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GEOLOGY AND DEFORMATION OF THE SERBO-MACEDONIAN MASSIF IN THE NORTHERN PART OF THE ATHOS PENINSULA, NORTHERN GREECE: INSIGHTS FROM TWO DETAILED CROSS-SECTIONS

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Abstract

The Athos peninsula occupies the south-eastern part of the wider Chalkidiki peninsula in Central Macedonia, Greece. It is mainly built up by crystalline rocks belonging to the Serbo-Macedonian massif, traditionally constituting, along with the Rhodope massif, the Hellenic hinterland. According to the basic geological map of the peninsula, its northern part is mainly composed of marbles grouped into the Kerdyllion Unit, and biotite gneisses and two-mica gneisses grouped into the Vertiskos Unit of the Serbo-Macedonian massif, whereas the contact between the units is considered as a normal contact, although it has been re-evaluated as tectonic later on. Moreover, amphibolites and ultramafic rocks exist along with the previously mentioned rocks, making the geology and relationship between the two units much more complicated. Two detailed cross-sections and structural analysis permit us to revise the geology of the region concluding that the marbles, the amphibolite gneisses, formerly independent amphibolites, and the biotite gneisses belong to the Kerdyllion Unit that is strongly characterized by migmatization and anatexis, whereas the Vertiskos Unit is represented predominantly by two-mica gneisses that were not extensively, if at all, affected by these phenomena. Isoclinal folding and intense shearing with an overall top-to-the-S sense of shear resulted in the main fabric of the rocks and the mylonitic shear zone between the units. More importantly, the two-mica gneiss of the Vertiskos Unit is sandwiched between the rocks of the Kerdyllion Unit. We attribute both isoclinal folding and shearing to a Mesozoic tectonic event associated with an amphibolite facies metamorphism, leading to an Alpine reworking of the Serbo-Macedonian massif. This

Alpine reworking continues during Eocene times with an ENE-WSW compression, giving rise to asymmetric to inverted folds, co-axially refolding pre-existing fabrics and structures. Our work strongly suggests that the overall structure and tectono-stratigraphy concerning the Vertiskos and Kerdyllion Units as well as the contact between them should not be based on the existence of the marbles, as traditionally followed up till now, but on the migmatization and anatexis processes that are almost absent from the rocks of the Vertiskos Unit.

Keywords: *Geology, deformation, metamorphism, Serbo-Macedonian massif, Athos*

Περίληψη

Η χερσόνησος του Αγίου Όρους βρίσκεται στο νοτιο-ανατολικό τμήμα της ευρύτερης χερσονήσου της Χαλκιδικής στην κεντρική Μακεδονία, Ελλάδα. Δομείται κυρίως από κρυσταλλικά πετρώματα, τα οποία ανήκουν στη Σερβομακεδονική μάζα. Η τελευταία μαζί με τη μάζα της Ροδόπης παραδοσιακά συνιστούν την Ελληνική Ενδοχώρα. Σύμφωνα με το βασικό γεωλογικό χάρτη της χερσονήσου, το βόρειο τμήμα της αποτελείται κυρίως από μάρμαρα της Ενότητας Κερδυλλίων, και βιοτιτικούς γνευσίους καθώς και διμαρμαρυγιακούς γνευσίους της Ενότητας Βερτίσκου της Σερβομακεδονικής μάζας, ενώ η επαφή μεταξύ των δύο ενοτήτων θεωρείται κανονική, παρόλο που αναθεωρήθηκε αργότερα ως τεκτονική. Επιπλέον, αμφιβολίτες και υπερβασικά πετρώματα συνυπάρχουν με τα προαναφερθέντα πετρώματα, καθιστώντας τη γεωλογία και τη σχέση μεταξύ των δύο ενοτήτων ακόμη πιο περίπλοκη. Η κατασκευή δύο λεπτομερών γεωλογικών τομών, σε συνδυασμό με την τεκτονική ανάλυση, μας επιτρέπει να αναθεωρήσουμε τη γεωλογία της περιοχής συμπεραίνοντας ότι τα μάρμαρα, οι αμφιβολιτικοί γνεύσιοι, πρότεροι αμφιβολίτες, και οι βιοτιτικοί γνεύσιοι ανήκουν στην Ενότητα Κερδυλλίων, η οποία και χαρακτηρίζεται έντονα από μιγματιτίωση και ανάτηξη, ενώ η Ενότητα Βερτίσκου αντιπροσωπεύεται κυρίως από τους διμαρμαρυγιακούς γνευσίους, οι οποίοι δεν επηρεάστηκαν εκτενώς έως και καθόλου από αυτά τα φαινόμενα. Ισοκλινής πτύχωση και έντονη διάτμηση με κίνηση του άνω τεμάχους προς τα Ν διαμόρφωσαν τον κύριο ιστό των πετρωμάτων καθώς και τη μυλωνιτική, διατμητική ζώνη μεταξύ των δύο ενοτήτων. Ιδιαιτέρως σημαντικό είναι το γεγονός ότι η Ενότητα Βερτίσκου περιβάλλεται άνωθεν και κάτωθεν από την Ενότητα Κερδυλλίων. Αποδίδουμε αυτή την ισοκλινή πτύχωση και την διάτμηση σε ένα Μεσοζωικό τεκτονικό γεγονός, σχετιζόμενο με μια μεταμόρφωση αμφιβολιτικής φάσης, το οποίο οδήγησε σε μια Αλπική αναδιαμόρφωση του τεκτονο-μεταμορφικού ιστού της Σερβομακεδονικής μάζας. Αυτή η Αλπική διαδικασία συνεχίζεται μέχρι το Ηώκαινο με μια ΑΒΑ-ΔΝΔ συμπίεση, δημιουργώντας ασύμμετρες ως ανεστραμμένες

πτυχές και πτυχώνοντας εκ νέου ομοαξονικά τον προϋπάρχοντα ιστό και δομές. Σύμφωνα με την παρούσα εργασία, η συνολική δομή και η τεκτονο-στρωματογραφία των ενοτήτων Κερδυλλίων και Βερτίσκου, καθώς και η μεταξύ τους επαφή, δεν πρέπει να βασίζεται στην ύπαρξη των μαρμάρων, ως είθισται μέχρι τώρα, αλλά στις διαδικασίες μιγματιτίωσης και ανάτηξης, οι οποίες απουσιάζουν σχεδόν παντελώς από την Ενότητα Βερτίσκου.

