THE GEOLOGY OF CYPRUS AND ITS PLACE IN THE EAST-MEDITERRANEAN FRAMEWORK[1)]

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ABSTRACT

Cleintuar, M.R., G.J. Knox and P.J. Ealey (1977). The geology of Cyprus and its place in the East-Mediterranean framework. Geol. Mijnbouw, 56, p. 66-82.

New datings and sedimentological observations seem to confirm the Cretaceous age and submarine origin of the Troodos igneous complex in central Cyprus. Troodos rocks, of marked calc-alkali character, form the basement to an Upper Maastrichtian-Tertiary sequence, 500-1800 m thick, of bathyal-shallow abyssal marls and chalks. In N Cyprus these relatively undisturbed sediments are in contact with southward thrusted flysch deposits (2000-3000 m) of prevailing Miocene age, indicating a tectonic weld of major order. Allochthonous Permian-Lower Cretaceous shelf limestones are exposed in what seems to be the core (Kyrenia Range) of the N Cyprus thrust belt.

In SW and S Cyprus a thin, exotic rock complex (Mamonia) wedges in between the Upper Maastrichtian-Tertiary sediments and Troodos basement. The Mamonia comprises a Triassic-Lower Cretaceous allochthonous, mainly deep marine assemblage that rests on Campanian dated andesitic pyroclastics.

The geological evolution of Cyprus is conceived by the authors as follows: The Troodos igneous complex formed part of an ocean rise in a Cretaceous sea bordered by continental margins. In about Campanian time Troodos was underthrust by the southern (Afro-Arabian) margin. Some of the continental margin rocks (the allochthonous Mamonia), preceded by pyroclastic slope deposits, came to rest on the leading edge of Troodos. The andesitic source of the pyroclastics was probably in the former margin. Quartz sandstone blocks of Lower Cretaceous age, included in the allochthonous assemblage, are possibly Nubian sandstones derived from the southern continent. Continued underthrusting forced Troodos to rise without disturbing its sedimentary cover. Eventually, in the Upper Miocene and Pliocene, slope deposits and detached shelf limestones from a northern(?) source were thrust on the Troodos north flank.

The tectonic setting of Cyprus is analogous to that of other peri-Arabian thrust belts in that ophiolite/deep-sea sediment associations appear thrown on the southern continent. The Troodos "ophiolite", however, seems unique because of its enormous size and relative rigidity.

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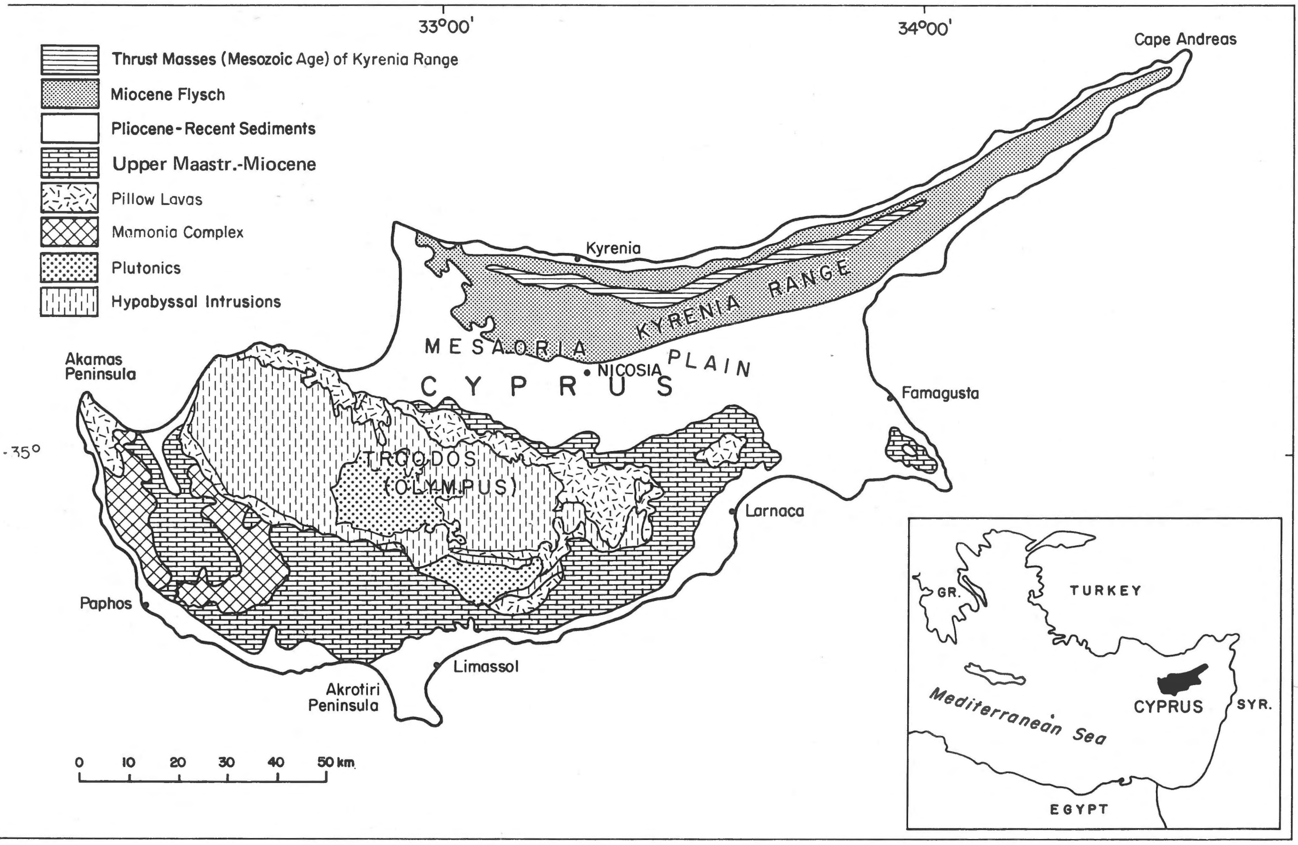


Fig. 1. **OUTLINE GEOLOGY OF CYPRUS**

INTRODUCTION

From October to early December 1971 a field survey was carried out by the writers on the island of Cyprus. Some selected areas, mainly in the south, were studied in semi-detail. while other parts of the island were visited and sampled on a reconnaissance basis. The field studies were in part guided and supported by air-photo interpretation.

In addition to their own observations, first in the field and later in the laboratory in Rijswijk (The Netherlands), a search of the extensive literature on Cyprus and eastern Mediterranean geology was carried out, while certain data from unpublished Cyprus Geological Survey reports have also been of help to arrive at the conclusions set out in this paper.

DISTINCTIVE FEATURES OF CYPRUS GEOLOGY (Fig. 1)

The Troodos igneous massif occupies the central and highest part of the island (Mt. Olympus, 1940 m) and forms the basement to a sequence of Upper Maastrichtian-Tertiary sediments that are exposed north, east and south of the major Troodos outcrop. The Troodos north flank is downfaulted and becomes deeply buried north of Nicosia. An important tectonic zone, referred to as Ovgos fault zone in this paper, runs across this deep N Cyprus basin. The Ovgos fault zone forms the contact between relatively undisturbed sediments on the Troodos north flank and a belt of steep north-dipping thrust slices in mainly Miocene flysch-like deposits that occupies a wide area in N Cyprus.

The N Cyprus thrust belt culminates in the Kyrenia Range, which is an arcuate mountainous feature, not more than 5 km wide on the average, convex to the south. Pre-Tertiary, largely allochthonous rocks, and Lower Tertiary sediments outcrop in the core of this range.

On the Troodos south flank mildly structured Upper Maastrichtian-Tertiary sediments similar to those in the north are found. However, in SW Cyprus these sediments do not usually rest on the Troodos basement directly, but appear separated from it by a wedge of partly autochthonous, partly allochthonous pre-Maastrichtian rocks, together referred to as Mamonia Complex.

The main rock types found on Cyprus are shown in relation to local biozonation (adapted from M a n t i s, 1970) and time in the stratigraphic scheme of Fig. 2.

