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STRUCTURAL EVOLUTION AND KINEMATICS IN THE CONTACT ZONE BETWEEN SERBOMACEDONIAN AND RHODOPE MASSIFS, CENTRAL MACEDONIA, GREECE

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ABSTRACT

We present field evidence and kinematic indicators collected along a traverse through Serbomacedonian and Rhodope massifs, emphasizing more to the nature of deformation along their contact. Based primarily on overprinting structural criteria we have distinguished three principal deformation phases.

Ductile syn-metamorphic deformation phase D_1 is accompanied by a regional foliation S_1 and a mineral-stretching lineation L_1 defined by streaks of high-grade minerals. This L_1 shows a regional scale pattern with a dominant ENE- to ESE-orientation. Local deviations to a general N-S orientation are observed close to the major thrust contacts. Associated sense-of-shear criteria demonstrate a general top-to-the W-SW ductile shearing. The second phase D_2 is mainly characterized by outcrop scale close to tight folds that formed under semi-ductile conditions. These folds overprint the S_1 and their axes are dispersed around a NE-orientation. They generally exhibit vergence towards NW and are commonly associated with an axial planar cleavage.

The deformational phase D_3 has produced well developed meso- to map scale structures which formed under semi-brittle to brittle conditions. Deformation is accommodated by NNW-trending oblique thrust faults indicating a general NE movement direction. A similar sense of movement is supported by asymmetric kink-folds, which are also associated with a dense WSW-dipping cleavage. In map scale the contact between the lower parts of the Serbomacedonian (Kerdilia sequence) and Rhodope massifs (Pangeo unit) is considered to be a major W-dipping, low-angle D_3 thrust. The fault core of the thrust consists of a 15 m thick ultracataclasite and a zone of tectonic breccia with a thickness of ca. 50 m. Kinematic indicators within the fault zone demonstrate a clear top-to-the east D_3 shearing along this contact. In the footwall of this thrust, the marbles of Pangeo unit display a 50 m thick zone of intense mylonitic foliation.

1. INTRODUCTION

Despite numerous studies published the last four decades, the kinematics and the tectonic significance of the 'Strimolinie' defining the contact between the Serbomacedonian (SRM) and the Rhodope (RHM) massifs in Central Macedonia (Kockel and Walther 1965) are still a matter of debate (Fig. 1). The 'Strimolinie' originally described and interpreted by Kockel and Walther (1965) as a major west-dipping thrust fault (Strymon overthrust) carrying the SRM to the west over RHM to the east. More recently, a series of sound publications (e.g. Dinter and Royden 1993; Kilias et al. 1999) considered the 'Strimolinie' to be a huge shallow-dipping extensional detachment zone which caused the progressive unroofing of the RHM units during Oligocene-Miocene. Moreover, based on similarities in metamorphic grade and structural style between SRM and the RHM some authors (e.g. Burg et al. 1995) disputed the significance of this tectonic line and viewed it as a single tectonic element. In this study we provide new structural data for the kinematic characteristics of the controversial 'Strimolinie' as well as the deformation history of both the SRM and the RHM, focusing especially on the geometry and kinematics of its late-stage deformation.

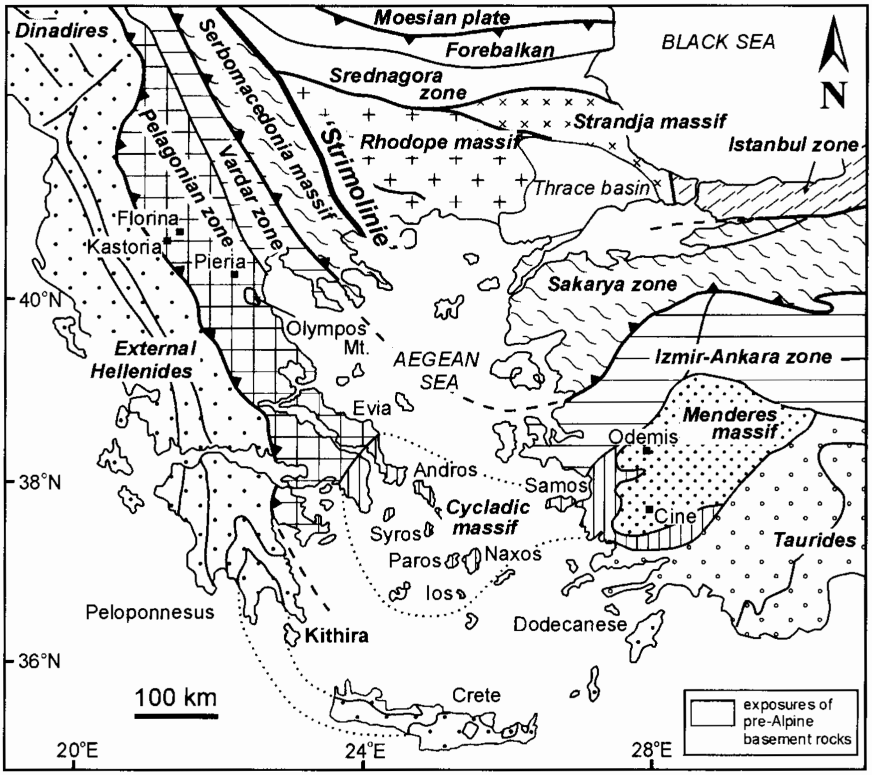

Fig. 1 Simplified geological map showing the main isopic zones in Greece, as well as the exposures of pre-Alpine basement rocks. The "Strimonlinie" is also shown on map with a thick black line separating Rhodope from Serbomacedonia massifs.