Λέξεις-κλειδιά: Γεωλογία, παραμόρφωση, μεταμόρφωση, Σερβομακεδονική μάζα, Άγιο Όρος

1. INTRODUCTION

The Serbo-Macedonian massif, along with the Rhodope massif, constitute the innermost part of the Internal Hellenides, formerly known as Hellenic Hinterland. The latter, being part of the Alpine orogeny, results from the convergence-related processes between the Eurasian plate and Gondwana-derived continental blocks (e.g., Dercourt et al., 1993; Papanikolaou, 1997; Stampfli and Borel, 2002; Jolivet and Brun, 2010), during Mesozoic and Cenozoic times. The Serbo-Macedonian massif comprises of crystalline rocks that were initially attributed to Precambrian and were considered as already consolidated, stable pieces of crust during and throughout the Alpine orogenic processes (Kober, 1928; Dimitrievic, 1966, 1974). However, later studies suggested that these crustal segments have undergone significant reworking during Alpine deformation and metamorphism and should be considered instead as complex, Mesozoic, syn-metamorphic nappes stacked in an active Alpine margin, that were later subject to extension and consequent exhumation of high-grade metamorphic rocks (e.g., Ivanov, 1988; Burg et al., 1990, 1996; Kilias et al., 1998; Brun and Sokoutis, 2007).

The Athos peninsula is the south-eastern part of the wider Chalkidiki peninsula in Central Macedonia, Greece protruding 50 km into the Aegean Sea. Based on the geological map of Kockel et al. (1977) (Fig. 1), the northern part of the peninsula is mainly built up by rocks belonging to the Vertiskos and Kerdyllion Units of the Serbo-Macedonian massif. However, since then, later studies provided new subdivisions of the crystalline rocks. For example, a new unit, namely Ammouliani Unit between the Kerdyllion and Vertiskos Units, has been suggested by Plougarlis and Tranos (2014), the Kerdyllion Unit was incorporated to the Rhodope massif (Burg et al., 1995; Ricou et al., 1998; Brun and Sokoutis, 2004; 2007, Himmerkus et al., 2007; 2011), and the Vertiskos Unit was considered as a separated individual tectonic terrane (Burg et al., 1995; 1996; 2012 and references therein).

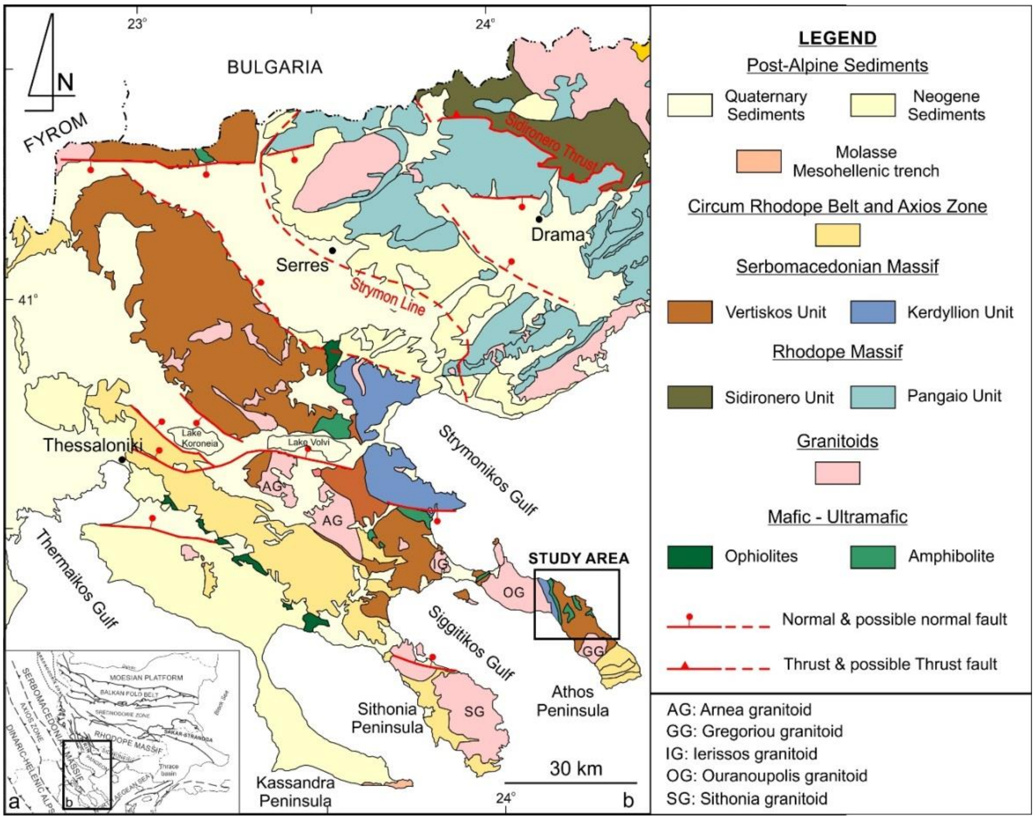

Fig. 1. Simplified geological maps of: a) the main geotectonic framework of the Balkan peninsula including the Dinarides-Hellenides and Balkanides, as the main Alpine orogenic belts. Modified after Tranos and Lacombe (2014), b) the Internal Hellenides and their innermost part, represented by the Serbo-Macedonian and the Rhodope massifs. The study area is also indicated at the northern part of the Athos Peninsula. Modified after Kockel et al. (1977) and Plougarlis and Tranos (2014).

Kockel and Mollat, I.G.M.R. (1978), based mainly on the interpretation of aerial photos and some cross-sections, have mapped rocks of both Vertiskos and Kerdyllion Units in the Athos peninsula. However, the area has not been studied in detail up to now, a fact that makes it of much more interest, concerning the structural relationships between the two units, and the Alpine reworking, documented in other parts of the Serbo-Macedonian massif (e.g., its western contact with the Circum Rhodope Belt Thrust System; Tranos et al. 1999) and having led to the amalgamation of the innermost part of the Internal Hellenides. For this purpose, we carried out fieldwork, which allowed us to collect structural data from the basement rocks of the central northern part of the peninsula. This work is mainly presented as two E-W trending detailed cross-sections, through which we better describe and decipher (a) the different lithologies, (b) the deformation structures, (c) the contact between the units and (d) the overall structure and tectono-stratigraphy of the Serbo-Macedonian massif under the Alpine orogeny.

