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STRATIGRAPHY AND GEOLOGICAL STRUCTURE OF THE LAVRION AREA (ATTICA, GREECE).

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ABSTRACT

The geological mapping of the Lavrion area lead to a revision of the lithostratigraphic subdivision and the recognition of three superposed tectonic units. The lower unit, the so-called autochthonous system, consists of a Triassic – Jurassic metamorphic Pelagonian series, a disconformity related to the Eohellenic orogenic phase, and a Tithonian – Lower Cretaceous non-metamorphic transgressive cover. Upon the lower unit, the "phyllite" nappe lies (middle unit), having on the top some remnants of a non-metamorphic Pelagonian nappe (upper unit).

KEY WORDS: mapping, stratigraphy, transgression, autochthonous, allochthonous, internal Hellenides, Lavrion, Attica.

1. INTRODUCTION

The Lavrion area (or Lavreotiki peninsula) constitutes the northwestern part of the Attic-Cycladic Metamorphic Complex; it also belongs to the Median Metamorphic Belt of the Hellenides (Dórr *et al.,* 1978; Papanikolaou, 1984) and is built up of various alpine tectonic units (Papanikolaou, 1984; Katsikatsos *et al.,* 1986).

It is known that at the Lavreotiki peninsula and generally in the central and south Attica (Fig.1) a lower metamorphic system, relatively autochthonous, crops out (Kober, 1929; Marinos & Petrascheck, 1956). This system consists of the following formations, from the lowermost to the uppermost: a) Vari schists, b) Pirnari dolomites, c) Lower marble, d) Kamariza (old name of the Aghios Konstantinos village) or Kessariani schists and e) Upper marble (Lepsius, 1893; Kober, 1929; Sindowski, 1948; Trikkalinos, 1955). In the Lavreotiki area, this succession was named «Kamariza series» (Leleu, 1966a).

This metamorphic and relatively autochthonous system is overlain by the «Plaka series» (Leleu, 1966a; 1966b), which is composed by limestones at the base (member P1) and then by phyllites (member P2) and carbonate remnants (P3). The «Plaka series», under various names, was interpreted as a transgressive cover (Lepsius, 1893; Negris, 1915-1919; Sindowski, 1948; Leleu, 1966a; Leleu & Neumann, 1969), or as an overthrust nappe (Marinos & Petrascheck, 1956; Katsikatsos, 1977; Papanikolaou & Syskakis, 1991), while Kober (1929) accepted as transgressive only the lower member (P1) and as a nappe the overlying formations.

The consideration of the position of the "autochthonous" unit of Attica (including Lavreotiki) within the Hellenide framework has been subject to various modifications. According to an opinion, the Attica "autochthonous" and the Euboea Almyropotamos units have been indirectly considered to belong to the Internal Hellenides (Leleu & Neumann, 1969; Katsikatsos, 1977; Katsikatsos *et al.,* in Marinos *et al.,* 1977). According to another, the Attica and the Almyropotamos unit belong to the external Hellenides (Katsikatsos *et al.,* 1982; Katsikatsos *et al.,* 1986). Finally, Papanikolaou (1986), on a general overview, ascribes the Almyropotamos unit to the external Hellenides and the Attica autochthonous to the internal.

In this study, based on a geological mapping on a scale of 1:50.000 of the LAVRION sheet, the stratigraphy and the structure of the area are reexamined and

the consideration of the Lavreotiki "autochthonous" unit within the geotectonic context of the Hellenides is documented.

2. TECTONO-STRATIGRAPHIC SETTING

In the Lavrion area the following units have been recognized, from the lowermost to the uppermost (Fig. 1):

- the metamorphic formations of the «Kamariza series» which belong to the relatively autochthonous unit,

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and

- the non-metamorphic, lower carbonate formation of the «Plaka series», i.e. the member «P1», which is transgressive and thereby belongs to the "autochthonous" unit, as well;
- the metamorphic, allochthonous unit of the «phyllite nappe», consisting only of the middle and upper parts of the «Plaka series» (phyllites-P2 and carbonate remnants-P3);
- the non-metamorphic Cretaceous limestone remnants, associated with an ophiolite tectonic sole, which constitute relicts of an upper tectonic unit.

2.1. "AUTOCHTHONOUS" UNIT (LOWER TECTONIC UNIT)

2.1.1. «LOWER» KAMARIZA MARBLE

This formation is also known as «Lower Attic Marble» (Lepsius, 1893). It crops out largely in the eastern Attica and Lavreotiki; its thickness reaches 350-500 m.

