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The Molasse of Paros Island, Aegean Sea

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(With 7 textfigures)

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Zusammenfassung

Auf der Insel Paros bildet die Molasse die höchste Formation der Marmara-Decke. Diese ist ein Teil der regionalen Kykladen-Decke und umfaßt alle vorobermiozänen, nichtmetamorphen Gesteine des Gebietes. Das Alter der Molasse und ihrer Transgression auf den Ophiolithen wurde mit Foraminiferen und kalkigem Nannoplankton als Burdigalien bestimmt. Daraus ergibt sich eine Platznahme der Kykladen-Decke in der Zeit nach dem Burgidalien und vor dem Messinien, da die frühesten autochthonen Sedimente auf Milos dieses Alter haben. Die Kykladen-Decke stammt wahrscheinlich aus einem Gebiet südlich der Kykladen, etwa aus dem jetzigen Kreta-Becken.

Abstract

The Molasse of Paros Island is the upper formation of Marmara nappe, which is part of the regional Cycladic nappe comprising all the pre-upper Miocene non-metamorphic rocks of the area. The age of the Molasse as well as of its transgression on the ophiolites was determined by foraminifera and calcareous nannoplankton as Burdigalian. Hence, the emplacement of the Cycladic nappe is of post-Burdigalian and of pre-Messinian age (from the age of the first autochthonous sediments of Milos). The origin of the Cycladic nappe is probably from the area south of Cyclades, approximately from the present Cretan Basin.

I. Introduction

The existence of Neogene sediments in the Cyclades was known since last century. PHILIPPSON (1901) showed the most important outcrops of Naxos, Paros and Myconos on his geological map of the Cyclades of scale 1/300000. However detailed studies were not available until recently and these sediments were considered as the result of a Neogene transgression on the metamorphic basement. On Naxos various ages were proposed ranging from Eocene to Miocene (NEGRIS & BOUSSAC 1914 a, b; NEGRIS 1915; OEKONOMIDES 1935), but they were mainly obtained by reworked fossils within the clastic sequences. More recent studies (ROESLER 1972, 1978; JANSEN 1973, 1977; ANGELIER

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et al. 1978) concluded to ?Oligocene — lower Miocene ages. JANSEN (1973) was the first to propose an allochthonous origin of these neogene sediments, something later approved by many others (PAPANIKOLAOU 1977; ANGELIER et al. 1978; DÜRR et al. 1978; ROESLER 1978).

In Paros island the only stratigraphic determination of the Neogene has been reported by PAPAGEORGAKIS (1968b), based on Miocene corals. PAPANIKOLAOU (1977) distinguished some structural units in Paros, the higher of which — Marmara Unit — is composed of non-metamorphic rocks comprising ophiolites, Barremian limestones with a basal conglomerate and a transgressive ?Oligo-Miocene Molasse on top. This Marmara Unit constitutes a late nappe emplaced during middle-upper Miocene onto the metamorphic rocks of Paros.

A detailed geological research of the metamorphics of Paros including geological mapping at scale 1/50000 (PAPANIKOLAOU 1979c) gave the opportunity of a more detailed study of the Molasse with sampling of the more suitable sections. The results of this study are given in this paper with stratigraphic determinations based on planktonic foraminifera and calcareous nannoplankton.

II. Geology

I. Geological structure of Paros Island

According to PAPANIKOLAOU (1979c) the structure of Paros Island comprises three nappes: the Marathi nappe, the Dryos nappe and the Marmara nappe. The Marathi nappe is the lower one and comprises the three previously distinguished structural units of Paroikia, Marathi and Lefkes (PAPANIKOLAOU 1977), all metamorphosed in amphibolite facies. The Dryos nappe is made of very low grade metamorphic rocks comprising phyllites, greenschists and marbles of Permian age, found also in the nearby Antiparos Island. The Dryos nappe crops out in three regions along the southwestern coastline of Paros and at the area of Dryos in southeastern Paros, where it is underlain by the ophiolites of Marmara nappe (see also geological sketch within the geological map of fig. 1). The Marmara nappe crops out mainly at Northeastern Paros and at low altitudes (not higher than 150 m).

