Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXX, 2007
Πρακτικά 11ου Διεθνούς Συνεδρίου, Αθήνα, Μάιος 2007

Bulletin of the Geological Society of Greece vol XXXX, 2007
Proceedings of the 11th International Congress, Athens, May, 2007

LATE- AND POST-MIOCENE GEODYNAMIC EVOLUTION OF THE MESOGEA BASIN (EAST ATTICA, GREECE): CONSTRAINTS FROM SEDIMENT PETROGRAPHY AND STRUCTURES

Mposkos E.[1], Krohe A.[2], Diamantopoulos A.[1], and Baziotis I.[1]

[1] *National Technical University of Athens, School of Mining and Metallurgical Engineering, Section of Geological Sciences, mposkos@metal.ntua.gr*

[2] *University of Munster, Institute of Mineralogy, Laboratory for Geochronologie, krohe@nwz-uni-muenster.de*

Abstract

In Attica, from the Miocene through the Quaternary, successive generations of detachment faults caused exhumation and denudation of Alpine HP rocks and – later on – formation of sedimentary basins. The Mesogea low angle detachment fault separates the HP rocks exposed at the southern flank of the Penteli Mt from the Late – post-Late Miocene Mesogea basin. Combined sedimentary-petrologic and structural analyses reveal the following: (i) Late Miocene sediments include material from unmetamorphosed source areas suggesting that, until then, parts of the HP rocks were buried under the (largely unmetamorphosed) Pelagonian nappe unit. (ii) Post-Late Miocene sediments exclusively contain clasts from high-P source areas and show downward bending of the layering that accommodates slip along a listric fault surface. Close to the Penteli Mt, within the post-Late-Miocene sediments gravity sliding-blocks of metamorphic rocks occur. All this indicates post-Late Miocene activity along this detachment fault controlled rapid surface uplift/relief formation, denudation and fast erosion of HP rocks in the Penteli Mt.

Key words: *Debris material, gravity-sliding block, detachment, Penteli.*

Περίληψη

Κατά την διάρκεια του Νεογενούς διαδοχικές γενεές ρηγμάτων αποκόλλησης συνέβαλαν στην εκταφή των μεταμορφωμένων πετρωμάτων της Αττικής και στην διαμόρφωση λεκανών πληρωθέντων με ιζήματα. Το ρήγμα αποκόλλησης των Μεσογείων διαχωρίζει τα μεταμορφωμένα πετρώματα του Πεντελικού όρους απο τα άνω μειοκαινικά-μετα μειοκαινικά ιζήματα της λεκάνης των Μεσογείων. Ιζηματολογικά, πετρολογικά και τεκτονικά δεδομένα έδειξαν τα ακόλουθα: (I) Ιζήματα άνω μειοκαινικής ηλικίας περιέχουν υλικό τροφοδοσίας, το οποίο προέρχεται απο αμεταμόρφωτα πετρώματα της Πελαγονικής ζώνης, γεγονός που μαρτυρεί ότι τμήματα των μεταμορφωμένων πετρωμάτων καλύπτονταν τουλάχιστον μέχρι τότε, από αμεταμόρφωτα. (II) Μεταμειοκαινικά ιζήματα, που το υλικό τροφοδοσίας τους προέρχεται μόνο από μεταμορφωμένα πετρώματα, παρουσιάζουν μεγάλες κλίσεις στρωμάτων, μαρτυρώντας ολίσθηση κατα μήκος ενός ρήγματος αποκόλλησης. (III) Στα μετα-μειοκαινικά ιζήματα

της νότιας πλευράς της Πεντέλης, εγκλείονται ολισθόλιθοι μεγάλων διαστάσεων αποτελούμενοι απο μεταμορφωμένα πετρώματα. Όλα αυτά δείχνουν ότι το ρήγμα αποκόλλησης των Μεσογείων ήταν ενεργό μετά το Άνω Μειόκαινο ελέγχοντας την ταχεία ανύψωση της Πεντέλης, το σχηματισμό αναγλύφου και τη διάβρωση των μεταμορφωμένων πετρωμάτων της.

Λέξεις κλειδιά: *Κλαστικό υλικό, ολισθόλιθος, αποκόλληση, Πεντέλη.*

1. Introduction

Formation of sedimentary basins is the surface expression of deformation processes affecting the deep crust. Therefore, sedimentary and structural records of such basins provide clue information on large-scale deformation processes within the crust.

This article is a combined structural and sedimentary study of the Neogene formations of the Mesogea basin in east Attica. A basin and range topography characterizes that area, where insulated mountain ranges – the Penteli and Hymettus Mounts (Mts) confine Neogene-Quarternary basins (Fig. 1). Surface elevation in the Penteli and Hymettus areas and basin formation seem to be correlated processes. Tilted (rotated) Miocene to Pliocene terrestric and lacustrine sediments indicate that tectonic movements associated with the basin formation have continued until recently.

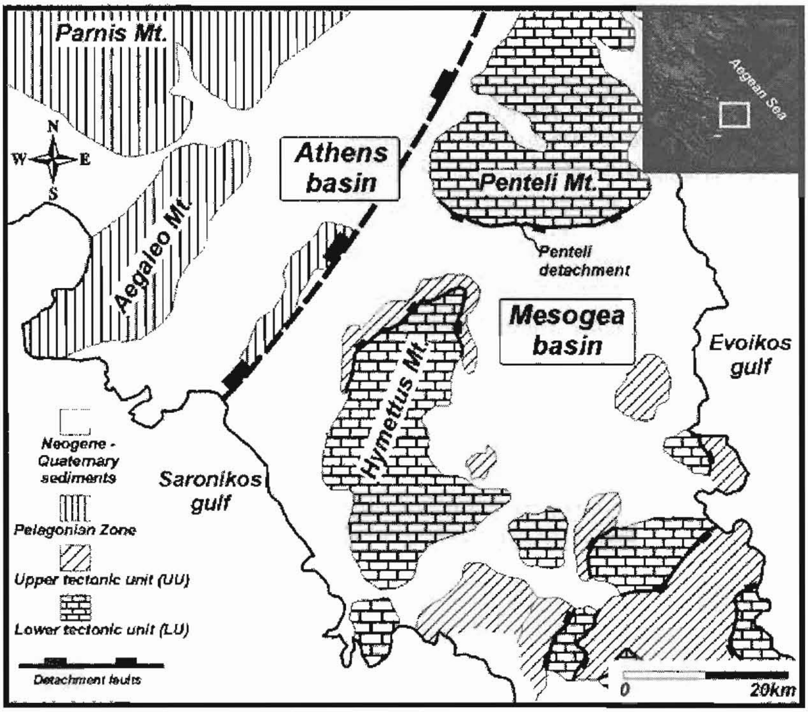

Figure 1 - Simplified tectonic map of Attica (from Katsikatsos *et al.* 1986) showing the Mesogea and Athens basins

