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THE STRATIGRAPHIC AND PALEOGEOGRAPHIC EVOLUTION OF THE EASTERN PELAGONIAN MARGIN DURING THE LATE JURASSIC-CRETACEOUS INTERVAL (WESTERN VERMION MOUNTAIN-WESTERN MACEDONIA, GREECE)

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ABSTRACT

The thrust stacking geological structure of the western Vermion Mountain includes Triassic - Jurassic metamorphic rocks, overthrusted ophiolites, transgressive "middle" Cretaceous - lower Senonian carbonates and Senonian flysch, of the eastern margin of the Pelagonian Zone, tectonically overlaid by ultramafic and carbonate rocks of the Almopias Zone.

The Late Jurassic - Early Cretaceous in-situ lateritization of the ophiolites created Fe-Ni ore deposits. The carbonate sedimentation started with Cenomanian - Turonian, clastic facies, continued with platform and pelagic carbonates and recessed during the middle Coniacian - early Santonian, with the arrival of the detrital material announcing the beginning of the flysch deposition in the western Vermion mountain during the Santonian. The facies differentiation indicates an important relief with different environmental conditions.

During the Eocene post-flysch compressive tectonic phase, sheared serpentinite outliers with overlying carbonate conglomerates of Almopias origin, overthrusted the Pelagonian flysch.

KEY WORDS: ophiolite; stratigrpahy;paleogeography;Pelagonian zone; Vermion; Greece.

1. INTRODUCTION

As the title implies, this note aims to provide new evidences on the stratigraphic and paleogeographic evolution of the eastern Pelagonian margin, with certain implications on the emplacement and the lateritization of the ophiolites.

The investigated area is a part of the western Vermion and consists of formations deposited on the eastern margin of the Pelagonian Zone and on the western Almopias border (BRAUD, 1967; BRAUD et al., 1984).

In fact, the southern part and the western slopes of the Vermion mountain range belong to the Pelagonian Zone, while the eastern and northern parts include tectonic klippes of the western Almopias Zone, overthrusted during the Eocene and usually referred as "High Vermion Nappe" (BRUNN, 1956, 1959; MERCIER 1960, 1966). These klippes consist of Cenomanian conglomerates with a serpentinite tectonic sole (BRAUD et al., op. cit.).

2. STRATIGRAPHIC DATA

The stratigraphic sequence of the Pelagonian Zone, exposed in the area of investigation (Profitis Ilias - Metallia) includes, from the bottom to the top, the following formations (Fig. 1):

a) marbles of Triassic-Jurassic age, overlaid by metavolcanosedimentary rocks, mainly schists;

b) ophiolitic nappe, consisting of dismembered units of serpentinized hartzburgites and dunites and

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c) conglomerates and (d) debris flows, containing mainly carbonate elements;
e) rudist - bearing limestones and
f) flysch