The only autochthonous sediments on Paros, except the Quaternary deposits, are some ?Pliocene travertine limestones and breccias, usually silicified. They correspond to a marine terrace very rich in algae (perfectly preserved) with gradual transition to a terrestrial terrace observed mainly at the area of Aghios Andreas to the southwest of Naoussa. These travertines are found transgressive either on the Molasse or on the ophiolites or on the metamorphic rocks.

2. The Molasse of Paros Island

The outcrops of the Molasse in Paros are not suitable for detailed sampling along big sections. This is due to the very smooth relief with extensive cultivation at northeastern Paros and to the intense tectonism which interrupts the sequences. Additionally, the lack of distinctive marker beds, hardens the observation of the continuity of the various horizons. Thus, a stratigraphic succession of the molassic formations is very difficult to be well documented. A very small percent of the marly horizons was fossiliferous and the best samples come from sections not depassing 20—25 m of thickness. The localities of the best fossiliferous samples are shown on the geological map (fig. 1).

The transgression of the Molasse on the ophiolites is rarely observed. One of the best outcrops occurs at about 1200 m WSW of Naoussa and about

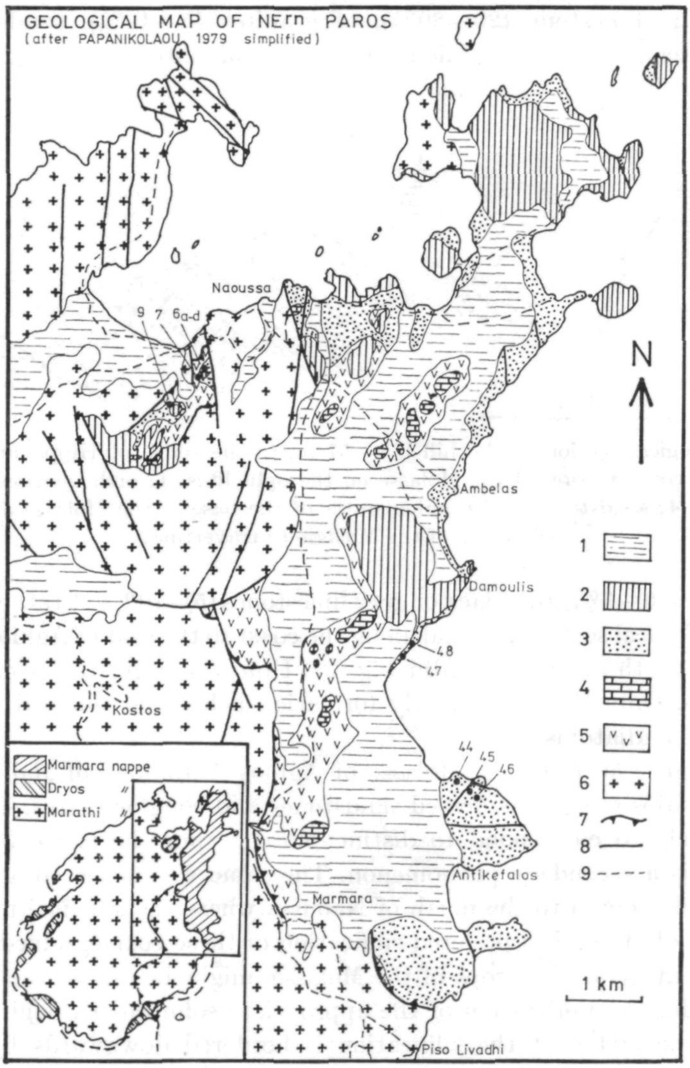

Fig. 1. Geological map of NE Paros. 1: Quaternary 2: Pliocene ? travertines 3: Burdigalian Molasse 4: Barremian limestones 5: ophiolites 6: metamorphic rocks 7: overthrust 8: fault 9: main roads.