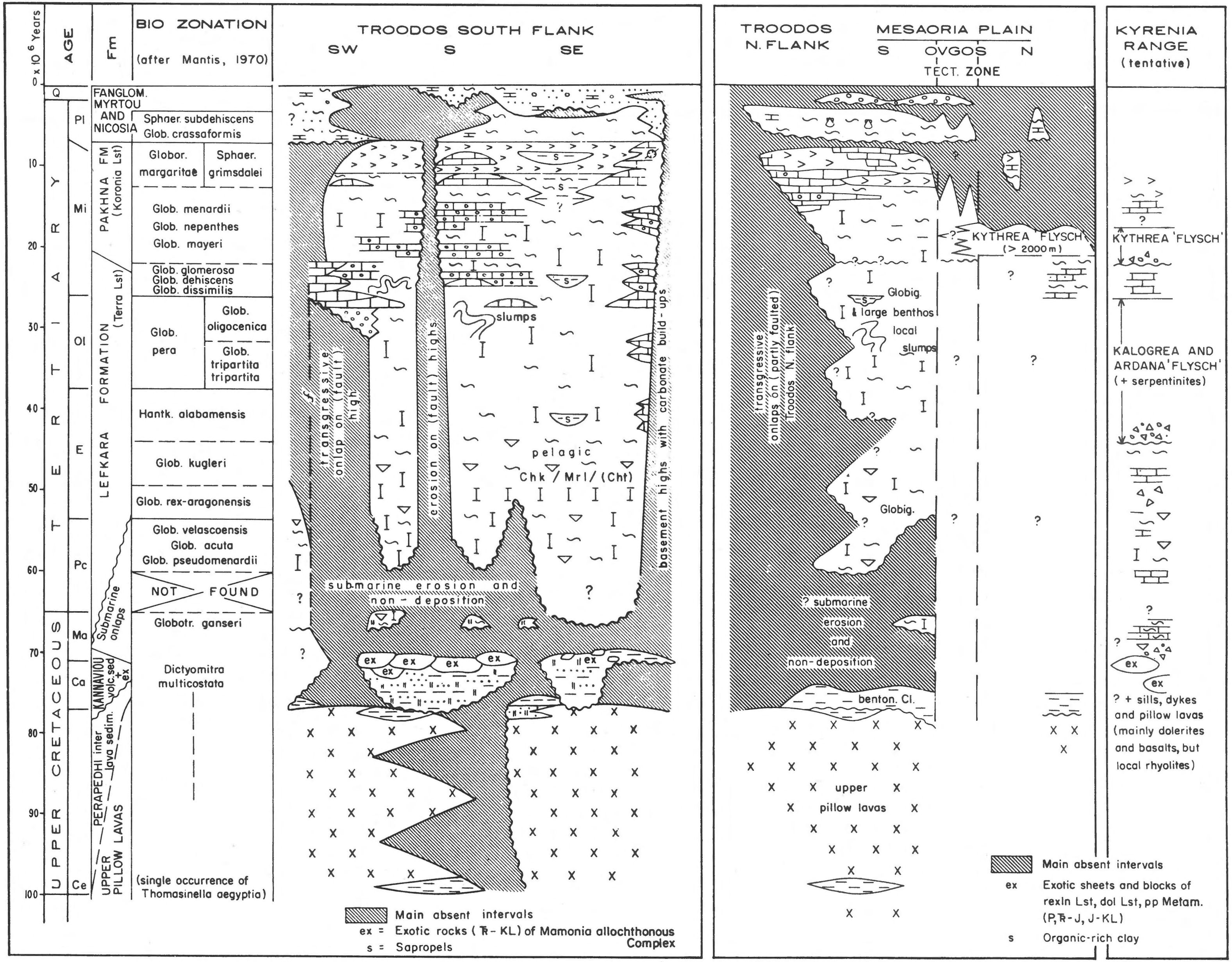


Fig. 2.

STRATIGRAPHIC SCHEME CYPRUS

THE TROODOS IGNEOUS COMPLEX

The Troodos complex covers about one third of the island. It has a centre of ultramafic rocks fringed by gabbros and their acid differentiates, mainly trondhjemites. This plutonic mass is enclosed within an altered dolerite dyke complex and pillow lavas. The Troodos rocks are considered to be a consanguineous igneous group of marked calc-alkali character.

The plutonic rocks consist of dunites, harzburgites, peridotites and pyroxenites, surrounded by gabbros. Part of these rocks show considerable serpentinisation. The gabbros exhibit transitional and back-veining relationships with the trondhjemites, in a syn-intrusive association, in which the gabbros consolidated first.

The dolerite dyke complex occupies the widest area of the Troodos outcrop. The dykes are a few centimetres to several metres thick. Seemingly endless repetitions occur, showing several phases of injection, the older dykes being practically contemporaneous with the gabbroic/trondhjemitic intrusions. Dyke dips are usually steep to subvertical. Their trends vary between N-S and NE-SW.

Pillow lavas overlie the dyke complex in a transitional relationship so that the oldest lavas are host rocks to the dykes. From petrographic character, mineralisation and field relationships, a distinction is commonly made between Upper and Lower Pillow Lavas (Constantinou and Govett, 1973; Gass and Smewing, 1973). The main lava types are often separated by thin weathered layers of ochreous sediment or hematitic shales which very locally contain radiolarians or agglutinated forams. Similar deposits, considered to be in part the products of submarine weathering, also occur in patchy outcrops above the pillow lavas and are referred to as Perapedhi Formation.

On the south flank of Troodos the lavas are often represented by massive basalt/diabase breccias, sometimes associated with graded beds containing reworked volcanic debris and radiolarian-rich shales assigned to the Perapedhi Formation.

The age of the Troodos rocks

Based on fossil datings of inter-lava sediments and some radiometric age-determinations on igneous members of the complex, a pre-Maastrichtian Cretaceous age is assigned to the visible part of Troodos.

a. The Upper Pillow Lavas are probably Cenomanian to Campanian, based on radiolarian associations (Dictyomitra multicostata zonule) in the Perapedhi Formation, and on the agglutinated foram *Thomasinella aegyptia* OMARA, 1956, found in an ochreous inter-lava bed (Mantis, 1970, 1971).

b. Radiometric datings by Lapierre and Rocci (1969) gave ages of 73 million years (Upper Campanian) for a basaltic lava and 114 million years (Barremian-Aptian) for an ophitic microgabbro, while two of our own samples from the central Troodos mass were dated 75.3 ± 2.5 and 76.8 ± 3.8 milllion years (Campanian).[5)]

The deep structure of Troodos. Review of geophysical data

Although the massif seems dissected by a number of normal, reverse and minor thrust faults, the structure of Troodos is considered to be essentially simple, comprising a shallow dome with a plutonic core surrounded by its former roof rocks, i.e. the dyke complex and the pillow lavas. Around the central serpentinised complex the dyke and fault trends appear to diverge from the overall pattern. This could be a rearrangement related to the formation of the central dome.

Mega-structural interpretations have given much consideration to the strong positive gravity anomaly associated with the Troodos massif. A model proposed by Gass and Masson-Smith (1963) consists of a rectangular slice, 190 by 110 km, of 11 to over 32 km thickness, with a density of at least 3.3. Isostasy requires this high-density mass to be supported by a layer of lower-density material separating it from the mantle proper. This lighter material could be sialic crust.

Local gravity lows also occur. The largest one coincides with the exposure of serpentinised ultramafics at Mt. Olympus and has been interpreted by Gass and Masson-Smith (*op. cit.*) as a conical low-density body extending to a depth of about 11 km.

The Troodos mass has been interpreted (Greenbaum, 1972 and others) as a slice of ocean crust generated at an ocean ridge. A paleomagnetic study bij Moores and Vine (1971) revealed no magnetic reversal zones of the type found on present ocean ridges. It was reasoned that the visible part of Troodos represents a relatively short time of crust generation (10 million years?) falling within a long period of normal polarity in the Cretaceous (Helsley and Steiner, 1969).

Khan *et al.* (1972) have carried out deep seismic refraction work on the north flank of Troodos. Three velocity layers were recognised. Except for the very low velocity of the first layer that probably correlates with surface lavas, the values are similar to or only slightly below those of the refracting layers 2 and 3 of modern oceans.

THE MAMONIA COMPLEX (SW FLANK OF TROODOS)

This partly autochthonous, partly allochthonous rock assemblage has been the subject of an earlier publication by

5) ZWO Laboratorium voor Isotopen-Geologie, Amsterdam, Director Prof. Dr. H.N.A. Priem.