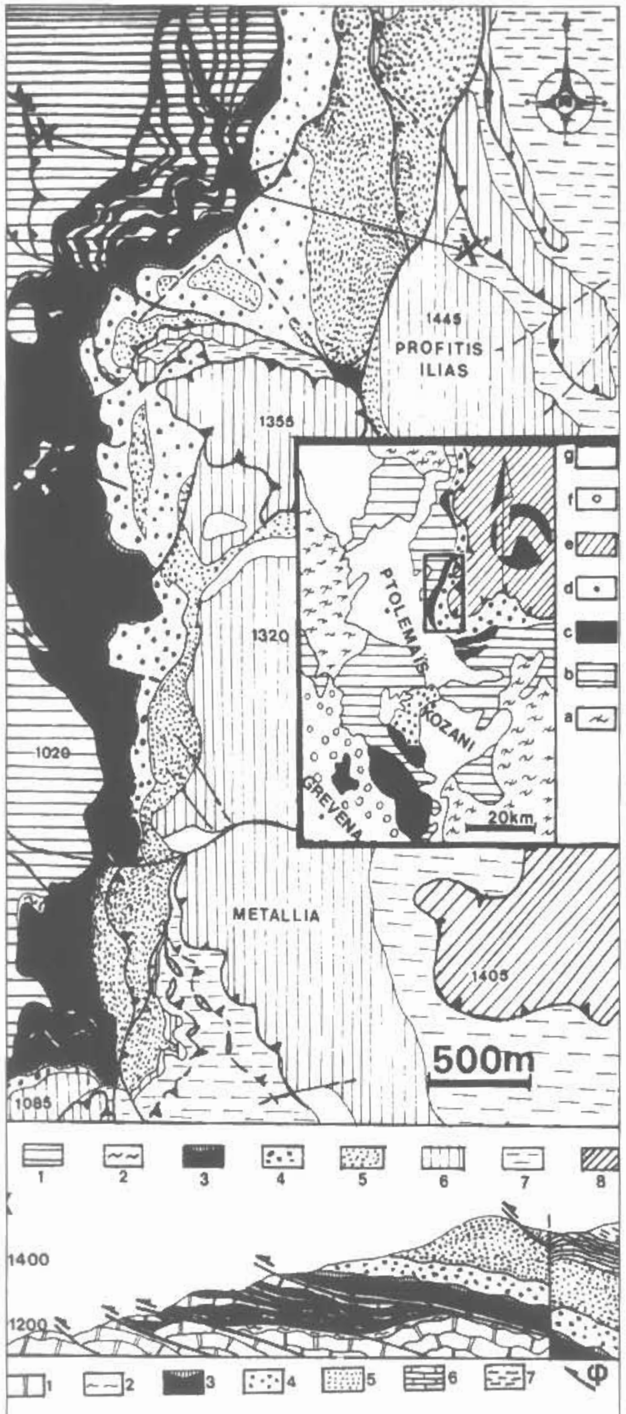

Fig. 1: Geological map and cross section (X-X') of Profitis Ilias - Metallia area of eastern Pelagonian margin (Western Vermion). **a.** gneiss; **b.** pelagonian marble; **c.** ophiolites; **d.** ophiolite cover; **e.** High Vermion nappe; **f.** molasse; **g.** Plio-Quaternary. **1.** pelagonian marble; **2.** metavolcanosedimentary formation; **3.** ophiolites and lateritic horizon; **4.** carbonate conglomerates; **5.** debris flows; **6.** rudist-bearing limestones; **7.** flysch and transitional beds; **8.** High Vermion nappe (Almopias Zone); φ.post-flysh compressive tectonic phase.

(a) The marbles and the metavolcanosedimentary rocks (schists)

They include banks, 10 to 50cm thick, of white to gray microcrystalline marbles, with white silex nodules and cherty intercalations, becoming thin-banded towards their upper part and schists, in beds of 1 to 2m thick.

The lowermost parts consist of dolomitic marbles, containing algae of Triassic age. The deposition of the entire carbonate sequence did not exceed the Early Jurassic (BRUNN, 1956; MERCIER, 1968).

During the Late Jurassic, an early tangential tectonic phase affected the marbles and created characteristic isoclinal and recumbent folds of long length, accompanied by flow schistosity.

Towards the top, the carbonate sequence with silex passes gradually to calcschists and brown metapelitic schists, containing quartz veins and passing, in their turn, to chloritoschists with lenses of metavolcanic rocks.

These Middle Jurassic metavolcano-sedimentary beds include material of volcanic and sedimentary origin, accumulated on the sinking Pelagonian continental margin, due to the vicinity and the tectonic

(b) The ophiolitic nappe with the lateritic horizon

The emplacement of the ophiolitic nappe in the area of investigation took place during the Late Jurassic (PICHON, 1977; SPRAY et al., 1984). The ophiolitic complex consists of ultramafic rocks with hartzburgites and dunites, with chromite ore deposits, carried along with serpentinitic masses, schistosed and intensely crushed in their base. They present imbricated and dismembered unit structures with sub-ophiolite tectonic soles, underlined by the presence of amphibolite and marble lens-like blocks.

In the upper part of these ultramafic rocks a Fe-Ni lateritic horizon with an ochreous transitional zone of limonitic alterations is developed.

(c) The carbonate conglomerates

The carbonate conglomerates formation overlies, uncomformably, either the Fe-Ni horizon or its lateral equivalent, a thin, lateritic argilo-pelitic bed, or, finally, directly, the ultramafic rocks. It develops in compact banks of various thickness and consists of well-rounded carbonate elements, with a diameter 2 to 2,5 cm, mainly originated from the Triassic-Jurassic marbles and platy fragments of green schists, in a gray, micritic or microclastic carbonate matrix, often becoming, red due to the concentration of Fe oxides-hydroxides. No ophiolitic element has been observed.

