Δελτίο Ελληνικής Γεωλογικής Εταιρίας τομ. XXX/1, 47-61, 1994
Πρακτικά 7ου Επιστημονικού Συνεδρίου, Θεσσαλονίκη, Μάιος 1994
Bulletin of the Geological Society of Greece vol. XXX/1, 47-61, 1994
Proceedings of the 7th Congress, Thessaloniki, May 1994

LATE JURASSIC - LOWER CRETACEOUS OCEANIC CRUST AND SEDIMENTS OF THE EASTERN ALMOPIAS ZONE, NW MACEDONIA (GREECE); IMPLICATIONS FOR THE EVOLUTION OF THE EASTERN "INTERNAL" HELLENIDES

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ABSTRACT

Volcano-sedimentary units of the **eastern Almopias zone** can be correlated as a single, intact **MORB** ophiolite, **the Meglenitsa Ophiolite**, interbedded with and overlain by a thick succession of deep-sea sediments (radiolarites and turbiditic flysch) of Late Jurassic-Lower Cretaceous age. This ophiolite was first deformed by thin-skinned tectonics during the Early Tertiary, and not during the Late Jurassic "Eohellenic" deformation. This is in marked contrast to ophiolites of the Pelagonian and western-central Almopias zones, which were emplaced and deeply eroded prior to being unconformably overlain by Late Jurassic (Oxfordian-Kimmeridgian) shallow-marine sediments. Consequently, the Meglenitsa Ophiolite represents either: **1)** a remnant of Mesozoic oceanic crust that escaped Late Jurassic deformation; or **2)** a younger basin that formed after Late Jurassic deformation between the Pelagonian and Paikon carbonate platforms (i.e. a pull-apart basin). Sedimentological and structural data do not support a recent hypothesis that this ophiolite was thrust over the Paikon zone from the east (Peonias zone) during the Early Tertiary.

INTRODUCTION, REGIONAL SETTING AND PREVIOUS WORK

The Axios (Vardar) zone of northern Greece is divided into three tectonic zones: the Almopias, Paikon and Peonias zones from west to east, respectively (Mercier 1968, Fig 1b). This study is concerned with the Almopias zone, and in particular with ophiolitic sequences exposed in the **eastern** part of the Almopias zone (Fig 1c). An understanding of the setting, genesis and age of emplacement of these ophiolitic lithologies and associated sediments is critical to understanding the evolution of the Eastern "internal" Hellenides and thus is discussed here.

The Almopias zone was first defined by Mercier (1968) as an "ophiolitic root zone" sandwiched between the Pelagonian and Paikon platforms (Fig 1c). Mercier essentially concluded that the ophiolites of the Almopias zone were obducted westwards onto the Pelagonian carbonate platform during the Late Jurassic, culminating in complete suturing of the Axios (Vardar) strand of Neotethys. Since this work, Bechon (1981) has given a limited petrographic description of the lavas of the eastern Almopias zone, whilst Bijon (1982) re-evaluated Mercier's original stratigraphy, and Vergely

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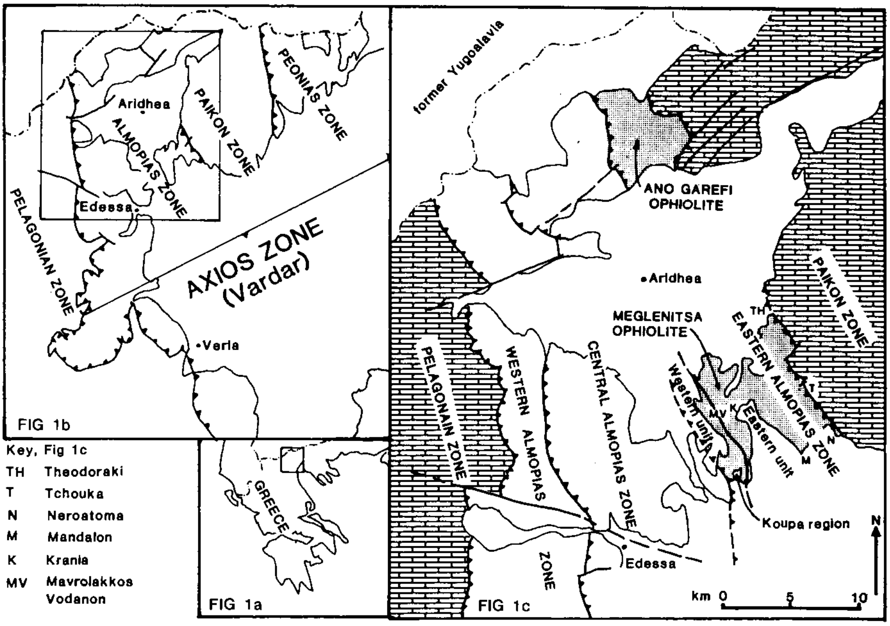
Fig. 1a. Location of the study area and subdivisions of the Axios (Vardar) zone of northern Greece. Subdivisions of the Almopias zone (Fig. 1c) modified after Mercier (1968).



