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THE PAIKON MASSIF REVISITED, COMMENTS ON THE LATE CRETACEOUS - PALEOGENE GEODYNAMICS OF THE AXIOS-VARDAR ZONE. HOW MANY JURASSIC OPHIOLITIC BASINS ? (HELLENIDES, MACEDONIA, GREECE)

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ABSTRACT

In the Axios-Vardar zone, the Paikon massif has been revisited. To the west, it is composed of a pile-up of SW dipping slices. These have been thrust toward the NNE while the Almopias zone was folding with a SSW vergence. Subsequently thrusting with a SW vergence occurred on the eastern flank of the Paikon massif and in the Almopias zone. These tectonic events took place during the Paleocene - early Eocene and during the upper Eocene - lower Oligocene respectively. During the late Cretaceous, the Almopias zone was a trough whose floor was a late jurassic ophiolitic sheet. It was located between the Paikon carbonate platform and the Pelagonian platform. This analysis leads to the conclusion that the ophiolites were already located in the Almopias zone before the late Cretaceous and even before the upper Jurassic-lower Cretaceous. It is concluded that during the Jurassic the Almopias zone was an oceanic crust basin, the Paikon zone an island arc and the Peonias zone a back-arc basin. This analysis is a first step which is necessary to precise the geodynamic significance of the Axios-Vardar zone as a whole during the Triassic - Jurassic taking into account the stratigraphic, paleogeographic and structural data and the location in space and time of the magmatic and metamorphic belts.

KEY WORDS : stratigraphy, paleogeography, tectonics, geodynamics, ophiolitic basins, late Cretaceous, Paleogene, Axios-Vardar zone, Macedonia, Greece

1. INTRODUCTION

In the internal (eastern) Hellenides the Axios-Vardar zone, defined by F. Kossmat (1924), is divided into three zones (Mercier, 1968) from east to west : the Peonias, Paikon and Almopias zones (fig. 1A). Ophiolitic rocks outcrop in the Peonias and Almopias zones. To the east, the ophiolites of the Evzoni-Guevgueli massif with underlying units of sedimentary and volcanic formations are thrust westward on the Paikon massif. To the west the ophiolites are thrust westward onto the Pelagonian zone (Osswald, 1931, Mercier et al., 1975). The Paikon massif and the Malarupa-Tzena massif (fig. 1A) have been considered (Kossmat, 1924, Osswald, 1931, 1938) as a large bulge in the core of which the crystalline basement outcrops. Then, J. Mercier (1968) has considered that this Paikon zone was a volcanic shelf separating two ophiolitic basins during the Jurassic. Subsequently, it has been suggested (Mercier et al., 1975) that the Almopias basin might be an oceanic basin separated from an eastern Peonias back-arc basin by a Paikon island-arc.

Since these already ancient works a lot of researches have been conducted on the Axios-Vardar zone. In such a short paper we cannot review all these works, therefore we only discuss the always debated problem, is there a single oceanic crust basin or several ones in the Axios-Vardar zone. Examinating the structure of the Paikon massif we have recently revisited. The complex structure of the Paikon massif is an important question because it concerns the geodynamic significance of the Almopias zone during the late Cretaceous-Paleogene and the origin of the ophiolites which outcrop there. Thus, it is a first step which is necessary to put constraints on the Triassic-early Cretaceous paleogeography of the Axios-Vardar zone and the position in space of the ophiolitic basins. This can be also enlightened by recent detailed analyses of Triassic to Early Cretaceous sedimentary formations and igneous rocks which have brought new informations on the Triassic-Jurassic paleogeography of this zone. Moreover studies of the syn-metamorphic deformations particularly in the Serbo-Macedonian massif and along its western border («the Circum Rhodope zone») have renewed the ideas on the significance of the Serbo-Macedonian massif and on the possible origin of the ophiolites which outcrop along there.

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*Η ΜΑΖΑ ΤΟΥ ΠΑΪΚΟΥ, ΣΧΟΛΙΑ ΓΙΑ ΤΗΝ ΓΕΩΔΥΝΑΜΙΚΗ ΤΗΣ ΖΩΝΗΣ ΤΟΥ ΑΞΙΟΥ ΚΑΤΑ ΤΟ ΑΝΩ ΚΡΗΤΙΔΙΚΟ - ΠΑΛΑΙΟΓΕΝΕΣ. ΠΟΣΕΣ ΙΟΥΡΑΣΙΚΕΣ ΟΦΙΟΛΙΘΙΚΕΣ ΛΕΚΑΝΕΣ (ΕΛΛΗΝΙΔΕΣ, ΜΑΚΕΔΟΝΙΑ, ΕΛΛΑΣ)

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2. STRUCTURE OF THE PAIKON MASSIF

Based on findings of Rudists in marbles underlying the Evzoni-Guevgueli ophiolites, Godfriaux and Ricou (1991) have drastically reinterpreted the structure of the Paikon massif proposed by Mercier (1968) and Vergely (1984). They have proposed that it is a complex tectonic window composed of five superimposed thrust sheets, from top to bottom (fig. 2B) : (1) the Malarupa-Tzena massif considered as a tectonic klippe belonging to an uppermost sheet of Serbo-Macedonian origin ; (2) an ophiolitic sheet which groups together the ophiolites of the Peonias and Almopias zones ; (3) a Pelagonian sheet which groups together the eastern and western parts of the Paikon massif. Subsequently, Ricou and Godfriaux (1995) have sugested that, in the core of the Paikon massif, this sheet pile-up rests upon lower units equivalent to those observed in and around the Olympos window (fig. 1B). These are a unit (4) (Mercier's 1968 Livadia fm.) considered as an equivalent of the Ambalakia metabasalt sheet which overthrusts a lowermost window (5) in the Gandatch massif which would belong to the Olympos zone.

We have already shown the impossibility of such a structural model (Mercier and Vergely, 1995 ; Vergely and Mercier, 2000 ; fig. 2A). Therefore, here we only summarize our argumentation, the reader may find more detailed data in the above papers.

- (1) The Malarupa-Tzena massif dips under the Evzoni-Guevgueli ophiolites (fig. 1A) as it has been undoubtedly demonstrated by Kossmat (1924). This is also undoubtedly seen on Kossmat's (1924) 1:500 000 map, on Osswald's (1931) 1:300 000 geological map of Greek Macedonia, and on Polic et al's (1952) 1:50 000 geological map of Demir Kapija. Therefore, the Malarupa-Tzena massif cannot be a tectonic klippe thrust over an ophiolitic sheet.

- (2) The ophiolitic sheet according to Godfriaux and Ricou (1991) overthrusts the Paikon massif from east to west subsequent to the deposition of its late Cretaceous limestone cover.

