say that these schists have crystallized in the quartz-albite-muscovite-chlorite subfacies of the greenschist-facies (Fyfe, Turner & Verhoogen).

Nearer to the gneisses, biotite and abundant almandine make their appearance; as biotite is appearing relatively late, the stage of the quartz-albite-epidote-biotite subfacies is greatly reduced or absent; associations with almandine, with chloritoid still surviving, belong already to the quartz-albite-epidote-almandine subfacies.

Rarely, and only where mica-schists are found in synclinal position between the gneisses, as in the Koçarlı-Mersinbeleni syncline (see map) a next higher metamorphic grade is reached by the schists. Herc associations of kyanite-staurolite-muscovite, muscovite-staurolite-biotite and biotite-staurolite-almandine, with quartz have been found, associated with garnet-bearing amphibolites. These are crystallized in the staurolite-quartz subfacies (Francis) of the almandine-amphibolite facies, as shown in Fig. 2. Here an example of metamorphic differentiation was found. The original rock of mineralogical composition «l» (see Fig. 2) had partly split into kyanite-nests and a muscovite-staurolite-biotite schist. In the same figure we have indicated with dashed arrows the effect of feldspathization (migmatization) on the mineralogical composition. All the hyper-aluminous associations are changed into the association potash feldspar-muscovite-biotite (-quartz-plagioclase).

As muscovite remains stable throughout the gneisses, metamorphism is never of sillimanite-almandine grade. As the reaction

muscovite + quartz   sillimanite + potash feldspar + water

takes place between 450° and 590°, dependent on pressure, it seems safe to assume, that temperatures of metamorphism never exceeded 590°.

Corundum forms from diaspore (at least in the region between PH_2O from 200-10,000 bars) between 350 and 480° C. Taking 4-5 km as the stratigraphic thickness of the gneisses from their deepest exposed level + the thickness of the schists between the gneisses and the emery-deposits, we arrive at a figure for the thermal gradient during metamorphism of 25-35°/km, which can be regarded as a quite normal figure. When, however, corundum deposits formed at a very low water-pressure of less than 200 bars, corundum may start to form at temperatures as low as 200°. In that case the thermal gradient might have been as steep as 70°/km.

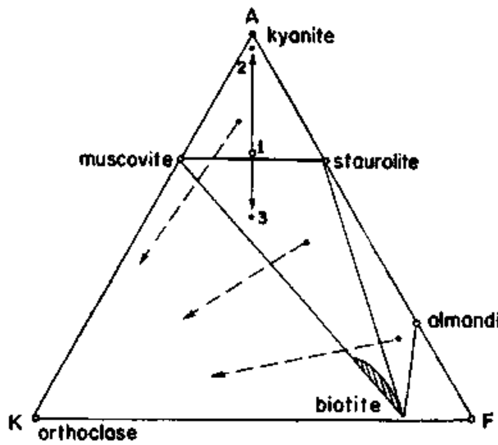


Fig. 2 - AKF-diagram showing associations of rocks near Akmesçit Köy, in the Koçarlı-Mersinbeleni schist-syncline. Staurolite-quartz subfacies, modified after Francis

«1» indicates the position of a normal mica-schist (M.T.A. number 32145). «2» and «3» are rock-types originated by metamorphic differentiation of «1». Dashed arrows indicate the disappearance of the hyper-aluminous associations on account of migmatization

The pre-Hercynian orogeny of N-S direction in Western Turkey

In order to show the divergence of opinion concerning the age of the Menderes Massive and related crystalline rocks in Western Turkey, the Cyclades and SW-Bulgaria it seems best to quote from several writers on this subject :

Philippson (1918) states : «Ob die kristallinen Schiefer und Marmore alle archaisch sind, ist namentlich für die Randzone, zweifelhafy; sicher aber sind sie alter als das südlich benachbarte Palaozoikum».

Erentöz (1956) maintains a correlation between the crystalline basement of the Istranca Massive in Thrace and among others the Menderes Massive, and continues : «the crystalline schist gravels of the Istranca massive form the elements of the basal conglomerate of the Istanbul Silurian, which proves that the age of the massive is older than Silurian». Here a pre-Silurian age of the crystalline basement throughout Western Turkey is indicated. Speaking of the old crystalline cores of Kaz-Dağı and Uludağ (near Bursa), which both display the typical N-S tectonics and mcso-catazonal metamorphic character, v.d. Kaaden (1959) says: «....make the assumption of a pre-Variscan age (Caledonian ?), at least for a part of the rocks, highly probable».