2. GEOLOGICAL SETTING

The Serbo-Macedonian Massif is divided into two distinct units (Kockel et al. 1977): a) the upper Vertiskos Unit to the west, which occupies the largest part of the Serbo-Macedonian massif and consists mainly of two-mica gneisses and schists, as well as amphibolites and ultra-mafic rocks; the latter have been separated by Dixon and Dimitriadis (1984) to the Therma-Volvi-Gomati Complex, and b) the lower Kerdyllion Unit to the east, which consists mainly of biotite gneisses, migmatitic gneisses, amphibolites, and marbles.

The Vertiskos Unit, with the most dominant lithology that of two-mica gneiss, has been interpreted as an initially thick series of greywackes, arkoses, and shales (Kockel et al., 1977, Sakellariou, 1989), whereas Himmerkus et al., (2006; 2009a) has interpreted the same unit as consisting of orthogneisses, belonging to a continental magmatic-arc. The Kerdyllion Unit constitutes mainly of fine to medium-grained biotite gneisses and amphibolites, migmatites, due to an extensive regional anatexis (Kockel et al., 1977; Sakellariou, 1989), whereas characteristic is the presence of three distinct marble horizons, of similar lithology. The Kerdyllion Unit has been interpreted as an originally monotonous greywacke-arkose and occasionally marl series of great thickness, with embedded limestone horizons (Kockel et al., 1977; Sakellariou, 1989), whereas the migmatitic biotite gneisses have also been interpreted as of ortho-gneissic origin and incorporated to the Rhodope massif (Burg et al., 1995; Ricou et al., 1998; Brun and Sokoutis, 2004; 2007, Himmerkus et al., 2007; 2011).

As already mentioned, Dixon and Dimitriadis (1984) considered the mafic and ultra-mafic rocks, and more specifically the complexes of Therma, Volvi, and Gomati as ophiolite complexes that are frequently present along the contact between Vertiskos and Kerdyllion Units, implying that the contact between Vertiskos and Kerdyllion Units is tectonic, a conclusion which is also enforced by the presence of extensive shearing along the afore-mentioned contact in adjacent study areas (Sakellariou, 1989; Sakellariou and Durr, 1993; Himmerkus, 2005; Plougarlis and Tranos, 2014).

Evidence of Tertiary magmatism, represented by granitic intrusions within the Serbo-Macedonian crystalline rocks, are evident throughout the Chalkidiki region, with the most characteristic being the Sithonia, Ierissos, Ouranoupolis, and Gregoriou plutons, of Eocene age (DeWet et al., 1989; Christofides et al., 1990; Tranos et al., 1993; Frei, 1996). The Ouranoupolis and Gregoriou granites were emplaced into the crystalline rocks in the study area to the W and the E, respectively.

3. GEOLOGY OF THE STUDY AREA

The rocks identified during fieldwork in the northern part of the Athos peninsula, are the following:

Marbles: They are mainly white and blueish gray, but also reddish-pink at places, generally coarse-grained, strongly foliated and banded, due to the alternations between purely carbonate and more clastic layers, ranging in thickness up to tens of cm (Fig. 2a). They intercalate at places with amphibolites and calc-silicate-amphibole schists, which may reach tens of meters in thickness. They appear as strongly deformed rocks, under ductile conditions, with a mylonitic foliation, and at places exhibit overprinting relationships among multiple deformational events.

Amphibolite gneisses: The amphibolite gneisses are dark green to black, mainly due to the prevalence of hornblende, well foliated and layered, as in most parts, they have developed a migmatitic layering, differentiating melanocratic amphibolitic material from leucocratic material (Fig. 2b-c). They often include feldspar or feldspar-quartz-aggregate augens and garnet porphyroblasts. The layering ranges from 1-2 mm to approximately 10 cm in thickness. Mineralogical variations occur within the amphibolite gneisses, from coarse-grained and massive to fine-grained and thinly banded. Also, flecky and nebulitic textures are signs of migmatization in numerous localities. Frequent leucosome bodies of a coarse-grained biotite-muscovite quartzofeldspathic gneiss, which occasionally acquires a flaser to augen gneiss texture, are found (sub) parallel to the main foliation (Fig. 2g). They are concordant leucosomes of few cm to several m in thickness that are more prominent in part underlying the two-mica gneisses.

The amphibolite gneisses intercalate with calc-silicate gneisses or schists, especially near their contact with the underlying marbles. Lastly, they grade at places, to amphibole-biotite gneiss or biotite-amphibole gneiss, especially at their contact with the overlying biotite gneisses. A fact that implies the gradational metamorphic character of the contact between them and the overlying biotite gneisses, although at places their contact appears sheared.