On the Pelagonian zone (Mercier et al., 1987) the ophiolites overthrust a marble substatum of Triassic- ? Jurassic age. Limestones of late Santonian-early Campanian age (~83 My) and clastic limestones and conglomerates of Vraconian age (~100 My) transgressively overlap both the ophiolites and their substratum sealing the thrust. In the western units of the Almopias zone, the ophiolites (serpentinites) were already emplaced before the activity of large faults which controlled the sedimentation on both the Pelagonian and western Almopias zones during the late Cretaceous. South of the WNW-ESE striking Nission fault (fig. 1A) the base of the late Cretaceous deposits which lie transgressively on the ophiolites are of late Santonian - early Campanian age (~83 My) on the Pelagonian zone and of Turonian-Campanian age (90 to 80 My) in the western Almopias zone while they are respectively of late Maestrichtian (~65 My) and of late Aptian-Albian (~110 My) age north of the fault (Mercier, 1968). Therefore, the ophiolites of the Pelagonian and western Almopias zones where already located there before the late Aptian-Albian (~110 My) to the Vraconian (~100 My) and cannot have been thrust from east to west above the late Cretaceous limestones of the Paikon massif whose uppermost levels contain a *Globotruncana* fauna of late Maestrichtian age (~65 My) (Mercier, 1968).

The eastern Almopias units (Mavrolakkos - Krania units, fig. 1A) comprise radiolarites, lavas, diabases and clastic deposits of Triassic and of late Jurassic - Hauterivian ages (Staos et al., 1990 ; Sharp and Robertson, 1994). The eastern Almopias ophiolites are thrust onto the Maestrichtian limestones of the Paikon massif (Godfriaux and Ricou, 1991). According to Godfriaux and Ricou, the vergence of the eastern Almopias ophiolites, considered as the base of the ophiolitic sheet, is toward the west, according to Sharp and Roberston (1992), Brown and Robertson (1994), the vergence is top-to-the-NE to ENE. Indeed, below the lavas, we have observed ramps in the Paikon Cretaceous limestones, shear planes between the limestones and the underlaying late Cretaceous flysch and shear planes in the flysch which really demonstrate a NE vergence (points 17, 18, 19 on fig. 3) of the eastern Almopias ophiolites (Vergely and Mercier, 2000). Moreover radiolarites, tuffites and lava of eastern Almopias ophiolite characters outcrop below the late Cretaceous limestones of the upper slices of the western Paikon (east of Smolika Tchouka on fig. 3, M. Bonneau and J. Ferrière's pers. communication). They are located at the base of a slice thrust toward the NE although field analysis have shown that they are also affected probably subsequently by reverse faults with a western vergence. This outcrop implies that the eastern ophiolites were already located in the Almopias zone when the Paikon late Cretaceous carbonate platform has transgressively covered them. In summary, stratigraphic, paleogeographic and structural data made impossible the overthrusting of a large (Peonias plus Almopias) ophiolitic sheet from East to West above the Paikon zone subsequent to the Maestrichtian.

- (3) The Pelagonian sheet described by Godfriaux and Ricou (1991) in the Paikon massif comprises a volcanic formation which [illegible] of western Paikon and rhyolitic

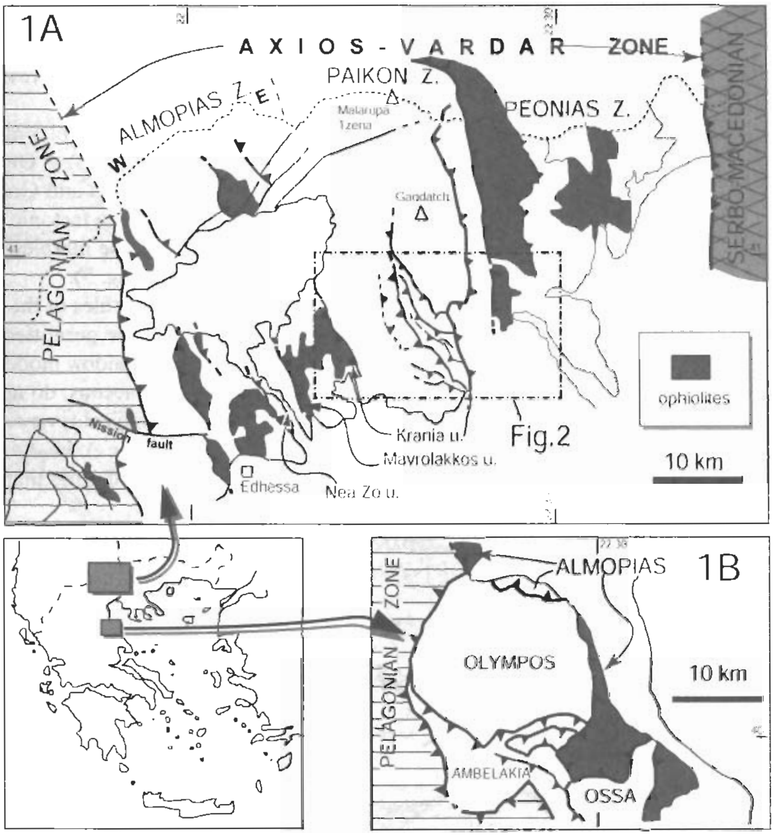

Fig. 1A : Structural schematic map of the Axios Vardar zone ; B : Structural sketch of the Olympos window and the metabasalt Ambelakia sheet.

Kastaneri fm. of eastern Paikon both covered by marbles and limestones of late Jurassic and late Cretaceous age. The Kastaneri metarhyolites are considered from regional reasons as equivalent of the Permian rhyolites of the Pelagonian zone. The thrust is supposed to have a vergence toward the west and the thrust line is described as surrounding a lower window (fig. 2 in Godfriaux and Ricou, 1991). Indeed the western Paikon is constituted by a pile-up of S to SW dipping tectonic slices and the eastern Paikon by two sheets (the lower Kastaneri and upper Evzoni-Guevgueli sheets, fig. 3). Detailed mapping of the 1:50 000 Jannitsa sheet (Vergely and Mercier, 2000 ; Mercier et al., 2001) demonstrates that the Kastaneri sheet is thrust onto the western slices of the western Paikon (fig. 1A and 3). The vergence of the slices of the western Paikon is toward the NNE to NE (fig.3) ; this has been defined using about one hundred of kinematics markers (fig. 4) such as asymetric folds, striated shear planes (C), relations between shear (C) and cleavage (S1) planes or between cleavage (S1) and bedding (So) planes. At pt 22 on fig. 3A, the strike of the Kastaneri thrust is orthogonal to the strike of the W. Paikon lower slice whose Cretaceous marbles (Bonneau et al., 1994) are overturned toward the west below the thrust. This and overturned folds (pt 23, fig. 3) affecting the limestones of the Kastaneri fm. along the thrust demonstrate a top-to-the west vergence of the eastern Paikon sheets. Therefore there is no continuity between the eastern and western flanks of the Paikon massif. This agrees with petrological data which lead to separate the potassic metarhyolites of the eastern Paikon from the keratophyres of the western Paikon which are persodic metarhyolites to metadacites (Mercier, 1968). From a geochimical point of view the former have calcalcaline or anatectic characters of intracontinental areas whereas the latter show intraoceanic island arc affinities (Bébien et al., 1987, 1994). Hypovolcanic granitic small bodies are observed in the Kastaneri fm. particularly around the Kastaneri village (Davis et al., 1988). They have the same geochimical characters as the rhyolites and tuffites (Bébien et al., 1994). Toward the south these tuffites and rhyolitic pyroclastites are interbedded at a scale of some tens of centimeters with limestones containing a microflora and microfauna of late Jurassic age (Mercier, 1968) excluding that they belong to the Pelagonian Permian rhyolites. Thus, the eastern and western Paikon are formed by tectonic units having opposite vergence (Sharp and Robertson, 1992). Yet, these vergences are neither in the same direction nor of the same age. The NNE to NE vergence of the western Paikon slices is previous to the SW vergence of the eastern Paikon sheets.