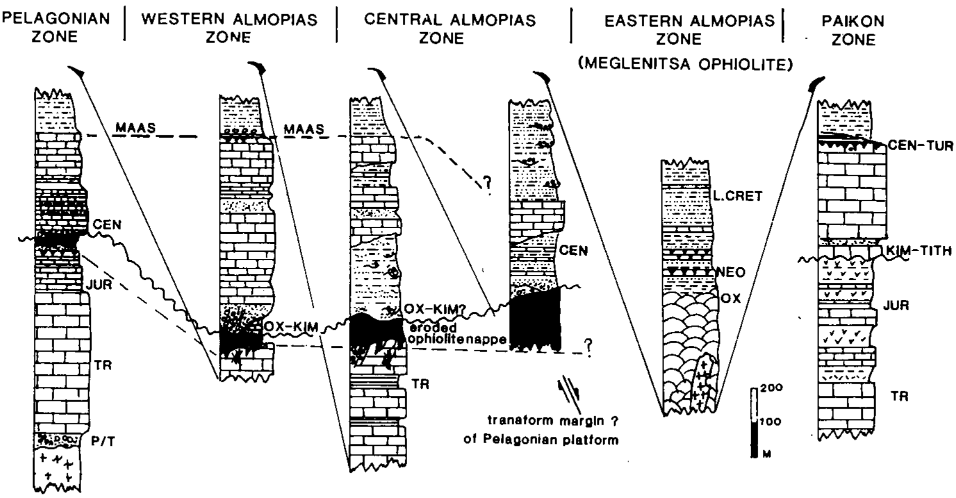


Fig.2. Simplified tectono-stratigraphic logs of the Pelagonian, Almopias and Paikon zones of NW Macedonia (modified from Mercier 1968 & Mercier & Vergely 1984). The ophiolites of the Pelagonian and western-central Almopias zone were emplaced onto the eastern margin of the Pelagonian platform during the Mid-Late Jurassic ("Eohellenic" JE1 pre-Tithonian event of Vergely 1984), and then deeply eroded and unconformably overlain by Late Jurassic (Oxfordian-Kimmeridgian) and/or Cretaceous conglomerates and neritic carbonates. The Paikon zone also underwent deformation and HP/LT metamorphism during the Mid-Late Jurassic, prior to being unconformably overlain by Late Jurassic carbonates. In contrast, the eastern Almopias zone (Meglenitsa Ophiolite) was not deformed during the Late Jurassic, but did receive a thick turbiditic flysch. The major tectonic contacts between the zones are of Early Tertiary age.
P/T - Permo-Triassic. TR - Triassic. JUR - Jurassic. OX-KIM - Oxfordian - Kimmeridgian. KIM-TITH - Kimmeridgian - Tithonian. OX-NEO - Oxfordian - Neocomian. L.CRET - Lower Cretaceous. CEN - Cenomanian. CEN-TUR - Cenomanian - Turonian. MAAS - Maastrichtian.

(1984) briefly studied the structural evolution of the region. Stais *et al.* (1990) and Stais and Ferrière (1991) have recently suggested the existence of a deep-water basin in the eastern Almopias zone during the Late Jurassic-Lower Cretaceous, based on palaeontological evidence. In this paper we first give a description of two volcano-sedimentary units in the eastern Almopias zone (the Mavrolakkos and Krania units of Mercier, 1968) and show that they can, in fact, be correlated. A combination of igneous petrological, geochemical, sedimentological and palaeontological information is presented and allows the recognition of a single ophiolitic unit in the eastern Almopias zone, **the Meglenitsa Ophiolite** (Figs 1c & 2). These data show that the eastern Almopias zone was not emplaced during the Late Jurassic "Eohellenic" deformation event. This has several important regional implications which are discussed.

DEFINITION OF THE MEGLENITSA OPHIOLITE

The eastern Almopias zone is formed by NNW-SSE trending thrust slices of dolerites, pillow lavas, acidic intrusives, radiolarian cherts and a thick sequence of deep-water clastic sediments. Mercier (1968) divided the eastern Almopias zone into two units: the **Mavrolakkos unit** in the west and the **Krania unit** in the east. The contact between these two units was thought to be a westward-verging Tertiary thrust, running roughly along the line of the Meglenitsa River. During the course of this study, however, field mapping (Fig 3) has clearly demonstrated that this contact, although folded and locally reverse faulted, is in fact a **normal contact**, and that the Mavrolakkos and Krania units are essentially part of the same ophiolitic unit. A new name, the **Meglenitsa Ophiolite**, is introduced here for the combined Mavrolakkos and Krania units, which are here termed the **Western** and **Eastern units**, respectively (Table 1). The western limit of the Meglenitsa Ophiolite is a regionally important Tertiary thrust, with the Western (Mavrolakkos) unit tectonically overlying Triassic lava and radiolarite, and Cretaceous flysch of the central Almopias zone (Vrissi and Nea Zoi units of Mercier 1968 and Stais *et al.* 1990; Figs 1c, 2 & 3). The eastern margin of the Meglenitsa Ophiolite is also a well defined Tertiary thrust, with pillow lava and radiolarite of the Eastern (Krania) unit thrust towards the NE over Cretaceous carbonates of the Paikon zone (Sharp & Robertson 1992; Figs 1c & 2).

THE WESTERN (MAVROLAKKOS) UNIT

The Western (Mavrolakkos) unit is well exposed in the Kopua region, the type area of previous workers (Figs 1c & 3a). Using way-up criteria (e.g. pillow lava, graded bedding, sole structures and bedding-cleavage relationships) it is now clear that the Western unit exposed in the Koupa region consists of a simple sequence repeated by folding and thrusting, and that the contact between the Western and Eastern units is a normal contact, albeit locally fold inverted and faulted. The contact between the Western and Eastern units is particularly well exposed working uphill from the Meglenitsa River northwards towards Fteri (Fig 3a), with the thrust contact between the Western and Eastern units "tipping-out" into an incipient hangingwall anticline and footwall syncline pair (Fig 3b). Previous stratigraphic studies (Mercier 1968, Bijon 1982 and Stais *et al.* 1990) did not take these structural complexities into account, and hence a revised, four-fold sequence is proposed here (Table 1), based on field logging and mapping. The new type section starts 150m WSW of farm buildings at the col