500 m south of Hippokampos Hotel (fig. 2). The ophiolites of this outcrop are found in tectonic contact to the marbles and orthogneisses of Marathi nappe. The Molasse begins with a marly limestone of 0,5—1 m of thickness which is overlain by some 10 m of sandstones and conglomerates. Then, a formation of gray-blue siltstones is observed with 2—3 decimetric beds of calcarenites and sandstones. The small klipp on top of the hill (h = 57 m) is made of the unconformable travertines which are silicified.

The lithology of the Molasse is dominated by sandstones and conglomerates while marls are rare. The thicker marly horizons hardly surpasse the 15 m of thickness. The pebbles of the conglomerates are made of white marble or crystalline limestone (20—80%), of granites (5—40%), sandstones and conglomerates usually of red colour (5—30%), ophiolites (5—15%), gneisses &

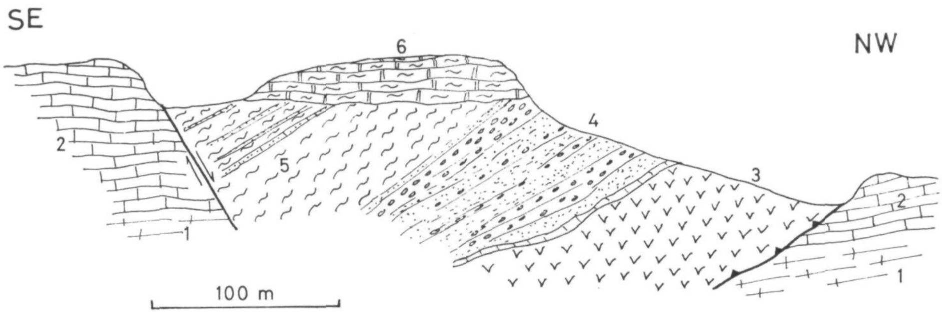

Fig. 2. Geological section of the hill h = 57 m, to the south of Hippokampos Hotel, showing the transgression of the Molasse on the ophiolites. 1: orthogneisses 2: marbles 3: ophiolites 4: sandstones and conglomerates of the base of the Molasse 5: marls and siltstones of the Molasse 6: travertines

amphibolites (0—5%) and black or gray limestones (5—10%). A rather representative lithological section is found along the coast to the east of Aghios Antonios hill to the north of Piso Livadhi (fig. 3). Unfortunately, this section is not fossiliferous. Only the upper marly formation below the silicified sandstones contains some diatoms.

The higher 50 m of the Molasse of Aghios Antonios hill and of Kefalos and Antikefalos are hard silicified sandstones and conglomerates. These rocks are not likely to correspond to distinct stratigraphic horizons, because the silification is a secondary phenomenon. The same was observed at the small island of Oikonomou to the north of Naoussa where the silicified rocks attain a thickness of 10 m. The prefered silification of these coarsegrained sediments of the present higher outcrops of the Molasse, might be due to the favourable conditions for the infiltration of the appropriate solutions through their high porosity. The fact that the silification is bordered downwards by the wall of some important marly horizons indicates that the role of atmosphaeric water is essential for the above process. The same phenomenon is also observed on the travertines of the area of Pyrgos to the south of Dryos.

The overlying travertines are found in angular unconformity to the molasse. This is observed at the area of Damoulis (fig. 4) and also at the northeastern extremity of Paros. The travertines are also found in transgression on the ophiolites at the area of Isternia village and on the metamorphic rocks at the area of Cape Tsakamaki. Their thickness varies but at the area of Isternia as well as at the northern peninsula of Paros it depasses 40 m.

An important tectonism is observed within the Molasse, with decametric folds trending N 20°—60° E, accompanied by thrusts and imbrications (see also ANGELIER 1977). An example in the mesoscopic scale is given in fig. 5.