- (4) and (5) The lowermost units. We have mapped again the thick bedded white marbles of the Gandatch massif supposed to be of Triassic age and being the antiforme core of a tectonic window (5) of Olympian affinity (fig. 1B) below a metabasalt (Livadia fm.) sheet (4) of Ambelakia sheet affinity (Ricou and Godfriaux, 1995). Mapping has shown that indeed the marbles of the Gandatch massif do not appear as a tectonic window but as a synform which lies upon the Livadia fm. and its metabasalts. We propose that these marbles are the lateral equivalent of the late Cretaceous Rudist bearing marbles of the Gola Tchouka fm (fig. 5).

As a conclusion, findings of fossils of late Jurassic and late Cretaceous age in marbles of the Paikon massif (Godfriaux and Ricou, 1991 ; Bonneau et al., 1994 ; Vergely and Mercier, 2000) have permitted to revisit this massif and to propose a new structural model (fig. 2A). Yet, the multiple tectonic window model (fig. 2B) as a consequence of thrusts having a western vergence and subsequent to the late Cretaceous, do not resist to detailed mapping, kinematic analysis, petrological and geochimical data and stratigraphical review. This is of first interest because this imposes strong constraints on the geodynamic significance of the Axios-Vardar zone during the late Cretaceous-Paleogene that we now attempt to examine. In particular, this implies that the ophiolites were already located in the Almopias zone before the late Cretaceous.

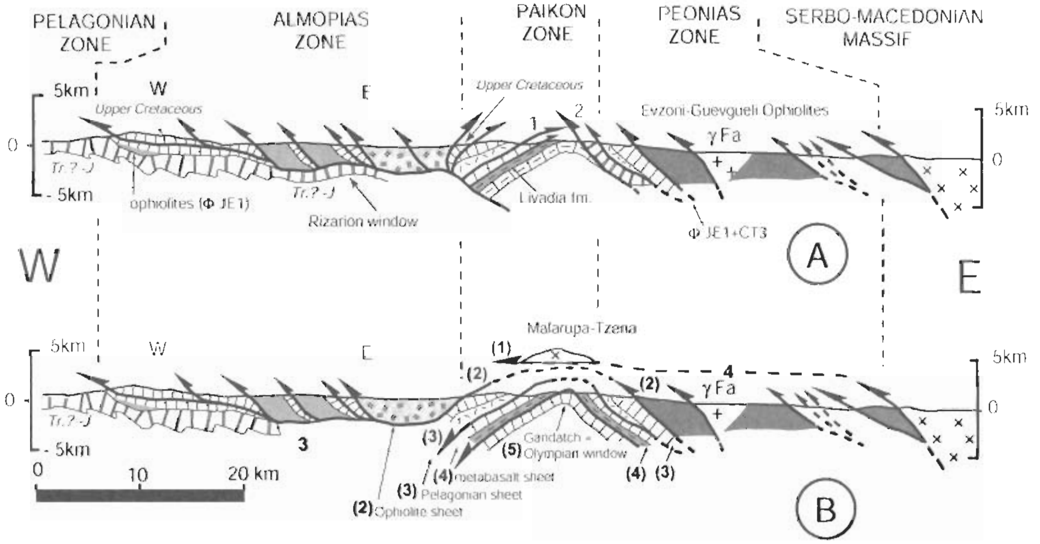

Fig. 2. Schematic cross-section of the Axios-Vardar zone. A : drawn from Vergely (1984), modified ; B : Schematic sketch of Ricou and Godfriaux's (1995) multiple tectonic window model.

3. GEODYNAMICS OF THE AXIOS-VARDAR ZONE DURING THE LATE CRETACEOUS - PALEOGENE

3.1. Paleogeographic sketch of the Axios-Vardar zone

During the late Cretaceous, the Almopias zone was a trough located between two platforms, the Paikon carbonate platform to the east and the Pelagonian platform to the west.

- **The Paikon platform**. Transgression of the sea began during the late Albian (~105 My) (fig. 5). A thick Rudist bearing carbonate platform unconformably covered either a conglomeratic formation of early Cretaceous age or a late Jurassic - lower Cretaceous limestone formation (the Khromni fm.). This attests a tectonic activity between the early Cretaceous and the Albian. Sedimentological analyses (Brown and Robertson, 1994) have shown that these carbonate deposits are characterized by shallow-water, neritic facies exhibiting periodic emergences. These gradually pass upward to deeper-water, pelagic, *Globotruncana* bearing limestones of Turonian to Maestrichtian age. These and clastic deposits interbedded with Turonian radiolarites (Brown and Robertson, 1994) or pelagic Campanian limestones (Mercier, 1968) indicate a rapid deepening of the platform related to extensional tectonics ; this is supported by normal, probably synsedimentary, faults we have observed on the