2. Tectonic subdivision of Attica

On a broader scale Penteli and Hymettus Mts are part of the Attic – Cycladic metamorphic belt, which in Attica emerges underneath the Pelagonian zone as a tectonic window described as Attica core complex (Diamantopoulos 2006). From the bottom to the top all tectonic units from the Attica area are characterized as follows:

(i) The Attic-Cycladic belt making up NE, E and S Attica (Mts of Penteli, Hymettus, Panion, parts of the Mesogea area and the Lavrion peninsula) comprises two tectonometamorphic units (Marinos and Petraschek 1956, Katsikatsos *et al.* 1986, Lozios 1993) that are themselves separated by low angle detachment surfaces. The lower unit (LU) consists of alternating marbles, calc-schists and metapelites with intercalations of orthogneisses, metamigmatites, metabasic rocks and serpentinites; locally (Hymettus and Panion Mts) a thick dolomite marble series (Pirnari dolomites) occurs. The LU undererwent a high-pressure/low-temperature (HP/LT) metamorphism with peak P-T conditions at 9-11 kbar and ~370 °C followed by decompression to 5-6 kbar combined with heating (Baziotis *et al.* 2006). Katsikatsos *et al.* (1986) argued that the LU is the SW continuation of the Almyropotamos unit exposed within the Olympos window at a similar tectonic position. The upper unit (UU) consists of phyllites, metasandstones, calc-schists, marbles and glaucophane bearing metasediments and metabasites (phyllite nappe according to Marinos and Petraschek 1956; neohellenic nappe according to Katsikatsos *et al.* 1988; allochthon of Penteli according to Lozios 1993). Mineral assemblages from metabasites record a HP/LT metamorphism with peak P-T conditions of ~9 kbar and 350-370 °C followed by decompression combined with cooling suggesting exhumation along a subduction channel (Baziotis *et al.* 2006). According to Altherr and Seidel (2002) the ages of HP/LT and greenschist facies metamorphisms are Eocene and Oligocene-Miocene, respectively.

(ii) Unmetamorphosed rocks of the Pelagonian zone overly the Attic-Cycladic belt in west Attica (Parnitha, Aegaleo and Poikilo Mts). They comprise; i) Late Carboniferous-Early Triassic clastic and carbonate sediments with volcanic intercalations, ii) Triassic-Jurassic platform carbonates, iii) Ophiolites associated with oceanic sediments (shale-chert formation), iv) transgressive Cretaceous limestones that pass upwards into Paleocene flysch.

Presently, only isolated blocks of the Pelagonian nappe are preserved in east Attica. On the Lavrion peninsula, a small isolated block (~50 m in thickness) consisting at the base of serpentinites and chert and at the top of Cretaceous fossiliferous limestones overlies the UU (Katsavrias 1991, Photiadis and Carras 2001). At the eastern slope of Hymettus Mt, 6 Km south of Koropi, also remnants of Eocene-Oligocene "Molasse" sediments tectonically overly the marbles of the LU (Alexoponlos *et al.* 1998). The "Molasse" sediments consist of alternating mudstones, sandstones and limestones; the sandstones contain clasts of quartz, albite, perthitic microcline, biotite, chlorite, chromite and garnet and rock-fragments like limestones, cherts, metabasalts and serpentinite.

On the western slope of Hymettus Mt, equivalents to the Pelagonian nappe are the Athens schists tectonically overlying phyllites of UU and marbles of the LU of the Attic-Cycladic belt. Cherts and limestones of the Pelagonian zone overlay the Athens schists (Akropolis, Lykabettus and Tourkovounia hills, Marinos *et al.* 1971). In north Attica and south Evia a low-angle detachment surface separating the UU from the Pelagonian zone (Diamantopoulos 2006) is exposed.

3. Geology of the Neogene basins

In Attica there are two major basins that contain Late Miocene to recent sediments: The Athens basin being confined to the NNW by the Parnitha, to the NE by the Penteli, to the E by the Hymettus, and to the W by the Aegaleo and the Poikilo Mts and the Mesogea basin being situated S of the Penteli and E of the Hymettus Mts. (Fig. 1). We focus on formation of the Mesogea basin.

Sediments of the Mesogea basin are in tectonic contact with metamorphic rocks of the lower unit of the Attic-Cycladic crystalline belt. The sediments overlay the LU at the southern slope of Penteli Mt (marbles, calc-schists and mica-schists with rare intercalations of orthogneisses and metabasites) and at the eastern slope of Hymettus Mt (marbles with subordinate calc-schists and mica-schists). They overlay the UU at the southern, eastern and western border of the basin (Fig. 2,