Tokay and Erentöz (1959) : «the basement, which is probably Hercynian in age and best known as the Menderes Massive. ...».

Ketin (1959), however, states : «the effects of the pre-Alpine orogenic movements are not visible; the transition from the Paleozoic to the Mesozoic took place without a disconformity», and in another paper (1960) : «les mouvements orogeniques *initianx* (italics mine—R.D.S.) les plus importants ont eu lieu pendant la phase laramienne».

Leuchs (1943) makes the following statement: «Im Hauptteil lasst sich keine herrschende Streichrichtung erkcnnen, vielmehr ist sehr grosser Wechsel vorhanden, wobei die Streichrichtungen zwischen NNO und ONO überwiegcn. Da auch mit den Streichrichtungen der umgebenden Gebieten keine Übercinstimmung besteht und die Gesteinsfolgen von dem sicheren Palaozoikum der Umgebung sehr verschieden sind, kann frühe Entstehung dieser alten Masse angenommen werden, wobei es vorlaufig noch unentschieden bleiben muss, ob sie in alt- oder in vorpalaozoischer Zeit gebildet wurde».

Contrary to Leuchs'view Nebert and Ronner (1956) state: «Diese scharfe Trennung zwischen Menderes-Massiv und tauriden Elementen erscheint nach unseren Ergebnissen nicht mehr gerechtfeitigt».

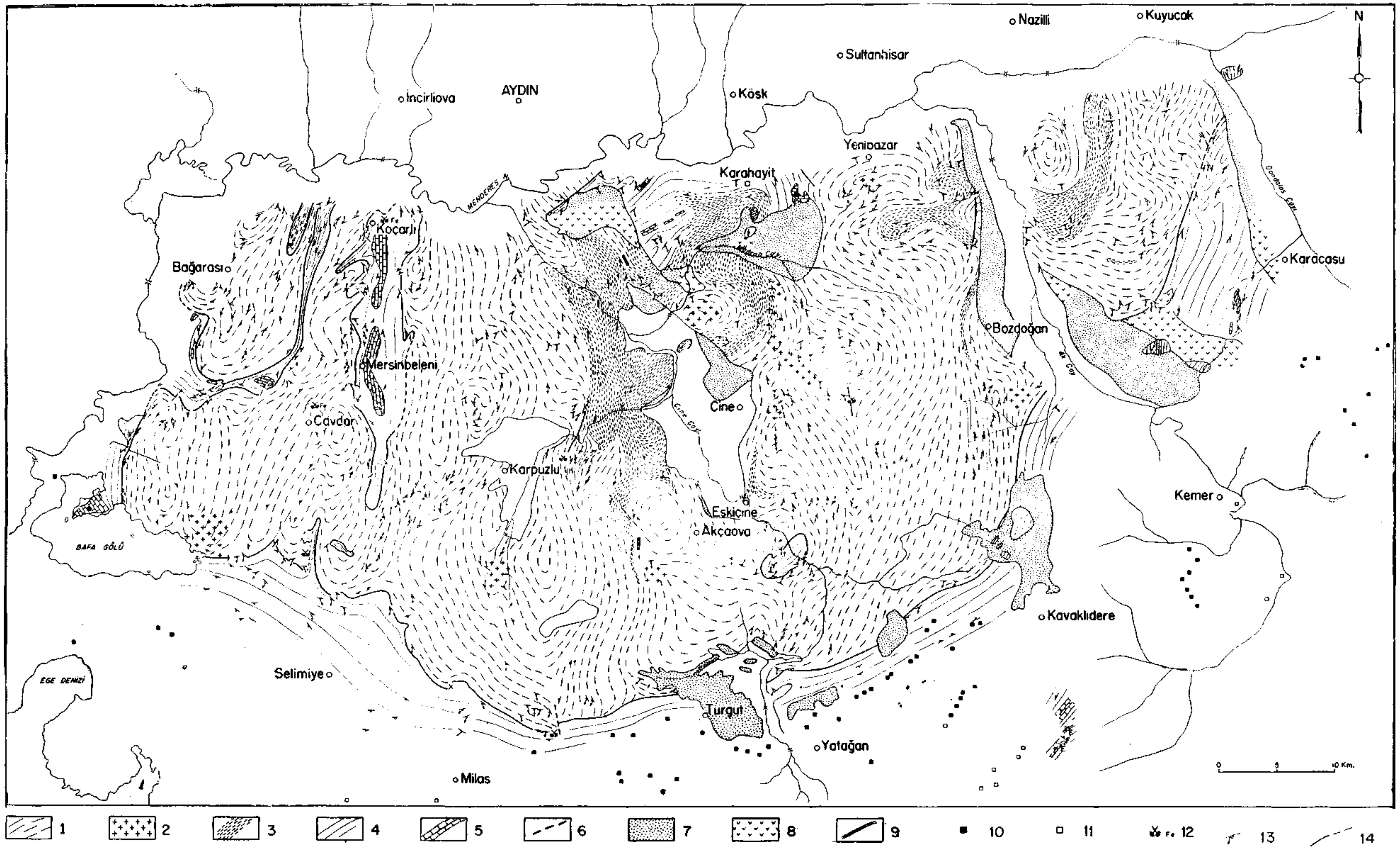
Pınar and Lahn (1955) : «Toutes ces structures pre-ulpines ont ete reprises par le plissement alpin» and further on they remark : «nous n'avons pu trouver aucune preuvc de l'existence de massifs caledoniens».