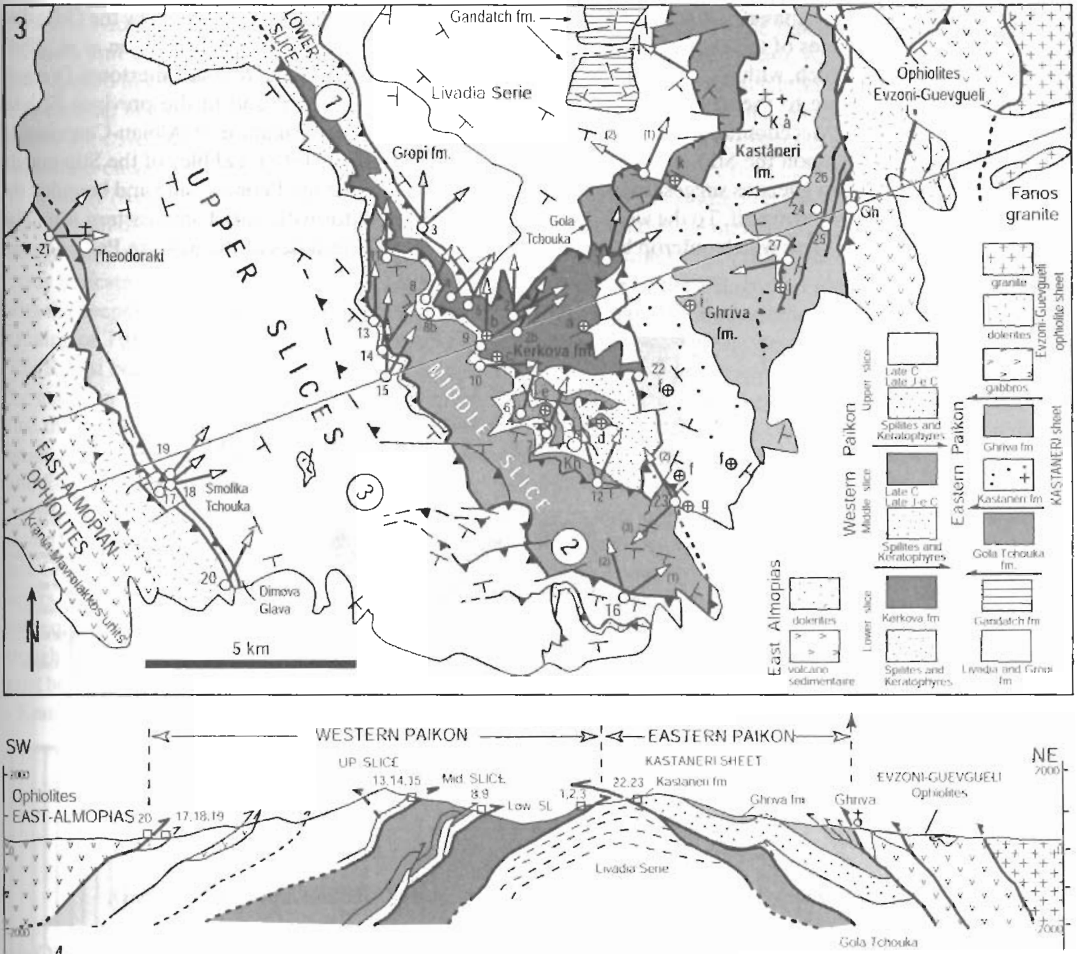

Fig. 3 A. Schematic map of the southern part of the Paikon massif. B. Schematic geological cross-section of the Paikon massif.

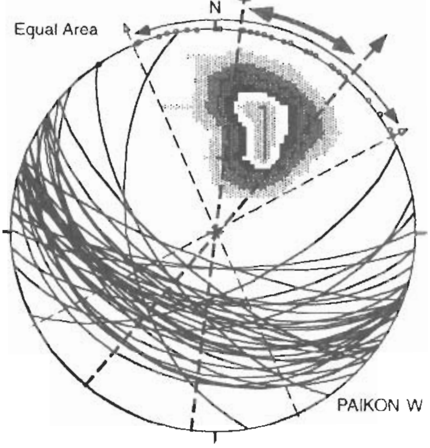

Fig. 4 : Stereographic projection of the bedding planes (So), shear planes (C) and cleavages planes (S1) whose relations show a top-to-the NNE vergence of the western Paikon slices (Equal area, lower hemisphere projection).

western flank of the Paikon massif. This carbonate platform extended eastward as shown (fig. 5) by the *Orbitolina* and Rudist bearing marbles of the central Paikon and by the *Orbitolina* bearing marbles (Bonneau et al., 1994) of the Kastaneri sheet which, with a coarse breccia at the base, score and rest upon Jurassic limestones (Vergely and Mercier, 2000). More to the east, one late Cretaceous outcrop has been found in the previous Federal Yougoslav Republic of Macedonia. There, a conglomeratic, shallow-water formation of Albian-Cenomanian age rests transgressively upon the Stip granite (Markovitch, 1954 in Mercier, 1968). Pebbles of the Stip granite and of Serbo-Macedonian gneisses suggest that a shallow-sea locally covered the Peonias zone and bounded the emerged Serbo-Macedonian massif. To the west, the Paikon carbonate platform extended onto eastern Almopias Jurassic radiolarites and lavas which outcrop below the late Cretaceous limestones of the western Paikon massif (fig. 3 and 5, see § 2).

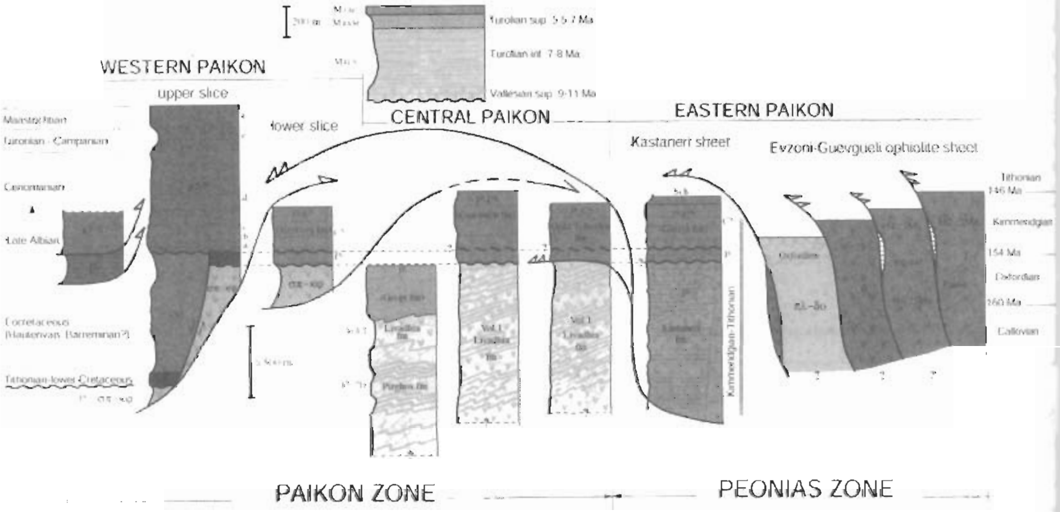

Fig. 5 : Stratigraphic columns of the tectonic units in the Paikon massif (Paikon and Peonias zones).

- The Pelagonian platform. The Pelagonian massif emerged subsequently to the late Jurassic - early Cretaceous. The transgressive sea spread over the eastern Pelagonian border during the Vraconian (100 My) (Mercier et al., 1987) or earlier during the Albian (105 My) at some places (Brunn, 1982). A thick shallow-water clastic limestone and conglomeratic formation deposited. Where it rests upon the ophiolites a nickeliferous laterite bed is sometimes observed at its base. The conglomerates contain pebbles of serpentinites and of Pelagonian marbles which demonstrate a deep erosion of the ophiolitic sheet thrust onto the Pelagonian zone during the late Jurassic. A second step of the sea transgression occurred during the late Santonian - early Campanian. It is marked by an accumulation of reworked Rudists laying on an erosional surface which scores the late Cretaceous conglomeratic formation, the ophiolites and the underlying marbles. It passes upward to a thick carbonate formation which essentially consists of Rudist bearing limestones but with a level of pelagic *Globotruncana* bearing limestones of Campanian age (Mercier, 1968). These latter with the transgressive overlap of the sea upon the Pelagonian massif as late as the late Maestrichtian suggest some episodes of deepening of the platform. This is possibly related to extensional tectonics suggested by the synsedimentary activity of large normal faults affecting the Pelagonian and Western Almopias zones as discussed above (§ 2.). The carbonate sedimentation ended during the upper Maestrichtian, with pelagic *Globotruncana* bearing limestones then a thick clastic flysch began to deposit onto the Pelagonian zone.