The lowermost members of the formation crop out in the Skordi hill area. They are composed of alternations of violet muscovite-bearing schist, of greenschist and of thin-bedded dolomitic marble, they present a limited thickness, and correspond to the "Vari Schists". Upon these beds, dolomite and grey-white, medium- to thick-bedded, dolomitized marble are developed, 150 m thick ca., corresponding to the "Pirnari dolomites". These two members have probably a Permian – Triassic age.

Upwards, white to grey-bluish, massive, thick- or mid-bedded, coarse-grained marbles follow. Towards the top they become white, thin-bedded and microcrystalline and, mainly in the western parts of the Lavrion peninsula, they become breccious to red nodular.

Within the formation, the following fossils have been identified: at Paneion hill, the Rhaetian *Terebratula* and the Triassic – Jurassic *Macroporella* (Petrascheck & Marinos, 1953); in the northern Hymettus, corals (Bócking, 1881), *Calamophyllia* (Steinmann, 1890), *Lithodendron* (Kober, 1929); in the southern Hymettus, Triassic corals (Renz, 1910); at Kessariani area the Triassic *Gyroporella vesiculifera* and *Isastraea guembeli* (Negris, 1915-19). This formation was considered of Triassic – Jurassic age; however, we presume that these citations and the whole stratigraphic context indicate a Triassic - ? Lower Jurassic age. (The pre-Carboniferous age assigned by Papadeas, 2000, is affirmed without any stratigraphical indication).

2.1.2. KAMARIZA SCHISTS

The Kamariza schists are homologous to the Kessariani schists. They are grey, dark grey, brownish, rich in muscovite, quartz, albite and chlorite, with granoblastic to lepidoblastic texture; the thickness is up to 200 m. The existence of volcanic activity and hydrothermal circulations has been supported by the presence of porphyritic rock (known as "epidotite" in the literature) at the top of the Kamariza schists, and by the spatial relation with massive sulphides and Fe – Mn mineralisations (Marinos & Petrascheck, 1956; Leleu, 1966a; 1969). Moreover, at Kessariani area, the presence of mafic and ultramafic ophiolitic bodies at the top of the formation has been reported (Lepsius, 1893; Ktenas, 1909; Voreadis, 1920; Kober, 1929).

During the Miocene Plaka granodiorite intrusion (Marakis, 1968), the adjacent to the metamorphic aureole schists were metamorphosed into hornfels or "plakites" (Marinos, 1937).

In some marble intercalations in the basal part of the formation, the following fossils have been identified: at Kessariani area, but also at Aghios Konstantinos (Serpieri shaft), *Teutloporella triasina* (?) (Negris, 1915-19); west of Hymettus, the Triassic coral *Thecosmilia* (Renz, 1910); corals were also identified east of Hymettus (Bücking, 1881).

The species *T. triasina* (today named *Euteutloporella triasina*) is a marker of the Middle Triassic (De Castro, 1993; Granier & Deloffre, 1994). The «Triassic» age indicated by these citations can be justified if we consider these «marble intercalations» as redeposited bodies from the underlying marble (limestone at that time) in a Jurassic basin of clastic sedimentation. The Jurassic age of the schists and the whole depositional context indicate a volcano-sedimentary melange, in accordance with Sindowski (1948) who, based on the presence of ophiolite bodies, considered this formation corresponding to the volcano-sedimentary formation of the «Eastern Hellenic zone».

2.1.3. «UPPER» KAMARIZA MARBLE

The «Upper» Kamariza marble, synonymous of the «Upper Attic marble», consists of grey to white, mid- to thin-bedded and banded microcrystalline marble; the upper beds are rich in metasilex and dolomite boudins.