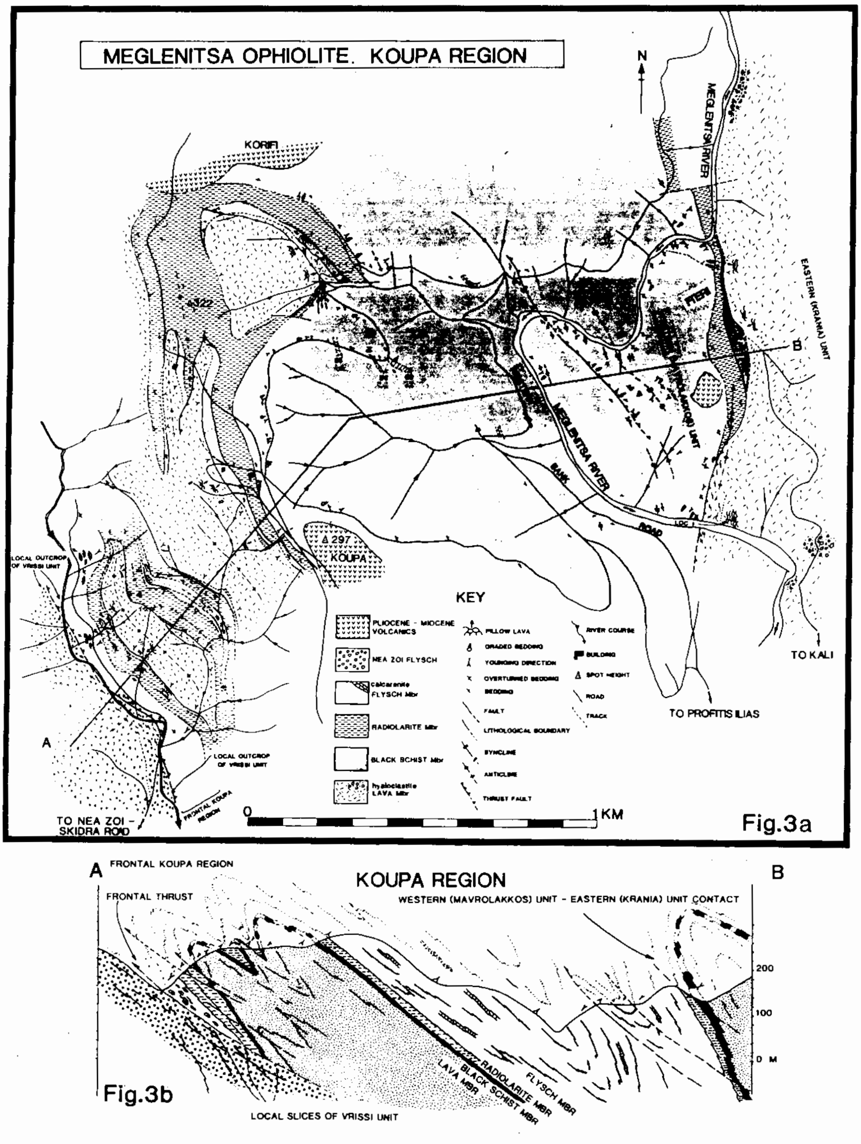


Fig. 3a & 3b: Detailed map and section of the Meglenitsa Ophiolite, Koupa region. The western (Mavrolakkos) unit is in thrust contact over the Nea Zoi and Vrissi units of the centrla Almopias zone in the west (Frontal Koupa region). The contact between the Western (Mavrolakkos) and Eastern (Krania) units is also well exposed east of the Meglenitsa River, where it is seen to be a normal contact, albeit locally inerted and faulted due to Tertiary fold and thrust propagation. The sections of Bijon (1982) and Stains et al. (1990)roughly follow the line of section A - B. The new type section (Fig. 4.) starts 150m west of the farm buildings at the col NW of Koupa summit, and follows the track north then east down towards the Meglenitsa River, terminating just after the hairpin bend horizon 69).

Table 1: Revised stratigraphy of the Western and Eastern units of the Meglenitsa Ophiolite, eastern Almopias zone.

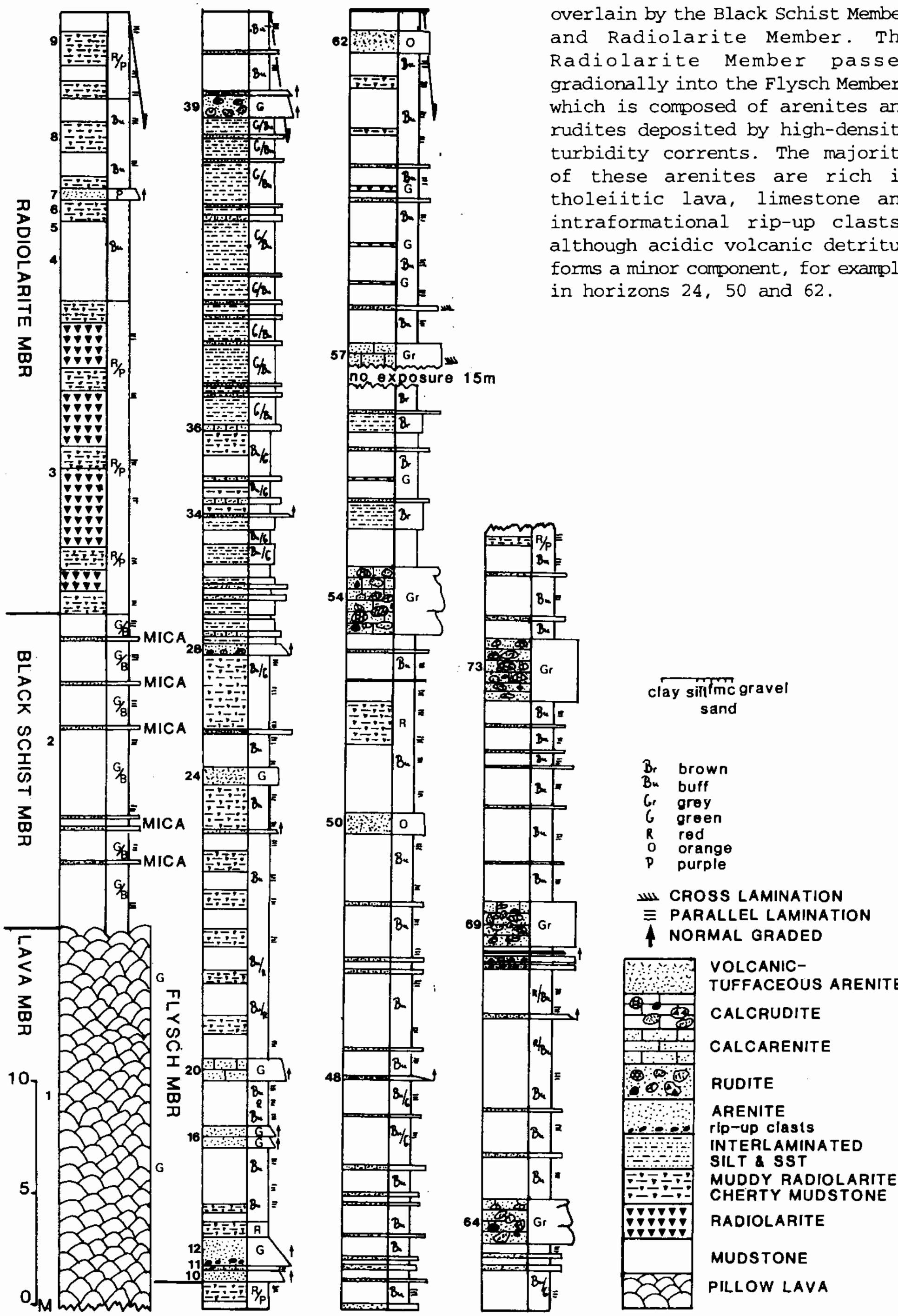
Western (Mavrolakkos) unit	**Eastern (Krania) unit**
Flysch Member. Terrigenous and calcareous, clastic "flysch", displaying classic features associated with deposition by turbidity currents, interbedded with siliceous mudstones (predominantly at base of member) and siltstones. *Thickness*: Top not seen, at least 250m.	**Flysch Member.** Terrigenous and calcareous "flysch". Predominantly rudites and arenites with interbedded volcanics and volca-niclastics. This member, and all underlying members, are cut by granitic, granophyric and basaltic sills and dykes. *Thickness:* Top not seen, up to 200m.
Radiolarite Member. Ribbon-bedded radiolarite, muddy radiolarite, argillaceous chert and siliceous mudstone. Rare pillow lava and thin-bedded sandstones. *Thickness*: Variable, commonly 15-25m.	**Radiolarite Member.** Ribbon-bedded radiolarite, muddy radiolarite, argillaceous chert, siliceous mudstone and thin sandstones. *Thickness*: Variable, 0-25m. Only developed adjacent to Paikon Thrust and along contact with Western unit.
Black Schist Member. Planar-laminated, black and green, ferruginous and micaceous mudstones, thin sandstones and cherts, with minor pillow lava intercalations, *Thickness*: Very variable, commonly 8-15m.	**Black Schist Member.** Planar-laminated, black, ferruginous and micaceous mudstones, sandstones and iron-pyrite-carbonate concretions. Local massive sulphides along lava - sediment interface. Interbedded vesicular, greenish-brown coloured lava. *Thickness*: Up to 50m where fully deve-loped.
Lava Member. Thick volcanic pile of MORB pillow lava and local hyaloclastite. *Thickness*: Base not seen, at least 200m.	**Lava Member.** Thick pile of MORB pillow lavas, dolerites, hyaloclastite and local ribbon radiolarite. *Thickness*: Base not seen, at least 200m.