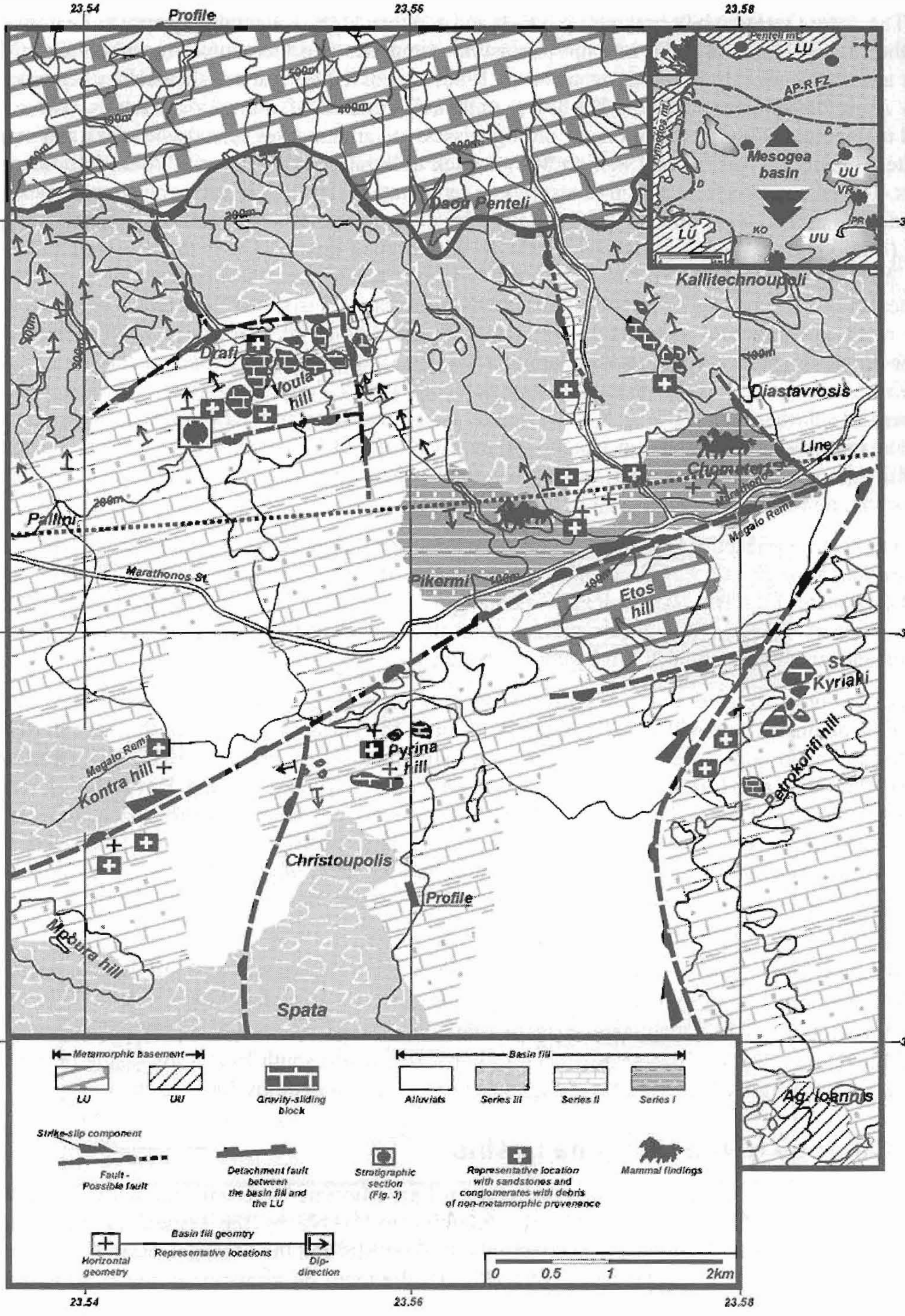

Figure 2 - Geological map of the northern part of Mesogea basin. Iuset map: Simplified geological map of the Mesogea basin and surrounding Mts., (modified by Lepsius 1893). Black circles confine the mapped area. AP-R FZ: Agia Paraskevi-Rafina fault zone, VR :Vravronas, PR : Porto Rafti, KO : Koropi, D : Detachment separating UU from LU

insert map) predominantly consisting of marbles, phyllites, calc-schists and metabasites containing blue amphiboles. Those are also common in metasediments of the UU from the Marathon Lake area (western slopes of Penteli Mt, Lozios 1993). Blue amphibole clasts in the basin sediments is thus a positive indicator for the provenance of clastic material from the UU. Major structures confining the Mesogea basin are gently south dipping Penteli detachment to the north (Fig. 2) and a N-S trending high angle normal fault to the west, following the E slope of the Hymettus Mt. A steep post-Miocene fault zone confines isolated topographic highs south of the Rafina-Stavros stripe, where the basement (marbles and schists) emerges on the Etos hill (Fig. 2). The formation of both, the Athens and Mesogea basins is related to Aegean back-arc extension and temporally coincides with denudation of the metamorphic LU in Attica (see below). The sedimentary record gives evidence on the source areas of deposits, and provides thus information on now eroded parts in this area, the paleotopography and synsedimentary tectonic movements.

3.1. Sediments of the basin

Since 18th century many geologists have studied the Mesogea basin (i.e. Lepsius 1893, Papachatzis 1953 Marinos and Symeonidis 1974, Mettos 1992 and references therein). The area attracted great interest from the discovery of fossils of mammals at the famous localities "Megalo Rema" and "Chomateri" near Pikermi. Sediment formations include Late Miocene (Turolian, Mettos 1992, Ioakim *et al.* 2005) fluvioterrestrial and lacustrine sediments. They cousist of alternating and laterally changing sandstones, mudstones, conglomerates and limestones. At the southern slope of Penteli post-Late Miocene fluvioterrestrial conglomerates discordantly overlie the Micoene sediments. Mud- and sandstone intercalations are abundant. Lepsius (1893), Papachatzis (1953), Marinos and Symeonidis (1974) described these as Diluvial deposits, while Mettos (1992) and Katsikatsos (2002) included the conglomerates into the Miocene sediments.

Figure 2 shows the distribution of sediments in the northern part of Mesogea basin mainly based on our own field observations, and including the maps of Lepsius (1893), Papachatzis (1953), Marinos and Symeonidis (1974). Field observations combined with petrographic investigations confirm that a large amount of clasts from Miocene conglomerates and sandstones originate from sedimentary and ophiolitic rocks that are notably absent in the mountain ranges now bordering the basin. Clasts include limestones with or without fossils, cherts, radiolarites, silt and sandstones, altered basalts, serpentinite as well as chromite grains. Corresponding source rocks are widely distributed through the Pelagonian zone that overlies the metamorphic rocks in West Attica. Thus, the Pelagonian nappe (now eroded) contributed to Mesogea basin fill. Based on different provenances of the dominant clasts and facies, from the bottom to the top, three sediment series are distinguished. Lateral and vertical transitions from one series to another suggest areal variations in relief and a general increase of relief with time related to denudation of the lower metamorphic unit.

Series I: At the base, it consists of up to 10-15 m thick red to yellow-red sandy-to silty mudstones with intercalations of sandstones and conglomerates. The basement onto which this series deposited does not emerge at the surface thus the thickness of series I is unknown. The mudstones comprise fossils of mammals and micromammals (Marinos and Symeonidis 1974 and references therein) and predominantly consist of quartz, illite, smectite, calcite and dolomite. The sandstones contain rock fragments mainly of muscovite – oxychlorite schists, marbles and quartzites, as well as grains of quartz, albite, more rarely epidote and blue amphibole. Oolites show clasts of quartz, marble, or muscovite schists in the core and shells of micritic calcite (Fig. 4A) indicating deposition in a shallow, near the shore lacustrine environment. Clasts and oolites are cemented with sparitic calcite (50-70 μm grain size). In metapelites and calc-schists of Penteli Mt, muscovite-oxychlorite schists are common. The presence of such clasts in the sandstones of Series I suggests that at the time of their deposition, the LU partly emerged at the surface and was subjected to erosion. The conglomerates contain pebbles of marble, micaschist, chert and limestone.