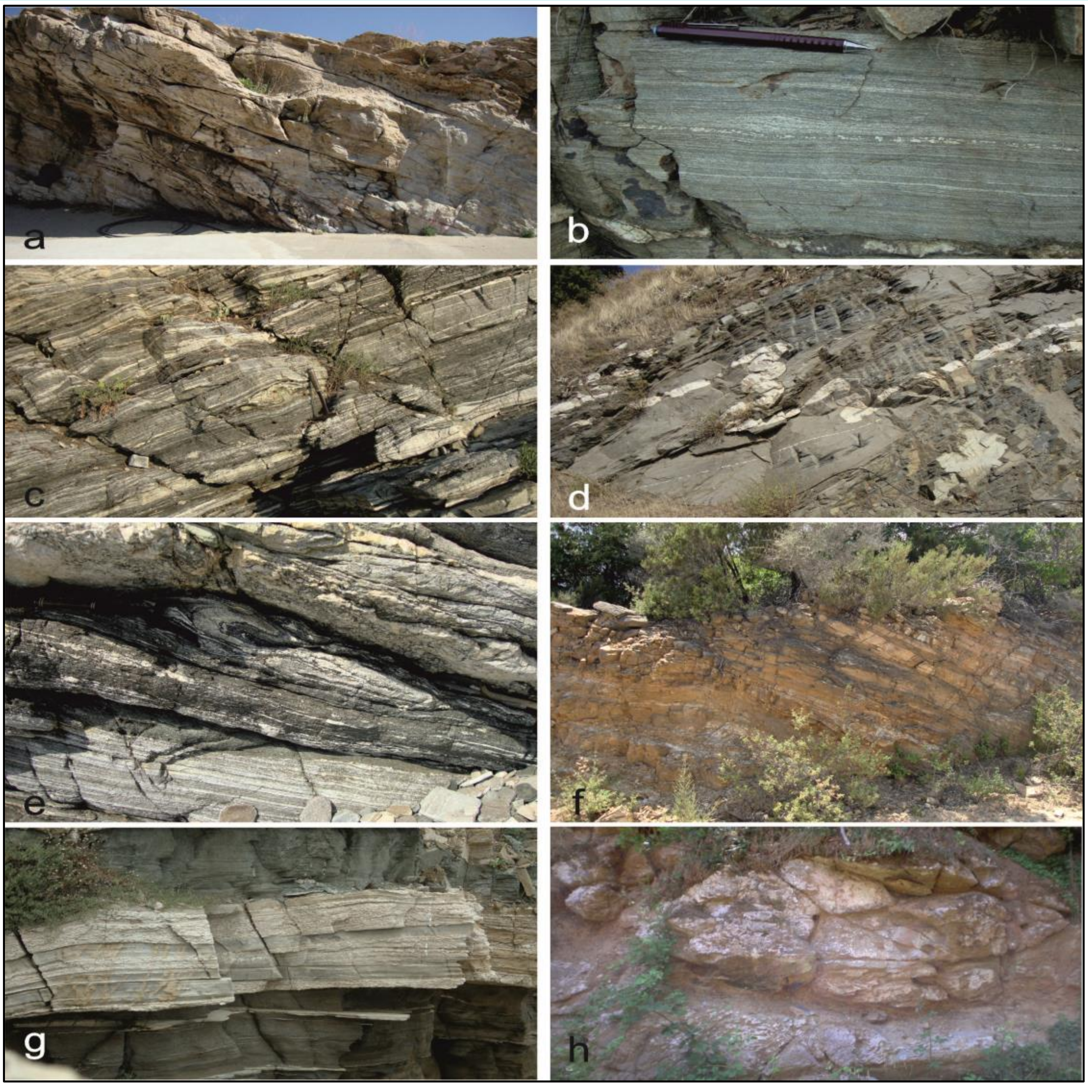

Fig. 2. The crystalline rocks comprising the basement of the northern part of the Athos peninsula: a) Reddish-pink, tightly foliated marbles, b) Tightly foliated amphibolite gneiss, c) Migmatitic, tightly foliated, hornblende-biotite gneiss, with boudinaged, calc-silicate lenses, parallel to the foliation, d) Biotite-gneiss cut by folded and boudinaged pegmatoid veins, e) Migmatized biotite-hornblende layered gneiss, with foliation-parallel leucogneissic bands, f) Two mica gneiss, g) Leucosome with a characteristic flaser to augen texture, concordantly emplaced within the amphibolite gneisses, h) Small tectonic lenses of serpentinized ultramafic rocks within amphibolite gneisses.

Biotite gneisses: The biotite gneisses are black to dark gray, medium to coarse-grained, and well foliated (Fig. 2d-e). A remarkable feature is the migmatization resulting in the migmatitic texture and layering (Fig. 2e), with the occasional, appearance of feldspar or feldspar-quartz aggregate augens from few mm to several cm wide and the occurrence of the respective leucosomes previously mentioned within the amphibolite gneisses. The leucosomes are more prevalent up-section towards the overlying two-mica gneisses, whereas the two-mica gneisses exhibit little to no migmatization. Calc-silicate-gneisses, quite frequently boudinaged, can also be observed at places within the biotite gneisses.

Two-mica gneisses: The two-mica gneisses are grey to brownish grey, predominantly fine- to medium-grained, and acquire a flaser or even augen texture only at places (Fig. 2f). The ratio of the two micas, biotite, and muscovite, varies from place to place, leading to either biotite-muscovite or muscovite-biotite gneiss composition. At certain localities, the contribution of biotite to the overall mineral composition diminishes, and the rock transcends to a light beige muscovite gneiss. The two-mica gneisses are well-foliated and banded, the thickness of the latter usually being a few cm, and it is scarcely run through by sub-parallel or concordant pegmatoid veins or boudinaged beads. Migmatization is almost absent compared to that observed within the amphibolite and biotite gneisses.

Mafic-ultramafic rocks: The mafic-ultramafic rocks are dark to light green meta-peridotites, quite frequently serpentinized, lherzolitic at places, subordinated by dark green pyroxenites, often partly altered to a pale green color, gabbros, and pale greenish-white talc-schists. They occur as scattered, elongate, lenticular bodies, forming tectonic slivers, from tens of m to few hundreds of m in length and up to tens of m in thickness (Fig. 2h). They are in contact with the marbles, the amphibolite gneisses, and biotite-gneisses, and especially close to their contact with the two-mica gneisses. They are absent from the two-mica gneisses.

3.1. Description of the two cross-sections

Two detailed cross-sections were constructed, after the collection of structural data and observations in the field, in the western and eastern part of the study area (Fig. 3), in order to understand better and consequently interpret the structural relationship between the basement rocks and the units they represent.