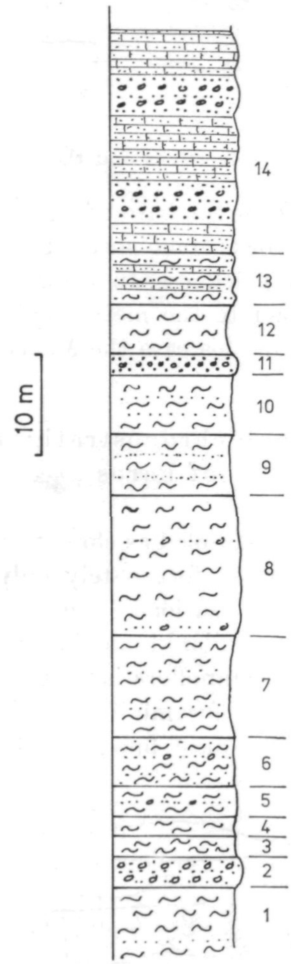

Fig. 3. Lithological section from the molasse along the coast to the east of Aghios Antonios hill. 1: gray-blue sandy marl 2: red sandstones and conglomerates 3: gray-blue marl 4: reddish sandy marl 5: reddish marl with sandstones and conglomerates 5: gray-blue marl with sandstones and conglomerates 7: gray-blue sandy marl 8: reddish sandy marl and conglomerates with ophiolitic detritus 9: alternations of blue and red sandy marls 10: blue marl with sandstones 11: yellow sandstone and conglomerate with granitic detritus 12: blue marl with diatoms 13: sandy marls and silicified calcareous sandstones. 14: silicified calcareous sandstones and conglomerates

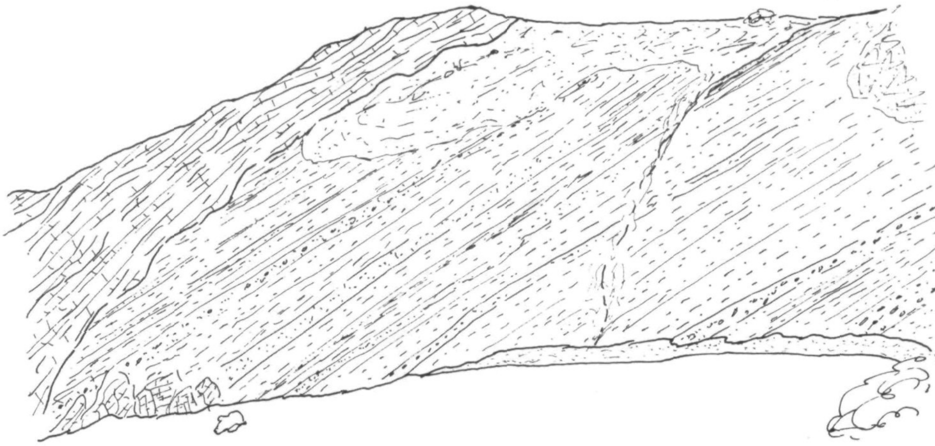

Fig. 4. The contact between the travertines and the Molasse at the area of Damoulis

The ophiolites usually form the base of the nappe. Almost all along the thrust on the metamorphic rocks some sheared ultramafic rocks are present, sometimes of only 1—2 m of thickness. In a few regions however the Molasse is found in immediate contact to the metamorphic rocks, as at the area of Marpissa and Piso Livadhi. In this case the Molasse is intensively tectonised with important brechification.

III. Biostratigraphy and chronostratigraphy of the Molasse of Paros

1. Introduction

The studied sections were sampled as closely as possible in order to arrive at a biostratigraphic conclusion. Unfortunately, only some samples are suitable for study because of recrystallizations. The samples generally contain a small number of Foraminifera. Planktonic Foraminifera are more frequent than the benthonic ones. The nannoflora is poor and not diversified. A qualitative analysis of the planktonic foraminiferal and calcareous nannoplankton associations recovered from the most fine-grained sediments was attempted.