300m NW of Kopua summit (Fig 3). In this area, the proposed **Lava, Black Schist and Radiolarite Members** are well exposed, and are seen to pass gradationally upwards into a thick **Flysch Member** (well exposed in track cuts north and east of the col). Figure 4 is a detailed log of this section. The characteristics of the four members are briefly described below.

Lava Member

The basal Lava Member consists almost entirely of tholeiitic lava. River sections (e.g. in the Mavrolakkos Vodenon region 6km NNW of Koupa, Fig 1c) expose pillows, tubular lobes and bolsters (up to 3m long). Pillow budding

Fig. 4: Type section of the Western (Mavrolakkos) unit of the Meglenitsa Ophiolite in the Koupa region (Fig. 3a). In this section the Lava Member is conformably overlain by the Black Schist Member and Radiolarite Member. The Radiolarite Member passes gradionally into the Flysch Member, which is composed of arenites and rudites deposited by high-density turbidity corrents. The majority of these arenites are rich in tholeiitic lava, limestone and intraformational rip-up clasts, although acidic volcanic detritus forms a minor component, for example in horizons 24, 50 and 62.



from lava tubes is also visible. Significant interlava sediment is not seen, although green interpillow chert, or mudstone lenses are observed locally. Hyaloclastite and breccia margins to pillows are locally visible (e.g. in the Mavrolakkos Vodenon region).

Black Schist Member

The basal lava pile is conformably overlain by a sequence of interbedded planar-laminated, green and black mudstones, siltstones and sandstones (Fig 4). The sediments are generally ferruginous and highly micaceous. Sedimentary structures are largely absent, although the mudstones and siltstones are planar-laminated on a mm scale. The sandstones are up to 50cm thick, generally structureless, poorly-sorted quartz greywackes (with minor carbonate and lava fragments). This unit equates to Mercier's (1968) "black schists" and proved to be a laterally extensive marker horizon during mapping, although the thickness of this member varies greatly (Table 1). In the Mavrolakkos Vodenon region detached pillows, lava talus and metalliferous mudstones are present in this member.

Radiolarite Member

The Black Schist Member is conformably overlain by a thick sequence of interbedded siliceous mudstones, radiolarites and muddy radiolarites (Table 1 & Fig 4). The contact with the underlying unit is clearly gradational, with the siliceous content of the mudstone gradually increasing upwards, until bedded ribbon radiolarite is developed. Stais *et al.* (1990) extracted **Late Jurassic (Callovian)** to **Lower Cretaceous (Neocomian)** radiolarians from this radiolarite. In thin section, many of the radiolarites show sedimentary structures indicating current deposition (e.g. grading, scouring and lamination). Towards the top of the Radiolarite Member a normal-graded, medium-to fine-grained, purple sandstone horizon is mapped in both the Koupa and Mavrolakkos Vodenon regions (Horizon 7 of Fig 4). This sandstone is rich in grains of **tholeiitic basalt**, **carbonates, minor acidic volcanics** and **rip-up clasts of radiolarite**, and signifies the first signs of a transition to flysch sedimentation. Importantly, the contact with the overlying Flysch Member is **gradational**, with cherty, radiolarian-bearing mudstone persisting as interbeds into the lower 50m of the Flysch Member (Fig 4).

Flysch Member

This member is well exposed (e.g track cuts in the Koupa region and along the banks of the Meglenitsa River, Fig 3). It comprises interbedded green, buff and red, siliceous and locally calcareous mudstones, siltstones, thicker-bedded sandstones and calcarenites (Fig 4).