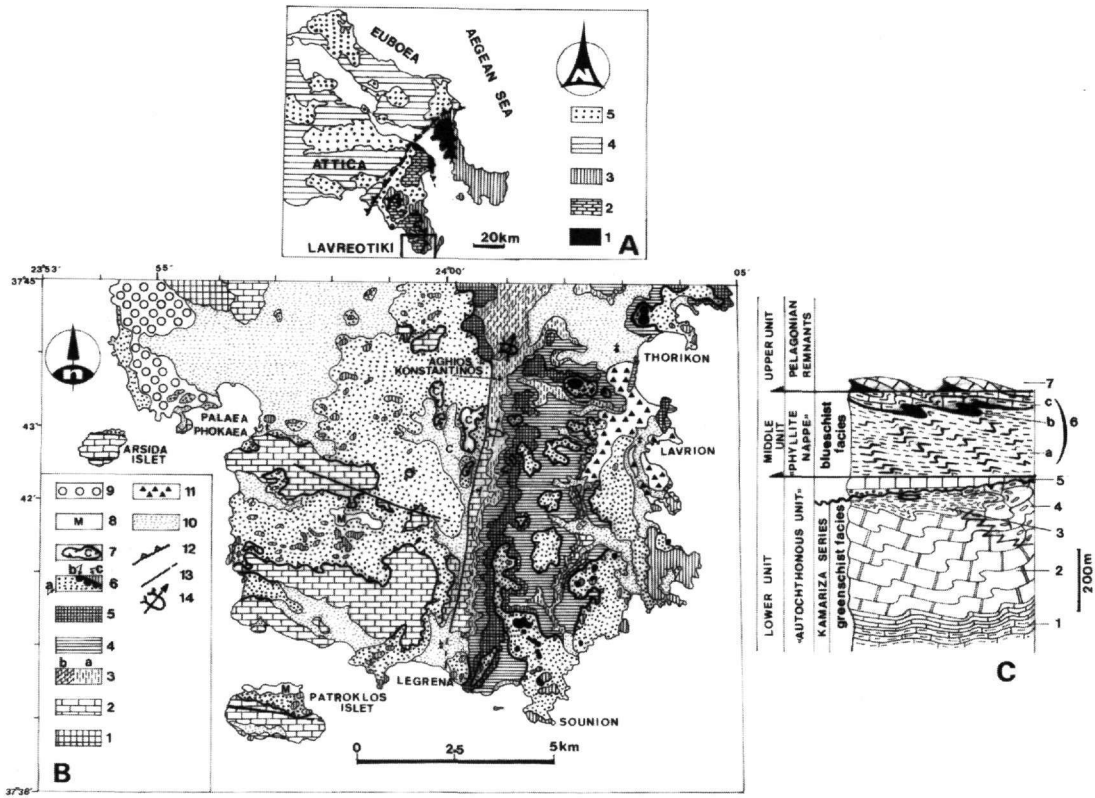

Fig. 1. The tectonic units of Attica and Euboea (Katsikatsos* et al., *1986), modified (A); geological map of the Lavrion sheet (B) with its interpretative stratigraphic column (C).

A: (1) Almyropotamos unit; (2) Attica unit (the lower unit at Lavrion); (3) blueschist unit (the middle unit); (4) non-metamorphic Pelagonian unit (the upper unit); (5) Neogene and Quaternary deposits.

B & C: (1-5) lower tectonic unit: (1) dolomite and schist; (2) "Lower" Kamariza marble; (3a) Kamariza schist with (3b) hornfels and volcanic rocks; (4) "Upper" Kamariza marble; (5) transgressive calcareous formation; (6) middle tectonic unit: (6a) schist; (6b) meta-ophiolite; (6c) crystalline limestone; (7) upper tectonic unit (limestone and ophiolite remnants); (8) Miocene deposits; (9) Pliocene deposits; (10) Quaternary deposits; (11) mining wastes; (12) thrust; (13) fault; (14) synclinal axis with its plunging direction.

The thickness is various (from some meters to 150) due to penetrative structure deformational phases (Lozios, 1991) and to uplift and erosion of the whole Kamariza series.

In this formation, the following fossils have been identified: the Triassic – Jurassic *Lithodedron* in the Sounion area (Petrascheck & Marinos, 1953); crinoids at Lavrion (Cordellas, 1878); *Diplopora, Lithodedron* and brachiopods in the Northern Hymettus (Kober, 1929); at Kessariani monastery, *Gyroporella vesiculifera* (Kober, 1929; Negris, 1915-19), and *Thecosmilia*, algae and gastropods of Triassic – Lower Jurassic age (Katsikatsos, 1977). These citations indicate a Triassic - ? Lower Jurassic age, identical to the «Lower» Marble age (see § 3).

The whole Triassic – Jurassic Kamariza series has been tectonized and metamorphosed under greenschist to amphibolite facies (Marinos & Petrascheck, 1956; Paraskevopoulos, 1957; Leleu, 1966a).

2.1.4. TRANSGRESSIVE CALCAREOUS FORMATION

This formation, up to 50 m thick, lies transgressively either on the "Upper" Marble, or directly on the Kamariza schists. The basal part consists of a conglomerate, followed by limestones. When the formation overlies the marble, the substratum frequently presents some dissolution cavities (1 m large or more), filled with the conglomerate.