2. GEOLOGICAL SETTING

Both the SRM and the RHM lie between the Vardar and Strandja suture zones (Fig. 1), which are interpreted as Mid-Late Mesozoic oceanic sutures between Apulia and the SE-European margin.

The SRM of northern Greece is a complex zone comprising heterogeneous metamorphic lithological units of Palaeozoic or older age, intruded by Mesozoic and Cenozoic granitoids (Kockel et al. 1971; 1977; Jacobshagen et al. 1978; Papadopoulos and Kilias 1985). It has been divided into two major tectonic sequences (e.g. Kilias et al. 1999): the structurally lower Kerdilia sequence to the east and the upper Vertiskos sequence to the west (Fig. 2). The Kerdilia sequence comprises mainly biotite gneisses with minor marble intercalations, hornblende gneisses and amphibolites. Rocks of this sequence locally show migmatitic textures. The Kerdilia sequence is also correlated with the lower terrane of RHM (Burg et al. 1996). The overlying Vertiskos sequence is mainly composed of biotite-muscovite gneisses and some amphibolite intercalations. Lenses of an amphibolite-metagabbro complex occur between the two sequences, interpreted as an ophiolitic rock sequence within a quartzo-feldspathic schistose matrix, showing a mylonitic fabric. The SRM has been correlated with pre-Alpine continental basement with Palaeozoic and locally Pre-Cambrian rocks (Aleksic et al. 1986) that extend northwards to the former Yugoslavia. Recently, this interpretation has been questioned by several authors

(Godfriaux et al. 1996; Burg et al. 1996), who suggest a correlation of the SRM with the RHM.

Further east, the RHM consists of a series of distinct tectonic nappe units comprising both oceanic and continental metamorphic rocks (Kilias and Mountrakis 1990). These units are intruded and overlain by post-metamorphic plutonic and volcanic rocks (Mposkos et al. 1989; Koukouvelas and Doutsos 1990; Dinter 1998; Burg et al. 1996). The RHM has been subdivided into two major units (Papanikolaou and Panagopoulos 1981): an upper unit (also known as Sidironero unit) and a lower one (also known as Pangeo unit), separated by a NE-dipping thrust fault (Fig. 2; Koukouvelas and Doutsos 1990). An alternative subdivision suggests two major thrust domains, a "lower terrane" and an "upper terrane", representing the crystalline footwall and hanging wall of a crustal-scale duplex (Burg et al. 1995;1996). The upper unit is also subdivided into several thrust nappes (from base to top: Echinos, Siroko, Konstantini and Kidari nappes; see Koukouvelas and Doutsos 1990 for details). The upper unit comprises mainly bi-mica gneisses, amphibolites and marbles. The lower Pangeo unit comprises schists, marbles, para- and orthogneisses with mica-schist and amphibolites. The metamorphic grade is inverted, passing from greenschist facies in the south to sillimanite-bearing migmatites in the north (Mposkos et al. 1989). The thrust that bound the nappes strike NW-SE and dip to the NE, indicating a regional vergence toward the southwest. Rb-Sr isochrones from the paragneisses and ortho- from the lowest part of Falakron Mt. (Pangeo unit) and on Thassos Island give late Palaeozoic ages (Del Moro et al. 1990; Wawrzenitz et al. 1994). These ages may reflect regional Hercynian deformation and metamorphism that may be restricted to the lowest part of the Falakron marble series. The marble series are being metamorphosed in the greenschist-facies (Kronberg and Raith 1977), while metamorphic grade increases down section.

Both RHM and SRM crystalline rocks were intruded by late-Oligocene post kinematic granodiorites of I-type (Christofidis 1977; Soldatos 1985) that supplied extrusive calc-alcaline magma. Oligocene plutons of the Rhodope zone, such as the Xanthi and the NE-Vrondou are composite, predominantly granodiorite plutons with minor gabbro and monzonite. In addition the Early Miocene Symvolon (or Kavala) pluton intruded the Pangeon gneisses and emplaced at about 21 Ma, based on U-Pb and $^{40}Ar/^{39}Ar$ dating (Dinter et al. 1995). This plutonic body lies along the trend of the Kavala-Komotini fault zone (Fig. 2).

3. STRUCTURAL ANALYSIS

Our structural survey in the area establishes the bulk geometry of the tectonic contact between the SRM and RHM and unravels the successive deformation phases. Based primarily on overprinting criteria observed in map to outcrop scales as well as on microstructural data, we have distinguished three principal deformation phases (D_1-D_3) to constrain the evolution of the thrust belt.