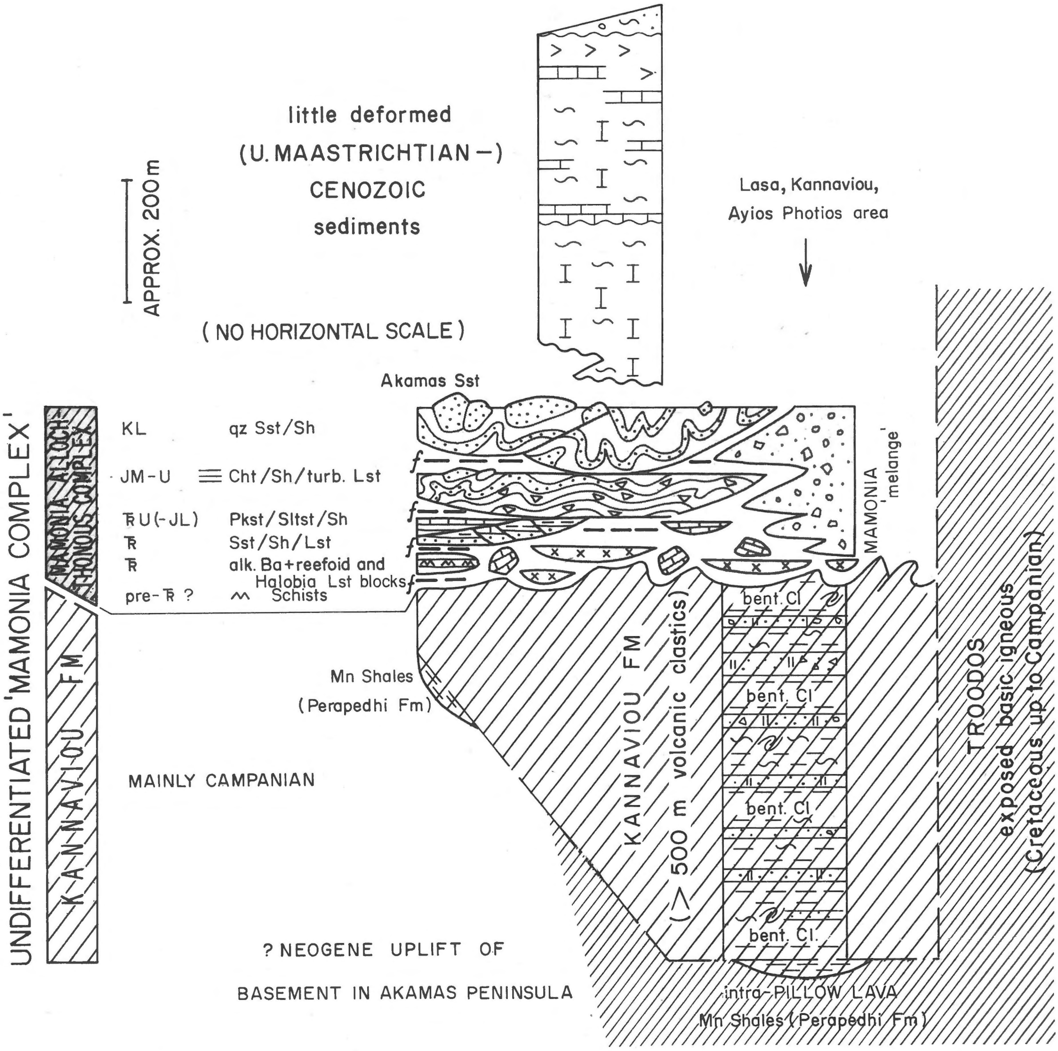


Fig. 3. **SCHEME OF STRATIGRAPHY, THICKNESS AND CONTACT RELATIONS OF 'MAMONIA COMPLEX', SW CYPRUS**
(Ealey & Knox, 1975)

two of us (E a l e y and K n o x, 1975). The main results of this study are reported below.

The autochthonous part of the Mamonia Complex, following earlier writers, is called Kannaviou Formation. The allochthonous rock assemblage, which lies on top of the Kannaviou, has been termed Mamonia Allochthonous Complex by the present authors. A third assemblage locally referred to as "Mamonia Melange", is essentially composed of fragments derived from the Mamonia Allochthonous Complex; it is considered as tectonic debris of this complex, and has not therefore been treated as a distinguishable unit. The stratigraphic, thickness and contact relations of the Mamonia Complex are shown in the scheme of Fig. 3.

The Kannaviou Formation

This autochthonous unit rests either directly on Troodos igneous basement or it is separated from it by thin iron-rich shales of the Perapedhi Formation. In the best exposed sections it comprises 500 m or possibly more of mudstone, bentonitic clay and marl, and up to 20 m thick banks of fine- to coarse-grained tuffaceous sandstone. The age of the Kannaviou is considered to be mainly Campanian on the basis of its radiolarian fauna (M a n t i s, 1970), late Cretaceous *Globotruncana* (L a p i e r r e, 1972) and Santonian-Campanian microplankton in one of our own samples.

Synsedimentary slumping, local graded bedding, convolute sedimentary structures, together with the predominantly radiolarian fauna suggest a deeper-marine slope deposition for the bulk of the Kannaviou.

The sandstones often contain β-quartz, zoned plagioclase, hornblende, pyroxenes and biotite, in addition to pumice and volcanic glass. This points to a pyroclastic nature and an andesitic source of volcanism, very unlike the exposed Troodos rocks. The sandstones also contain subrounded fragments of chert, muscovite-quartzite, crystalline limestone, basalt and trachyte, possibly indicating a source related to the allochthonous Mamonia rocks or to the Mamonia Melange (see below). Fragments and pebbles of Troodos-type igneous rocks are very locally included, indicating that parts of the Troodos complex were exposed at the sea floor.

The Mamonia Allochthonous Complex

This is an assemblage of broken-up sheets and isolated blocks, several hundred metres in size or much smaller, embedded in a jumble of rock detritus, collectively termed Mamonia Melange. The whole complex seems to rest on the Kannaviou Formation or directly on Troodos pillow lavas.

At the base of the complex serpentinites, alkali basalts or gabbros occur as exotic masses associated with blocks of reef limestone. Also spatially related to such basalts and limestone blocks are undated but probably much older metamorphic rocks including garnet-amphibolites, epidote-amphibolites, metapelites, quartzites and marbles. Huge blocks of algal/coral boundstone and shell-detrital limestone that occur at the legendary Petra tou Romiou outcrop (SE of Paphos), according to our own sample material, contain an Upper Triassic (Upper Norian-Lower Rhaetian) microfauna. An alkali basalt from the same site was dated as L-M Triassic, 215±10 million years (L a p i e r r e and R o c c i, 1969). Basaltic lavas, intercalated with pelagic lamellibranchs, including Halobia, were found at several other locations at the base of the allochthonous complex.

Bigger rock slices that represent a more or less continuous stratigraphic sequence of Upper Triassic to Lower Cretaceous age overlie these basal assemblages. The total reconstructed section is probably 200-250 m thick and comprises the following stratigraphic units in ascending order:

a. 0.2-1 m thick quartz sandstones with shales and lime-mudstones which contain radiolaria and pelagic lamellibranchs. The sandstones show finely disseminated plant remains and local grading and are considered to be at least in part turbiditic. The age of this unit is probably Upper Triassic.
b. Mixed lime-packstones/quartz siltstones, alternating with radiolarites and reddish shale/lime-mudstone with radiolaria. Graded bedding, slump balls and small-scale channelling indicate a deep-marine, partly turbiditic emplacement. Fragmented fossils in the packstones have an Upper Triassic age. The undated upper part of the sequence may grade into the Jurassic.
c. Well-bedded, red brown, green and white cherts and cherty limestones interbedded with reddish shales. Thin intercalations of graded lime-packstones and grainstones with ooliths, skeletal fragments and lithoclasts suggest distal turbiditic deposition in deep water. Thicker-bedded detrital grainstones occur locally. These could be proximal equivalents of the thin limestone turbidites and are dated as Middle to Upper Jurassic.
d. Fine to coarse quartz sandstone interbedded with reddish-brown shales and minor limestone bands. The shales contain a rich Hauterivian-Barremian microflora and microplankton fauna. This sequence is intensely folded or contorted by massive slumping. In the Akamas peninsula a more massive similar type of coarse sandstone (Akamas Sandstone), up to 50 m thick or more, rests on strongly deformed shales. The Akamas Sandstone is considered the proximal equivalent of the Lower Cretaceous sand-shale sequence.

Structure of the Kannaviou Formation and the Mamonia Allochthonous Complex

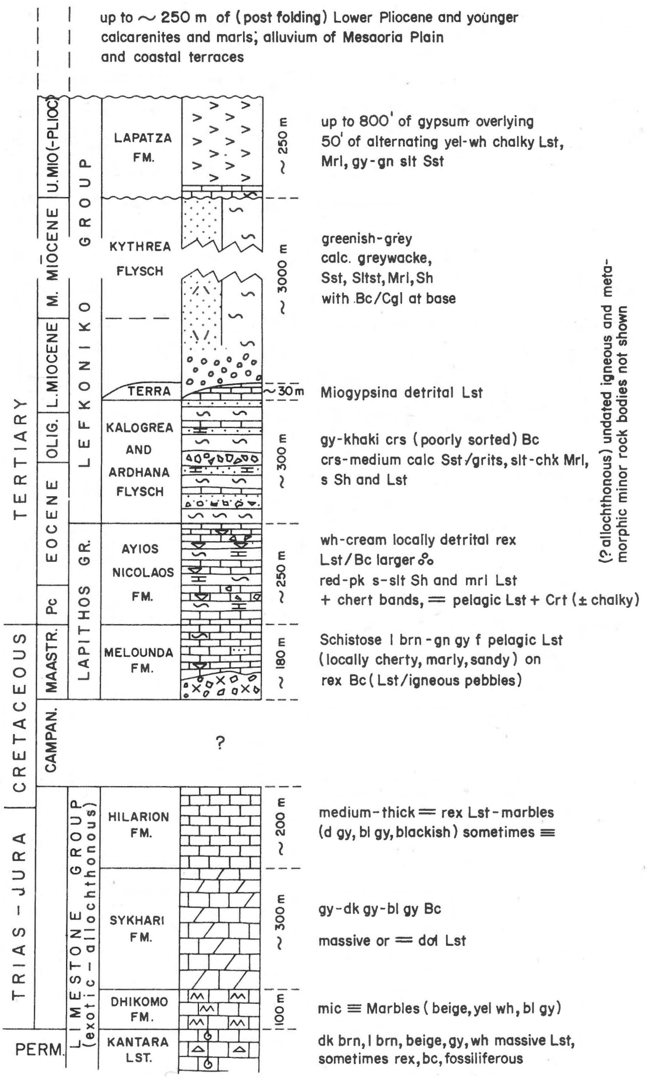
The Kannaviou sediments show moderate dips, 10°-30° on the average, but narrow zones with steeper dips and locally overturned folds occur. Some of these steeper structures are spatially related to the presence of allochthonous Mamonia sheets, and were probably pushed up when the latter slid into the Kannaviou basin in Campanian-early Maastrichtian time.