The sandstones and calcarenites are often poorly sorted and show features typically associated with deposition by turbidity/density currents and debris flows. These include the Bouma Ta-Te sequence (Bouma 1962), slump folds, convolute bedding, water-escape features, overturned cross bedding, flutes, groves, load structures, intraformational rip-up clasts and deep-water trace fossil assemblages (i.e. *Nerites* ichnofacies of Seilacher 1967). Typically, complete Bouma sequences are not developed, and individual flow horizons show evidence of amalgamation and absent divisions (notably Tc). Such amalgamation is indicative of deposition by high-density turbidity currents in relatively proximal, high gradient, settings, or within channel fan systems capable of reaching the basin plain. The widespread occurrence of relatively coarse-grained, angular sand, pebbles and intraclasts, deposited at the base of individual flows as traction carpets is in keeping with this setting. The traction carpets typically consist of coarse-grained, planar-laminated and rarely cross-bedded conglomeratic sand, with discrete internal scour surfaces. Both normal and inverse grading are developed. The upper levels of these horizons are commonly structureless, or faintly planar-laminated, with rare, normal graded horizons that probably resulted from rapid settling of sediments from suspension. Other calciturbidites (e.g. horizons 54 and 64, Fig 4) show little internal sorting and were probably deposited as debris flows. As well as being rich in limestone and lava clasts, these two horizons contain angular rip-up clasts of sandstone and siltstone, testimony to rapid deposition. Background sedimentation to the turbiditic units consists of relatively homogeneous, buff, red and green planar-laminated, silty mudstone, often siliceous, particularly towards the base of the unit, with thin siltstone and fine-grained sandstone interbeds. Tuffaceous mudstones and arenites are also locally present (e.g. horizons 24, 50 & 62, Fig 4).

A detailed provenance study of the Western flysch reveals that **tholeiitic lava** (petrographically identical to the underlying Lava Member) and **micritic carbonates**, in the form of reworked clasts or as redeposited micrite, form by far the most common detrital constituents of the flysch. **Rare acidic volcanics** (e.g. rhyolites, tuff), **volcanic quartz** and **radiolarite rip-up clasts** are also present. Several of the volcanic fragments posses an earlier-formed schistocity. Fragments of echinoderms and shells are the only identifiable skeletal components. These are often bored and have developed syntaxial overgrowths **prior** to incorporation within the calcarenites, consistent with derivation from a neritic carbonate shelf area. The matrix to both the calcarenites and the arenites consists of chlorite and micrite, which is invariably recrystallized to microspar.

Measureable palaeocurrent and palaeoslope indicators are rare. Limited data from observed slump folds, cross bedding/overturned cross bedding and asymmetrical ripple crests imply an **east** or **north-east** facing slope and a general **west to east** flow direction. This would favour **derivation of the flysch from the eastern Pelagonian margin and western-central Almopias zone** (Fig 2). The basal Kerassia, Liki, Margarita and Klissochori units would, in this case, be the probable source area for the flysch, and could have supplied mixed carbonate and volcanic detritus (Sharp 1994).

THE EASTERN (KRANIA) UNIT

This unit forms the eastern part of the Meglenitsa Ophiolite (Fig 1c), previously defined as the Krania unit by Mercier (1968). This unit is not well exposed, no one section exposing the complete sequence. The stratigraphy presented here is thus a composite one, based on detailed field mapping and logging (Sharp 1994). The Eastern unit displays a similar succesion to the Western unit, but with several significant differences, as detailed below and in Table 1.

Lava Member

The Lava Member of the Eastern unit includes pillowed tholeiitic lavas, interbedded hyaloclastite (including flow-front talus horizons), rare massive flows and dolerites. Significant radiolarite interbeds are developed adjacent to the Paikon Thrust (Nerostoma, Tchouka and Theodoraki regions, Fig 1c), where they have been dated as **Upper Jurassic (Mid-Oxfordian)** to **Lower Cretaceous (Valanginian)** (A. Stais, pers. comm., 1992). One sample from the Tchouka region is diagnostic of the Tithonian stage alone (A. Stais pers. comm., 1992). Thin calcarenites are found towards the upper levels of this radiolarite, similar to those encountered in the Western unit. Structural data suggest that the radiolarite belongs to the upper levels of the lava pile.

Black Schist Member

This member directly overlies the lava pile, although it is only locally developed in the Eastern unit. It consists of interbedded mudstones (with local *Nerites* trace fossils), turbiditic quartz-arenites and lavas. Lavas of the Black Schist Member are distinctive in the field, being light greenish-brown, vesicular tholeiitic basalts. These extrusives include primary flows and epiclastic talus (cm-to 10m-sized pillowed blocks). The contact with the underlying Lava Member is gradational, as is the contact with the overlying flysch. One small, oxidised, massive sulphide deposit was identified at the interface between the Black Schist Member and the underlying lava pile (along the Theodhraki-Mandalon dirt road) indicating the former presence of sea-floor hydrothermal systems, which would account for the presence of local metalliferous mudstones in the Black Schists Member of both the Eastern and Western units.

Radiolarite Member

Radiolarite is only developed in the extreme eastern and western parts of the Eastern unit. As described above, the radiolarite exposed adjacent to the Paikon Thrust is interbedded with pillow lava, whilst radiolarite exposed in the west is stratigraphically above the Black Schist Member. In the majority of sections of the Eastern unit, however, radiolarites are absent and the Black Schist Member passes gradationally into the Flysch Member.

Flysch Member

The Flysch Member forms an NW-SE trending belt in the centre of the Eastern unit and typically consists of interbedded mudstones, arenites, calcarenites, rudites, calcrudites and lava (Table 1). Calcarenites and calcrudites of the Flysch Member of the Eastern unit are rich in the following detrital components: **neritic limestones** (including oosparites, packed biomicrites, calcarenites, dolomites and individual echiniderm and shell debris), **rhyolitic** and **acidic volcanics** (including individual embayed quartz grains), **tholeiitic lava** and **minor dolerite**, **pelagic micrites** and **sparse granitic/granophyric pebbles**. Of these clasts, the first three (neritic limestone, acidic volcanics and tholeitic lava) are the most important constituents volumetrically. Of note, tholeiitic lava clasts are not abundant in thin section, but do form large, angular blocks within the calcrudites at outcrop. This suggests that the lava clasts underwent little sedimentary transport from their source. Primary lava flows are also clearly interbedded with these sediments. In terms of a source region, the Eastern unit flysch has a very similar provenance to the Late Jurassic-Lower Cretaceous Ghrammos Formation (Brown & Robertson, this volume) of the Paikion zone. Very rare fossiliferous clasts of Late Jurassic age were also identifed within debris flows of the Eastern unit flysch. These are faunally and lithologically similar to Late Jurassic carbonates of both the Paikon and western Almopias zones. Fossils identified include *Palaeomiliolina strunsum, Lenticulina sp., Clypeina Jurassica, Cladocoropsis* *sp., Ammobaculites sp., Saingoporella sp. and Thaumatoporella sp.*

Clast-supported textures are typical of the rudites within the flysch of the Eastern unit, with clast-clast contacts being picked out by stylolites rich in insoluble clay and a ferruginous residue. Sorting is generally very poor and clasts vary from very well-rounded to very angular. Sedimentary structures are generally absent within the calcrudites, although faint grading and traction carpet features are locally observed. In contrast, the calcarenites are commonly planar-laminated, and locally faintly graded or ripple-bedded, often forming the tops of calcrudites. Calcilutite is also present in the upper part of these horizons and is locally rich in poorly preserved radiolarian tests, calcispheres and thin-shelled bivalves; one sample yielded probable ?*Saccocoma sp.* fragments.