Onay (1949), however, is of opposite opinion: «Das Alter dieser Gesteine (i.e. of the Menderes Massive) ist nicht genau bekannt; für einen grossen Teil wird prakambrische Herkuuft angenommen. Der ganze Komplex ist jedenfalls alter als Karbon». Further on he remarks : «Das Massiv zeigt wahrscheinlich noch Spuren vorherzynischer Gebirgsbildung. Wahrend der herzynischen Orogenese wurde es nochmals stark verfaltet, so dass. altere und herzynische Falten sich komplex liberlagern» (note of the present author: presumably Onay is referring to the interaction of pre-Hercynian N-S tectonics and Hercynian doming). He states further : «Es darf mit Sicherheit angenommen werden, dass die alpine Faltung auf den bcreits verfestigten Menderes-Sockel aufprallte, ohne neue Falten zu verursachen».

Borchert (pers. comm.) : «Ich selbst kenne bisher *kein* Beispiel dass die alpidische Orogenese «gefiigepragend» und «in regionalem Ausmass ummineralisierend» in der Türkei gewirkt hatte».

Opinions, as we see, differ largely. Let us now consider the problem of the N-S orogeny on a larger scale. Next to the Menderes Massive, the Kaz-Dağı Massive and the gneisses of Demirci-Gördes a N-S or NNE-SSW direction has also been reported from the gneisses of the Uludağ range, which are intruded by-young Paleozoic granodiorites (v.d. Kaaden, 1959). This same N-S or NNE-SSW direction has also been reported by Trikkalinos (1942) from Naxos and other islands of the Cyclades. In his diagram No. 5 he presents a tectonic axis N 24 E for Naxos, and states that this is the direction of the «older, main orogeny, which lent the basement rocks their tectonic structures In his 1954 paper the same author remarks : «Die von Ktenas und anderen Forschern ausgeführten Vergleichsuntersuchungen liber die Kykladen- und Lydisch-Karische Masse (=Menderes Massive) haben die petrographische Verwandtschaft der Kykladen- und Lydisch-Kari.'chen Masse bewiesen» and continues on p. 13: «Man kann. .. .mit Sicherheit sagen, dass die orogenen Bewegungen des kristallinen Unterbaues vorsilurisch sind».

Sindowski (1949) arrives at the same conclusion : «Das Grundgebirge hat eine Regionalmetamorphose der Mesozone durchgemacht, die Sedimente und Granite erfasste und spatestens mit der kaledonischen Faltung im wesentlichen beendet war. Die Granite der NNO-NO-Grundgebirgsfaltung haben bereits ein regionalmetamorphes Grundgebirge vorgefunden».