- The Almopias trough. In the Almopias zone, the late Cretaceous transgression started during the late Aptian - early Albian (~110 My) (Mercier, 1968). In the western Almopias (Kerassia unit, fig. 6) it is marked by shallow-water, neritic, reddish, *Orbitolina* and *Nerinea* bearing limestones of late Aptian - Albian age. Sedimentological analyses in the Loutra Aridhea unit (Galeos et al., 1994), north of the Kerassia unit, have shown that these reddish limestones have been deposited in a near-shore shallow shelf environment with intermittent subaerial expo[illegible]ceous and the late Aptian -

Albian is evidenced in the Almopias units (phase JE2, Vergely, 1984) and in the Paikon zone (see above). In the Kerassia unit the neritic *Orbitolina* and *Nerinea* bearing limestones of late Aptian, Albian and Cenomanian age pass upward to *Globotruncana* bearing pelagic and clastic limestones of Coniacian-Santonian age which attest of a deepening of the western slope of the Almopias trough along the Pelagonian platform. These pelagic limestones are covered by Rudist bearing limestones of late Campanian - Maestrichtian age. This carbonate sedimentation ended with the deposit of a thick clastic flysch formation whose base is of upper Maestrichtian age.

Locally (Kedronas unit, fig. 6) a thick conglomeratic formation deposited on the Almopias western slope. It contains pebbles of micaschistes, cipolins, marbles and gabbros and large marble olistholites reworked from the Pelagonian zone. This conglomeratic formation and clastic limestones are of late Turonian (?) to Santonian age ; they indicate a tectonic activity in and along the eastern border of the Pelagonian platform contemporaneous with the deepening of the western Almopias slope. This may be related to the synsedimentary probably extensional faulting of Turonian (?) - Campanian age we have already mentioned in the Pelagonian and Paikon platform. The Rudist bearing limestone formation of late Campanian - Maestrichtian age which covers the conglomeratic formation in the Kedronas unit (fig. 6) becomes thinner (~80 m to 0 m) eastward (Mercier, 1968). This indicates that the western slope of the Almopias trough became deeper eastward. This is confirmed by a pelagic sedimentation in the median part (Nea Zoi unit) of the Almopias zone during the Cenomanian attested by *Globotruncana* and *Rotalipora* bearing pelagic limestones interbedded with some beds of brown radiolarites.

More to the east, no late Cretaceous deposits are known covering the late Jurassic - early Cretaceous formations (Staos et al., 1990) of the eastern Almopias zone (Mavrolakkos - Krania units). Yet we have shown that the late Cretaceous Paikon platform has extended to the west onto radiolarites and lavas of eastern Almopias characters. We suggest that the Paikon carbonate platform has extended onto these eastern Almopias units and that subsequently, the late Cretaceous limestones have been eroded. In any case, any eastern slope of the Almopias trough toward the Paikon platform is evidenced by deposits of late Cretaceous age. Thus, a major thrust does exist between the deeper part of the Almopias trough in the Nea Zoi unit and the eastern Almopias Mavrolakkos - Krania units.

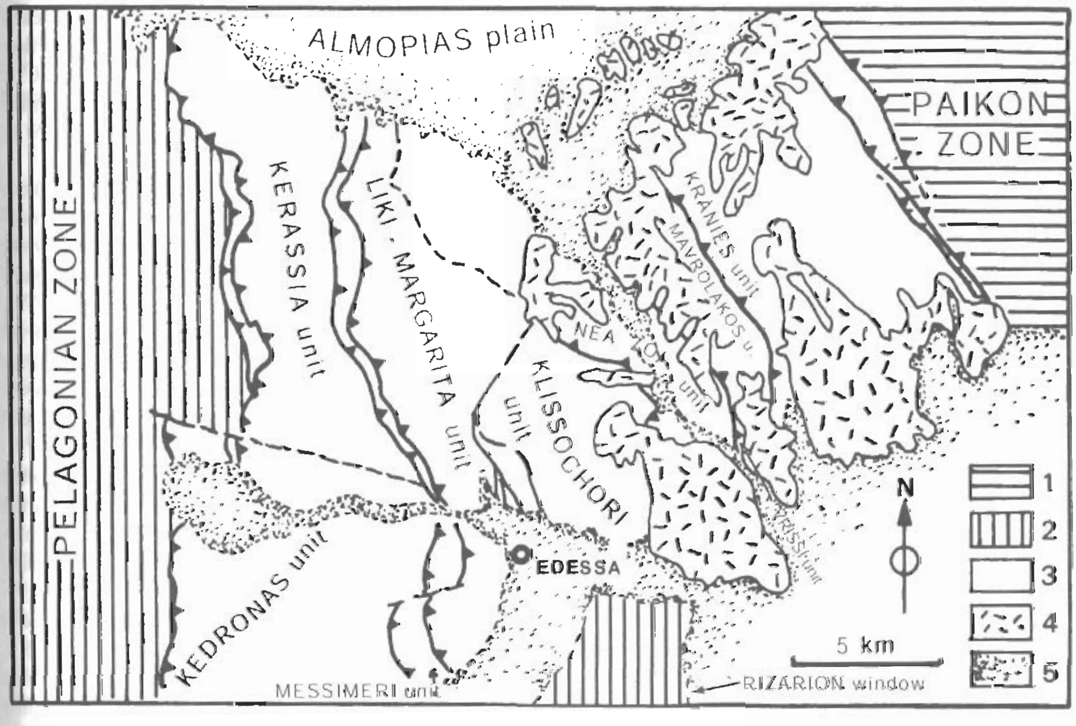

Fig. 6 : Schematic sketch of the structural units of the Almopias zone quoted in the text and of the Pelagonian marbles outcroping in the Rizarion tectonic window.

3.2. Tectonic evolution of the Axios-Vardar zone during the late Cretaceous-Paleogene

- Thrusting and Folding in the Axios-Vardar zone subsequent to the late Cretaceous - Paleogene

We first analyze the folds and thrusts which affect the late Cretaceous formations in the Pelagonian, Almopias and Paikon zones. These allow us to define the characteristics of the deformations subsequent to the upper Maestrichtian. Then, we compare them with the deformations in the Peonias zone and the western border of the Serbo-Macedonian massif where few outcrops of late Cretaceous - Paleogene deposits have been described.