3.1 Ductile to semi-ductile deformational phases (D_1, D_2)

The ductile syn-metamorphic deformational phase D_1 comprises a S_1 foliation and an ENE- to ESE-trending mineral-stretching lineation L_1, which is defined by the alignment of high-grade minerals (Fig. 2, stereonets 1-4). The marbles in the study area are fine to coarsely crystalline, well foliated to massive. Foliation is defined by alternating dark to light bands of calcite, small amounts of impurities within the marble and minor variations in grain size. Lineation is formed by coarse calcite grains and quartz impurities. Our structural survey, as well as published data, suggests difference in the L_1 orientation within the SRM and the RHM. Throughout RHM, the L_1 shows a constant ENE-WSW orientation. Therefore, we assume that this orientation indicates the tectonic transport direction during D_1 shearing of RHM units. Within the rocks units of the SRM (Vertiskos and Kerdilia units), the mineral-stretching lineations show a more complex regional scale pattern involving a dominantly WNW-ESE orienta-

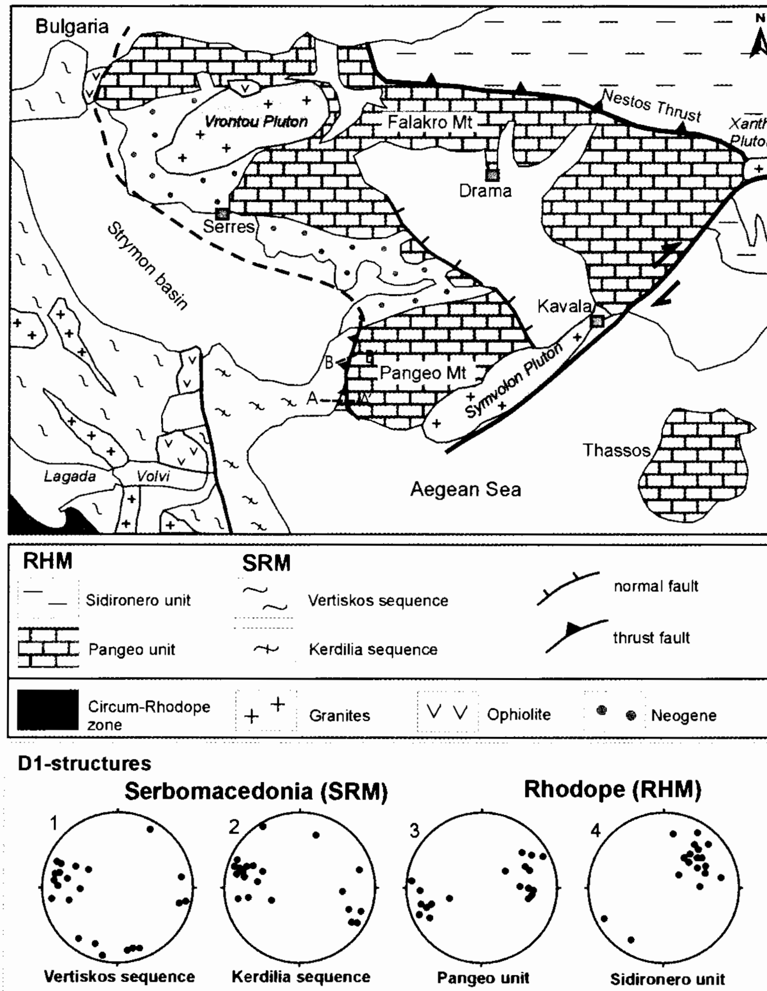

Fig. 2 Simplified geological map of the broader study area with the main tectonic structures. Stereonets 1-4 show the orientation of stretching/mineral lineations in SRM and RHM.

tion and a weak nearly NNE-SSW orientation (Fig. 2, stereonets 1,2). Structural mapping in the area showed that NNE-trending lineation is commonly observed close to the major fault contacts. Therefore, this local deviation of the L_1 can be interpreted as a result of local strain partitioning. The dominant WNW-ESE orientation of L_1 is interpreted to indicate transport direction during D_1 ductile shearing of SRM rock units.