Series II: This is the most-widespread Late-Miocene to Pliocene fluvio-lacustrine series in the Mesogea basin. It comprises alternating limestones, mudstones, sandstones and conglomerates.

Northeast and west of Chomateri (Fig. 2) marly limestones, sandstones, and conglomerates dominate. The conglomerates contain pebbles of limestones, cherts and sandstones. Sandstones from the Kalitechnoupoli area predominantly contain clasts of fossiliferous and non-fossiliferous limestone, chert, radiolarite, mudstone, serpentinite, diabase and chromite. In these sandstones clastic grains originating from metamorphic rocks of the UU and LU are absent. In the Kontra hill area conglomerates with pebbles of limestones, cherts and sandstones (~1 to 3 cm in size) dominate showing more or less horizontal bedding. In the area of Palini-Drafi, Series II comprises alternating sandstones, mudstones, conglomerates and limestones, dipping with 30-35^0 toward the north.

Figure 3 shows a lithological column of Series II from Voula hill (Fig. 2). Four types of sediments occur showing a rhythmic alternation in the lithological succession.

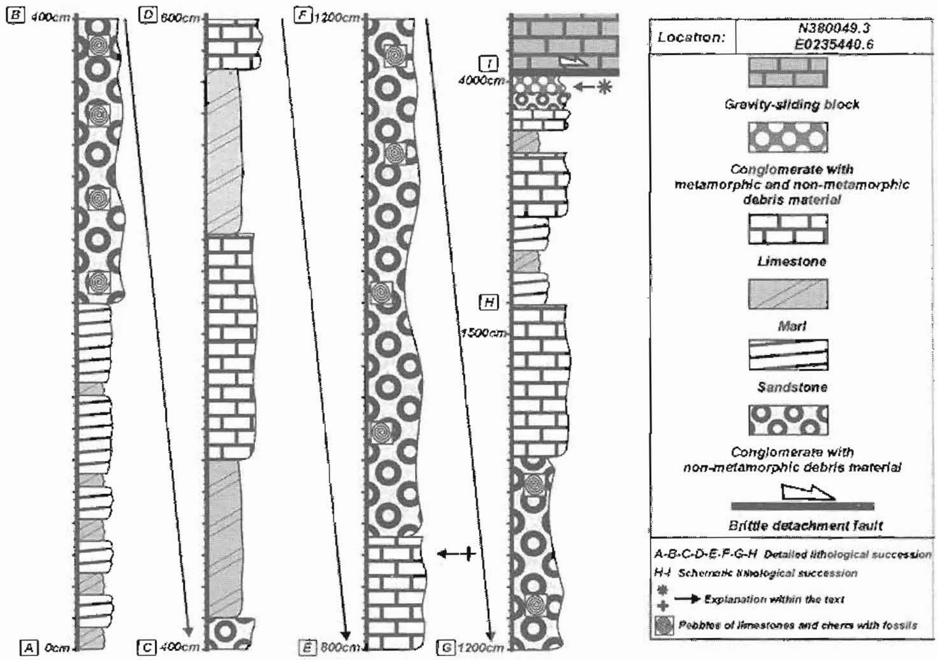

Figure 3 - Lithological column of sediments from Series II in Voula hill

a: Sandstones. The clastic grains of the sandstones comprise rock fragments of micritic limestone, chert, radiolarite, serpentinite, basalt, mudstone, two mica gneiss and grains of quartz, feldspar, calcite, chlorite, muscovite, chromite (predominant in the heavy mineral fraction), garnet and epidote. They are cemented with sparitic calcite.

b: Unconsolidated or loosely consolidated sandy-silty clays. The clay fraction consists of smectite, quartz, calcite and illite. The grains from the sand fraction are similar to those reported above for the sandstone. The grains are well-rounded indicating transport from greater distances or multiple reworking. Neither the sandy-silty clays nor the sandstones contain clastic grains that would indicate provenance from metamorphic rocks typical of the Penteli area.

c: Unconsolidated or loosely consolidated conglomerates. They consist of well-rounded spherical to ellipsoidal pebbles, 2 to 6 cm in size, and a sandy matrix. Dominant are: (i) Pebbles of light grey to white coloured micritic limestones (frequently rich in microfossils (Figs 4b, c), sparitic, oolitic limestones and limestones with spheroidal SiO_2 aggregates. (ii) Pebbles of red to greenish cherts mostly full of radiolaria (Fig. 4d). (iii) Pebbles of sandstones possibly derived from the Eocene-Oligocene "Molasse" sediments with clasts of quartz, plagioclase, microcline, biotite, muscovite, garnet, chromite, rutile, and composite grains of chlorite-muscovite schist indicating provenance from magmatic, metamorphic and ultramafic rocks, similar to those of the Pelagouian zone.

(iv) Pebbles of metabasalt (diabase Fig. 4e) consisting of augite, plagioclase, magnetite, and of chlorite, calcite and pumpellyite being alteration products of magmatic minerals. Only in upper parts of series II, in the Voula hill (star in Fig. 3), a conglomerate predominantly contains pebbles of chert, metabasalt and of chloritoid bearing chlorite-muscovite schist. As in the metapelites from Penteli Mt, chloritoid-bearing chlorite-muscovite schists are common; this indicates that some clasts originated from metamorphic rocks of the Penteli area.