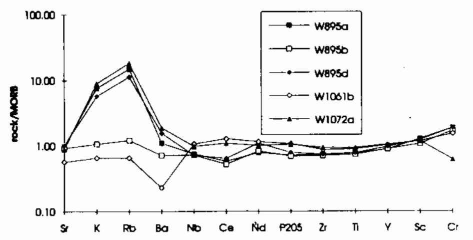
The similarity between the calcarenites/rudites of the Eastern and Western units is obvious. However, there are two significant differences: **1)** A greater abundance of **calcrudites/rudites** in the **Eastern flysch**, whilst the **Western flysch** is generally richer in **thinner-bedded calcarenites**; **2)** An abundance of **rhyolitic/acidic volcanic fragments** and **large angular tholeiitic lava** blocks within the **Eastern flysch**, whilst the calcarenites and rudites of the **Western flysch** are generally richer in **sand-sized tholeiitic fragments**, with **minimal rhyolitic-acidic clasts**. A proximal (Eastern unit), distal (Western unit) relationship can be inferred from this. The entire Eastern unit sedimentary sequence is also very poorly sorted and immature, as well as including primary volcanic horizons. In addition, the fact that the flysch directly overlies the lava pile and Black Schists in the central outcrops of the Eastern unit, and the presence of large tholeiitic blocks in the flysch, suggests some degree of erosion and/or faulting of the oceanic crust prior to, and during, deposition of the flysch.

All of the lithologies of the Eastern unit are cut by granitic and granophyric intrusives, which are concentrated in the central outcrops. These have sill-to dyke-like geometry, and are up to 10m wide, typically associated with epidote veins. Chilled margins are commonly present and the granophyres often display spectacular graphic and spherulitic textures. Basaltic andesite dykes are also encountered (e.g. seen to cut the Flysch Member in road cuts along the new Krania-Mandalon road). Similar granitic intrusives are found in the Guevgeli Ophiolite (e.g. Fanos Granite), the Ano Garefi Ophiolite (Migiros & Galeos, 1990) and have also recently been identified in Late Jurassic volcanics of the Paikon zone (S. Brown, pers. comm., 1993). No such intrusives were encountered in the Western unit of the Meglenitsa Ophiolite.

PETROGRAPHY AND GEOCHEMISTRY OF EXTRUSIVES

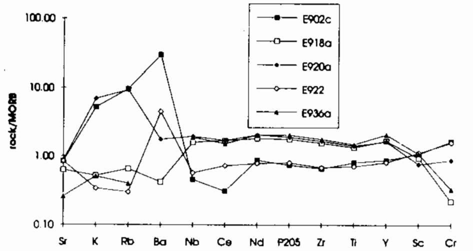
Petrographically, the majority of lava samples studied are tholeiitic basalts. Spherulitic, glomeroporphyritic and variolitic textures are common, and the majority of studied samples are amygdaloidal and vesicular. Plagioclase is typically present, as prismatic phenocrysts and as microlaths within the groundmass, whilst augite commonly forms equant, subhedral crystals (commonly twinned). Titanaugite is present in several samples. Features indicative of rapid quenching include box textures in plagioclase, variolitic augite, chilled pillow margins and rare skeletal olivine crystals. Numerous samples of the Eastern unit are also rich in primary euhedral or prismatic iron-titanium oxides.

Over 100 samples were geochemically analysed from the Meglenitsa Ophiolite (Sharp 1994). Selected data are given in Figure 5 and Table 2. All the



MORB normalized trace element plots of Western unit basalts. MORB values from Pearce (1982)

Fig. 5b



MORB normalized trace element plots of Eastern unit basalts. MORB values from Pearce (1982)

Fig. 5c

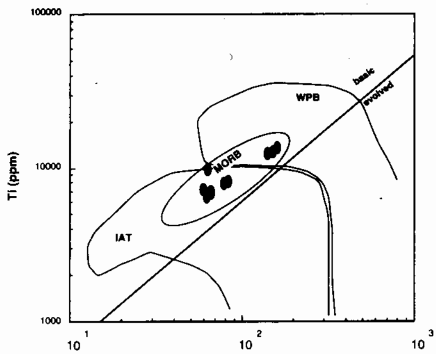


Fig. 5a

Zr (ppm)