In outcrop scale, the ductile deformation (D_1) in both the SRM and RHM is mainly expressed by widespread folding (F_1). The S_1 is axial planar to F_1-folds which are commonly tight to isoclinal, almost recumbent in style with curvilinear hinges. Throughout the study area the F_1-fold axes are oblique to sub-parallel to the L_1. Asymmetrical F_1-folds with axes at a high angle to L_1, exhibit a general southwestward vergence. Abundant isoclinal and similar in form F_1-folds with highly attenuated limbs and thickened crests are mainly observed near NW-

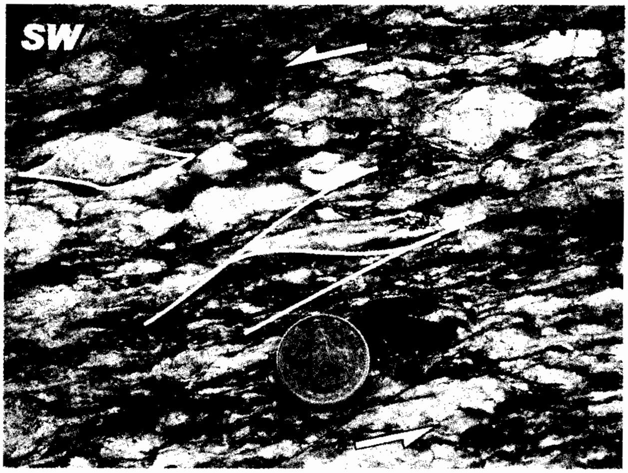

Fig. 3 Outcrop scale field photograph with kinematic indicators, such as σ-shaped objects and C/S structures, showing a top-to-the-SW sense of movement in the Rhodope massif.

trending ductile thrust zones implying a genetic relation between these structures. In the upper units of the RHM, a such major ductile thrust zone (Nestos thrust; Fig. 2), which dips slightly to the NE, are accompanied by thin protomylonites and sigmoidal flexures indicating SW-movement under ductile flow conditions. A similar top-to-the-SW sense of movement is also confirmed by kinematic indicators such as C/S fabrics and σ-shaped objects (Fig. 3), found within all rocks units of the RHM. Based on similar kinematic indicators a general top-to-the-WNW sense of shear during D_1 deformation was also identified for the rock units of the SRM.

D_2 deformational phase comprise outcrop scale open to tight asymmetric F_2-folds which occasionally refold F_1-folds. F_2-folds deform S_1 surfaces but are characterized typically by the absence of an axial planar cleavage. They display a semi-ductile type of deformation and their axes show a NE-orientation, verging towards NW. These two folds sets (F_1, F_2) seem more a continuous sequence of deformation than a temporal separated deformation phase. Probably they developed during progressive deformation under declining temperature conditions. However, It should be noted that a detail analysis of the highly complex interrelation of two folds sets is out of the focus of the present study. The spatial and temporal correlation of these fold generations is the aim of a forthcoming work.

3.2 Brittle to semi-brittle deformational phase (D_3)

The D3 deformational phase has produced well developed meso- to map scale structures that formed under brittle to semi-brittle conditions. Deformation is mainly accommodated by roughly NW-trending oblique thrust faults showing a general NE-ENE directed movement. Similar sense of motion is also supported by asymmetric kink folds which are associated with a dense SW-dipping cleavage.

A detailed structural analysis was made along two roughly NE-SW cross sections across the contact ("Strimolinie") between the Kerdilia unit and the Pangeon marble unit, north of Ofrynion area (Fig. 2, sections AA' and BB'). As indicated in both cross-sections (AA', BB' in Fig. 4), a major west-dipping low-angle thrust fault (D_3), which coincides with the 'Strymon overthrust' mapped by (Kockel and Walther 1965), carries the gneisses of Kerdilia unit to the west over the Pangeo marbles to the east. In the southern cross-section, this thrust contact is defined by 50 m thick fault zone (Fig. 4; inset in section AA'). In detail, the fault zone is characterized by a 20 m thick zone of ultracataclasites and foliated cataclasites that pass progressively eastward to a 30 m thick zone of tectonic breccia (Fig. 5d) close to the marbles. Numerous kinematic indicators such as minor