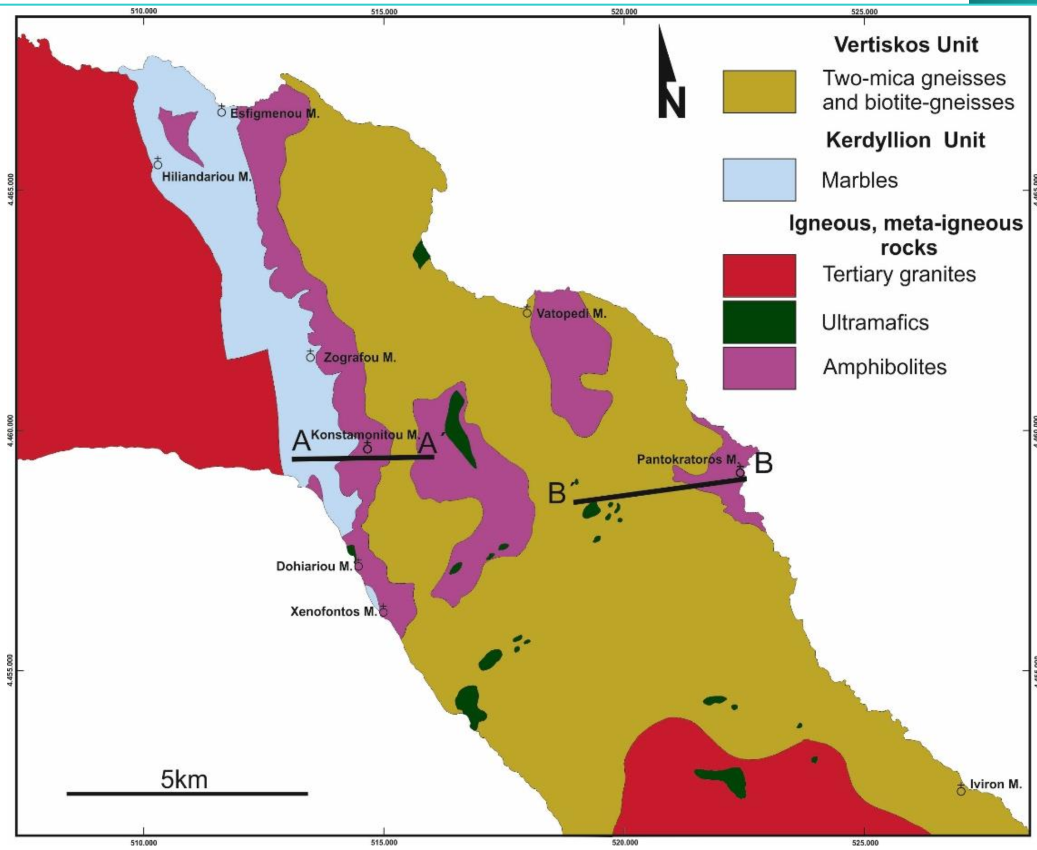

Fig. 3. Geological map of the study area based on the geological mapping and lithological descriptions of Kockel and Mollat (1969) and published by the Publication Department of Geological Maps of I.G.M.R. (1978). Profiles A-A´ and B-B´ are shown in Fig. 4 and Fig. 8, respectively.

The A-A´ cross-section refers to the western coast of the northern part of the Athos peninsula and is located in the vicinity of Konstamonitou monastery (Fig. 3). It trends E-W, and the following can be observed, gradually moving from the W to the E and the lower to the higher structural levels (Fig. 4):

- At the western part of the cross-section, the marbles gently dip towards the E and underlie conformably the amphibolite gneisses. Numerous locations along this contact, where alternations of marbles and amphibolite gneisses exist, advocate for the normal contact with the overlying amphibolite gneisses. Within the marbles calc-silicate schists, occasionally, amphibole-schists have been found, especially close to mafic-ultramafic rocks. The latter occur as tectonic slivers tectonically emplaced parallel to the main foliation of the marbles.

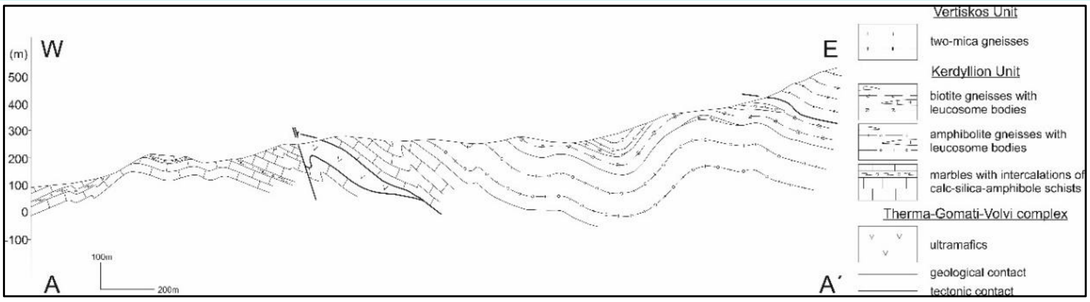

Fig. 4. A-A´ cross section, at the western part of the study area, for location, see map in Fig.3. For greater detail of this Figure see supplementary section.

- At the central part of the cross-section, the amphibolite gneisses pass upwards to biotite gneisses through successive alternations between them; a fact that advocates for the normal contact between them. However, these alternations could be further enhanced from multiplications due to isoclinal to tight folding, as shown by the many folds of this type that have been observed in both lithologies (Figs 5, 6b). The above-mentioned lithologies indicate intense migmatization and shearing. Because of this, abundant are the concordantly emplaced lense-shaped leucosomes, which form distinct layers being more abundant towards the uppermost part of the biotite gneisses, underlying the two-mica gneisses.

- At the easternmost part of the cross-section, the biotite gneisses gently dip to the E and underlie the two-mica gneisses. The contact is a ductile shear zone associated with an intense mylonitization and strongly imprinted N-S trending stretching lineation. Shear sense indicators observed both in the field and rock thin-sections show a top-to-the S sense of shear (Fig. 7).

- Variations on the geometry of the main foliation and deviations from the low undulating angles governing the overall structure (Fig. 4) are due to refolding from horizontal, inclined to inverted and close to open folds. However, occasionally upright folds can be observed. These folds trend N-S to NNW-SSE and form synforms and antiforms with medium to high angles as depicted in the cross-sections (Fig. 6c) with vergence mainly to the W.