	W895a	W895b	W895d	W1061B	W1072A	E902c	E918a	E920a	E922	E936a
Sio2	51.86	47.92	50.33	48.56	48.97	48.32	51.47	46.51	49.03	47.24
Al2O3	15.44	15.42	15.54	14.3	14.99	15.09	13.25	13.91	14.34	13.64
Fe2O3	9	10.1	9.58	10.48	10.4	10	12.86	14.28	9.42	14.38
MgO	6.86	6.37	7.05	6.48	7.25	8.3	5.96	6.93	8.72	6.28
CaO	7.6	12.66	8.21	11.76	8.9	9.29	8.4	9.62	10.16	8.8
Na2O	3.92	2.33	4.01	2.11	3.17	3.9	3.72	2.09	3.35	3.29
K2O	1.135	0.159	0.885	0.098	1.343	0.773	0.078	1.036	0.051	0.076
TiO2	1.152	1.094	1.157	1.32	1.374	1.22	2.033	2.142	1.076	2.247
MnO	0.139	0.163	0.135	0.198	0.164	0.154	0.204	0.2	0.146	0.231
P2O5	0.085	0.082	0.094	0.127	0.124	0.089	0.213	0.229	0.097	0.245
LOI	2.32	3.21	2.93	4.26	2.99	3.48	2.52	2.86	3.3	3.53
Total	99.51	99.51	99.89	99.69	99.67	99.71	100.71	99.81	99.7	99.97
Sr	117.1	110.2	121	68.3	106	101.4	75.2	104.8	101.6	31.1
K2O	1.135	0.159	0.856	0.098	1.343	0.773	0.078	1.036	0.051	0.076
Rb	29.9	2.4	22.5	1.3	36.5	19.3	1.3	18.5	0.6	0.8
Ba	21.7	14.2	30.6	4.6	37.1	602.2	8.4	35.1	89.3	-10.5
Th	2.7	2.5	2.3	2.5	3.4	2.2	3.2	4.9	1.3	4.3
Nb	2.6	2.5	2.5	3.7	3.4	1.6	5.6	6.8	2	6.6
La	1.6	0.3	1.3	2.2	1.1	0.9	4	2.9	1.1	6
Ce	5.8	5.2	6.4	12.7	10.8	3.1	16.9	17	7.3	15.2
Nd	6.2	6.6	8.6	9.1	8	7	14.5	16.5	6.3	16.5
P2O5	0.085	0.082	0.094	0.127	0.124	0.089	0.213	0.229	0.097	0.245
Zr	65.6	62.6	65.5	77.5	83.3	59.5	140.1	150.5	61.9	159.8
Ti ppm	6912	9780	6942	7920	8244	7320	12198	12852	6456	13482
Y	26	26.3	28.5	30.4	31.1	26.5	50.4	49.4	24.6	62.8
Sc	50.1	42.2	48.2	46.3	46.1	43.6	38.1	31	45.3	43.7
Cr	458.9	413.6	457.2	373.5	152.7	417.8	55.4	221.1	399.6	83.7
Ni	78.5	66.5	81.9	77.5	54.6	83.5	30.5	106.5	69	47
V	281.6	260.7	289.3	297.2	305.6	264.3	405.1	367.1	245.7	426.2
Cu	94.9	91.4	98.7	65.3	84.9	93.1	44.8	50.2	98.5	44
Zn	81.6	77.6	78.6	80.6	97.3	75	123.6	118.1	62.5	131.7
Pd	0	0.4	1.1	1.3	1.2	0	2.1	1.8	1	2.5

Table 2.

Fig. 5: Geochemical descrimination plot of Zr against Ti ad MORB normalised trace element plots of lavas from the Western (Fig. 5b) and Eastern (Fig. 5c) units (after Pearce & Cann 1973 and Pearce 1982). Table 2 shows major and trace element analyses of the lavas plotted.

lavas analysed from the Western unit are of definite **MORB** affinities (**Fig** 5b), as are samples from the Eastern unit (Fig 5c). Out of the 100+ basalts analysed, 9 samples (not shown here) from the Eastern unit, notably from the **upper levels** of the Lava and Black Schist Members, and two late-stage dykes which cut the Flysch Member, show slight Nb depletion, Ce-P205 enrichment and a slight negative slope between Zr and Ti. These features suggest a very weak subduction related geochemical signature, although this need not indicate contemporaneous subduction.

DISCUSION OF IGNEOUS - SEDIMENTARY EVOLUTION

Based on the new data given here, the thick subaqueous lava pile of MORB lavas, hyaloclastites, rare massive sulphides and a conformable cover of ribbon radiolarites, which characterise the eastern Almopias zone, are here interpreted as the upper levels of an ophiolite. The presence of thin sandstones which overlie the ophiolite extrusives (i.e. within the Black Schist Member) indicates derivation from a landmass capable of supplying terrigenous sediment as distal turbidites. This suggests that the Meglenitsa Ophiolite preserves part of a relatively narrow basin, or, at least the margins of a larger one. Radiolarites mantle the underlying lavas and sandstones and locally show evidence of deposition as low-density turbidites.

The detached lava blocks in the Black Schists Member of both the Western and Eastern units could be flow-, or fault-scarp derived and suggest the existence of a marked sea-floor topography. The arenites interbedded with the upper levels of the radiolarites record the transistion from an active spreading setting to a flysch basin during Late Jurassic-Lower Cretaceous times.

The flysch which overlies the ophiolite was deposited by high-density turbidity currents and mass flow mechanisms. At least in the Eastern unit, this deposition was locally accompanied by continuing volcanism. The flysch was derived both from a mature volcanic/neritic platform region and from an ophiolitic terrane. The abundance of intraformational clasts within the flysch (e.g lava and radiolarite) suggests that the Meglenitsa Ophiolite (or adjacent oceanic crust) was undergoing some form of ?deformation or erosion at this time. Both the Paikon and western-central Almopias zones were capable of supplying acidic volcanic and neritic carbonate detritus during the Late Jurassic-Lower Cretaceous. However, only the central and western Almopias zone could supply ophiolitic debris (unless an ophiolitic nappe was emplaced and eroded from the Paikon zone **prior** to deposition of the Tithonian Khromni limestones). Limited palaeocurrent data from the Western unit favour input from the west, whilst provenance and facies analysis suggest that the Eastern unit flysch could have been derived, at least in part, from the Paikon zone to the east. Hence a dual source of sediment input is implied, **with detritus supplied into a small ocean basin sited between the Paikon and Pelagonian platforms**. These sedimentary data obviously disagree with the recent proposal that the ophiolites of the eastern Almopias zone are completely allochtonous (i.e. thrust-derived from the Peonias zone during the Tertiary).

SUMMARY OF STRUCTURE

A detailed study of the structural evolution of the Meglenitsa Ophiolite has also been undertaken (Sharp 1994). The main conclusion of this work is that the Meglenitsa Ophiolite has only been subject to fold and thrust deformation during the Tertiary. Tertiary fold axes trend **NNW-SSE** in the **Western unit** and **face and verge south-westwards** (Fig 3b), whilst fold axes also trend **NNW-SSE** in the **Eastern unit**, but **face and verge north-eastwards** (Sharp & Robertson, 1992). This divergence might be due to thrust "ramping" of the western edge of the Meglenitsa Ophiolite (Western unit) over the Pelagonian margin during the Tertiary. This could have induced a pop-up structure in the hanging-wall, with back-folding and back-thrusting of the Meglenitsa Ophiolite (Eastern unit) over the Paikon zone in the east. Regionally significant divergence cannot be ruled out, but no such fold and thrust divergence is developed in the Ano Garefi Ophiolite (a probable continuation of the Meglenitsa Ophiolite north of the Loutraki Fault, Fig 1c). Importantly, no structural evidence was found of major Late Jurassic "Eohellenic" deformation and emplacement of the Meglenitsa Ophiolite. Also, no structural data were forthcoming to support thrust derivation of the Meglenitsa Ophiolite from the east (Peonias zone) over the Paikon zone during the Tertiary.