STRUCTURAL MAP OF THE SOUTHERN PART OF THE MENDERES MASSIVE

1 - Gneiss; 2 - Granite; 3 - Fine-grained basic gneiss; 4 - Mica-schist; 5 - Marble; 6 - Amphibolite; 7 - Neogene; 8 - Fanglomerate; 9 - Lamprophyre; 10 - Emery deposit; 11 - Diasporite; 12 - Iron occurrence; 13 - Strike and dip of schistosity and direction of lineation and fold-axis; 14 - fault.

In Southern Bulgaria essentially similar conclusions are reached by Dimitrov (1959): «Wie die Frage. . . .auch gelost werden mag, so kann vorlaufig als feststehend gelten, dass auch beide Phasen der Regionalmetamorphose im kristallinen Grundgebirge noch vor den jungen Granitintrusionen ihren Abschluss gefunden haben. . . .Hiernach (as a result of absolute age determinations) wird auch das Alter der Granite vorwiegend als wahrscheinlich kaledonisch bestimmt, was auch den geologischcn Angaben entspricht».

Mrs. Dimitrova, who kindly informed me on this matter, wrote (letter of 24.11.1961) : «Das Alter der metamorphen Komplexe wird als prakambrisch angenommen und zwar auf Grund, dass in SW-Bulgarien die Ordovicium-Silurischen Sedimenten nicht von der Tiefenregional-metamorphose angegriffen sind». Die wichtigsten Faltenstrukturen in diesem Gebiet (i.e. the crystalline Rhodope Massive) sind einige Antiklinalen. . . .mit vorwiegend N-S bis NW-SO Richtung».

This N-S (or NNE-SSW) tectonical trend of all these interrelated crystalline massives has been interpreted by us as the direction of a pre-Hercynian orogeny, which made itself felt in Western Turkey, many of the Greek Islands and towards the north as far as Bulgaria. This interpretation has been found to be valid too for the Menderes Massive (in this paper), notwithstanding a recent series of publications (Ketin, Lahn & Pınar, Nebert) which maintain a younger, alpine origin for this massive. Nebert (1960) found some N-S strike directions in Mesozoic sediments, and in some places around the old core of the Menderes Massive E-W strike directions in epimetamorphic schists. From these observations he concludes to the general invalidity of the concept :

E-W strike directions = alpine
N-S strike directions = pre-alpine (Variscan).

We are personally not aware that any geologist seriously defends such an oversimplification of the structural history of Turkey. We rather follow the view which for some areas has been worked out among others by v. d. Kaaden, although it is still rather schematic and exceptions occur :

Table 2 — Schematic relationship of dominant strike direction, metamorphic facies and age of orogeny in Western Turkey

Dominant direction	*Metamorphic grade*	*Age of orogeny*
E-W (locally adaptation to older structures and cross-folding may cause large deviations from this direction).	Non-metamorphic	Alpine
NE-SW or WSW-ENE	Low-grade regional metamorphism (partly glaucophane-facies).	Hercynian
N-S to NNE-SSW	meso-catazonal regional metamorphism, in part migmatites.	pre-Hercynian

Evidently, where epimetamorphic schists mold around pre-Hercynian cores, E-W directions may occur; this does in no way invalidate our generalized concept.

Table 3, below, summarizes our tentative views concerning the origin of the Menderes Massive.

Table 3 — Summary of tentative view concerning the origin and history of the Menderes Massive

Sedimentation	*Orogeny*	*Metamorphism and migmatization*
Mesozoic unconformity and hiatus		Non-metamorphic
Permo-Carboniferous	Hercynian orogeny (several phases ?)	(Part of) chloritoid metamorphism mineralization in final stage of migmatization : 268 ± 60.10^6 years. (Devonian ?) bauxites metamorphosed to diasporites and emeries.
		Migmatization, swelling and doming of the migmatite complex and metamorphism (garnet, kyanite, staurolite) of surrounding schists.
Unconformity and hiatus (masked by Hercynian orogeny)		Formation of bauxites in Devonian limestones, emerged above sea-level.
	N-S orogeny	Regional metamorphism of deeper levels.
Devonian (?) limestones Silurian (?) graphitic schists and quartzites.		
Cambrian and pre-Cambrian (?), now present as migmatized sediments.		

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