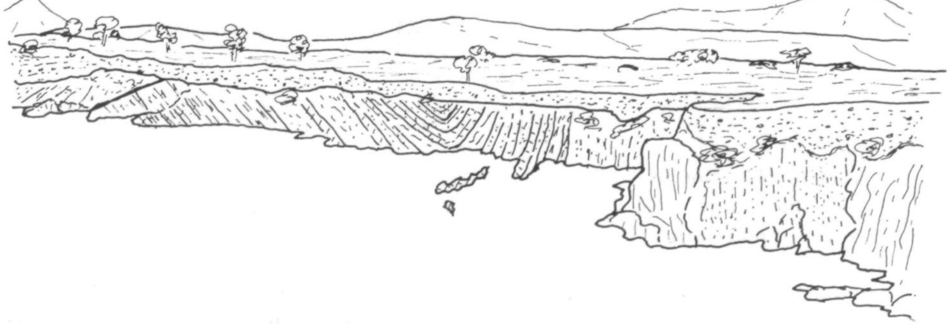

Fig. 5. Important folds with subvertical strata trending N 30° E along the eastern coast between Ambelas and Alyki seen from the North

The stratigraphic columns of the studied sections are given schematically in fig. 6. The small length of the sections, the small thickness of the marly horizons and the existence of many faults characterize the conditions of study and underline the difficulties as far as stratigraphic correlations are concerned.

2. Planktonic Foraminifera

The distribution of planktonic foraminiferal taxa in the studied sections — Antikefalos, SW Damoulis, S Hippokampos Hotel, E Panayia — is represented in the range charts (fig. 7). The associations obtained from these sections will be discussed in more detail and some markers from the benthonic foraminifera will be also refered in the studied samples.