Their broken-up appearance suggests that the allochthonous Mamonia rocks were not emplaced as one nappe sheet, but as isolated slices or small thrust sheets of kilometre size at the most, and not thicker than a few hundred metres. Although no persistent structural trends could be detected between individual rock slices, field observations supported by air-photo interpretation suggest that south of the Akamas peninsula the allochthonous sheets are warped along a regional NNW-SSE trend probably as a result of Tertiary uplift.

PRE-MAASTRICHTIAN ROCKS NORTH OF TROODOS

No massive, quartz-rich rocks, equivalent to those of the allochthonous Mamonia assemblage, have been found north of Troodos. Subsurface data from wells drilled in the

Fig. 4. KYRENIA RANGE COMPOSITE STRATIGRAPHY



Mesaoria Plain indicate the presence of bentonitic clays, up to about 250 m thick, between Troodos basalts and the Upper Maastrichtian-Tertiary sediments. These bentonites are of probable Campanian to early Maastrichtian age (Mantis, pers.comm., 1971) and are considered the equivalents of the Kannaviou Formation of SW Cyprus. However, north of Troodos the late Cretaceous bentonitic beds are devoid of erratic fragments that are so typical of the Kannaviou.

Large blocks or sheets of Permian to Lower Cretaceous shelf carbonates (Fig. 4) of a few metres to several kilometres extent outcrop in the Kyrenia fold belt. Their allochthonous nature is evident as they override late Cretaceous and Lower Tertiary, partly turbiditic limestones and greywackes or are enveloped by these. In addition, small sheets of basic igneous rocks, intensely weathered lavas with less frequent rhyolites and small slices of metamorphic schists are found as exotic bodies in the core of the Kyrenia fold belt.

UPPER MAASTRICHTIAN-TERTIARY STRATIGRAPHY

The sediments south of the Ovgos fault zone and occurring on the flanks of Troodos form a contrast, both in facies and degree of deformation, to the deposits of the N Cyprus thrust belt. The Upper Maastrichtian-Tertiary sediments (Fig. 2) will therefore be discussed according to their occurrence south or north of the Ovgos fault zone.

Sediments south of the Ovgos fault zone

The sequence can be divided into three main sedimentary cycles, whose boundaries coincide with periods of island uplift. Local formation names, more or less in accordance with those used by earlier writers, have been adopted to describe these cycles.

1. The Lefkara Formation up to 700 m thick. Age: Upper Paleocene (locally Upper Maastrichtian) to Lower Miocene. It is composed of plankton-rich marls and thick-bedded chalks, with chert intervals in its basal part. At the base of the Lefkara, tuffs or thin volcanic grids are sometimes found. These are considered to be redeposited from the Upper Cretaceous volcanic sediments and thus form a transition

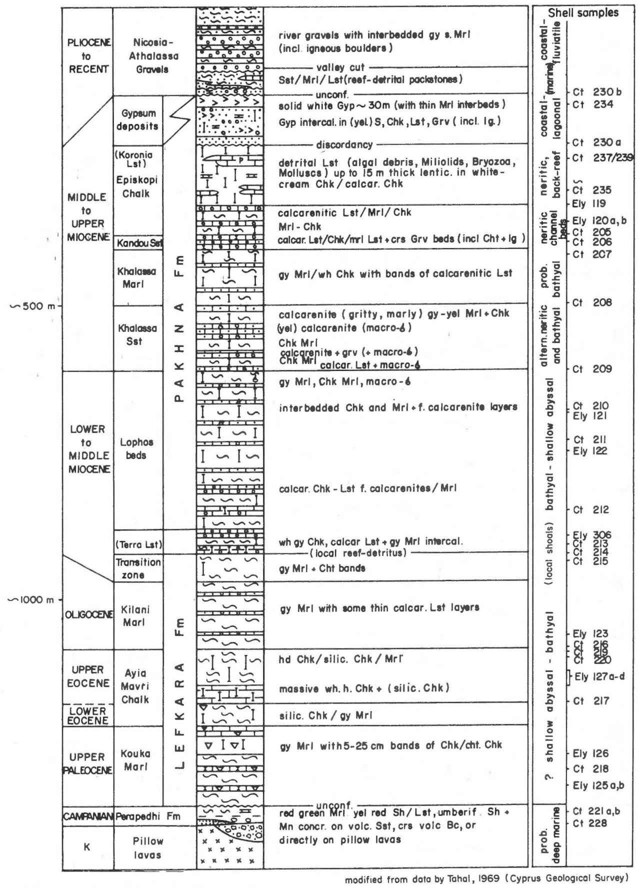


Fig. 5. COMPOSITE SURFACE SECTION, KOURIS RIVER, S. CYPRUS

between Troodos basement or Kannaviou equivalents and the essentially non-volcanic Lefkara.

The absence of subaerial erosive features and the presence nearly everywhere around the Troodos outcrop of plankton-rich cherty deposits at the base of the non-volcanic Lefkara indicate that the latter were laid down in a continuously submarine environment. The mildly unconformable contacts and the stratigraphic hiatuses sometimes seen in marls and chalks with plankton oozes at the base of the Lefkara, e.g. on the east plunge of Troodos between Nicosia and Larnaca, are therefore explained by the authors as being due to submarine erosion or non-deposition.

The uppermost part of the formation (L. Miocene) may show development of reef-detrital limestone, preceded by thin layers of fragmental limestone with larger forams in marls and chalks. In SW Cyprus a more compact limestone (Terra Limestone) of Oligo- Miocene age occurs and is described as a shell-detrital, algal/coral lime-packstone, 20-100 m thick; locally it lies almost direct on Troodos pillow lavas and is associated with conglomerates containing dark igneous and cherty-marly Lefkara components. These form the earliest evidence of surface erosion of Troodos rocks and corroborate the existence of (Oligo-)Miocene highs.

2. The Pakhna Formation probably up to 600-700 m, but usually less. Age: Lower Miocene to basal Pliocene. It succeeds the Lefkara with local unconformity. Main lithologies are pelagic (globigerina) marls and chalks, but in S Cyprus important calcarenite layers are intercalated (Fig. 5).

The end of the Pakhna cycle shows a renewed occurrence of compact limestones, usually lenticular features, 5-15 m thick, which are bioclastic packstones containing algal fragments, Bryozoa, Miliolids and other benthonic forams in a matrix of mud or chalk. These limestones (Koronia Limestone) grade upwards and probably laterally into layers of gypsum.

In the Famagusta area (SE Cyprus) the Upper Pakhna development was somewhat different; sections drilled by shallow Government wells indicate that plankton-rich marls, chalks and clays were deposited, probably in elongated deeps, with very little detrital influx from the bordering highs. Late Miocene gypsiferous marls occur, interbedded with thin organic-rich, locally pyritic, dark clays, suggesting local euxinic conditions.

3. The Myrtou and Nicosia Formations (and Fanglomerates), in north Cyprus presumably up to 700 m or more. Age: Lower Pliocene to Recent.