· The Almopias and Pelagonian zones. Several NNW-SSE striking slices form the structural pattern of the Almopias zone (fig. 6). The median and western slices with a sole of serpentinites at their base, are thrust westward ; the westernmost slices (Kerassia, Kedronas, and more to the south the Vermion sheet, Braud, 1967) are thrust onto the Pelagonian upper Maestrichtian - (?) Paleocene flysch. Near Rizarion southeast of Edhessa (fig. 6), a formation of foliated marbles interbedded with white-mica calcschists and siliceous schists outcrops among the median Almopias slices. To the south (Brunn, 1982), these marbles are covered by serpentinites ; marbles and serpentinites are thrust southwestward onto the late Cretaceous Almopias formations. This marble and schist fm. appears to be the equivalent of the Triassic - (?) Jurassic marbles of the Pelagonian zone overthrust by the ophiolitic sheet during the late Jurassic (see Vergely, 1984). This suggests that the late Cretaceous Almopias formations deposited upon a Pelagonian substratum already covered by the ophiolitic sheet. Subsequently to the late Cretaceous, these are deformed together and the Almopias slices detached from their Pelagonian substratum along the ophiolite (serpentinite) level. The major thrust is located east of the Rizarion Pelagonian window between the Nea Zoi slice and the eastern Almopias slices as said above (§ 3).

Analysis of the deformations in the upper Maestrichtian - (?) Paleocene flysch of the Almopias and Pelagonian zones demonstrates three successive tectonic events (Vergely, 1984). Small similar folds (B1) several 10 cm -in-size, exhibing a flow cleavage (S1) affect the flysch formation of the Almopias slices (Kerassia and Margarita - Liki, fig. 6) and of the Pelagonian zone. These folds strike WNW-ESE and have a top-to-the SSW vergence. Deformation occurred under regional metamorphic conditions of low grade greenschist facies (quartz-albite-sericite-chlorite-epidote-stilpnomelane-actinote) (Braud, 1967, Mercier, 1968, Vergely, 1984) ; it is followed by a static recristallisation (calcite-quartz-albite-stilpnomelane) which is previous to the subsequent event. Nearly isopach folds (B2), some meters -in- size, with small drag folds refold the previous ones (B1) and the flow cleavage (S1). They exhibit a strain-slip cleavage (S2) parallel to the fold axial plane They strike N 70 to 80° E and do not exhibit a constant vergence. Thrusting of the slices as shown by mapping (fig. 6) is subsequent to the two previous events. The strike of the slices is NW-SE to NNW-SSE and their vergence is top -to- the SW to WSW.

· The Paikon zone. We have already described the structural pattern of the Paikon zone (§ 2, fig. 3). It results in a pile-up of S to SW dipping slices. The degree of cristallinity in the late Cretaceous carbonate formations increases from the top to the bottom. In the lower slices, the late Cretaceous Rudist bearing marbles exhibit a flow cleavage (S1) marked by the orientation of calcite and chlorite nearly parallel to the bedding plane ; relationships between the flow cleavage (S1) and shear planes (C) demonstrate a NNE vergence (fig. 4) This ductile deformation may evoluate in time to a ductile-brittle deformation having the same vergence. In the upper slices deformation is brittle. At pt. 16 (fig. 3) an upper slice overthrust the middle slice ; analysis of the kinematics of the fault shows two successive motions. The first one results from a reverse motion with a top -to-the NE vergence (arrow 1, pt 16) and a second one results from a dextral-strike slip motion due to a NNW-SSE shortening (arrow 2, pt 16).

· The Peonias zone. The structural pattern of the Peonias zone shown by geological mapping is constituted by NW-SE striking slices thrust westward as it has been already described for its western part constituted by the Kastaneri and Evzoni-Guevgueli units (§ 1. fig. 3). Thus, here we only present the successive deformations which affect the late Jurassic and the late Cretaceous formations of these units (Vergely, 1984 ; Vergely and Mercier, 2000).

The Kastaneri sheet is thrust westward onto the tectonic slices of the western Paikon whose vergence is toward the NE to NNE (see § 2). The late Jurassic limestones at the base of the Kastaneri sheet are folded. A weak flow-cleavage is marked by the orientation of white micas, quartz and calcite : relations between this cleavage (S1) and the bedding planes (S0) show a top -to- the NNW vergence (arrow 2. pt 23, fig. 3). A similar cleavage and vergence is observed in the lower Cretaceous flysch below the thrust. This flow-cleavage (S1) is deformed by folds (B2) several 10 m -in- size having a strain-slip cleavage (S2) parallel to the axial planes. These folds strike N 120-140° E and their vergence is top -to- the SW (arrow 3, pt 23, fig. 3). The Evzoni-Guevgueli ophiolitic sheet, with a sole of amphibolites, is thrust onto the late Cretaceous limestones of the Kastaneri sheet

3.2. Tectonic evolution of the Axios-Vardar zone during the late Cretaceous-Paleogene

- Thrusting and Folding in the Axios-Vardar zone subsequent to the late Cretaceous - Paleogene

We first analyze the folds and thrusts which affect the late Cretaceous formations in the Pelagonian, Almopias and Paikon zones. These allow us to define the characteristics of the deformations subsequent to the upper Maestrichtian. Then, we compare them with the deformations in the Peonias zone and the western border of the Serbo-Macedonian massif where few outcrops of late Cretaceous - Paleogene deposits have been described.

· The Almopias and Pelagonian zones. Several NNW-SSE striking slices form the structural pattern of the Almopias zone (fig. 6). The median and western slices with a sole of serpentinites at their base, are thrust westward ; the westernmost slices (Kerassia, Kedronas, and more to the south the Vermion sheet, Braud, 1967) are thrust onto the Pelagonian upper Maestrichtian - (?) Paleocene flysch. Near Rizarion southeast of Edhessa (fig. 6), a formation of foliated marbles interbedded with white-mica calcschists and siliceous schists outcrops among the median Almopias slices. To the south (Brunn, 1982), these marbles are covered by serpentinites ; marbles and serpentinites are thrust southwestward onto the late Cretaceous Almopias formations. This marble and schist fm. appears to be the equivalent of the Triassic - (?) Jurassic marbles of the Pelagonian zone overthrust by the ophiolitic sheet during the late Jurassic (see Vergely, 1984). This suggests that the late Cretaceous Almopias formations deposited upon a Pelagonian substratum already covered by the ophiolitic sheet. Subsequently to the late Cretaceous, these are deformed together and the Almopias slices detached from their Pelagonian substratum along the ophiolite (serpentinite) level. The major thrust is located east of the Rizarion Pelagonian window between the Nea Zoi slice and the eastern Almopias slices as said above (§ 3).