REGIONAL COMPARISONS

The contact between the Meglenitsa Ophiolite and the thrust sheets of the western and central Almopias zone is a well defined, SW-verging, Tertiary thrust, delineated by the conglomeratic Cretaceous sandstones of the Nea Zoi and Vrissi units (Mercier 1968; Stais *et al.* 1990; Sharp 1994 & Figs 2 & 3a). West of this contact the Almopias zone comprises a series of Tertiary thrust sheets, which are characterized by a basal horizon of **strongly deformed and eroded** ophiolitic lithologies, overlain, with a **marked unconformity**, by ophiolitic conglomerates and neritic carbonate sequences of **Late Jurassic** (Oxfordian-Kimmeridgian; Galeos *et al.* 1992, Sharp 1994) and/or Cretaceous age (Mercier 1968; Sharp 1994; Fig 2). The pre-ophiolite "basement" sequences of the central and western Almopias zone are little known as they are rarely exposed. However, outcrops south of Rizarion (Edessa region) and in the Voras massif to the north reveal an essentially Pelagonian-like stratigraphy, with the ophiolitic bodies preserved above deformed ?Triassic-Jurassic carbonates and beneath transgressive, Late Jurassic and/or Cretaceous sediments (Fig 2). Similarly, in the Pelagonian and Paikon zones, much eroded ophiolitic lithologies and deformed platform carbonates are unconformably overlain by Late Jurassic (Kimmeridgian) to Late Cretaceous carbonates (e.g. Mercier 1968; Brown & Robertson, this volume; Brunn *et al.* 1972; Mavridis *et al.* 1979). Importantly, the Triassic radiolarites of the Vrissi unit (Stais *et al.* 1990) might also represent the upper levels of this dismembed ophiolite, and were found to be in **normal contact** with **MORB** lavas at the type locality (Sharp, 1994). This would not only confirm the view of Stais *et al.* (1990) that a deep-water basin existed in the Almopias zone during the Triassic, but also that this basin was of **true oceanic affinities**.

Clearly then, ophiolitic exposures of the **eastern Almopias zone** preserve an essentially **undeformed ophiolitic sequence of Late Jurassic-Lower Cretaceous age and a conformable cover of Lower Cretaceous turbiditic sediments**, whilst ophiolitic and platform carbonates exposed to the west and east are characteristically **tectonically sliced, much eroded and ultimately transgressed by Late Jurassic** (Oxfordian-Kimmeridgian) **and Cretaceous red-bed and neritic sequences** (Fig 2). All formations underlying these transgressive carbonates underwent pervasive deformation and metamorphism ("Eohellenic", JE1 event of Vergely 1984) **prior** to this transgression.

With regard to other ophiolites of the Axios (Vardar) zone, a probable continuation of the Meglenitsa Ophiolite is the Ano Garefi Ophiolite (Migiros & Galeos 1990). The Ano Garefi Ophiolite comprises mainly plutonic rocks, including restite peridotites and dunites, and probably represents deeper structural levels of oceanic crust of Upper Jurassic-Lower Cretaceous age, formed in the same basin as the Meglenitsa Ophiolite. The Ano Garefi Ophiolite is, however, unconformably overlain by ?Aptian-Albian carbonates and conglomerates, and was uplifted and partially eroded prior to deposition of these sediments. This unconformity may relate to a Lower Cretaceous "event" (c.f. Vergely's JE2 and the 110-124 Ma radiometric dates obtained by Betrand *et al.*, this volume). The significance of this "event" is as yet unclear, possibly it reflects strike-slip (i.e. transpressive) deformation of the Almopias zone (Vergely 1984, Sharp 1994). The Meglenitsa Ophiolite can also be compared with the Guvegueli Ophiolite located to the east of the Paikon platform, which is essentially a Mid to Late Jurassic MORB ophiolite, interpreted as having formed in a pull-apart basin (Bebien *et al.* 1986).

In summary, the Meglenitsa Ophiolite was not affected by the Late Jurassic (JE1) deformation as seen in the ophiolites emplaced onto the Pelagonian zone to the west. This can be explained in two ways: **1)** the Meglenitsa Ophiolite represents the trailing edge of a large ophiolitic nappe which was emplaced onto the Pelagonian zone **prior** to the Kimmeridgian-Tithonian transgression, and survived as a remnant oceanic basin between the Pelagonian and Paikon platforms. This situation is similar to the model proposed by Robertson *et al.* 1991 for the Pindos Ocean. **2)** the Early Mesozoic ophiolites of the Almopias zone were completely sutured before the Late Jurassic, followed by the re-opening of new basins, including the Meglenitsa Ophiolite, during the Late Jurassic-Lower Cretaceous. This model is similar to that proposed by Bijon (1982) and Vergely (1984), but re-opening and ocean basin formation would have been considerably earlier than suggested by these authors. In both models the Meglenitsa Ophiolite was not finally emplaced to its present position or **deformed by thin-skinned tectonics until the Early Tertiary**.

CONCLUSIONS

Previously, the Mavrolakkos and Krania units of the eastern Almopias zone of northern Greece were regarded as two separate volcano-sedimentary units that were deformed during the Late Jurassic "Eohellenic" tectonic event. However, in this study it has been shown that the two units can, in fact, be correlated, and interpreted as **remnants of the higher crustal levels of a MORB ophiolite, of Late Jurassic-Lower Cretaceous age**. This ophiolite, and its sedimentary cover, is overlain conformably by **turbiditic, terrigenous flysch** of **Lower Cretaceous age**, **derived from two sources, one probably in the west (Pelagonian/western-central Almopias zone), and the other in the east (Paikon zone)**. In terms of a structural setting, the Meglenitsa Ophiolite could have formed in two scenarios: as a "remnant" ocean basin which escaped Late Jurassic "Eohellenic" deformation (dated as pre-Kimmeridgian throughout the Eastern "internal" Hellenides), or as a small, pull-apart ocean basin formed after the "Eohellenic" deformation between bordering platformal (Pelagonian and Paikon) units. On balance, we feel the majority of data favour the second model.

The Meglenitsa Ophiolite was emplaced to its present position during the **Early Tertiary**, and is in **thrust contact over the central Almopias zone in the west and the Paikon zone in the east**. These sedimentary and structural data disagree with the recent proposal that the ophiolites of the eastern Almopias zone were thrust-emplaced from the Peonias zone to their present setting during the Tertiary.

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