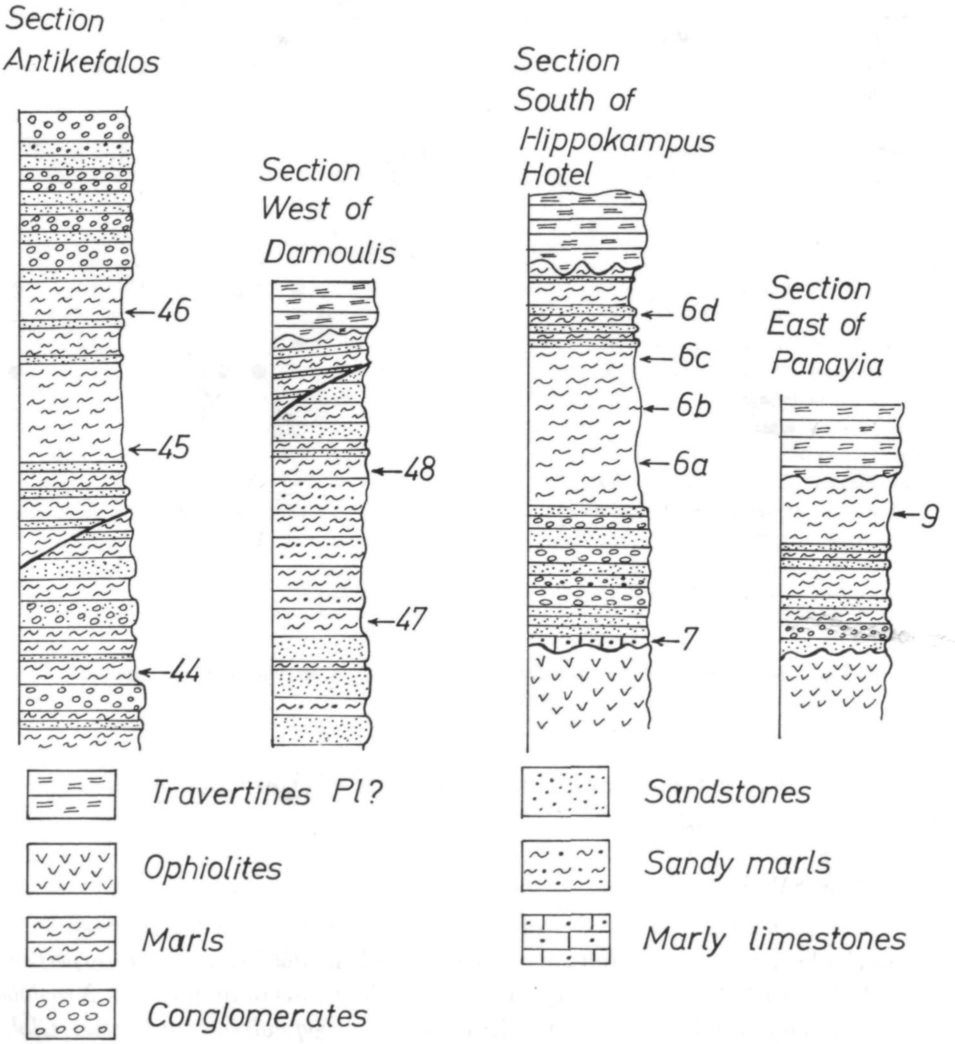

Fig. 6. Schematic stratigraphic columns of the studied sections of the Molasse of Paros (scale 1 cm aproximately 10 m)

i. Section Antikefalos

Three samples were studied in detail from this section. The associations derived from these samples contain *Neogloboquadrina mayeri*, *Globorotalia praescitula* and *Globigerinoides altiaperturus*, while *Orbulina* is absent. The cooccurence of *Globoquadrina altispira*, *Globoquadrina dehiscens*, *Globigerinoides trilobus* group, *Globigerina praebulloides* etc. allows a tentative correlation not younger as zone N_7 of BLOW. Consequently, the biostratigraphic data

species \ sections and samples	Antikefalos			West of Damoulis		South of Hippokambos Hotel					East of Panayia
	44	45	46	47	48	7	6a	6b	6c	6d	9
Globigerina apertura CUSHMAN					○					○	
Globigerina bulloides D'ORBIGNY	●	●	○		●	○	○	●	●		○
Globigerina cf. *ciperoensis* group			○	○			○	○			
Globigerina obesa (BOLLI)		○	○	○	○		○	○	○		
Globigerina praebulloides BLOW	●		○	●	○				○		○
Globigerina pseudobesa (SALVATORINI)			○		○		○	○	○		
Globigerina quinqueloba NATLAND				○							
Globigerina woodi JENKINS			○		○						○
Globigerinita glutinata (EGGER)											
Globigerinoides altiaperturus BOLLI			○	●	●		○		○		●
Globigerinoides bulloideus CRESCENTI											
Globigerinoides trilobus sacculiferus type	●			●							
Globigerinoides trilobus immaturus type		●	●	○	●	●	○	●	○		●
Globigerinoides trilobus (REIS.)	●	●	○	○		○	○	○		○	○
Globigerinoides subsacculiferus CITA, PREM.-SILVA & ROSSI	●	○		○			○	○			
Globoquadrina altispira (CUSHMAN & JARVIS)		○		○							
Globoquadrina cf. *baroromoensis* (LE ROY)		○			○		○	○			
Globoquadrina dehiscens (CHAPMAN, PARR & COLLINS)		○		○			●	●	○		
Globorotalia acrostoma WEZEL					●	○			○		○
Globorotalia praescitula BLOW	●										
Neogloboquadrina mayeri (CUSHMAN & ELLISOR)	○			○	●		○	●			○

● frequent – common   ○ rare

Fig. 7. The distribution of the planktonic foraminifera in the studied sections of the Molasse of Paros

demonstrates that the about 20 m of sediments of the section Antikefalos are of Burdigalian age.