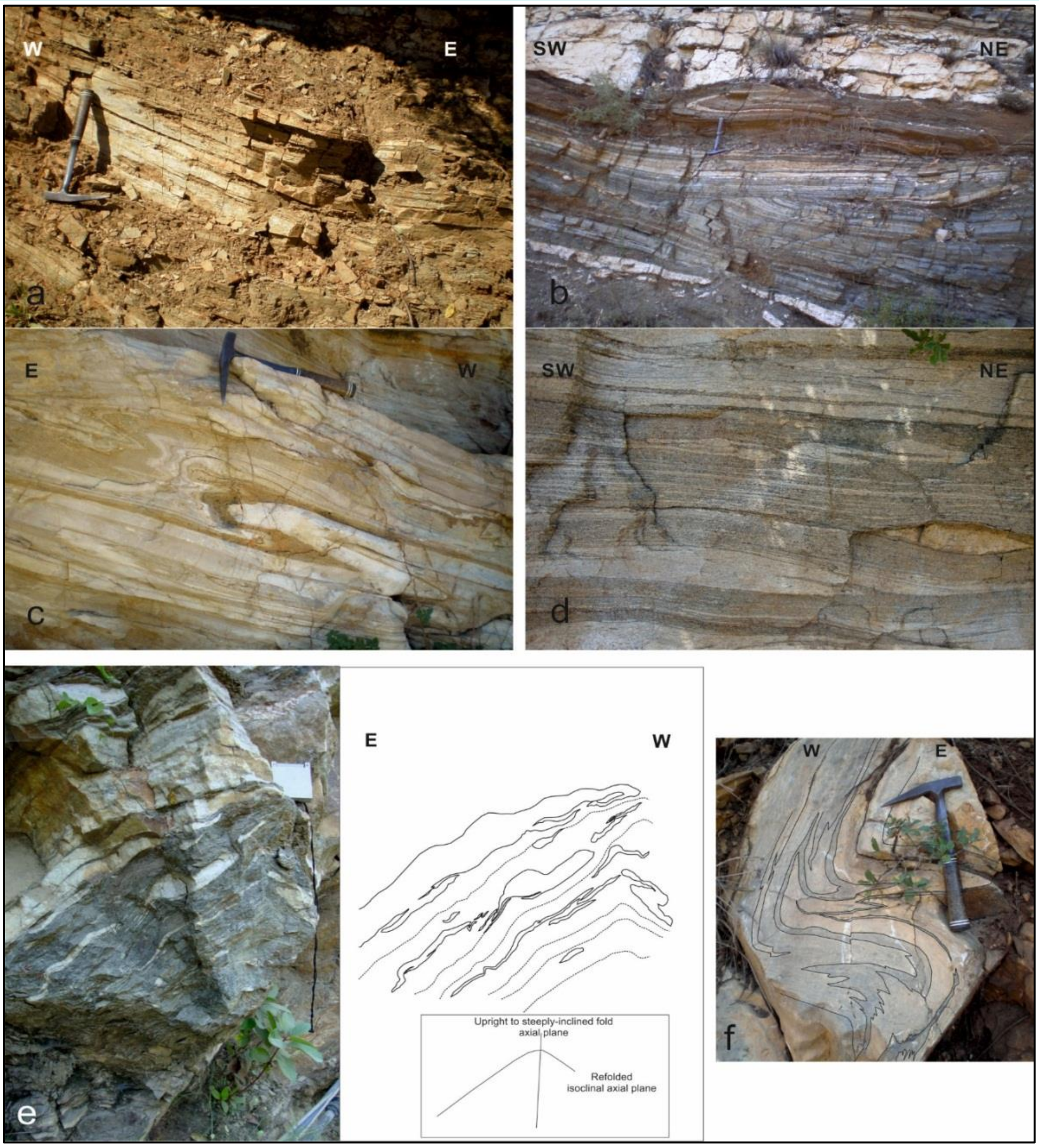

Fig. 5. Images of folds from the study area: a) Isoclinal folds within the two-mica gneisses (Vertiskos Unit), E of Konstamonitou monastery, b) Isoclinal fold within the amphibolite gneisses (Kerdyllion Unit), truncated by sharp shear zones, E of Esfigmenou monastery, c) Isoclinal to tight fold within the marbles (Kerdyllion Unit), WSW of Konstamonitou monastery, d) Isoclinal folds within the migmatitic biotite gneisses (Kerdyllion Unit), N of Dohiarion monastery, e) Upright to steeply inclined Eocene fold, verging towards the W and overprinting pre-existing isoclinal folds, within the marbles (Kerdyllion Unit), N of Dohiarion monastery, f) Steeply dipping limb of an asymmetric Eocene fold, overprinting two generations of pre-existing isoclinal folds, within the marbles (Kerdyllion Unit), SSE of Hiliandariou monastery.

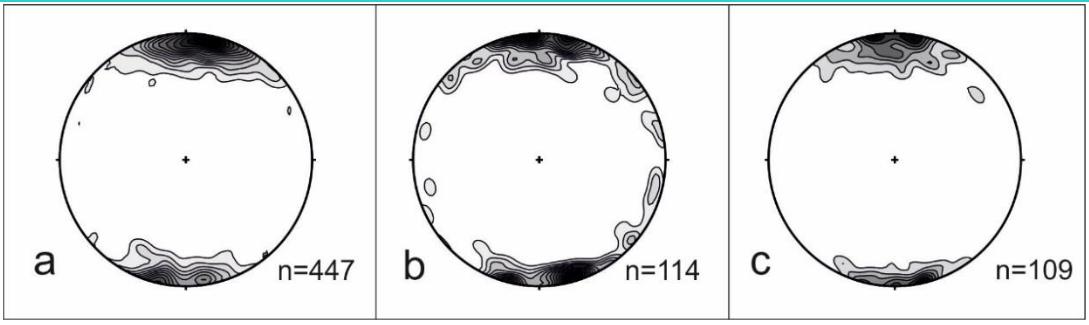

Fig. 6. Structural analysis of the basement rocks of the wider study area, spanning between the two Tertiary granites of Ouranoupolis and Gregoriou: a) Stretching and mineral lineation, generally trending about an N-S axis, b) Fold axes of isoclinal to tight, generally recumbent, horizontal to sub-horizontal folds, trending parallel to the stretching lineation, c) Fold axes of mainly asymmetric to inverted and upright, horizontal to sub-horizontal folds, also trending N-S to NNW-SSE refolding pre-existing, isoclinal folds shown in b). Equal area, lower hemisphere projection.