Occasionally, recrystallized fragments of lamellibranchiates and gastropods occur in the matrix (PICHON, 1977) and the age is considered to be "middle" Cretaceous.

(d) The debris flows

They form flyschoidal alternations of fine- and coarse- grained sandstones, with many intercalations of platy, calcareous conglomerates and microconglomerates, consisting of marble elements in a white-gray or red micritic matrix. Locally, reworked lateritic material is observed, forming red-brownish horizons, with rare and poor Fe-Ni concentrations.

Towards the top of the formation, coarser, white-red, carbonate conglomerates prevail, often alternating with platy, dark-brown clastic limestones.

The whole formation is genetically connected with the Turonian tectonic phase, that provoked the emersion and erosion of extended parts of the Pelagonian ridge. Consequently, a Turonian age is attributed to it.

(e) The rudist-bearing limestones

Over the above clastic, platy, dark-brown limestones, rudist-bearing reefal limestones of the same dark-brown colour are deposited. They are biomicrites, mainly floatstones, with rudist fragments and a few small, badly preserved, foraminifers as Ataxophragmiidae, Textulariidae and small-sized representatives of *Nezzazata* gr. *gyra* (SMOUT), indicating a reefal to back-reefal environment passing to micro-clastic to micro-bioclastic limestones, wackestones to packstones, with numerous *Stomiosphaera sphaerica* (KAUFMANN) and *Pithonella ovalis* (KAUFMANN) and rare, recrystallized, globotruncanids of the species *Marginotruncana coronata* (BOLLI), *Marginotruncana pseudolinneiana* PESSAGNO and *Marginotruncana* cf. *sigali* (REICHEL) indicating an external platform or upper slope environment, with probable action of turbidity currents. The age ranges from late Turonian to early Santonian.

The above dark-coloured limestones are overlaid by white-gray limestones with plentiful fossil fragments, mainly of rudist, bivalves and other macrofossils, containing also a rather poor foraminiferal microfauna, of Turonian-Senonian age, with *Cuneolina pavonia* D'ORBIGNY, *Dicyclina schlumbergeri* MUNIER-CHALMAS, *Nezzazatinella picardi* (HENSON) and some Miliolidae and passing, gradually upwards to thin-platy limestones, of dark-gray to white-gray colour, with Senonian globotruncanid microfauna, indicating a pelagic environment.

This succession is, usually, observed in the lithostratigraphic sequence of the Pelagonian Zone, while in the case of the "High Vermion", placed to the Almopias Zone, deeper environmental conditions prevailed, preventing the development of rudist-reefs and the deposition of rudist-bearing limestones, over the carbonate conglomerates and the clastic series.

Over the Senonian platy limestones lies the Pelagonian flysch, through a transitional formation of thin-platy, white-gray, marly limestones, with characteristic globotruncanid microfauna.

Its lower part consists of marly and silty beds passing, upwards, to alternations of sandstones and conglomerates, with plentiful pebbles of quartz and clastic elements, coming from the erosion of the metamorphic rocks of the Pelagonian substratum.

In the lower part of this succession, thin calcareous beds are intercalated,consisting of fossiliferous micritic limestones, wackestones to packstones, with various clastic grains and a rich planktonic microfauna with *Marginotruncana coronata* (BOLLI), *Marginotruncana sigali* (REICHEL), *Globotruncana linneiana* (D'ORBIGNY), *Archaeoglobigerina cretacea* (D'ORBIGNY), *Stomiosphaera sphaerica* (KAUFMANN) and *Pithonella ovalis* (KAUFMANN), often silicified, indicating a middle Coniacian - early Santonian age.

The flysch is tectonically overlaid by the "High Vermion Nappe". This thrusting tectonism is accompanied by a contact metamorphism of the flysch, forming chloritic and sericitic schists.

3. THE VERMION OPHIOLITES AND THE Fe-Ni HORIZON

In the wider area of Vourinos - Kozani - Vermion, various rocks, mainly serpetinitic, overlay the Pelagonian marbles of Triassic - Jurassic age.