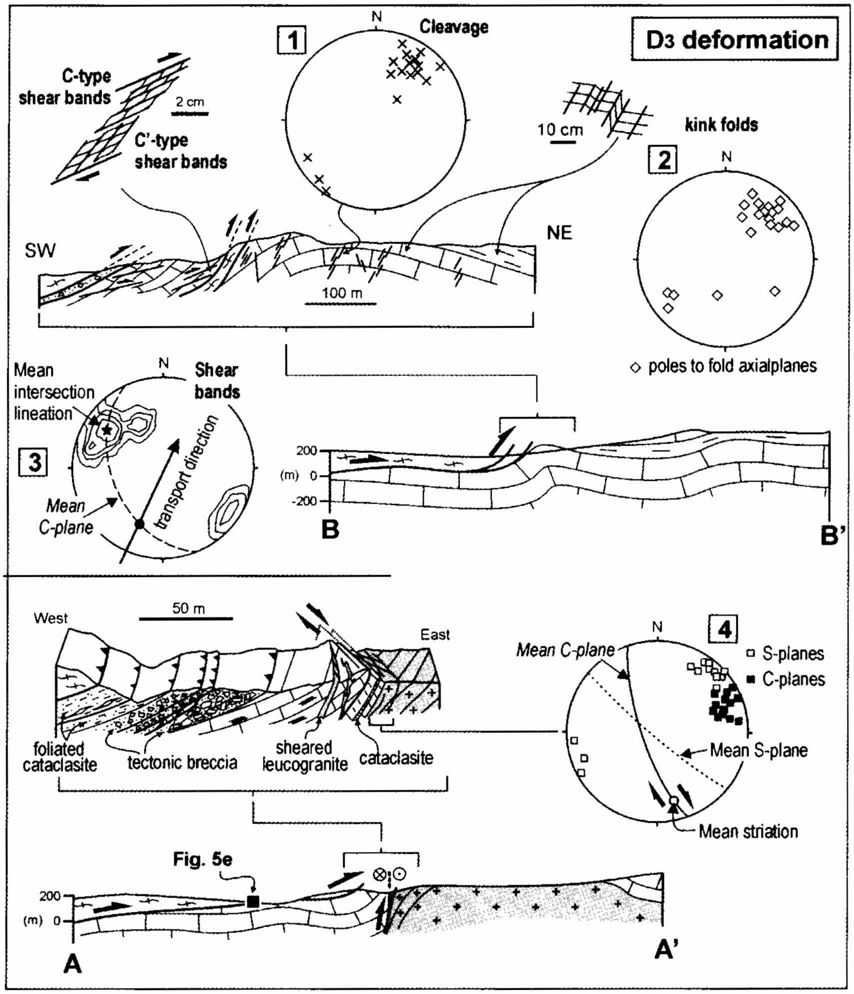

Fig.4 Schematic cross sections along the fault contact zone between SRM and RHM showing the structural and kinematic characteristics of the zone on stereonets (3-4) and inset illustrations.

thrust faults, C/S structures and folds indicate a clear top-to-the-E to NE sense of shear. In northern cross-section (BB' in Fig. 4), the thrust contact is characterized by a thinner zone of fault rocks which includes foliated cataclasite and tectonic breccia. Numerous shears surface that are compatible with simple shear model for brittle deformation were identified particularly within the zone of foliated cataclasites (Fig. 5a, b, c, e). The Riedel shear are often seen in the R1-orientation with the same sense of shear (synthetic) as the zone itself, while antithetic shears (R2) are less developed (Fig. 5b). The observed Y and P-shear surfaces are associated with minor folds. Mylonitic C/S structures are formed also in the marble unit showing a semi-brittle field of deformation (Fig. 5g). According to Sibson (1977) mylonite series can be formed in the semi-brittle field under lower greenschist grade of metamorphism. Tensile fracture arrays (T) are also common. They are formed initially normal to the least principal (zone interior) stress direction. Subsequently they are rotated