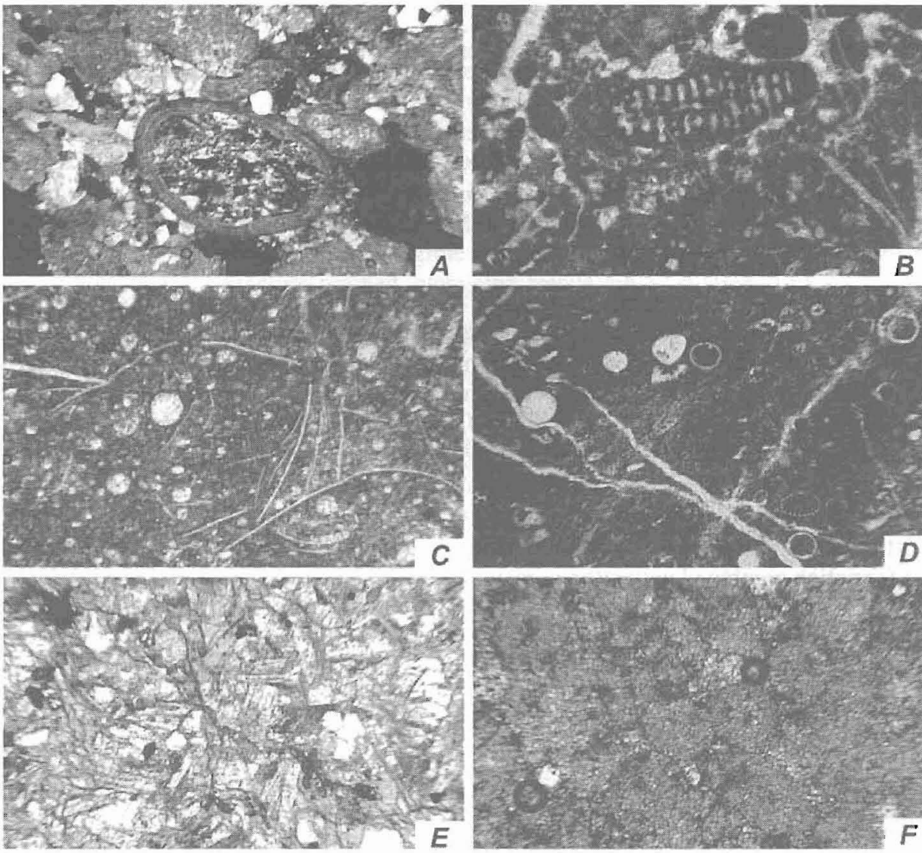

Figure 4 - A) Oolite with muscovite schist core and micritic calcite shell in sandstone of Series I. B) Pebble of limestone with foraminifera. C) Pebble of limestone with radiolaria and algae. D) Pebble of chert with radiolaria. E) Pebble of metabasalt with plagioclases with ophitic texture. F) Oolitic limestone: ooids cemented with sparitic calcite (B-F in conglomerates from Series *II*)

d: Limestones: Four limestone interlayers occur. They vary in thickness from 2 up to 20 meters (Fig. 3) are grey to light brownish and very hard with a flinty fracture. The third limestone interlayer (from the bottom to the top) is oolitic. Oolites consist of coarse-grained sparitic calcite (10-20 μm in size) cemented with isometric calcite crystals 40-50 μm in size (Fig. 4F). This indicates precipitation/recrystallization of calcite in shallow, quite warm water environment. Iron hydroxide impregnation coloured the matrix calcite brownish.

In the Petrokorifi hill area, at the base of Series II, un- or only loosely consolidated conglomerates (> 5m in thickness) crop out that upwardly pass into alternating beds of sand- and mudstones (some cm to dm in thickness). Pebbles in conglomerates consist of cherts, limestones and sandstones, while clasts in sandstones are mainly quartz, oxychlorite, muscovite, biotite, epidote, chloritoid, blue amphibole and fragments of muscovite-schists. Locally, the heavy-mineral fraction of the sandstone contains abundant blue amphibole. This suggests that both metamorphic units supplied debris material to the sandstones of Series II in the Petrokorifi hill, as blue amphibole is widespread in metabasites and schists of the UU, chloritioid and oxychlorite in metapelites and calc-schists of the LU. In contrast in Series II sandstones from the Voula hill, Kontra hill and Kallitechnoupoli debris material from unmetamorphosed domains dominate.

In the "Megalo Rema" river, well-cemented conglomerates upwardly grade into alternating mudstones, sandstones and conglomerates (~ 100-120 m thick) that are un- or loosely consolidated. Palynological investigation by Kaouras and Oikonomopoulos (unpublished 2007) in a dark-grey mudstone yielded Pliocene sedimentation age. Well-rounded pebbles and gravels (2 to 15 cm in size) within the conglomerates consist largely of calcite marbles, rarely dolomite marbles, schists and gneisses indicating a metamorphic source area. The presence of blue amphiboles in the sandstones suggests that metamorphic rocks of the UU contributed to the clastic material of this series. The contact to the underlying Series I (red mudstones) is probably tectonic as is indicated by a change of dip directions of the bedding from N in this series (north of the line A in Fig. 2) to S in the underlying Series I (red mudstones).

Series III: Series III unconformably overlies Series I and II reflecting an erosional event before onset of sedimentation of Series III. The clasts indicate a remarkable change in the provenance of the sediments of series III. In the Drafi area, north of the Voula hill (Fig. 1) Series III (> 200 m in thickness) start with silt- and sandstones. The clasts in the siltstones consist of calcite, quartz, while K-mica, chlorite, oxychlorite, chloritoid, albite, epidote and fragments of marble, calcareous schists, chloritoid schists. These are all widespread in the LU of the Penteli Mt. Angular shapes of the calcite and marble grains indicate material transport over only short distances. Sedimentation continues with fluvio-terrestrial conglomerates. These contain large gravels (up to 1 meter in size) consisting of marbles, calc-schists, metapelites and gneisses. This indicates rapid surface uplift / relief formation combined with strong erosion in the Penteli area at that time.

3.2. Gravity-sliding blocks

On the hills Voula near Drafi, near Kallitechnoupoli (both on the slope of Penteli Mt), Petrokorifi, and Pyrina (Fig. 1), isolated blocks of metamorphic rocks overlie the Late Miocene sediments *(Series II).*

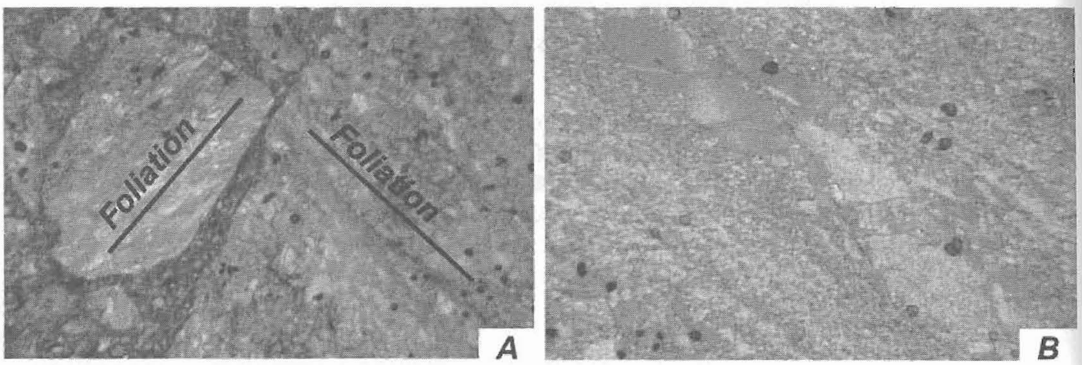

Figure 5 - Gravity-sliding blocks: A) Cataclastic texture in the marble (Voula hill); B) Marble with mylonitic foliation, reflecting polyphase deformation (Pyrina hill)

Such blocks have been alternatively considered as outcrops of basement (blocks of Voula and Kallitechnoupoli hills; Marinos and Symeonidis 1974), as Miocene limestones (blocks of Voula, Petrokorifi and Pyrina, Lepsius 1893) or as olistholites sliding from Penteli marbles within the Miocene sediments (blocks of Voula and Pyrina hills, Mettos 1992).