During the compressive tangential tectonic phase of the Late Jurassic, the Vermion ophiolites, of the eastern areas, as well as the western Kozani - Vourinos - Krapa - Asprocampos ophiolites, overthrusted the metavolcanosedimentary formations and marbles of the Pelagonian Zone (MERCIER, 1968; SPRAY et al., 1984) and the kinematic features indicate a SW to NE movement (NAYLOR & HARLE, 1976; GRIVAS et al., 1993). According to SMITH et al. (1979), SMITH & SPRAY (1984), JONES & ROBERTSON (1991) and SMITH (1993), their origin is placed in the paleogeographic area of the "Pindos ocean", extended to the west of the Pelagonian continental margin.

More precisely the ophiolitic rocks of Vermion cover a zone of 40km long and of several hundrends to some dekades of meters wide. They consist of serpentinized tectonites, of hartzburgitic (olivine-orthopyroxene-chromite) and dunitic composition, with high concentrations of chromite, dismembered and deformed, due to the fracturing tectonism and the mylonitization.

The deeper parts of the ultramafic unit contain schistosed serpentinites, serpentinitic rhauwackes, with the characteristic network of dolomitic veinlets, amphibolitic blocks and lenses, as well as meter-sized, lenses of thin-banded marbles, with chert nodules.

The upper parts, with high contents of hematite and argillaceous minerals, have suffered intense lateritization, originated to the uplift movements of the Pelagonian domain and the simultaneous closure of the "Pindos" and the Almopias oceanic basins, during the Late Jurassic - Early Cretaceous and resulted to the formation of a Fe-Ni mineral horizon, often forming lenses, with a maximum thickness of 10m.

The directly underlying this mineral horizon beds, present mineral impregnations and a network of veinlets of carbonate minerals (calcite and dolomite), quartz and Ni-siliceous minerals, of green to olive-green colour. The creation of this network is epigenetic and it has no connection with the typical lateritic alterations.

This Fe-Ni mineral deposits of Vermion, occur, mainly, in its western slope and their stratigraphic position is equivalent to that of the mineral occurrences in Euboea, in Ieropigi (near Kastoria) and in Albania, more to the north. They always lie over peridotites and are transgressively overlaid by carbonate rocks of "middle" Cretaceous age or they are covered by Miocene molassic conglomerates (MOUNTRAKIS, 1982).

4. PALEOGEOGRAPHIC CONDITIONS

During the Triassic and the Jurassic, a shallow marine environment prevailed along the Pelagonian ridge. In the Middle Jurassic, it was affected by a fracturing distentional tectonism, resulting to the

facies, cherts and radiolarites, or cherty nodules and intercalations in carbonate facies. Finally, the Late Jurassic is marked by the propagation of the extensive ophiolitic nappes and the concomitant formation of volcanosedimentary deposits. In the area of Vermion, the compressive tectonism of this period provoked the overthrust of the ultrabasic ophiolitic rocks on the folded and metamorphosed Pelagonian continental margin (MERCIER, 1968; MOUNTRAKIS, 1984).

During the Late Jurassic - Early Cretaceous, the simultaneous closure of the "Pindos" and the Almopias oceanic basins took place, causing compressive movements and uplifts all over the Pelagonian massif. The whole area emerged and stayed under oxidation conditions. The alteration and the lateritization of the ultrabasic rocks created extensive occurrences of laterites, while the erosion of the surrounding areas supplied with clastic elements, of marbles and schists, the overlain transgressive conglomerates of "middle" Cretaceous age.

The clastic sedimentation continued and reached a maximum during the Turonian, when extensive debris flows deposits were formed, due to an intra-Turonian normal faulting tectonism, forming a horst and graben relief (e.g. the "Kozani straits", after BRUNN, 1956).

This accentuated relief was reflected to the differentiation of the sedimentary facies, deposited during the Late Turonian - Early Senonian interval.

In the horst margins, rudist-reefs were developed, while pelagic limestones with globotruncanids microfauna were deposited in the deeper areas. Peri-reefal (fore- and back- reef) facies, with plentiful rudist fragments, were also formed.

By the middle Coniacian, pelagic conditions prevailed in the area of Vermion, while, gradually, fine-grained clastic material, coming from the emerged neighbouring areas, was added to the carbonate sedimentation. As a result, marly limestones were formed, announcing the beggining of the flysch deposition.

