TECTONIC EVOLUTION OF THE OLYMPUS-OSSA MOUNTAINS: EMPLACEMENT OF THE BLUESCHISTS UNIT IN E....

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TECTONIC EVOLUTION OF THE OLYMPUS-OSSA MOUNTAINS: EMPLACEMENT OF THE BLUESCHISTS UNIT IN EASTERN THESSALY AND EXHUMATION OF OLYMPUS-OSSA CARBONATE DOME AS A RESULT OF TERTIARY EXTENSION (CENTRAL GREECE)

ADAMANTIOS KILIAS*

ABSTRACT

High pressure metamorphic rocks in the area of Olympus-Ossa (Eastern Thessaly, Central Creece), were formed in Eocene under a pressure of 6-9 Kb and a temperature of 300°-350° C at a depth greater than 20 Km, during plate convergence and nappe stacking. Kinematic and strain analyses of the high pressure metamorphic belt and its surroundings showed that the uplift history of the high pressure rocks is related to an intense Upper Eocene/ Oligocene to Miocene subhorizontal stretching and subvertical thinning. It took place in two stages: During the first stage, the high pressure metamorphic rocks and the overlying nappe pile were emplaced over the nearly unmetamorphosed Olympus-Ossa carbonate unit of the foreland. The emplacement was possible due to changes in the rate or in the direction of plate convergence. Large scale antithetic normal movement of masses towards NE or SW, took place during the second stage causing the final uplift and exhumation of the high pressure rocks and the underlying sediments, of the Olympus-Ossa unit, in the form of a tectonic window. This extension regime is related with a large scale underplating of cold continental material of the foreland under the extending nappe pile of the upper plate, during the continuing plate convergence, as well as to the formation of the thrust belts and nappes in the external Hellenides.

INTRODUCTION

HP/LT rocks formed as a consequence of a rapid burial of basic rocks and sediments at a depth > 20 km, in the subduction zone of the Apulian plate under the Pelagonian continental block, during the Eocene (GODFRIAUX 1968, PAPANIKOLAOU 1987, SCHLIESTEDT et al. 1987, SCHERMER et al. 1989, KILIAS et al. 1991 b).

Through a rapid uplift, mechanism (<50 million years ENGLAND and THOMPSON 1984) without any major contribution of heat and retrograde postburial heating, the HP/LT parageneses were preserved in places, so that nowadays these rocks form the inner belt of the blueschists of the Hellenides. Distinctive occurences are preserved in the Olympus-Ossa area in eastern Thessaly, also known as the Ambelakia unit (GODFRIAUX 1968, KATSIKATSOS et al. 1982, SCHERMER 1990,

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KILIAS et al. 1991 b), as well as in the areas of Pelion, (FERRIERE 1977), Euboea (KATSIKATSOS 1977), and the Cyclades (ALTHERR et al. 1979, BLAKE et al. 1981, SCHLIESTEDT et al. 1987, AVIGAD 1990) (Fig. 1.).

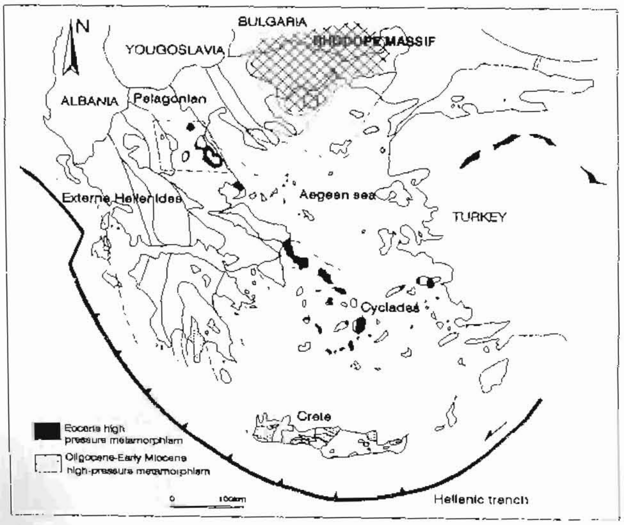

FIGURE 1: *Location of the study area in the Hellenides. Development of the two HP/LT metamorphic belts in the Hellenic orogen: The inner one of eocenic age and the outer one of Late Oligocene/Early Miocene age.*