Field observations and petrography show that the blocks of Voula hill consist of calcite marbles and light greenish grey phengite orthogneisses. The marble within the block shows a brecciated texture with mm to cm-sized clasts in the fine-grained matrix (Fig. 5A). The clasts show a well-developed mylonitic foliation and lineation defined by elongated grains showing dynamic recrystallization. The blocks of Petrokorifi hill consist of dolomitic marble with intercalations of a metabasite (Agia Kyriaki area), and a calcite marble (farther to the south; Fig. 2). The dolomitic marble is brecciated. Porphyroclasts are mm to cm in size consisting of dolomite single-grains or grain aggregates. The microcrystalline matrix is composed of 10-20 μm large isometric grains. The intercalated metabasite consists of brown hornblende+ albite+chlorite+epidote+actinolite+quartz. Calcite marbles are brecciated showing 20 to 50 cm large, angular blocks. Their mylonitic foliation is randomly oriented indicating clast rotation during brecciation.

The gravity-sliding blocks of Pyrina hill consist of calcite and dolomite marbles respectively overlying unconsolidated conglomerates with pebbles of limestone and chert, and sandstones with clasts of quartz, calcite, oxychlorite, dolomite, blue amphibole, chloritoid, and muscovite schist. The calcite marble is brecciated with up to 10 cm large clasts in a fine-grained matrix. The clasts show well-developed mylonitic foliation. This deformation possibly continued during decreasing temperatures, from the plastic to the brittle regime within discrete zones (μm to mm thick). Elongated ribbons consisting of medium grained, elongated calcite grains showing undulatory extinction alternate with elongated ribbons consisting of a fine-grained, equigranular grain mosaic, that underwent dynamic recrystallization (Fig. 5b). The dolomite marble is brecciated. The clasts consist of more or less isometric dolomite grains without internal deformation.

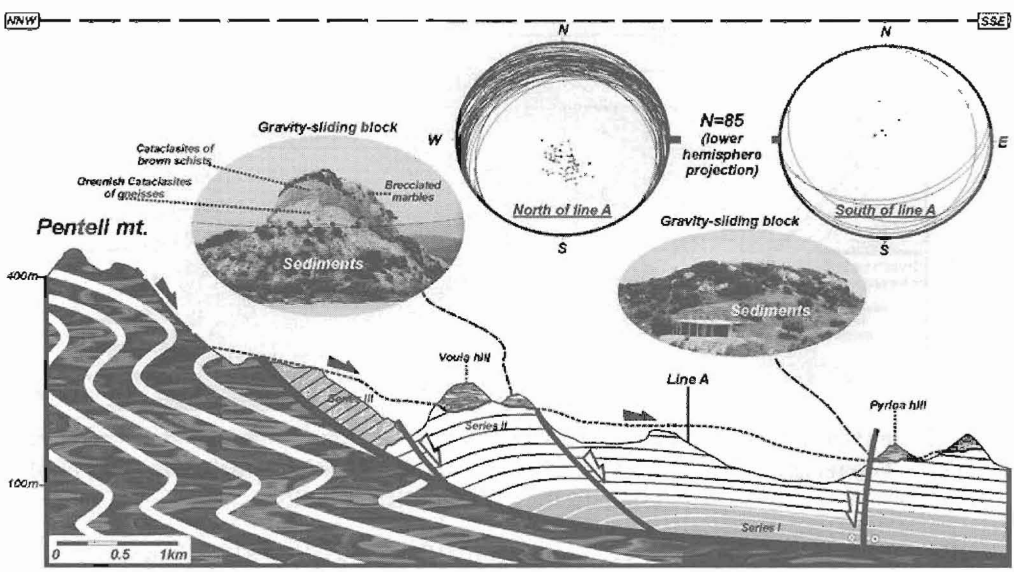

Figure 6 - Geological profile, showing the geometry of the northern part of Mesogea basin (see Fig. 2 for profile location)

The gravity-sliding blocks of Kalitechnoupoli occur at the base of Series III. They comprise quartz-muscovite bearing marble, almost pure calcite marble, and a block of metabasite. The calcite marble shows brecciated texture with mm to cm-sized clasts in a fine grained matrix. The clasts show well-developed mylonitic foliation and lineation imprinted by elongated calcite grains with shape and lattice orientation as shows the observation with the gypsum plate.

4. Structural relationships between Mesogea basin and basement

4.1. Syn-detachment evolution

Syn-detachment-evolution of the basin is suggested by the relationships between the orientation of detachment fault bounding the basin against the Penteli Mt and the orientations of bedding within the basin (block rotation; Fig. 6).

Systematic structural analyses indicate a uniformly north dip of the sedimentary layering in the northern part of the study area, towards the detachment exposed at the southern flank of the Penteli Mt. Also the thickness of the sediments increases towards Penteli Mt. In contrast, to the south of line A (Fig. 2), the bedding is about horizontally oriented. Rotation of the bedding to the north of line A contemporaneously with continuing sedimentation of Series II indicates that this detachment fault controlled the basin evolution implying a listric geometry (Fig. 6). The emplacement of gravity-sliding blocks onto the sediments further suggests that movements along this detachment surface were associated with formation of a steep relief, i.e. doming of the Penteli Mt. Actually en-echelon listric faults occur at the southern slope of the Penteli re-working the ductile structures of the metamorphic basement (Fig. 7). These 2nd order south-dipping listric fault surfaces, determine the present geomorphology. The structural profile in figure 6 shows the structures of the basin fill and of the detachment fault in the study area. Within the basin, steeply inclined secondary normal faults crosscutting the sediments rooting in the major detachment fault determine block rotation in the sedimentary basin (Fig. 6).