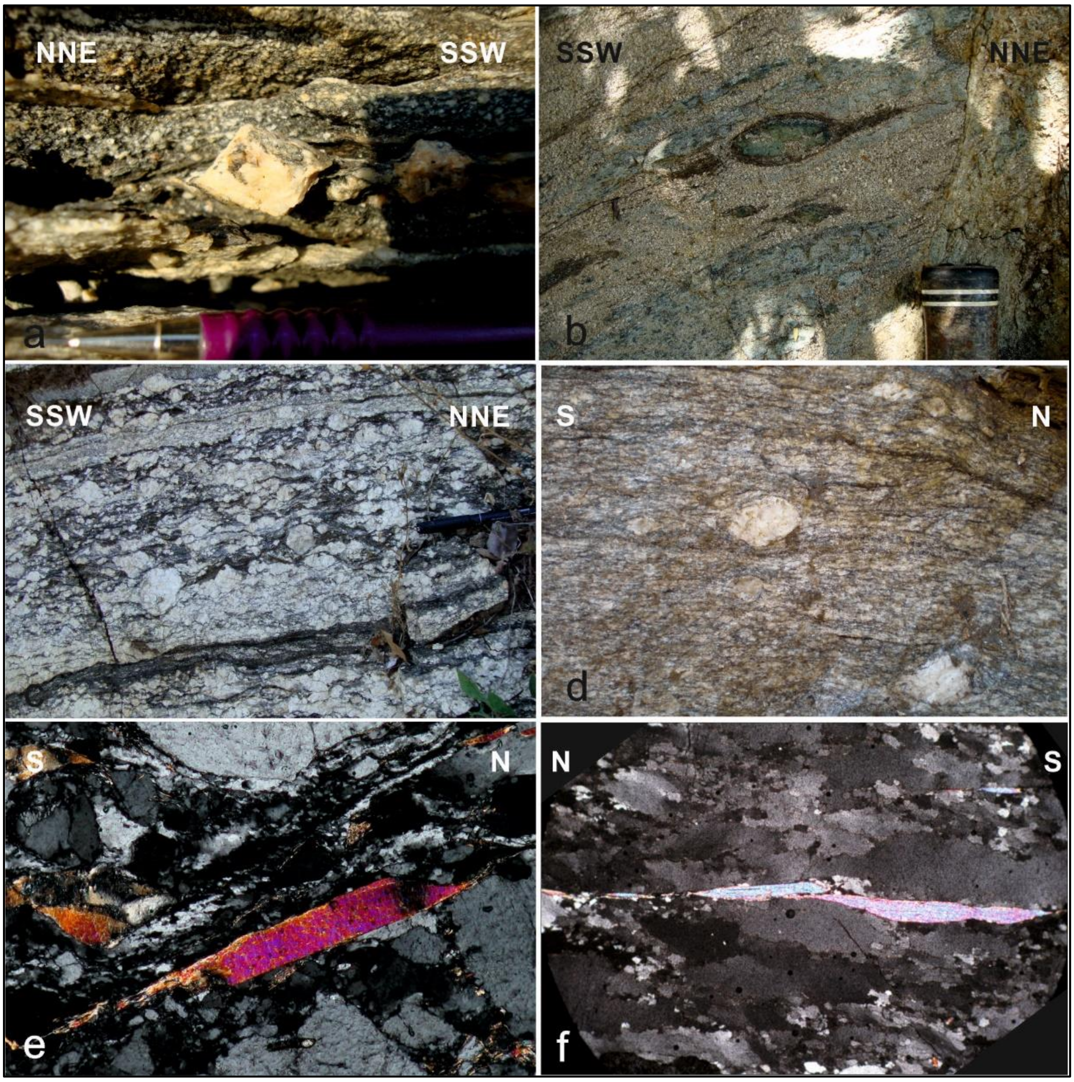

Fig. 7. Shear sense indicators and markers within mylonitic zones along the contact between the Vertiskos and Kerdyllion Units: a) Feldspar σ-clast in the migmatitic biotite gneisses (Kerdyllion Unit) underlying the two-mica gneisses (Vertiskos Unit)

indicating a top-to-the-S sense of shear, SE of Xenofontos monastery, b) Sigmoidal epidote-rich aggregate with biotite-rich tails in an ultramafic tectonic sliver within the amphibolite gneisses (Kerdyllion Unit) indicating top-to-the-S sense of shear, E of Dohiarion monastery, c) Sigmoidal feldspar, quartzo-feldspathic augens and C'-type shear bands in the migmatitic, biotite gneisses (Kerdyllion Unit) underlying the two-mica gneisses of the Vertiskos Unit indicating top-to-the-S sense of shear, E of Zografou monastery, d), Feldspar σ-clasts in the two mica gneisses (Vertiskos Unit) underlying the amphibolite gneisses (Kerdyllion Unit) indicating a top-to-the-N sense of shear, W of Pantokratoros monastery e) C'-type shear band, oblique foliation, formed by dynamically recrystallized quartz grains, under Sub-Grain Rotation mechanism and mica fish in two mica gneisses (Vertiskos Unit) overlying the biotite gneisses (Kerdyllion Unit) indicating top-to-the-S sense of shear, E of Konstamonitou monastery, f) Mica fish within the leucogneissic bodies of the amphibolite gneisses (Kerdyllion Unit) underlying the two mica gneisses (Vertiskos Unit) indicating top-to-the-N sense of shear, NW of Pantokratoros monastery.

The B-B΄ cross-section refers to the eastern coast of the northern part of the Athos peninsula and is located in the vicinity of Pantokratoros monastery (Fig. 3). It trends WSW-ENE, and the following can be observed, drifting upslope towards WSW and from the structurally lower to the structurally higher (Fig. 8):

- At the eastern part of the cross-section, amphibolite gneisses expose to dip gently to the WSW. Characteristic is the presence of the concordantly emplaced, leucosomes, parallel to the main foliation. WSW wards, they are overlain by two-mica gneisses. The contact, as identified in the field, is tectonic, and more precisely, a mylonitic shear zone similar to the contact described in the previous cross-section between the biotite gneisses and two-mica gneisses. Kinematic indicators, both in the field and under the thin sections, define a top-to-the S sense of shear for this ductile shear zone.

- The overlying two-mica gneisses dip to the WSW in a gentle undulating fashion, and at the western part of the cross-section, the amphibolite gneisses overlie them. Their contact exhibits the same features as those described in the western cross-section, apart from the sense-of-shear, which is the top-to-the N, i.e., opposite to the previously mentioned, suggesting inversion of the lithologies due to isoclinal folding.

- At the western part of the cross-section, mafic-ultramafic rocks, similar to those already mentioned in the western cross-section, outcrop as tectonic slivers within the amphibolite gneisses and closer to their contact with the tectonically underlying two-mica gneisses. At the westernmost part, biotite gneisses, once more gently dipping to the WSW, overlie the amphibolite gneisses, with a normal contact.