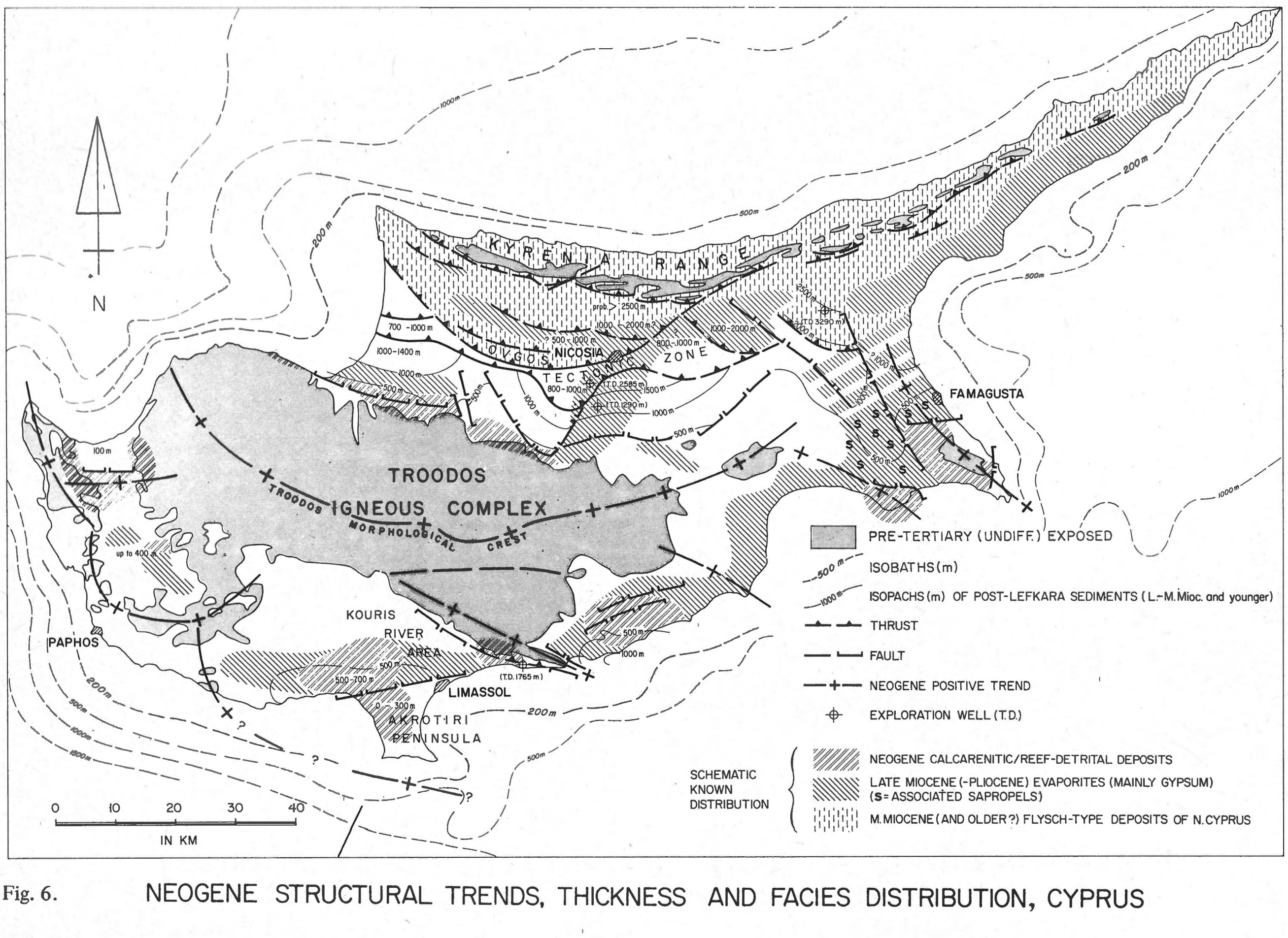


Fig. 6. NEOGENE STRUCTURAL TRENDS, THICKNESS AND FACIES DISTRIBUTION, CYPRUS

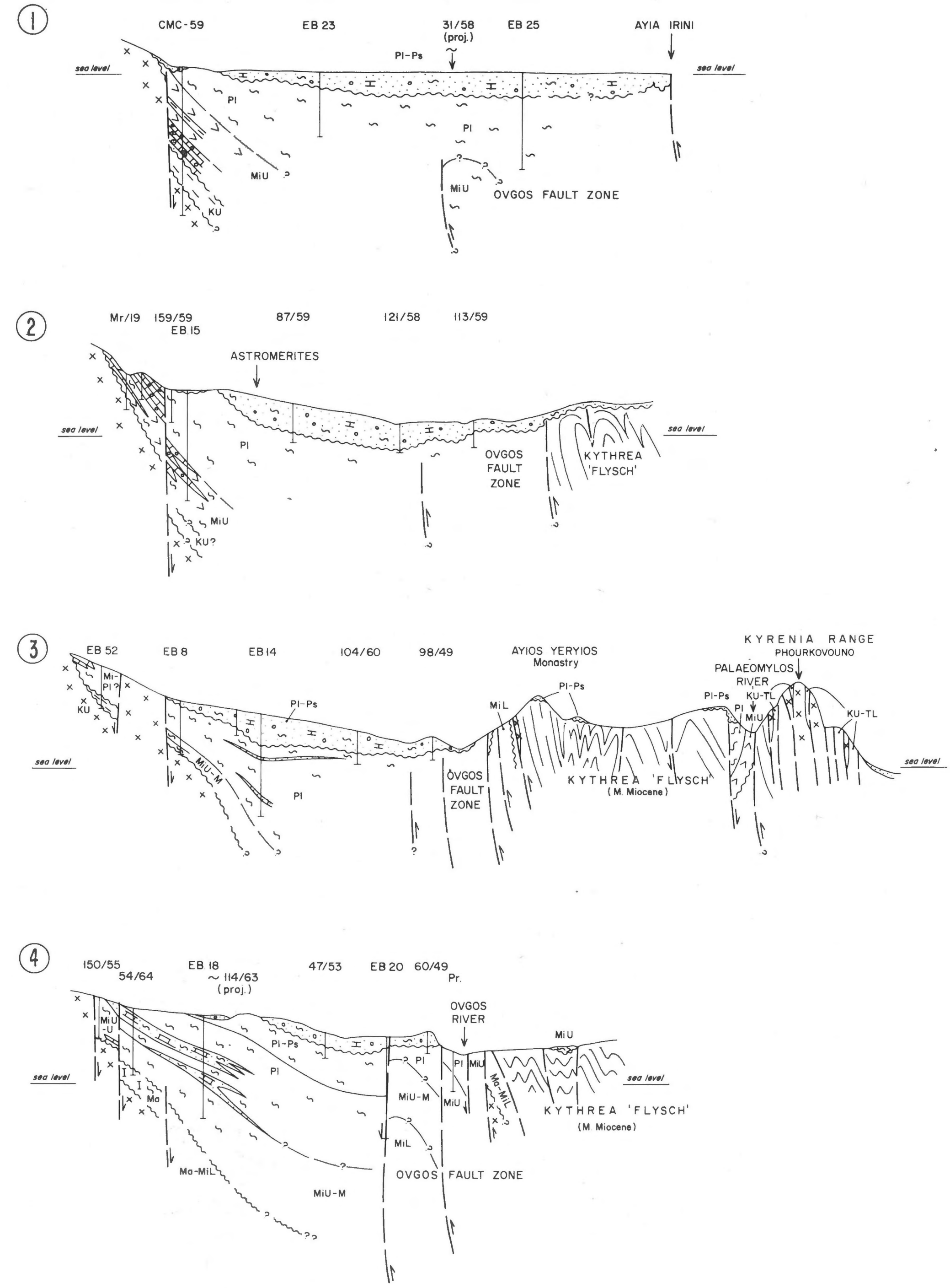


Fig. 7-1.

STRATIGRAPHIC SECTIONS OF TROODOS NORTH FLANK
(based on subsurface data from Cyprus Geological Survey)