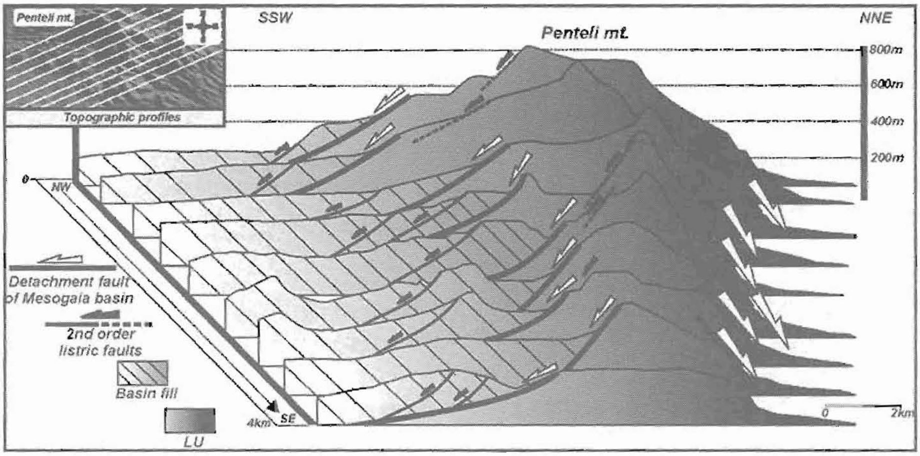

Figure 7 - Topographic profiles through Penteli Mt. showing the detachment fault of Mesogea basin and the 2nd order listric faults

4.2. Polyphase detachment faults: basin evolution and exhumation of the metamorphic rocks

In the Mesogea basin the early sedimentation stages start in the Late Miocene (Mettos 1992, Ioakim *et al.* 2005), after cooling and emplacement of the high-*P* rocks in the brittle upper crust, i.e. after 8 Ma (indicated by intrusion age of the Lavrion granodiorite; Altherr *et al.* 2002). Basin formation and simultaneous denudation of metamorphic rocks are related processes controlled by detachment faults (Diamantopoulos 2006). In detail, our data suggest a complex two-stage tectonic scenario as proposed in Figure 8.

In the earlier sedimentation stages deposits include material from the Pelagonian zone as well as from the metamorphic rocks of the underlying units. This suggests that removal of the Pelagonian nappe from the Attic-Cycladic belt may have already started, by translation along older (Miocene) detachment faults similar to that exposed e.g. in southern Evia.

In a subsequent stage, rapid surface uplift of LU in the Penteli Mt occurs. This is interpreted to be related to a younger (post-Miocene) detachment fault crosscutting the LU as is e.g. exposed at the southern-flank of the Penteli Mt. This detachment controlled sedimentation in the uppermost coarse-grained parts of the Mesogea basin close to the Penteli Mt (Fig. 8). In either stage extension occurred in north-south direction.

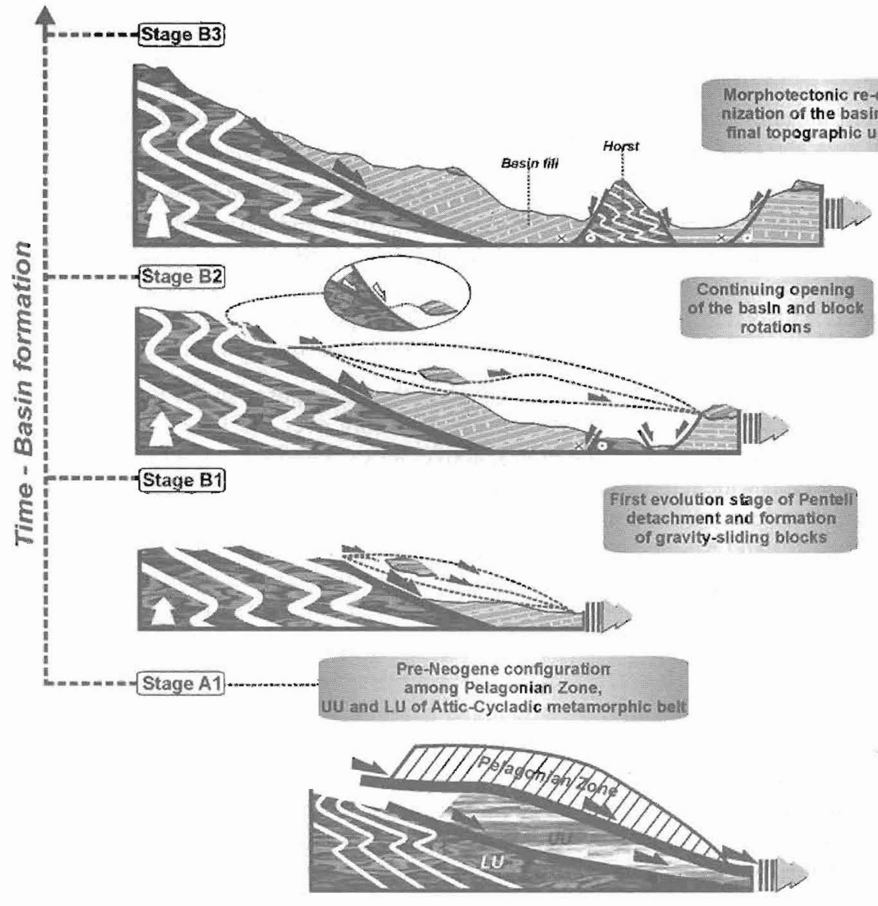

Figure 8 - Tectonic scenario, depicting the pre-Neogene configuration of tectonic units and the evolution of Mesogea basin during and after Late Miocene

5. Discussion and Conclusions

Hymettus and Penteli Mts represent tectonic windows of the Attic-Cycladic HP metamorphic belt in Attica. Structures bounding the metamorphic rocks against the sedimentary basins are either low angle detachment surfaces or steep normal faults reflecting tectonic movements related to denudation of metamorphic rocks and subsequent tectonic stages. Deposition of sediments in the basins, denudation and doming seem to be mutually related processes as is concluded from the sedimentary and structural data. Though decoding the temporal evolution of the deposition environment of the study area is obscured by rather narrow horizontal changes in deposition environments, in sum, field observations and petrography of the sediments from Mesogea basin suggest the following basin evolution and the related tectonic processes:

1: Sediments of the base of Series I are largely pelitic suggesting either material transport over large distance or smooth relief. Intercalations of coarse-grained sediments (sandstones, conglomerates) appear rather related to climatic changes than to changes in topography at that time. Calcareous ooids in sandstones typically indicate sedimentation in shallow-water lacustrine conditions.

2: Conglomerates, sandstones and mudstones of Series II document provenance of debris material from unmetamorphosed Pelagonian nappes. In Miocene conglomerates from the Voula hill, the area between Pikermi and Kallitechnoupoli, the Kontra hill, and from the basal series of Petrokorifi hill (Fig. 2), predominant clasts are cherts, sandstones, mudstones and limestones; subordinate are clasts of basalts and serpentinites. Chromite is also frequent. Conglomerates containing pebbles from an unmetamorphosed source region also occur on tbe road north of Vravrona, in Porto Rafti area and the area east of Koropi (stars in inset map of Fig. 2).