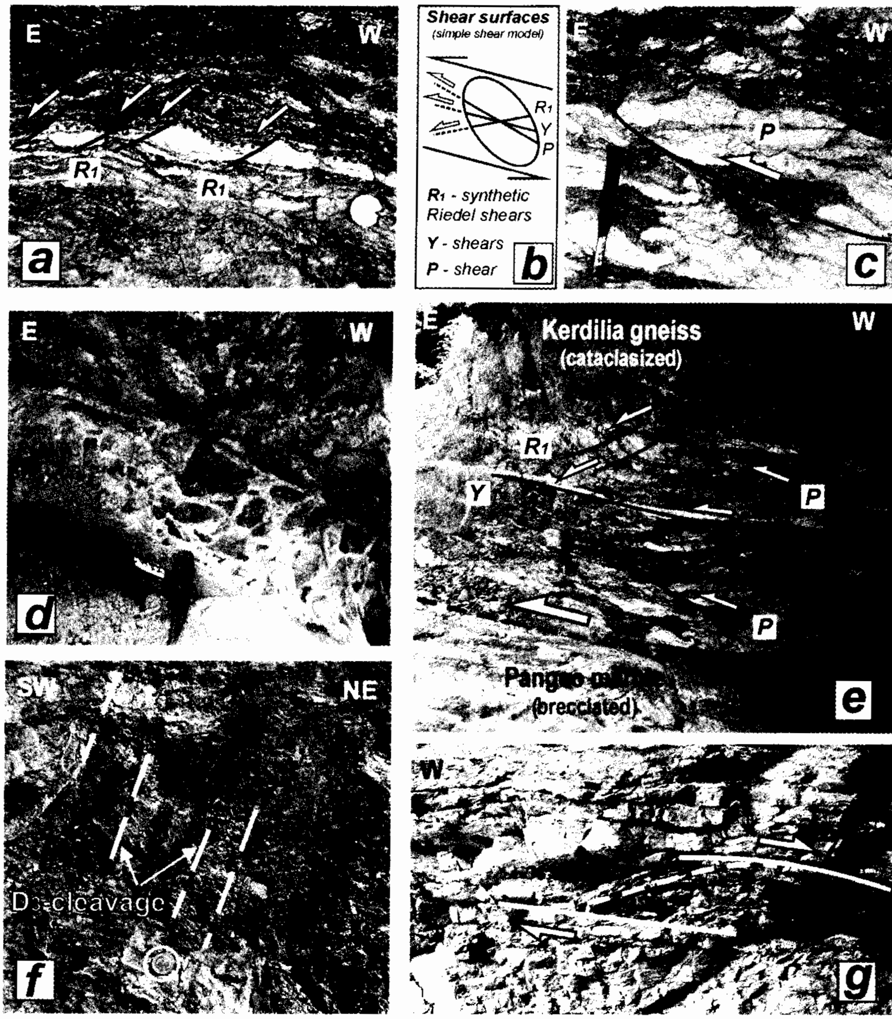

Fig. 5 Outcrop scale photographs along the low angle D_3-thrust contact between SRM and RHM showing: shear surfaces observed in the fault zone, compatible with a simple shear model for brittle deformation (b), such as the R_1-synthetic shears (a and e), P and Y-shears (c, e). The tectonic breccia along the fault (d) and the mylonitic C-S structures formed in the marble unit indicate the semi-brittle type of deformation.

by finite strain into more sigmoidal shapes (Fig. 5g). All structures observed in the fault zone have a distinctive geometrical relationship with the shear zone itself and confirm a general top-to-the-NE sense of shear. Their orientation is consistent with a simple shear condition of the fault and fabrics reflect the geometry of the strain field in the shear zone. These structures can be formed also prograding from a ductile to brittle deformation.

Another remarkable feature in the southern cross-section (Fig. 4, section AA') is the contact between the marbles of Pangeon unit with the granodiorite intrusion of Mesolakia, which mapped at the footwall of Strymon overthrust. A more detailed view of this contact depict a complex imbricate thrust fan (D_3-phase) that is developed 150 m from the main thrust. The contact between the marbles and the granodiorite is a NNW trending high angle fault, which dips steeply to the WSW, and displays sub-horizontal SSE trending lineations, a dense spaced pattern of C/S structures, formed in the granodiorite body, all compatible with dextral shearing. From all the above structural features this contact can be characterized as a dextral transpressional fault (Fig. 4, stereonet 4). Sheared leucogranites are also occurring along splays of the main fault contact.

4. STRUCTURAL SYNTHESIS

On the basis of kinematic analyses, this study distinguished three main deformational phases (D_1-D_3) for the tectonic evolution of the SRM and the RHM in Central Macedonia. The first two phases which recorded within both massifs were primarily associated with southwestern directed ductile thrusting. In agreement with previous interpretations for the area (e.g. Kilias et al. 1999), we consider an early Oligocene minimum age for the above-described D_1-$_2$ structures. The third brittle to semi-brittle phase of deformation resulted in the formation of NE-SW compression related structures. It is noteworthy that D_3 deformation was responsible for the formation of the contact ("Strimolinie") between the SRM and the RHM which is considered to be a large-scale thrust fault (D_3) with a 50 m thick fault zone. Moreover, based on the fact that D_3 transpressional deformation contributed to unroofing of Mesolakia granodiorite we assume that a significant part of this phase occurred during early Miocene time. Therefore, the D_3 deformation described here possibly coincide with a Late Oligocene-Early Miocene contraction phase described by Kockel et al. (1977) causing overthrust of SRM rocks over Oligocene molasse sediments and the creation of a conjugate set of strike-slip faults. A similar in age D_3 deformation phase was extensively described by Koukouvelas & Doutsos (1990) and Koukouvelas and Pe-Piper (1991), related also to the late orogenic phase observed further east in Thrace, as suggested by Karfakis and Doutsos (1995).

5. CONCLUSIONS

Three stages of deformation are recognized in this study, which are similar in character and style with the stages described elsewhere in SRM or RHM (e.g. Koukouvelas & Doutsos 1990; Burg et al. 1996).

In contrast to previous works (e.g. Burg et al. 1995) it seems that the 'Strimolinie' is a major tectonic zone significant for the orogenic evolution of the massif in the Central Macedonia.

The main Oligocene-Miocene stage of deformation is characterized by the formation of contraction related structures involving mainly large-scale (oblique) thrust faults, kink folding and densely spaced cleavage. Kinematic indicators along the SRM-RHM contact zone indicate a top-to-the E to NE sense of shear.

Further work is needed in order to examine the role and the kinematics of this significant fault zone during the closure of the Vardar Ocean further west.

REFERENCES

Aleksic V., Dimitriadis S., Kalenic M., Stojanov R., Zagorcev I., 1986. Precambrian in the Serbo-Macedonian massif, In: Zoubek V., (ed.) Precambrian in younger fold belts; Europe an Variscides, the Carpathians and Balkans, Wiley, pp. 779-820.

Burg J. P., Godfriaux I., Ricou L. E., 1995. Extension of the Mesozoic Rhodope thrust units in the Vertiskos-Kerdilion Massifs (northern Greece), C R Acad Paris 320, 889–896.

Burg J. P., Ricou L. E., Ivanov Z., Godfriaux I., Dimov D., Klain L., 1996. Syn-metamorphic nappe complex in the Rhodope Massif. Structures and kinematics, Terra Nova 8, 6–15.

Christofidis G., 1977. A contribution to the study of the plutonic rocks of Xanthi area (in Greek, English abstract), Ph.D. Thesis, University of Thessaloniki, 249 pp.