Finally, during the Late Senonian the largest part of the Pelagonian ridge remained emerged and exposed to an intense erosion suppling the clastic facies of the flysch with big quantities of quartzo-phyllitic material, originated from its foliated crystalline substratum.

Generally, during the Late Cretaceous the uplift was associated with ductile normal faulting, at depth and tectonic unroofing, at shallow crustal levels (DOUTSOS et al., 1993).

5. TECTONIC DATA

The actual geological setting of the Vermion area is the result of successive tectonic deformations, provoked by the propagation of the ophiolitic nappes, during the Late Jurassic, as well as by the compressive tectonic phase of the Eocene, resulting to the overthrust of the Almopias Zone on the Pelagonian Zone and to the formation of extensive nappes, affecting the visible thickness of the Pelagonian formations (Fig.1, cross section).

The Late Jurassic compressive tectonic phase caused the overthrust of the ophiolites as well as the folding and the metamorphism of the underlying Pelagonian carbonate formations.

The ophiolites formed successive folded nappes with a N-S axis of folding, while amphibolitic blocks, coming from the subophiolitic sole and marble lenses from the underlying, metamorphic, carbonate continental margin, of Triassic - Jurassic age, were detached and carried with the ophiolitic masses.

Another compressive tectonic phase, of probably Eocene age, succeding the flysch deposition, provoked the final overthrust of the Internal Zones on the External Zones, connected with the wide detachements of the serpentinites and the Cretaceous formations of the Pelagonian Zone and the N-S micro- and macro- folding structures.

During the same tectonic phase the less plastic formations suffered dextral and strike-slip faulting with a N-S or E-W direction.

On the other side, the very complex relationships of the basic and ultrabasic units, in the Almopias Zone, including serpentinitic tectonic melange (MERCIER, 1968; MERCIER et VERGELY, 1972), are

(BRAUD, 1967, MERCIER et VERGELY, op. cit.; SMITH et SPRAY, 1984).

These sheared serpentinite outliers, with the overlying conglomeratic limestones of Almopias origin, overthrusted the Pelagonian flysch, during the above post-flysch compressive tectonic phase.

After this Tertiary thrust stacking of nappes, the area of Vermion was affected by normal faults, perpendicular to the N-S general dinaric direction. This faulting tectonism reactivated older faults and gave the actual morphology of the area.

6. CONCLUSIONS

The geological structure of the western Vermion includes the complete sequence of the eastern margin of the Pelagonian Zone, consisting of Triassic - Jurassic metamorphic rocks, ophiolites, middle Cretaceous - lower Senonian carbonates and Senonian flysch, overlaid by carbonate and ultramafic rocks of the Almopias Zone.

It is generally accepted that the emplacement of the ophiolites, in the area of Vermion, took place during the Late Jurassic.

These ultrabasic ophiolites, of western origin, overthrusted metavolcanosedimentary rocks and marbles and have suffered intense in-situ lateritization, resulting to the formation of Fe-Ni ore deposits, during the Late Jurassic - Early Cretaceous, after the compressive tectonic phase that caused the uplift of the Pelagonian domain and the closure of the "Pindos" and the Almopias oceanic basins.

The transgression of the overlying carbonate sedimentary formations started during the "middle" Cretaceous, probably earlier than the Cenomanian. The clastic sedimentation continued and reached a maximum during the Turonian, when extensive debris flows deposits were formed, due to an intra-Turonian normal faulting tectonism. The carbonate sedimentation recessed during the middle Coniacian - early Santonian, with the first arrival of the detrital material announcing the flysch deposition.

The facies differentiation indicates an important relief, where different environmental conditions can be identified.

After the transgression of the sea during the "middle" Cretaceous, and the concomitent depostion of conglomerates and clastic facies, rudist-reefs were developed in the margins, peri-reefal facies with plentiful rudists fragments were deposited, both in the fore- and in the back-reef areas, while pelagic limestones were formed in the deeper parts.

By the beginning of the Senonian, the sea invated the whole area and deeper conditions prevailed. In this pelagic environment the arrival of fine grained clastic material during the middle Coniacian - early Santonian, announced the deposition of the detrital facies of the Pelagonian flysch, in the western Vermion. Sheared serpentinite slices with overlying carbonate conglomerates, of Almopias origin, overthrusted the Pelagonian flysch during the Eocene, forming the Tertiary thrust stacking of Vermion mountain.

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