3: Post-Miocene sediments unconformably overlay the deeper series indicating post-Turroliau erosion of the Miocene sediments. The post-Miocene sandstones and mainly fluvial conglomerates of Series III indicate continuing basin formation accompanied with increased relief formation in Penteli area. Fragments of these sediments only originate from the LU of Penteli area (marbles, calcschists, pelitic schists and orthogneisses), being angular, poorly sorted with apparent grain sizes ranging from some mm to more than 1 meter, in line with short transport distances.

4: Gravity-sliding blocks of marbles originating from the LU exposed in the Penteli only occur at a distance of ~1 km to 5 km from the Penteli Mt, and only over the Late Miocene sedimeuts or within the post- Late-Miocene conglomerates, above Series II and within Series III. This is consistent with continuing widening of the basin along with rapid surface uplift and formation of a topographic relief and strong erosion also of the metamorphic LU from the post-Late-Miocene onward. In Petrokorifi and Kallitechnoupoli areas, gravity-sliding blocks mainly consist of mylonitic and cataclastic calcite and dolomite marbles with subordinate metabasites and phengitic orthogneisses (Voula hill) that are all typical for the LU from the Penteli area. Possibly isostatic rebound of the lower plate associated with translation along this detachment initiated post-Late Miocene surface uplift.

5: To the south of line A in figure 2, the bedding is either nearly horizontal or is gently inclined towards the south. 'But to the north of line A, toward the Penteli Mt., the dip of the Miocene and post-Miocene sediments is ~5-40°. Close to the south-dipping detachment surface that broadly forms the southern slope of Penteli, the bedding of Series III sediments dips at 30-40°, toward the north. This configuration is consistent with block rotation within the hanging wall block and downward bending of the hanging wall block above a listric normal fault surface thus indicating continuing translation along the detachment during and after the deposition of the conglomerates

Surface uplift in the Hymettus area also occurred after the Late Miocene time, as is the case in the Penteli area. At the eastern slopes of Hymettus Mt, 6 Km south of Koropi, Eocene-Oligocene "Molasse" sediments are tectonically overlain by a chaotic series (Alexopoulos *et al.* 1998), interpreted as gravity-sliding blocks. This chaotic zone consists of metagabbros, altered serpentinites, hematitic silica rocks and a cataclastic marble containing fragments of marble ultramylonites. A narrow cataclastic zone (~1-2 m in thickness) separating the "Molasse" sediments from the marble contains rounded fragments (pebbles) of fossiliferous limestones, sandstones and cherts typically for clastic components in the Late Miocene conglomerates. This suggests that this chaotic series is a gravity-sliding block evidently emplaced after the deposition of the Late Miocene sedimeuts, similar to the gravity-sliding blocks south of Penteli area.

6. Acknowledgments

We wish to thank L. Royden and an anonymous referee for helpful suggestions that helped to improve the style and content of this article.

7. References

Alexopoulos, A., Lekkas, S., and Moraiti, E., 1998. On the occurrence of a non metamorphic Uppper Eocene – Lower Oligocene clastic sequence, wedged between the allochthon and the relative autochthon system of Attiki (Greece), *Bulletin Geological Society of Greece*, XXXIV/1, 79-84.

Altherr R., and Seidel, W., 2002. I-type plutonism in a continental back-arc setting: Miocene granitoids and monzonites from the central Aegean Sea, Greece, *Contrib Mineral Petrol*, 143, 397-415.

Baziotis, I., Mposkos, E., and Perdikatsis, V., 2006. Reconstruction and correlation of the exhumation history of high-pressure/low-temperature metamorphic rocks from Attica, *NECAM 2006*, Milos island, Greece, 28.

Diamantopoulos, A., 2006. Non-coaxial stretching deformation dominating the Upper Structural Plate of the Metamorphic Core Complex of Attica (Internal Hellenides, Central Greece), *XVIIIth CBGA*, Belgrade, Servia, 101-105.

Ioakim, Ch., Rondoyanni, Th., and Mettos, A., 2005. The Miocene basins of Greece (Eastern Mediterranean) from a paleoclimatic perspective, *Revue de Paleobiologe*, 24, 735-748.

Katsiavrias, N., Solakius, N., and Salaj, J., 1991. The age of the Agios Konstantinos limestone at Lavrion, Southeastern Attica, Greece, *Geologica Carpathica 42*, No 5, 303-309.

Katsikatsios, G., Migiros, G., Triantafillis, M., and Mettos, A., 1986. Geological structure of Internal Hellenides (E. Thessaly – SW. Macedonia, Euboea – Attica – Northern Cyclades Islands and Lesvos), *Geological & Geophysical Research*, Special Issue, 191-212.

Katsikatsios, G., Mettos, A., and Vidakis, M., 2002. Kifisia sheet. *I.G.M.E.* 1/50.000 Scale.

Lepsius, R., 1893. *Geologie von Attika. Ein Beitrag zur Lehre vom Metamorphismus der Gesteine*, Berlin 1983, Translation by Vougiouka G. Library Marasli, 592pp. Athens 1906.

Lozios, S., 1993. Structural analysis of the metamorphic rocks of NE Attica (Greece), *Phd Thesis*, University of Athens, 299pp.

Marinos, G., and Petrascheck, W. E., 1956. Laurium, *Geological and Geophysical Research*, IV, 247.

Marinos, G., Katsikatsios, G., and Mirkou-Peripopoulou, R., 1971. The Athens' schists formation, II. Stratigraphy and structure, *Annales Geologique des Pays Hellenique*, XXV, 183-216.

Marinos, G., and Symeonidis, N., 1974. Neue funde aus Pikermi (Attika, Griechenland) und eine allgemeine geologische Ubersicht palaontologischen Raumes, *Annales Geologique des Pays Hellenique*, XXVI, 1-20.

Mettos, A., 1992. Geological and paleogeographical study of the terrestrial Neogene and Quaternary rocks of NE Attica and of NE Beotia, *Phd Thesis*, Department of Geology, University of Athens. 259pp.

Papachatzis, N. I., 1953. Morphogenetic research of the basin of Mesogaia, *Annales Geologique des Pays Hellenique*, V, 236-260.

Photiades, A., and Carras, N., 2001. Stratigraphy and geological structure of the Lavrion area, *Bulletin Geological Society of Greece*, XXXIV/1, 103-109.