Del Moro A., Kyriakopoulos K., Pezzino A., Atzori P., Lo Giudice A., 1990. The metamorphic complex associated to the Kavala plutonites: an Rb-Sr geochronological, petrological and structural study. Geologica Rhodopica 2, 143-156.

Dinter D.A., Royden L., 1993. Late Cenozoic extension in northeastern Greece: Strymon Valley detachment system and Rhodope metamorphic core complex, Geology 21, 45–48.

Dinter D.A., Macfarlane A., Hames W., Isachsen C., Bowring S., Royden L., 1995. U–Pb and $^{40}Ar/^{39}Ar$ geochronology of the Symvolon granodiorite: implications for the thermal and structural evolution of the Rhodope metamorphic core complex, northeastern Greece, Tectonics 14, 886–908.

Dinter D. A., 1998. Late Cenozoic extension of the Alpine collisional orogen, northeastern Greece; origin of the North Aegean Basin, Geological Society of America Bulletin 110, (9), 1208-1226.

Godfriaux I., Ricou L. E., Burg J. P., 1996. Extension of the Mesozoic Rhodope thrust units in the Vertiskos-Kerdilion massifs (Northern Greece), Terra Abstracts 12, 176.

Jacobshagen V., Dórr S., Kockel F., Kopp K.O., Kowalczyk G., Berckhemer H., Büttner D., 1978. Structure and geodynamic evolution of the Aegean region. In: Closs H, Roeder D, Schmidt K (eds) Alps, Apennines, Hellenides. Schweizerbart, Stuttgart, pp 537–564

Karfakis J., Doutsos T., 1995. Late orogenic evolution of the Circum-Rhodope Belt, Greece, N Jahrb Geol Palδont Mh 5, 305–319.

Kilias, A. and Mountrakis, D. (1990). Kinematics of the crystalline sequences in the western Rhodope massif. Geologica Rhodopica, 2nd Hellenic-Bulgarian Symposium, Thessaloniki, vol. 2, 100-116.

Kilias A., Falalakis G., Mountrakis D., 1999. Cretaceous-Tertiary structures and kinematics of the Serbomacedonian metamorphic rocks and their relation to the exhumation of the Hellenic hinterland (Macedonia, Greece), Int.Journ. Earth Sciences 88, 513-531.

Kockel F., Walther H., 1965. Die Strimonlinie als Grenze zwischen Serbo-Mazedonischem und Rila-Rhodope Massiv in Ost Mazedonien, Geol Jahrb 83, 575–602.

Kockel F., Mollat H., Walther H., 1971. Geologie des Serbomazedonischen Massivs und seines mesozoischen Rahmes (Nordgrienchenland), Geol Jahrb 89, 529–551.

Kockel F., Mollat H., Walther H., 1977. Erlδuterungen zur geologischen Karte der Chalkidhiki und angrenzender Gebiete, 1:100,000 (Nord-Griechenland), Bundesanstalt fur Geowisseschaften und Rohstoffe, Hannover, 119 pp

Koukouvelas I., Doutsos T., 1990. Tectonic stages along a traverse cross cutting the Rhodopian zone (Greece). Geol. Rundschau 79, 753-776.

Koukouvelas I., Pe-Piper G., 1991. The Oligocene Xanthi pluton, northern Greece : a granodiorite emplaced during regional extension. J. Geol Soc London 148, 749-758.

Kronberg P., Raith M., 1977. Tectonics and metamorphism of the Rhodope crystalline complex in eastern Greek Macedonia and parts of western Thrace, N. Jb. Geol. Palaont., Mh., 1977, 697-704.

Mposkos E., Papadopoulos P., Perdikatsis V., 1989. The Rhodope crystalline basement east of Komotini, Bulletin of the Geological Society of Greece 20, (2), 259-273.

Mposkos E., 1989. High-pressure metamorphism in gneisses and pelitic schists in East Rhodope zone (N. Greece), Mineral. Petrol 41, 337-351.

Papadopoulos C., Kilias A., 1985. Altersbeziehungen zwischen Metamorphose und Deformation im zentralen Teil des Serbomazedonischen Massivs (Vertiskos Gebirge, Nord-Griechenland), Geol Rundsch 74, 77–85.

Papanikolaou D., Panagopoulos A., 1981. On the structural style of southern Rhodope, Greece, Geol. Balc. 11, 13–22

Sibson R. H., 1977. Fault rocks and fault mechanisms, Journal of the Geological Society, London 133, (3), 191-213.

Soldatos T. K., 1985. Petrology and geochemistry of the Elatia pluton, (In Greek with English summary), Ph.D. Thesis, University of Thessaloniki, 262 pp.

Wawrzenitz N., Baumann A., Nollau G., 1994. Miocene uplift of mid-crustal rocks in the Rhodope Metamorphic Core Complex, caused by late alpine extension of previously thickened crust (Thassos Island, Pangaeon Complex, Northern Greece), Bull Geol Soc Greece 30, 147–157.