The conglomerate contains reworked schist and marble pebbles from the underlying formations. In several places the basal conglomerate is cemented by massive iron oxides and hydroxides; it must be noted the presence

of Ni (0,5 – 2%) in the form of garnierite (Cordellas, 1878; Leleu, 1966a), a known product of ultrabasic rock laterization.

The limestones are massive to thick-bedded, slightly recrystallized and dolomitized; the colour is yellow-, brown- and reddish, due to the iron infiltrations. They contain (Negris, 1915-19) fragments of *Ellipsactinia* in the lower part (Tithonian), Miliolidae and rudist fragments in the upper part (Cretaceous). According to Negris, the upper part corresponds to the calcareous level C1 of the Hymettus hill (Lepsius, 1893), in which he recognized *Orbitolina conoidea*; this species, today named *Neorbitolinopsis conulus*, is a marker of the Lower Upper Albian (Schroeder, *in* Schroeder & Neumann, 1985).

2.2. "PHYLLITE NAPPE" (MIDDLE TECTONIC UNIT)

The Lavreotiki "Phyllite" nappe, synonymous of the «Athens Schists» (Lepsius, 1893), is overthrust on the "autochthonous" unit; it overlies the transgressive formation in the eastern part, and lies directly on the «Lower» Marble in the western, due to a palaeo-uplift and erosion of this part. It consists of various metamorphic formations, which are, from the lowermost to the uppermost, schists, meta-ophiolite mafic rocks and crystalline limestones.

The schists largely crop out in the Lavrion area, as well as to the North and to the West; the thickness is from 100 to 250 m. They are principally microfolded, and bearing muscovite, quartz, albite, chlorite, glaucophane and epidote; quartzites also coexist, usually under the form of lenses, passing quite often into quartziferous schists.

The mafic meta-ophiolites (prasinites, metadiabases and metagabbros), rich in glaucophane (Kokkoros, 1928), are often schistose; they crop out mainly in the form of hillocks, i.e. remnants up to 10 m thick, upon the schists (and not intercalated within the schists).

The limestones overlie the meta-ophiolite bodies, constituting the uppermost part of the nappe, up to 40 m thick; they are crystalline, greenish, grey and dark-grey and contain metasilex intercalations and nodules; they are thick-bedded to massive at the lower part, and medium- to thin-bedded at the upper. In several places the colour is dark-brownish to reddish, due to an ankeritization process.

In general, the "phyllite" nappe consists of schists, locally overlain by some meta-ophiolite bodies, followed by crystalline limestones; this superimposition is clear, the members not being intercalated between them. The nappe is characterized by an Eocene blueschist facies and a Miocene retrogressive greenschist facies due to a granite intrusion (Marakis, 1968; Altherr *et al.*, 1982).

2.3. LIMESTONE AND OPHIOLITE REMNANTS (UPPER TECTONIC UNIT)

Limestone tectonic remnants, up to 50 m thick, bearing a tectonic sole of serpentinite or tectonized Jurassic (?) red chert, locally crop out upon the "Phyllite" nappe schists.

The limestone beds have been studied and variously interpreted in the literature: Leleu & Neumann (1969) reported them as Cenomanian (?) lenses within the Plaka phyllites. Katsikatsos (1977) considered them as Aptian – Albian limestones, transgressively lying on the phyllites. Katsiavrias (1990) and Katsiavrias *et al.* (1991) considered them as a new unit tectonically intercalated between the autochthonous and the phyllite systems; they found Middle Cenomanian inner platform facies at the base of an outcrop, and Campanian – Early Maastrichtian pelagic facies at the top.

The limestones are yellowish and brownish, locally ferruginous and ankeritized, thick- to thin-bedded. In some outcrops, we found Aptian inner platform facies with *Salpingoporella dinarica, Palorbitolina lenticularis, Vercorsella scarsellai, Spiroloculina* cf. *cretacea*, and *"Valvulineria"* sp., and Albian – Cenomanian inner to outer (?) platform facies with *Salpingoporella hasi* and *Cuneolina pavonia*. All the above indicate a carbonate sedimentation that started with neritic facies in the Aptian (and probably earlier), and turned to pelagic during the Senonian.

3. DISCUSSION

"Autochthonous" unit: The "autochthonous" unit of Lavreotiki corresponds to a Triassic - ? Early Jurassic carbonate platform (marble, see later) that, after a collapse, received the deposition of a Jurassic volcano-sedimentary melange (Kamariza schists), followed by a Late Jurassic tectono-metamorphic phase and then by a Late Jurassic – Early Cretaceous transgression.