ii. Section SW Damoulis

The associations derived from the terrigenous — clastic succession are fairly the best preserved from the studied samples. *Globigerinoides altiaperturus* is included with forms of the typical morphology, accompanied by *Neogloboquadrina mayeri* with forms identical to *Neogloboquadrina siakensis*. *Globoquadrina dehiscens*, *Globoquadrina altispira*, *Globoquadrina* cf. *baromoensis*, *Globigerina praebulloides* etc. are also present. The cooccurence of the above taxa indicates the same biostratigraphic interval of zones N_6 and N_7 of Blow, like in the previous section of Antikefalos. Consequently we may conclude that the sediments of the section SW Damoulis were deposited during the Burdigalian time-span.

iii. Section S Hippokampos Hotel

The associations recovered from four samples (Nos 6a—6d) can be correlated with zones N_6 and N_7 of Blow with the same as previously evidence. This is indicated by the cooccurence of *Neogloboquadrina mayeri*, *Globigerinoides altiaperturus* and the rest taxa.

Species of the genera *Spiroplectammina*, *Sigmoilopsis*, *Quinqueloculina*, *Gyroidina*, *Cibicides* etc. are also present in the benthonic foraminiferal associations. Specimens of the species *Haplophragmoides obliquicameratus*, whose biostratigraphic extinction is limited from Oligocene till Burdigalian age, were observed between them. It should be noted that the relatively higher percent of benthonic foraminifera observed in this section is probably related to the fact that they were derived from sediments lying only 15—30 m above the transgression on the ophiolites. On the contrary the sediments of the sections Antikefalos and W Damoulis are much higher from the transgression (more than 60 m).

The sample No. 7, which was taken from the base of the transgression does not contain characteristic taxa in order to conclude its biostratigraphic position with positive evidence. However the biostratigraphic evidence from the section S Hippokampos Hotel, based on the samples No. 6a—6d indicates a Burdigalian age.

iv. Section E Panayia

This section is located at about 600 m from the section S Hippokampos Hotel and with the same more or less geological conditions. The presence of *Globigerinoides altiaperturus* is significant but no other data allow us to consider its biostratigraphic position. However, the absence of *Orbulina* demonstrates that these sediments are tentatively placed in the lower Miocene.

3. Calcareous Nannoplankton

The calcareous nannoplankton content of the studied samples was generally poor and non diverse. The observed low diversity is possibly due to bad preservation which acts towards both solution and overgrowth and either masks the characteristics of the species, or has removed the less resistant ones.

In most samples only forms of *Reticulofenestra pseudoumbilica*, *Coccolithus pelagicus* and *C. miopelagicus* were resistant enough to persist the extremes of preservation. Discoasters were extremely rare and non-identifiable when encountered. The same applies to *Sphenolithus* species.

In samples 45, 46 and 47 however, specimens of *Helicosphaera ampliaperta* were quite common and unexpectedly well preserved, not to be confused with solution morphotypes of the species.

Sphenolithus heteromorphus, a species quite conspicuous even under extreme overgrowth of solution, was not observed.

Provided that *Helicosphaera ampliaperta* is indigenous in the mentioned samples, a fact supported by its common occurrence, the samples 45, 46 and 47 belong to an interval equivalent to the zones NN_2, to NN_4 of Martini's zonation. On the other hand, the absence of *Sphenolithus heteromorphus* could limit the interval to zones NN_2 and the lower part of zone NN_3. However we should like this implication to be used only in conjuction with the data received from the study of the planktonic and benthonic foraminifera.

IV. Conclusive Remarks

The stratigraphic determinations of the molasse of Paros showed both on the basis of planktonic and benthonic foraminifera and of calcareous nanno-plankton a Burdigalian age. It is important that this is also the age of the transgression of the molassic sediments on the ophiolites and on the relics of the Barremian limestones. It should be also noticed that the recent studies from the Mesohellenic trough in western Thessaly indicate a lower-middle Miocene age of the main molassic sediments along the western border of the trough (Papanikolaou & Sideris 1977; Georgiadou-Dikeoulia et al. 1977). while the upper Eocene — Oligocene sediments (Brunn 1956; Soliman & Zygojannis 1977a, b; Despraïries 1979) are found in more restricted areas below the lower Miocene sediments.