Analysis of the deformations in the upper Maestrichtian - (?) Paleocene flysch of the Almopias and Pelagonian zones demonstrates three successive tectonic events (Vergely, 1984). Small similar folds (B1) several 10 cm -in- size, exhibing a flow cleavage (S1) affect the flysch formation of the Almopias slices (Kerassia and Margarita - Liki, fig. 6) and of the Pelagonian zone. These folds strike WNW-ESE and have a top-to-the SSW vergence. Deformation occurred under regional metamorphic conditions of low grade greenschist facies (quartz-albite-sericite-chlorite-epidote-stilpnomelane-actinote) (Braud, 1967, Mercier, 1968, Vergely, 1984) ; it is followed by a static recristallisation (calcite-quartz-albite-stilpnomelane) which is previous to the subsequent event. Nearly isopach folds (B2), some meters -in- size, with small drag folds refold the previous ones (B1) and the flow cleavage (S1). They exhibit a strain-slip cleavage (S2) parallel to the fold axial plane They strike N 70 to 80° E and do not exhibit a constant vergence. Thrusting of the slices as shown by mapping (fig. 6) is subsequent to the two previous events. The strike of the slices is NW-SE to NNW-SSE and their vergence is top -to- the SW to WSW.

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In the median part of the Peonias zone late Lutetian - early Priabonian (~40 My) neritic limestones rest unconformably with a high angle (~50°) discordance onto the Jurassic to early Cretaceous formations of the Peonias slices (Mercier, 1968). Thus, these have been thrust before the late Lutetian - early Priabonian, during the tectonic events either of early Cretaceous age or subsequently to the late Cretaceous. More to the north in the previous F. Y. R. of Macedonia, the gneisses and serpentinites of the Serta region are thrust onto the molassic deposits of the «Vardar molassic trough» of Priabonian to early Oligocene age (~34-36 My) (Mercier, 1968) attesting that thrusting in the Axios-Vardar zone has continued until the early Oligocene.

Thus, analyses of the successive deformations which affect the late Cretaceous - Paleogene deposits of the Axios-Vardar zone have shown three successive tectonic events we have conveniently named CT1, CT2, CT3 (Mercier and Vergely, 1972 ; Vergely, 1984) ; these might be successive events of a continuous deformation. The events CT1 and CT2 are essentially characterized by folding and the event CT3 by brittle deformation resulting in thrusting. During the CT1 folding event a regional metamorphism of low grade greenschist facies affects the Almopias and Paikon zones. In the Almopias zone the vergence of the folds striking N 110-120° E is toward the SSW while the vergence of the slices in the Paikon zone is toward the NNE to NE, i.e in the opposite sense (fig. 2 A). We suggest that these opposite vergences may have been controlled by the opposite dips of synsedimentary normal faults on the western and eastern margins of the late Cretaceous Almopias trough. During the CT3 event, the late Cretaceous and the late Jurassic - early Cretaceous deposits of the Almopias zone are thrust westward and are detached from their Pelagonian substratum along the serpentinite level of the late Jurassic ophiolitic sheet. Paleogeographic arguments (§ 3.1) and the occurrence of Pelagonian marbles (Rizarion window, fig. 6) in the median Almopias units lead us to locate a major thrust between the Nea Zoi unit and the Mavrolakkos-Krania units. This should be the major thrust between respectively the Almopias trough with its Pelagonian substratum and the Paikon platform we suppose to have extended onto the eastern Almopias units. This major thrust could be inherited from a Jurassic subduction zone which have led to the late Jurassic obduction of the ophiolitic sheet onto the Pelagonian zone.

In the eastern Paikon, thrusting of the western Peonias sheets, appears to have begun during the CT2 event with a NNW vergence, eventually earlier during the CT1 event. Thrusting has continued (CT3 event) and the Kastaneri sheet southwestward overthrust the western Paikon slices.

· Age of the tectonic events subsequent to the late Cretaceous - Paleogene in the Axios-Vardar zone

The above tectonic events are subsequent to the flysch fm. of the Pelagonian and Almopias zones whose base contains a *Globotruncana* fauna of upper Maestrichtian age (~67-65 My). The event CT1 occurred under a regional low-grade greenschist metamorphism. The late Lutetian - Priabonian molassic formation of the «Vardar molassic trough» (Mercier, 1968) is free from any metamorphism. This suggests that the event CT1 is previous to the late Lutetian (~40 My). This is supported by some stratigraphic data in the previous F. Y. R. of Macedonia (Mercier, 1968 and ref therein). In the Tikvech basin, Priabonian molassic deposits unconformably rest upon metamorphic folded formations north of the Tzena massif (fig. 1A). West of the town Titov-Veles, in the lower course of the Babuna river, a coarse conglomerate unconformably rest upon a weakly metamorphosed, folded flysch of late Senonian age. This conglomerate passes upward to limestones and breccia with some marl levels bearing a *Globorotalia* fauna of lower Oligocene age (Bizon et al, 1966). Thus the first event CT1, possibly CT2, took place between about 65 and 40 My. Some radiometric data (see Mercier, 1968) coherent with the stratigraphic data have been obtained : 63 My (Rb/Sr method) for a white-mica quartzite of the Loutra Aridhea unit of the western Almopias zone, 40 My (K/Ar method) for a white mica micaschist of the Malarupa-Tzena massif and 43 My (39Ar/40 Ar method) for a chlorite bearing marble of the Livadia fm of the Paikon massif (P. Monnié, unpubl. data). The event CT3 is characterized by brittle deformation. In the previous F. Y. R. of Macedonia thrusts have been reactivated and affect the late Lutetian - Priabonian formations of the «Vardar molassic trough». We have suggested an upper Priabonian - lower Oligocene age (~34 My) for this event (Mercier, 1968). Westward thrusting of the Pelagonian crustal sheet, as defined by Mountrakis (1986), upon the Olympos zone occurred also during the Eocene (Godfriaux, 1968). Around the Olympos window a blueschist facies metamorphism is dated at 53-61 My (40 Ar/39 Ar method) and the authors date the thrusting of the blueschists onto the Olympos zone at 36-40 My (Shermer et al., 1990).

- The western border of the Serbo-Macedonian massif (the «circum Rhodope zone»)

Thrusting of the Serbo-Macedonian massif and of the Circum Rhodope zone subsequent to the late Cretaceous is observed at two places. In the F. Y. R. of Macedonia, west of Sopur, Serbo-Macedonian gneisses are thrust westward onto an Albian-Cenomanian formation (see § 3.1). South of the Doirani lake (Maltzakis et al., 1993), the Permian - lower Triassic volcanic formation of the internal zone of the Circum-Rhodope is thrust westward onto rhyolites interbedded with cinerous tuffs bearing sporo-pollinic association of late Eocene - early Oligocene age.

South of Thessalonique, a complex pile-up of metasedimentary and metavolcanic units of Permian-lower Triassic to Jurassic age associated with cristalline and serpentinites slices is thrust westward. A synmetamorphic deformation affects slices of metalavas and metagabbros below the Thessalonique ophiolites. Syntectonic cristallisations characterized a HP-LT epidote-blueschist facies which is followed by post-tectonic cristallisations of quartz, lawsonite, stilpnomelane (Vergely, 1984). Above the ophiolites the Livadi epidote - blueschist facies (Michard et al., 1994) demonstrates a prograde HP-LT metamorphism (7-8 Kbar, 300-400°c). Analyses of the successive deformations (Vergely, 1984) suggest that this is the first, major penetrative deformation characterized by folds with flow cleavage and shear deformation resulting in mylonites having a SW vergence. A second tectonic event is characterized by folds several -100 m- in size having a strain-slip cleavage ; they strike WNW-ESE and have a SSW vergence. Subsequent deformations are brittle and associated with thrusts having a SW vergence.