ΠΕΡΙΛΗΨΗ

ΤΕΚΤΟΝΙΚΗ ΕΞΕΛΙΞΗ ΚΑΙ ΚΙΝΗΜΑΤΙΚΗ της ΖΟΝΗΣ ΕΠΑΦΗΣ ΜΑΤΑΞΥ ΤΗΣ ΣΕΡΒΟΜΑΚΕΔΟΝΙΚΗΣ ΚΑΙ ΡΟΔΟΠΙΚΗΣ ΜΑΖΑΣ, ΚΕΝΤΡΙΚΗ ΜΑΚΕΔΟΝΙΑ

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Στην εργασία αυτή παρουσιάζονται τεκτονικά στοιχεία υπαίθρου και κινηματικοί δείκτες που συλλέχθηκαν κατά μήκος της επαφής μεταξύ των ισοπικών ζωνών της Σερβομακεδονικής και Ροδόπης με στόχο να περιγραφούν οι φάσεις της παραμόρφωσης της. Διαχωρίστηκαν τρεις κύριες φάσεις παραμόρφωσης, με βάση σχέσεις υπέρθεσης των διαφόρων τεκτονικών στοιχείων μεταξύ τους και τον πλαστικό ή εύθραυστο τύπο της παραμόρφωσης.

Η πλαστικού τύπου συν-μεταμορφική φάση παραμόρφωσης D_1 χαρακτηρίζεται από μια γενική φολίωση S_1 και μια κρυσταλλική γράμμωση έκτασης L_1 που καθορίζεται από επιμηκυσμένους κρυστάλλους ορυκτών υψηλού βαθμού μεταμόρφωσης. Η γράμμωση αυτή παρουσιάζει προσανατολισμό σε μια ΑΒΑ έως ΑΝΑ διεύθυνση. Τοπικές αποκλίσεις από αυτή τη γενική διεύθυνση προς μια διεύθυνση Β-Ν παρατηρήθηκαν κυρίως κοντά σε μεγάλες επωθήσεις. Όλες οι σχετιζόμενες με τη φορά κίνησης πλαστικές δομές στο μεσοσκοπικό πεδίο υποδηλώνουν μια γενική κίνηση προς τα Δ-ΝΔ. Η δεύτερη χαρακτηρίζεται κυρίως από μεσοσκοπικές κλειστές έως σφικτές πτυχές που σχηματίστηκαν κάτω από ημι-πλαστκές έως εύθραυστου τύπου συνθήκες παραμόρφωσης. Οι πτυχές αυτές επηρεάζουν τις δομές της προηγούμενης φάσης και πτυχώνουν την πρώτη φολίωση S_1 ενώ οι άξονές τους εμφανίζουν διασπορά γύρω από μια ΒΑ-ΝΔ διεύθυνση. Οι πτυχές της D_2 φάσης παραμόρφωσης παρουσιάζουν ασυμμετρία προς τα ΒΔ ενώ συχνά σχετίζονται με πυκνές επιφάνειες σχισμού αξονικού επιπέδου.

Τέλος, η φάση παραμόρφωσης D_3 σχετίζεται με τη δημιουργία μεσοσκοπικών και μεγάλης κλίμακας πτυχών και επωθήσεων και ένα καλά εκφρασμένο σχισμό αξονικού επιπέδου. Οι δομές αυτές σχηματίστηκαν σε σχεδόν-εύθραυστες συνθήκες παραμόρφωσης. Οι επωθήσεις της D_3 φάσης παραμόρφωσης έχουν διεύθυνση ΒΒΔ- και κινηματική η οποία χαρακτηρίζεται από σημαντική πλάγια συνιστώσα κίνησης. Η γενική διεύθυνση κίνησης των πετρωμάτων κατά την φάση αυτή είναι προς τα ΒΑ. Στην κλίμακα του χάρτη, το γεωλογικό όριο μεταξύ των κατώτερων ενοτήτων της Σερβομακεδονικής ζώνης (ενότητα των Κερδυλίων) και της Ροδόπης (ενότητα Παγγαίου) στην εργασία αυτή θεωρείται ως μια χαμηλής κλίσης επώθηση που σχετίζεται με την παραμορφωτική φάση D_3. Ο πυρήνας της ρηξιγενούς αυτής ζώνης περιλαμβάνει κατακλαστική ζώνη πάχους 15 μέτρων καθώς και μια ζώνη έντονης τεκτονικής παραμόρφωσης που πιστοποιείται από λατυποπαγές με πάχος που φτάνει τα 50 μέτρα. Οι κινηματικοί δείκτες εντός της ρηξιγενούς ζώνης υποδηλώνουν μια προς τα ανατολικά διατμητική παραμόρφωση κατά μήκος της ζώνης αυτής. Στη βάση της επώθησης αυτής, τα μάρμαρα του Παγγαίου εμφανίζουν μια ζώνη, πάχους 50 μέτρων, έντονης μυλονιτικής φολίωσης.