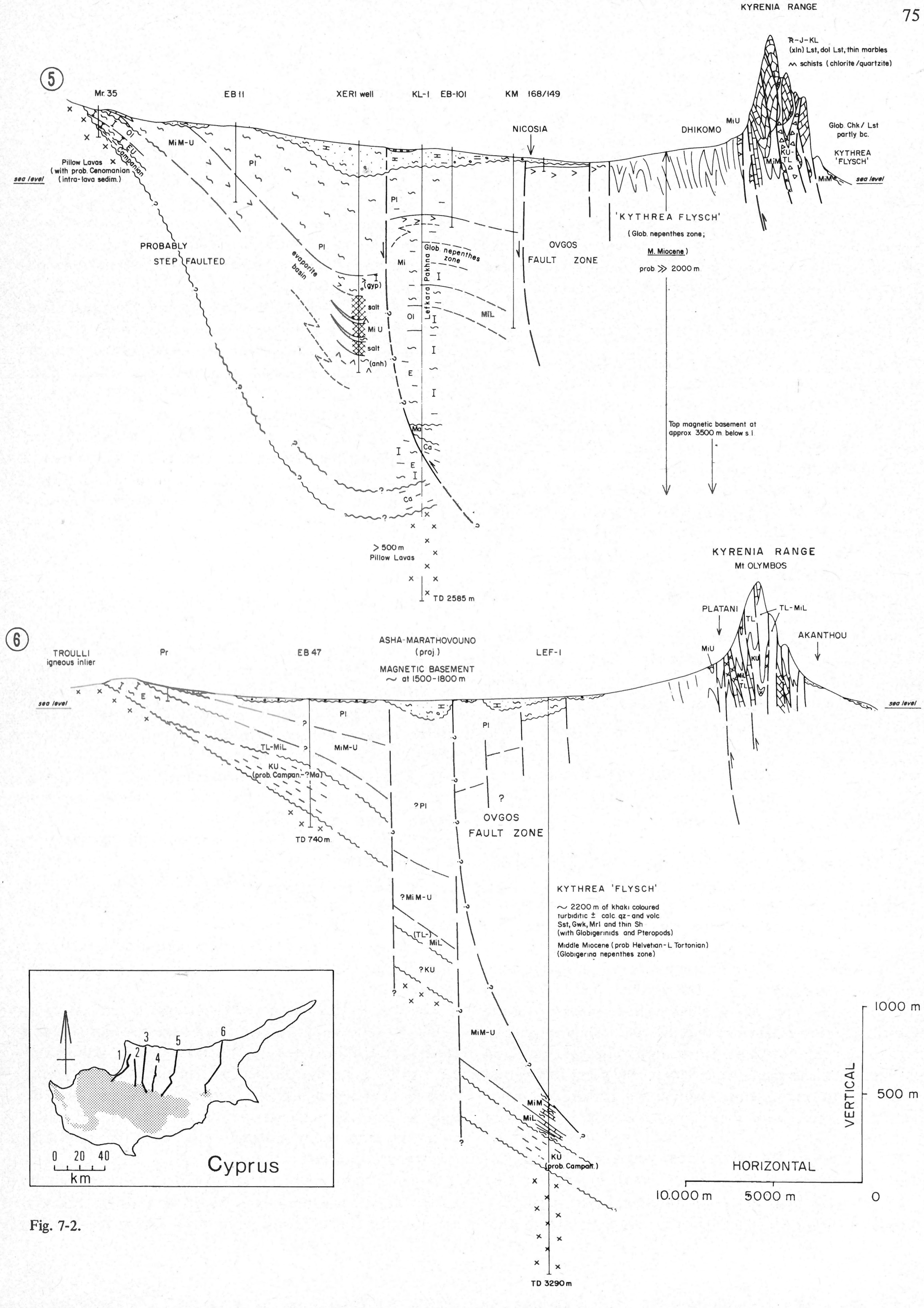

KYRENIA RANGE
R-J-KL
(xln) Lst, dol Lst, thin marbles
schists (chlorite/quartzite)
5
Mr. 35
EB 11
XERI well
KL-1 EB-101
KM 168/149
NICOSIA
DHIKOMO
MiU
Glob Chk / Lst
partly bc.
KYTHREA
'FLYSCH'
MiM-U
Ol
EU
Campanian
Pillow Lavas
(with prob. Cenomanian
(intra-lava sedim.)
sea level
Pl
'KYTHREA FLYSCH'
(Glob. nepenthes zone;
M. Miocene)
prob ≫ 2000 m
PROBABLY
STEP FAULTED
evaporite basin
Mi
Glob nepenthes zone
Lefkara Pakhna
OVGOS
FAULT ZONE
(gyp)
salt
Mi U
salt
(anh)
MiL
E
Top magnetic basement at
approx 3500 m below s l
Ma
Ca
> 500 m
Pillow Lavas
TD 2585 m
KYRENIA RANGE
Mt OLYMBOS
PLATANI
TL
TL-MiL
AKANTHOU
6
TROULLI
igneous inlier
Pr
EB 47
ASHA-MARATHOVOUNO
(proj)
MAGNETIC BASEMENT
~ at 1500-1800 m
LEF-1
KU
TL-MiL
KU
(prob. Campan.-?Ma)
?Pl
TD 740 m
OVGOS
FAULT ZONE
KYTHREA 'FLYSCH'
~ 2200 m of khaki coloured
turbiditic ± calc qz- and volc
Sst, Gwk, Mrl and thin Sh
(with Globigerinids and Pteropods)
Middle Miocene (prob Helvetian-L. Tortonian)
(Globigerina nepenthes zone)
?MiM-U
(TL-)
MiL
?KU
MiM-U
MiM
KU
(prob. Campan.)
TD 3290 m
Cyprus
0 20 40
km
1000 m
500 m
VERTICAL
HORIZONTAL
10.000 m
5000 m
0

Fig. 7-2.

Post-Pakhna sedimentation was only locally important in south and southwest Cyprus, and usually restricted to coastal or shallow inland basins. On the SE, E and N flank of Troodos marine sedimentation was resumed or continued in the Lower Pliocene after an Upper Miocene – early Pliocene period of uplift and local erosion. The main Pliocene lithologies are grey marls and clays. Coarse detrital material (carbonate and igneous) appears in large quantities in the Upper Pliocene when the whole of Cyprus was elevated to become the present island. Beach conglomerates and marly shell beds mark the end of this clastic infilling stage in the N Cyprus depression now occupied by the Mesaoria Plain.

Sediments north of the Ovgos fault zone

Late Cretaceous – Tertiary sediments north of the Ovgos zone show a variety of lithofacies (Fig. 4), but flysch-like deposits, locally referred to as Kythrea Flysch, form the main outcrop in a wide thrust belt that culminates in the Kyrenia Range (Figs. 6 & 7). The Kythrea deposits, 2000-3000 m thick, are composed of greenish-grey or beige marls, greywackes and calcareous sandstones that show local grading, groove and flute casts, thin limestones and occasional tuffs. No age datings have been obtained from our own samples, but according to Weiler (1965) the Kythrea yields fossils indicative of only one single biozone (*Globigerina nephentes*). Their age is probably Upper Helvetian (? Lower Tortonian).

Slump breccias embedded in an argillaceous matrix with Miocene larger forams are occasionally found in the foothill belt on the south flank of Kyrenia, which points to pre-Pliocene structuration of at least parts of the range.

TERTIARY MOVEMENTS (Fig. 6)

Movements south of the Ovgos fault zone

In the area of Famagusta a system of NW – SE trending basins or grabens, flanked by highs with carbonate build-ups (equivalents of Terra and Koronia limestone), was apparently present from the Oligo-Miocene onwards. Similar limestones related to Neogene highs occur in S and SW Cyprus.

Late Miocene to early Pliocene tectonic activity caused the Upper Maastrichtian and Tertiary beds on the flanks of Troodos to become mildly block-faulted, tilted or locally warped. Dips are usually less than 10° and mainly away from the Troodos exposure area. Some steeper dips occur high on the Troodos south flank, while very locally sharp folding and minor southward thrusting in presumed Lefkara sediments can be seen (e.g. near the Troodos outcrop northeast of Limassol).

Along the Troodos north flank, young step faulting has affected the edge of the present Tertiary outcrop so that Lower Pliocene beds appear downthrown to the north. The available subsurface data (Fig. 7) suggest that further north, toward the Ovgos fault zone, thrusts have affected the flank sediments, probably under influence of the movements north of the Ovgos fault zone.

Movements north of the Ovgos fault zone

The north Cyprus thrust belt consists of steep north-dipping thrust slices which may locally show internal folding (Fig. 7). Since the facies contrast across the Ovgos fault zone suggests a considerable amount of tectonic transport, it is likely that the thrusts become flatter at depth and pass into one or more major sole faults.

The presumed Middle Miocene Kythrea Flysch is discordantly overlain by gypsum so that the main thrusting period was around the Upper Miocene. However, these movements must have continued in younger periods because the gypsum (of late Miocene to early Pliocene age?) has locally been involved in steep upthrusting as well.

The assumption that the thick and at least partly turbiditic Kythrea deposits are time equivalent to only part of the pelagic Pakhna, leads to the conclusion that the Ovgos fault zone that brings the two rock groups in contact must be a tectonic weld of major order.

HYPOTHESIS ON THE EVOLUTION OF CYPRUS (Fig. 8)

The composition of the (Cretaceous) Troodos massif, according to several authors, is similar to what has been inferred for the oceanic lithosphere. The assumption that the massif is an elevated slab of ocean crust has support from gravity analysis, and recently from seismic refraction measurements.

There are further arguments, contained in the present paper, for the existence of the Troodos complex as a submarine topographic feature before the onset of Upper Maastrichtian – early Tertiary sedimentation, probably as early as the Campanian.

The origin of Troodos could have been at a spreading ridge along the model of the central part of modern oceans (Moores and Vine, 1971; Greenbaum, 1972) or, as Gass and Smewing (1973) have suggested for the Upper Pillow Lavas, on an ocean rise some distance away from the spreading axis.

The density distribution below Cyprus is thought to be caused by southward overthrusting of the Troodos slab on a crustal layer of lower density, which the present authors conceive to be a deeply subsided part of the (Mesozoic) Afro-Arabian continental margin ("continental margin" here defined as: a zone of shelf/slope, proximal and distal marine sediments, presumably underlain by a crust transitional between continental and oceanic.).

Some of these presumed palaeo-margin rocks (slope sediments, distal turbidites, alkali basalts and associated reefs) escaped the fate of being underthrust below the Troodos