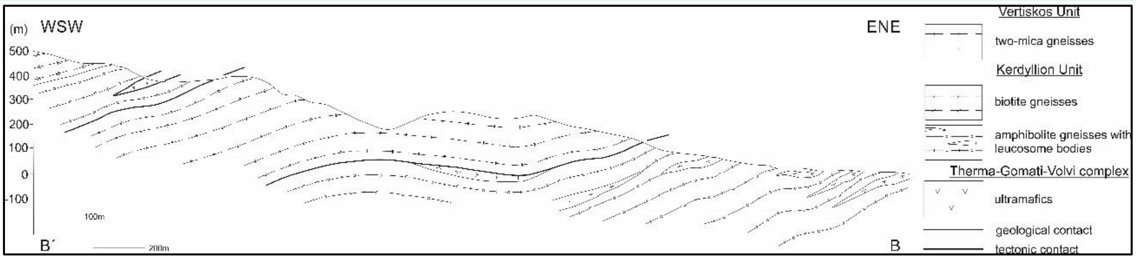

Fig. 8. B-B' cross-section at the eastern part of the study area, for location, see map in Fig.3. For greater detail of this Figure see supplementary section.

4. DISCUSSION-CONCLUSIONS

From the lithological description of the crystalline rocks, which have been grouped into the Serbo-Macedonian massif (Kockel et al. 1977), the description of the two cross-sections and the presentation of the structural data, the following can be concluded:

The exposed marbles, amphibolite gneisses, and biotite gneisses seem to belong to the same unit, based on the intercalations, alternations, and normal contacts among them. The rocks have affinities similar to the rocks described and grouped into the Kerdyllion Unit by Kockel et al. (1977). On the other hand, the lithological description of the two-mica gneisses fits really well with the main rock type attributed to the Vertiskos Unit also by Kockel et al. (1977). The leucosomes of the quartzofeldspathic gneiss, concordantly emplaced and sheared along with the amphibolite and biotite gneisses, lithologically refer to an initial granitic melt. They can be juxtaposed with either the Ammouliani Unit, described as quartzofeldspathic gneisses and anatexites-granitic gneisses by Plougarlis and Tranos (2014) or the plagioclase-microcline gneiss, described by Kockel et al. (1977). The migmatization signs the leucosomes bear in the study area advocate more towards its relation with the Ammouliani Unit.

The contact, however, between the Vertiskos and Kerdyllion Units is not a normal contact, as mapped by Kockel et al. (1977) in the central-eastern part of the Chalkidiki peninsula, but a tectonic contact, as already indicated in other parts of the Serbo-Macedonian massif (i.e., Sakellariou, 1989; 1993; Burg, 1995; 1996; Plougarlis and Tranos, 2014), and more precisely a large mylonitic shear zone with top-to-the-S sense of shear. Nonetheless, the tectonic contact between the Vertiskos and Kerdyllion Units is more complicated since it is locally inverted resulting in the sandwich of the rocks of the Vertiskos Unit between the rocks of the Kerdyllion Unit. As a result, an opposite top-to-the-N sense-of-shear occurs, and the two-mica gneisses appear sandwiched between the rocks of the Kerdyllion Unit, due to simultaneous shearing and isoclinal folding that prevails the deformation. This verifies the complexity of the tectono-metamorphic evolution of the study area, in the ductile flow regime, and indicates the need for future research, combining tectonic observations in the field with geochronological and P-T data.

The presence of mafic-ultramafic tectonic slivers, representing oceanic crust (Dixon and Dimitriadis, 1984), mainly with the rocks of the Kerdyllion Unit permits us to consider the Kerdyllion Unit as of being in closer relationship with the oceanic crust, possibly representing a deep submarine environment.

Our work strongly suggests that the overall structure and tectono-stratigraphy concerning the Vertiskos and Kerdyllion Units, as well as, the contact between them should not be based on the existence of the marbles as traditionally followed up till now, but on the migmatization and anatexis processes that omitted from the rocks of the Vertiskos Unit.

The biotite gneisses, which were only referred to as alternations with the two-mica gneisses, are not actually in alternations with the two-mica gneisses, but with the amphibolite gneisses. Therefore, they do not belong to the Vertiskos, but the Kerdyllion Unit. The two-mica gneisses, which were initially mapped to cover the largest part of the study area, seem to be of much more limited extent.

The main fabric and structures describing this large-scale deformation herein, which are the main foliation, the stretching/mineral lineation, and the isoclinal folds, are all associated with an amphibolite facies metamorphism. This conclusion stems from the fact that: a) the main foliation, which characterizes the metamorphic rocks of the study area is structurally uniform in all the afore-mentioned metamorphic rocks, it is constituted by minerals which indicate a lower-to-middle amphibolite grade (e.g. hornblende, plagioclase (An 20-40), epidote and zoisite, quartz, whereas garnet, rutile and titanite exist as accessory minerals in amphibolite gneisses), b) the stretching lineation (Fig. 6a) manifests itself, both as a stretching lineation in quartzofeldspathic aggregates and a mineral lineation in amphibole needles, and c) the afore-mentioned mylonitic foliation, is quite frequently expressed as an axial foliation to the recumbent, N-S trending isoclinal folds (Fig. 6b).

Previous researchers have assigned a Mesozoic age to this syn-tectonic, amphibolite facies, metamorphic event (Dixon and Dimitriadis, 1984; Papadopoulos and Kilias, 1985; Sakellariou, 1989; Kilias et al., 1999), which gave rise to the main fabric of the

Serbo-Macedonian massif elsewhere, thus verifying the main Alpine-reworking the Athos peninsula rocks underwent. The anatexis signified by the leucosome bodies can be relatively aged prior or contemporaneously with this main Mesozoic deformational event. Moreover, the inclined to inverted asymmetric folds with vergence towards the W, overprint the afore-mentioned structures and indicate a general ENE-WSW compression. This compression fits well with the well-established trend of the Hellenic orogen as driven by the Eocene Alpine contraction, resulted from the collision between the Apulia and Eurasia plates. These deformation events declare the Alpine reworking scenario of the crystalline rocks of the Athos peninsula, also verified in other parts of the Serbo-Macedonian massif (e.g. Ivanov, 1988; Burg et al., 1990, 1996; Sakellariou, 1989; 1993; Kilias et al., 1997; Brun and Sokoutis, 2007), that was previously considered as part of the stable Hellenic hinterland.

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