The scarcity of deposits of late Cretaceous - Paleogene age makes difficult to date the successive deformations. The first event of HP-LT synmetamorphic deformation is reported to the late Jurassic (Vergely, 1984 ; Michard et al., 1994). The second event (Vergely, 1984) is probably equivalent to the deformation synchronous with a low grade greenschist facies metamorphism which affects a clastic formation passing upward to *Pseudocyclammina* bearing limestones of late Jurassic - early Cretaceous age (Ricou, 1965) which rests transgressively upon the Monopygadion granite, south of Thessalonique. This is possibly related to the CT1 event described above and the subsequent thrusts to the CT3 event.

4. CONCLUDING REMARKS : HOW MANY JURASSIC OCEANIC CRUST BASINS IN THE AXIOS-VARDAR ZONE ?

The most important conclusion resulting from the revision of the Paikon massif is that the ophiolites were already located in the Almopias zone before the late Cretaceous and even before the upper Jurassic - lower Cretaceous (Mercier et al., 1987 ; Galeos et al., 1994). May have they been thrust westward above the Paikon from the Peonias ophiolitic massifs during the late Jurassic ? A radiolarian fauna of Oxfordian age (» 152-144 My) has been recognized in the volcanic part of the Evzoni-Guevgueli ophiolitic complex (Danelian et al., 1996) and diorites (fig. 5) associated with this ophiolitic complex (Bebien, 1982) have been dated at 163 ± 3 My and 154 ± My (K/Ar method, Spray et al., 1984) i.e. of Bathonian-Callovian (160-154 My) age according to the I.U.G.S. 1989 time scale. They are intruded by the Fanos granitic massif dated at 153 ± 2 My (K/Ar and Rb/Sr methods, Borsi et al., 1966 ; Spray et al., 1984 ; Danalian et al., 1996). These ophiolites emerged and have been eroded before the Portlandien (135-140 My) (Mercier, 1968 ; Karras, in Maltzakis et al., 1993) before the late Kimmeridgian according to Staos (1993). Thus, the obduction of the Evzoni-Guevgueli ophiolites occurred during the late Jurassic phase JE 1 (Vergely, 1984) around the Oxfordian - Kimmeridgian limit. As the Evzoni-Guevgueli ophiolites, the spilitic-keratophyric volcanic formation (fig. 5) of the Paikon zone emerged, has been eroded and transgressively covered by Portlandian-Berriasian limestones ; yet no remnants of an ophiolitic sheet outcrop there. Moreover, the rhyolitic volcanic Kastaneri fm (fig. 5) of Kimmeridgian - Portlandian age outcrops in the eastern Paikon and again no ophiolitic remnants outcrop there. Thus, it appears really improbable, if not impossible, that an ophiolitic sheet, at least 5-10 km thick, may have thrust above the Paikon zone during the Kimmeridgian. In other words, it appears that an ophiolitic (oceanic) crust basin was located in the Almopias zone during the Jurassic.

New stratigraphical data (Staos et al., 1990) have shown that the Almopias trough initiated as soon as the Triassic period with pure radiolarite deposits followed by abyssal tholeite lavas and breccias interbedded with radiolarites and pelites of Callovian-Kimmeridgian age.

It has been suggested that the Paikon was an island arc and the Peonias zone a marginal basin (Mercier et al., 1975, Vergely, 1984, Bebien et al., 1987, Asvesta and Dimitriadis, 1992, Ferriere and Stais, 1995). This is supported by geochimical studies (Bebien et al., 1987, 1994). The spilitic-keratophyric and Livadia fm (fig. 5) consist of typical island arc tholeites and dacites. More to the east, the Kastaneri rhyolitic fm has rather characteristics of either calc-alkaline or anatectic rocks similar to those of the Fanos granite (see below).

The Peonias ophiolitic complex formed in a marginal basin probably within a transcurrent zone (Bebien, 1992, Vergely, 1984, Bebien et al., 1987). Their association with granites and migmatites suggests that they formed in a continental rifting (Bebien, 1982, Zachariadou and Dimitriadis, 1994). They have geochemical characters of abyssal or island arc tholeites (Bebien et al., 1987 and ref. therein, Michard et al., 1998). New stratigraphical data (Ferriere and Staos, 1995) show that rifting of the carbonate platform began in the Ladinian-Carnian (235-220 My) period and was followed by basic flows (Mercier, 1968) of Ladinian - late Triassic age. Expansion resulting in the formation of the ophiolitic complex has began at least during the Mid-Jurassic (172 ± 5 My, Kreuzer in Mussalam and Jung, 1986) and continued during the Callovian (163-154 My, Spray et al., 1984), - Oxfordian (Danelian et al., 1986). The ductile extension resulting in partial melting of the continental crust ceased by the Oxfordian (Zachariadou and Dimitriadis, 1994) as suggested by the 153 and 157 ± 5 My age of the Piyi and Karathodoro migmatites respectively (Rb/Sr method, Borsi et al., 1986). The obduction of the ophiolites of the Peonias on the Paikon arc and of Almopias zone on the Pelagonian platform occurred before the Portlandian (Mercier et al., 1975, fig. 2B1 ; Pichon et al., 1975 ; Galeos et al., 1994).

The Serbo-Macedonian massif has been considered as a continental basement (Kockel and Mollat, 1977), as the eastern marge of the Peonias zone (Mercier, 1968). But recent studies has completely renewed the ideas on this massif. Indeed the Rhodopian and Serbo-Macedonian massifs are a pile-up of continental nappes thrust toward the West (Papanikolaou and Panagopoulos, 1981 ; Burg et al., 1995 ; Mposkos et al., 1994 and ref. therein). An early HP-LT metamorphism documented by eclogitic relics has been evidenced (Liati, 1986 ; Mposkos, 1989). It is reported to an eohellenic event (Liati and Mposkos, 1990). The Circum Rhodope nappes overlie the Rhodopian domain (Papanikolaou, 1981, Mposkos, 1989), there a low grade HP-LT metamorphism (Mussalam and Jung, 1986, Michard et al., 1994) has been also reported to an eohellenic event due to an arc-continent collision (Michard et al., 1998). It has been suggested that the meta-ophiolites (included meta-ultrabasites, Mposkos et al., 1994) associated with Rhodopian and Circum Rhodopian continental nappes may have their homeland east of the Serbo-Macedonian massif. In the Hellenides this topics is the most important challenge in the next years. A single ophiolitic suture is not a necessity. Several ophiolitic belts of different ages have been evidenced elsewhere as in Iran and Tibet.

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