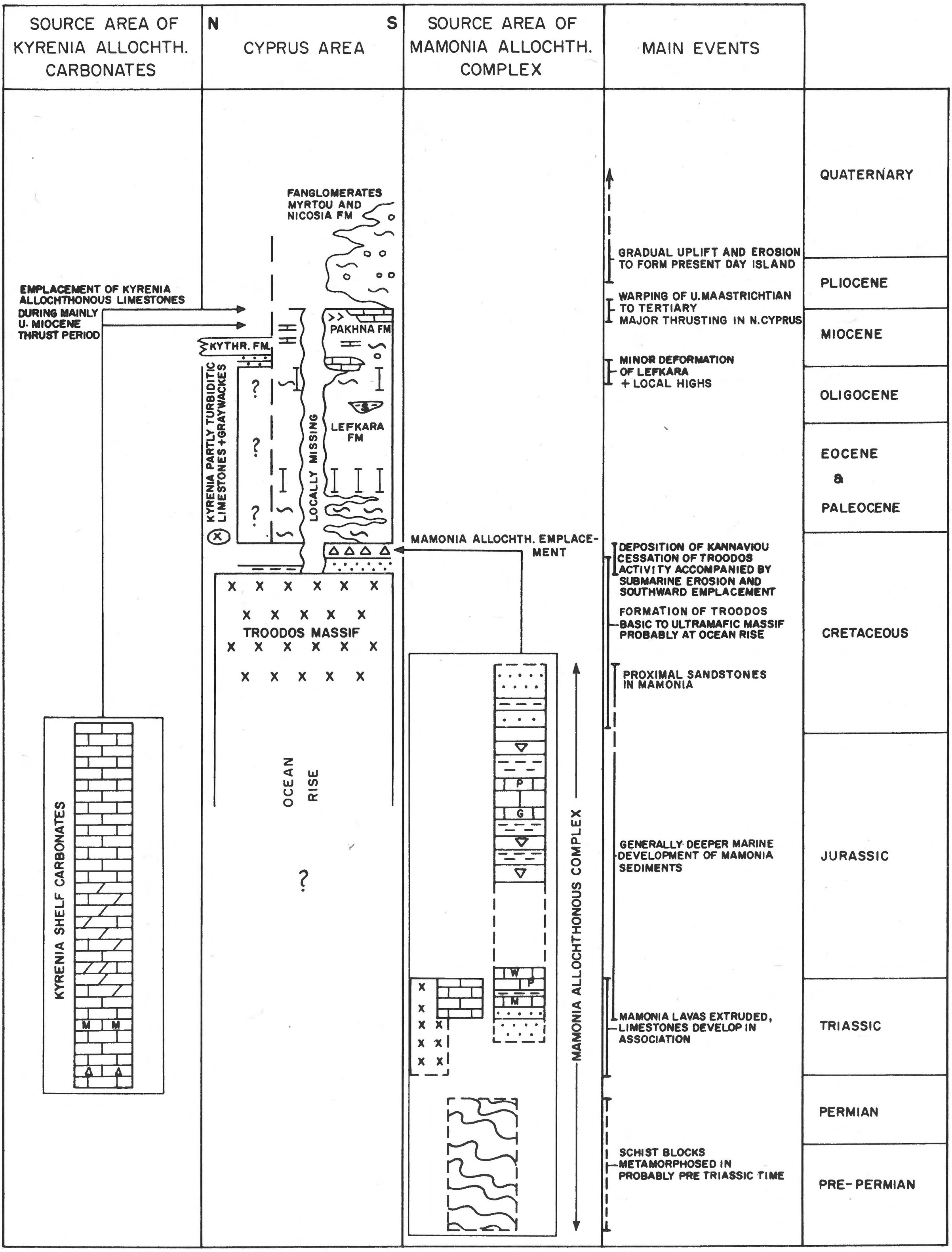


Fig. 8. SUMMARY OF EVENTS DURING THE GEOLOGICAL EVOLUTION OF CYPRUS

mass and slid, as part of the Mamonia Allochthonous Complex, on the leading edge of Troodos in late Campanian – early Maastrichtian time. In part they came to rest on a bed of Kannaviou slope sediments whose main andesitic pyroclastic source could also have been within the now sunken continental margin.

Rocks considered as being derived from a more landward part of the former Afro-Arabian continental margin are the metamorphic rocks found at the base of the Mamonia Allochthonous Complex, and the massive (Nubian type?) quartz sandstones of Lower Cretaceous age that occur in the uppermost part of the complex.

During subsequent Tertiary periods, continued underthrusting from the south forced the Troodos mass to rise without seriously disturbing the sequence of pelagic marls and chalks that were deposited on its flanks. Parts of the Troodos – Cyprus structure reached sea level around (late Oligocene–) Lower Miocene time, evidenced by the spotty but widespread appearance of the reef-detrital Terra Limestone.

In the Upper Miocene the Kythrea flysch deposits of N Cyprus were upthrusted and reached a near-surface position. Subsequent southward thrusting eventually brought the Kythrea in direct contact with Miocene and Pliocene pelagic sediments on the Troodos north flank. The sediments on the Troodos flanks were only marginally affected by these thrust movements.

General uplift took place in the Upper Pliocene and formed about the present island.

CYPRUS AND ITS EAST-MEDITERRANEAN SETTING

According to gravity analyses, the eastern-Mediterranean crust (density 2.88, thickness 23-31 km) is generally more than twice as thick as the western-Mediterranean crust (Woodside and Bowin, 1970; Rabinowitz and Ryan, 1970; Ritsema, 1970; Wong *et al.*, 1971).

The edges of the present Afro-Arabian continent

The Mediterranean shores east and south of Cyprus form part of the Afro-Arabian continental borderland that has but slightly been affected by Alpidic movements.

Pre-Cambrian basement, widely exposed in southern Sinai, dips regionally northwestwards and is overlain by up to 4000 m of Palaeozoic and Mesozoic, mainly unstable-shelf sediments. These include carbonates and marls and locally Nubian-type quartz sandstones; they are followed by 200-700 m of neritic to coastal Tertiary deposits.

Mega-structurally, the Afro-Arabian borderland opposing Cyprus is characterised by large rift systems, the most important being the Akaba-Dead Sea Rift, which is assumed to extend northward (Wolfart, 1967) into Turkey, and southward into the Red Sea rift.

North of Cyprus: the Anatolian-Tauric Fold system

To the north, less than 100 km away from Cyprus, mainland Turkey is bordered by the Tauric fold belt, which shows arcuate bending convex to the south. The Taurids were folded in the Upper Cretaceous and Tertiary. They are separated from the North Anatolian fold system, which borders the Black Sea, by the Central Anatolian pre-Mesozoic crystalline and metamorphic massifs.

Within the North Anatolian and Tauric fold belt ophiolite-radiolarite complexes are found which, following Aubouin (1965), represent eugeosynclinal associations.

The Tauric fold belt as a whole is characterised by intense overthrusting toward the south.

The boundary between the Tauric fold belt and the Afro-Arabian borderland

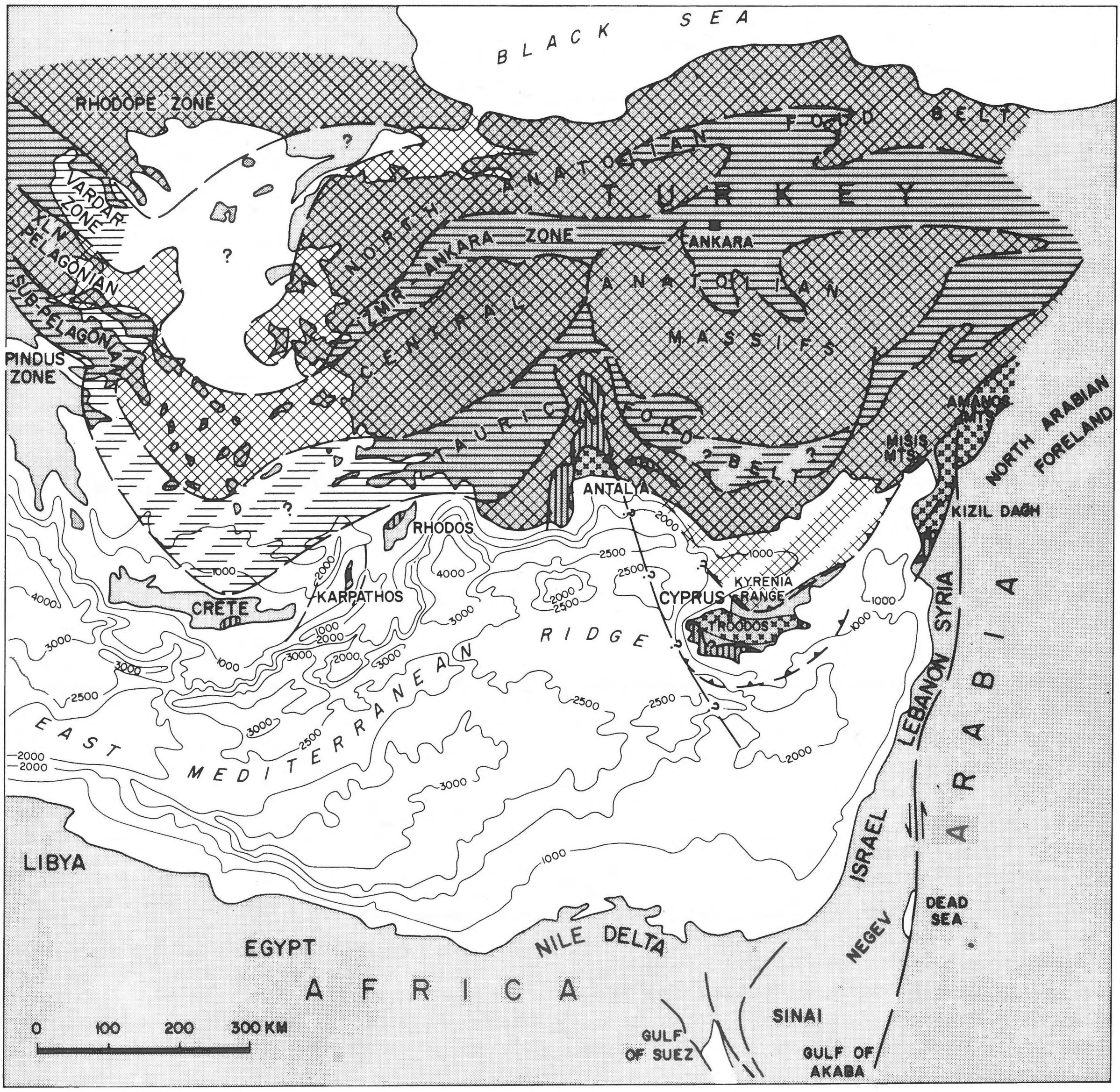
This boundary is well defined in southeastern Turkey, where strongly deformed overthrust nappes of the Taurus chain override the imbricated north-Arabian foreland. In a southwestern direction it extends to the Amanos-Kizil Dagh area at the Turkish-Syrian border near the Mediterranean coast. The continuation of this contact zone is represented in Cyprus by deep-seated thrusts north and south of the Troodos igneous mass. Further west it appears offset to the Antalya area of SW Turkey. From here this boundary zone might extend to Rhodes and Crete.