The Triassic - ? Lower Jurassic carbonate platform was chronologically undivided. Indeed, the "upper" and the "lower" marbles contain the same fossils, are of the same age and consequently represent the same formation, which is overlain by the Kamariza schists. The only difference between them is the presence of metasilex

nodules in the "upper" marble.

The identity between "upper" and "lower" marble into a single formation was previously supported by Kober (1929), who interpreted this repetition invoking a series of thrust slices, and Avdis (1991), who invoked a high-angle faulting. In the present paper, the repetition of the marble over the Kamariza schists is interpreted considering the "upper" marble as the reversed limb of a recumbent syncline, the schists occupying the core of the syncline. The "upper" marble would constitute the lateral transition of the «lower» towards the platform margin; this could justify the presence of the metasilex nodules.

Later, the collapse of the platform permitted the deposition of clastic and volcanogenic materials (the Kamariza schists).

A Late Jurassic tectono-metamorphic phase followed, during which the precedent formations were folded (e.g. the marble repetition) and affected by a greenschist to amphibolite metamorphic facies. This tectono-metamorphic phase corresponds to the known Eohellenic orogenic event of the Internal Hellenides, dated radiometrically by Mercier (1966) in the Northern Greece, and more precisely to the JE1 phase of Vergely (1984); this phase is related to ophiolite obduction, revealed by the presence of ophiolitic bodies at Kessariani and Fe-Ni laterites in the overlying transgressive conglomerate at Kamariza.

Upon this metamorphic substratum, a non-metamorphic transgressive formation lies, consisting of a basal conglomerate and Upper Jurassic – Lower Cretaceous limestones.

All the above-mentioned indicate that the so-called autochthonous unit of Lavreotiki presents the characters of the internal Hellenides and not those of the Olympus-Ossa-Almyropotamos series, which belong to the external ones. Its sedimentation was not continuous from the Triassic to the Eocene, since the succession presents an Upper Jurassic stratigraphic gap; moreover, this gap corresponds to a metamorphic unconformity. These features suggest that the relatively autochthonous unit of the Lavreotiki has suffered the action of the early orogenic phases of the Internal Hellenides, just like the metamorphic Pelagonian zone *sensu* Mercier (1966).

"Phyllite" nappe: The metamorphic conditions of the "phyllite" nappe (Eocene blueschist and Miocene retrogressive greenschist facies) are typical of the median metamorphic belt of the Hellenides, largely expressed in the Attic-Cycladic Metamorphic Complex (Altherr et al., 1982; Papanikolaou, 1984). According to various authors, the Cycladic Blueschist unit would be originated in the Pindos basin (e.g. Altherr et al., 1979). On the other hand, the stratigraphical features resemble an original succession consisted of a volcano-sedimentary melange, an ophiolitic nappe and its transgressive (?) calcareous cover, i.e. a succession of the Internal (?) Hellenides.

This unit identified with the «Neohellenic nappe» of the Southern Euboea (Maluski *et al.,* 1981; Vergely, 1984; Katsikatsos *et al.,* 1986), overthrust during the Middle - Upper Miocene (Dermitzakis & Papanikolaou, 1980; Papanikolaou & Syskakis, 1991) drifting along its base an Upper Eocene – Lower Oligocene non-metamorphic clastic formation (Alexopoulos *et al.,* 1998).

Limestone and ophiolite remnants: The non-metamorphic calcareous remnants are thrust, together with their ophiolitic sole, over the Lavreotiki "phyllite" nappe; so, they are emplaced not between the autochthonous and the phyllite systems as sustained by Katsiavrias (1990). Indeed, some equivalent non-metamorphic calcareous tectonic remnants associated with ophiolites constitute the Upper non-metamorphic tectonic unit within the Attic-Cycladic Metamorphic Complex (Dórr *et al.,* 1978; Papanikolaou, 1984), as well as the post-flysch nappes of the Pelagonian *s.l.* domain. In conclusion, the upper unit could be the upper part of a non-metamorphic Pelagonian nappe.

4. CONCLUSION

The suggested geological structure of the Lavrion area is the following: the relatively autochthonous (the lower tectonic unit) corresponds to the metamorphic Pelagonian zone with its non-metamorphic transgressive cover, while the Almyropotamos unit (external Hellenides), which would be the lowest tectonic unit, does not crop out there. Upon the lower unit, the "phyllite" nappe (the middle unit) lies having on the top some remnants

of a non-metamorphic Pelagonian nappe (the upper unit).

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