The first autochthonous sediments in the area of Cyclades occur in Milos and they are of Messinian age (Meulenkamp 1977). The radiometric ages reported on the granitic magmatism in central Cyclades (Altherr et al. 1976; Andriensen et al. 1979) indicate that the granitic rocks observed below the nappe with the Burdigalian molasse are of Serravalian-Tortonian age. Thus, it is rather well documented that within the intermediate time-span characterized as "post-Burdigalian" to "pre-Messinian" extremely important events have taken place in the Cyclades and more particularly the emplacement of the "Cycladic nappe". This nappe comprises all the non-metamorphic rocks of the Cyclades, Ikaria and Samos islands also included, and crops out in Naxos (allochthonous unit of Jansen 1973), in Paros (Marmara nappe of Papanikolaou 1977), in Myconos (Dürr & Altherr 1979), in Ikaria (Kefala Unit of Papanikolaou 1978), in Samos (Kallithea Unit of Theodoropoulos 1979 and Papanikolaou 1979b), in Thymaena (Köhne 1937 and Papanikolaou 1980) and in the surrounding islets of Naxos (Angelier et al. 1978 and Dürr et al. 1978). Dürr et al. (1978) have used the term "Pelagonian nappe" for this late nappe of the Cyclades, but we prefer the term Cycladic nappe because i) the term Pelagonian nappe is very confusing since its definition by Aubouin

(1959) is not valid after the new data on the metamorphic rocks of the former "Pelagonian zone" (for a detailed analysis see CELET & FERRIERE 1978) and ii) the Pelagonian nappe (or the Sub-Pelagonian nappe or what else terminology based on the "internal" Hellenides) is a term connected with a tectonism during Paleocene, while the nappe of the Cyclades was emplaced during upper Miocene.

The origin of the Cycladic nappe is of great importance for the Paleogeography and Geodynamics of the Aegean Region during the Miocene. At first sight a movement from North to South, concordant to the general movement of the Hellenides along the Aegean Arc seems suitable. However there are a series of indications which drive to the opposite conclusion of a movement from South to North. Some of them are the following:

— The molassic aspect of the Burdigalian molasse indicates that its tectonism is not necessarily related to the geometry of the tectonism of its basement.

— The age of the emplacement of the Cycladic nappe, being upper Miocene, confirms the "neotectonic" character of this movement. Thus, a rather different tectonic pattern than the Paleocene-Eocene one is expected.

— The stratigraphy of the basement of the molasse shows a great similartity with the "sub-Pelagonian zone" which mainly constitutes the basement of the Mesohellenic trough.

— If the origin of the Cycladic nappe was from the North, it should come from a more internal molassic basin, like the one of the Vardar zone; something not acceptable because i) the basement of the Burdigalian molasse does not have the characteristics of the Vardar zone and ii) the molasse of the Vardar zone is of upper Eocene to Oligocene age, the next younger sediments being the upper Miocene-Pliocene continental and paralic sediments (MERCIER 1973).

— The study of slip directions at the thrust of the nappe in Naxos and the neighboring islets (ANGELIER et al. 1978) showed a movement in direction N 10° W—N 50° E, something excluding a movement parallel to the tectonic zonation of the Hellenides.

— Finally DÜRR & ALTHERR (1979) based on the structures along the thrust at the base of the molasse in Myconos concluded a movement from South to North. The same conclusion was obtained by PAPANIKOLAOU (1980) in Thymaena island (between Ikaria and Samos), where 5 thrusts bring the middle Triassic formations onto the upper Triassic carbonates, with movement from South to North.

Based on the above indications DERMITZAKIS & PAPANIKOLAOU (1979) proposed the existence of a lower Miocene molassic basin at the area to the south of Cyclades, approximately at the area of the present Cretan Basin. This molassic basin is the probable prolongation of the Mesohellenic trough of continental Greece and of the molassic basin of Tavas of Southwestern Turkey.

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