The ophiolite-radiolarite belts

Ophiolites, (ultra) basic rocks of usually calc-alkaline chemistry, are interpreted as oceanic crust tectonically emplaced on top of sialic crust (Reinhardt, 1969). These rocks, commonly associated with radiolarian-rich beds interpreted to be deep-sea sediments, occur in the North-Anatolian and Tauric fold belts as more or less continuous zones (Fig. 9). Opinions differ widely as to the original position of the roots of these masses, because at least some of them are known to form part of large alpine overthrust nappes.

The ages of most east-Mediterranean ophiolite complexes are uncertain; Brinkmann (1972) has assigned ages to the ophiolite-radiolarite belts in general, based on the associated deep-sea sediments. These range from Jurassic to early Upper Cretaceous. It appears that within the east-Mediterranean area the oldest known and most continuous Mesozoic deep-marine assemblages are found in the outer, southernmost belt of the Anatolian-Tauric fold system. They occur, from east to west: in the southernmost part of the Amanos Mountains in NW Syria, on the south flank of Troodos in Cyprus, in south Antalya, the islands of Rhodes, Karpathos (Aubouin and Dercourt, 1970) and Crete, and probably the Pindos zone of Greece (Terry, 1971).

In south Cyprus and in Antalya (Dumont *et al.*, 1972) a more or less continuous Mesozoic rock sequence seems to be represented, which includes alkali basalts and slumped reefs of Triassic age, Jurassic and Cretaceous radiolarites, and



NE Mediterranean pre-Tertiary fold belts:

- pre-Mesozoic crystalline and metamorphic masses, with local cover of platform-type Mesozoic sediments
- Supposedly Jurassic and Cretaceous radiolarite-ophiolite belts (incl. partly proven overthrust nappes)
- Allochthonous Ҭ-J-K deep-sea sediments (incl. Ҭ basic igneous)
- Basic to ultramafic volcano-plutonic massifs of partly proven (upper) Cretaceous age

Depth contours in metres

Sources (mainland Turkey and Greece): Carte Tect. Intern. 1: 2 500 000, Brun et al (1970), Campbell (Ed, 1971), Brinkman (1972)

Fig. 9. EAST MEDITERRANEAN SETTING OF CYPRUS

Cretaceous slope deposits. In south Cyprus, NW Syria (K a z ' m i n, P o n i k a r o v *et al*., in: R i c o u, 1971), and possibly also in south Antalya, these Mesozoic assemblages rest as slump blocks, thrust masses or larger nappes on massive ophiolite complexes of Cretaceous age. In Antalya, Triassic to Cretaceous deep-sea sediments are contained in the lower and middle nappe units, which have been emplaced on their continental (autochthonous?) counterparts mainly during the late Paleocene (D u m o n t *et al*., *op.cit*.; B r u n n *et al* 1970). In Cyprus the Mamonia Allochthonous Complex, composed of smaller sheets but of similar composition as in Antalya, slid on the south edge of Troodos in the Campanian-early Maastrichtian, while in NW Syria similar events seem to have taken place during the Maastrichtian.

Conclusions regarding the east-Mediterranean evolution

A hypothesis explaining the rock associations present in the southernmost ophiolite-radiolarite belt of the Anatolian-Tauric fold system, in which Cyprus occupies an advanced position, would involve the following:

During the Upper Cretaceous, continental margins that bordered a "Tethyan" sea of unknown width started to move towards each other. From the resulting mainly compressional system, pieces of ocean crust, probably topographically structured to various degree, were thrust upon the edge of the southern (Afro-Arabian) continent. The oceanic slabs in turn were eventually overriden by nappes derived from the north (the Kyrenia Range in north Cyprus, the Misis Mountains in SE Turkey).

Meanwhile, marine sediments and igneous rocks from the Tethyan margins were pushed up and emplaced as exotic blocks and debris, broken-up sheets or larger nappes, all along the zone of major contact. This zone runs across Cyprus where Troodos forms a clenched, central element.

In southwest Cyprus the massive Lower Cretaceous quartz sandstones of the Mamonia Allochthonous Complex are possibly "Nubian" sandstones derived from the African or Arabian palaeo-continent.

In north Cyprus the allochthonous sheets of Permian-Lower Cretaceous shelf limestones have their equivalents in similar rocks in the "Upper Nappe" of Antalya (D u m o n t *et al*., 1972) and probably derive from a platform belonging to the "northern" continental margin.

To illustrate the possible relation of Cyprus geology to that of other peri-Arabian ophiolite belts, a number of same-scale profiles based on field sections from various authors have been constructed. These profiles (Fig. 10) show that the ophiolite masses, according to the proposed concept squeezed between opposing continental margins and thrust upon the edge of the southern (Afro-Arabian) continent, differ considerably in style of deformation and size. Variations range from melange-type jumbles of fractured serpentinites to huge bodies of layered plutonics and lavas, while Troodos in Cyprus appears to be an ophiolite of unique size, too heavy to be effectively supported by the margin of the Afro-Arabian continent.

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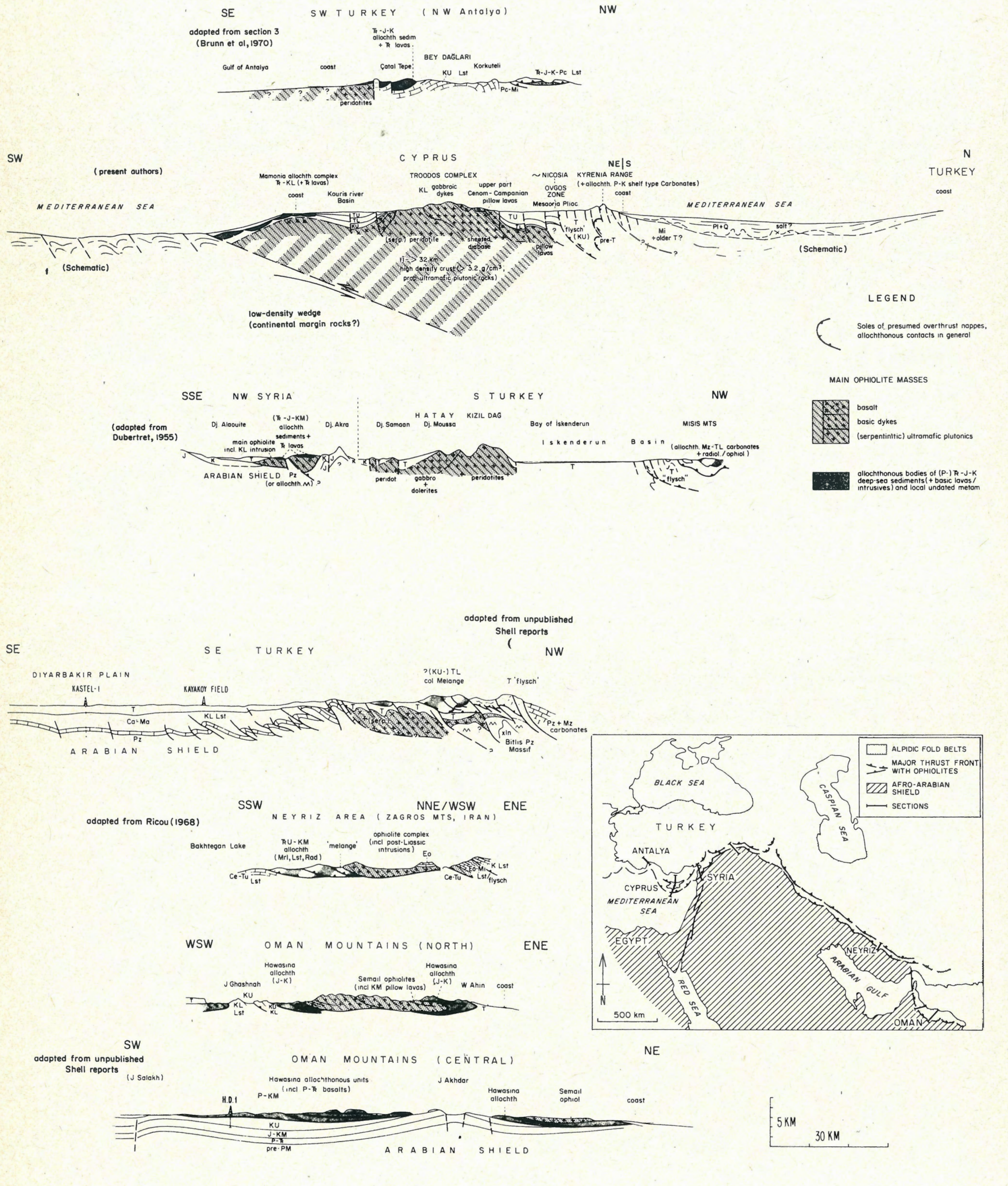

SAME SCALE SECTIONS THROUGH PERI-(AFRO-) ARABIAN OPHIOLITE BELTS (schematic, after various authors)

Fig. 10.

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