Wherever the post-Eocene reheating of the crust was significant, as in the case of the Cyclades the high pressure parageneses were intensely overprinted by high temperature barrovian type metamorphism (ANDRIESSEN et al 1979, ALTHERR et al. 1982, WIJBRANS & McDOUGALL 1988).

In this paper a new concept for the uplift and emplacement regime of the blueschists of eastern Thessaly is snggested. It includes the overlying Pelagonian nappes, and the nearly nonmetamorphosed carbonate Olympus-Ossa unit of the foreland (Fig. 2, 3). Furthermore, we offer an interpretation of the exhumation mechanism of the high pressure rocks and the underlying sediments of the foreland in the form of a tectonic window.

To reach our conclusions we have used the following: a) the symmetry and geometry of all recognizable structures of the blneschists and of the tectonic units directly underlying and overlying them, b) the modern methodology of kinematic analysis (RAMSAY & HUBER 1983/1987, SIMPSON & SCHMID 1983), c) the relations between metamorphism and tectonics and d) the method of strain analysis (Rf/Φ method, LISLE 1985; Fry method, HANA & FRY 1979; quartz c-axis diagrams LISTER & HOBBS 1980).

GEOLOGICAL SETTING

The geology of the Olympus-Ossa area has been studied by many investigators. It attracts the geologists' interest, since numerous questions concerning the evolution of the Hellenides are closely associated with the evolution of the suture zone between the lower Apulian plate and the upper Pelagonian continental fragment. This is actually reflected in the structure and tectonic evolution of the blueschists of the area (Fig. 1).

The blueschists unit in the Olympus-Ossa area consists of alternations of metabasites and metasediments which was subducted below the Pelagonian continental block, during the Eocene and was metamorphosed under HP/LT conditions (SCHERMER et al. 1989, SCHERMER 1990, KILIAS et al. 1991a). During the Oligocene, it was progressively affected by a retrograde low grade metamorphism, (KATSIKATSOS et al. 1982, KILIAS et al. 1991b).

This HP/LT-rock unit is emplaced over the slightly metamorphosed to nonmetamorphosed carbonate sediments of the Olympus-Ossa unit, ranging from the Triassic to the Eocene, and terminating in a flysch of late Eocene age (GODFRIAUX 1968).

The Olympus-Ossa unit belongs to the "lower plate", which acted as the foreland during the Tertiary collision of the southern branch in the Alpine orogene (GODFRIAUX 1968, JACOBSHAGEN et al. 1978, KILIAS et al. 1991a). Nowadays it appears in the form of a tectonic window. A similar tectonostratigraphy is recognized in the tectonic windows of Kranea, west of Olympus-Ossa (KILIAS & MOUNTRAKIS 1987, KILIAS et al. 1991a) and of Rizomata further to the north (KILIAS & MOUNTRAKIS 1985) (Fig. 2, 3).

The pile of the Pelagonian nappes constitutes the "upper plate" of the Tertiary collision zone, which was originally emplaced over the blueschists (GODFRIAUX 1968, YARWOOD & DIXON 1977, JACOBSHAGEN et al. 1978, KILIAS 1980, KILIAS 1991, NANCE 1981, KATSIKATSOS et al. 1982, MIGIROS 1983, MOUNTRAKIS 1983, KILIAS & MOUNTRAKIS 1987/1989, DOUTSOS et al. 1993). The unit of ophiolitic rocks (Eohellenic nappe. JACOBSHAGEN et al. 1976, VERGELY 1984), together with the Cretaceous transgressive carbonate

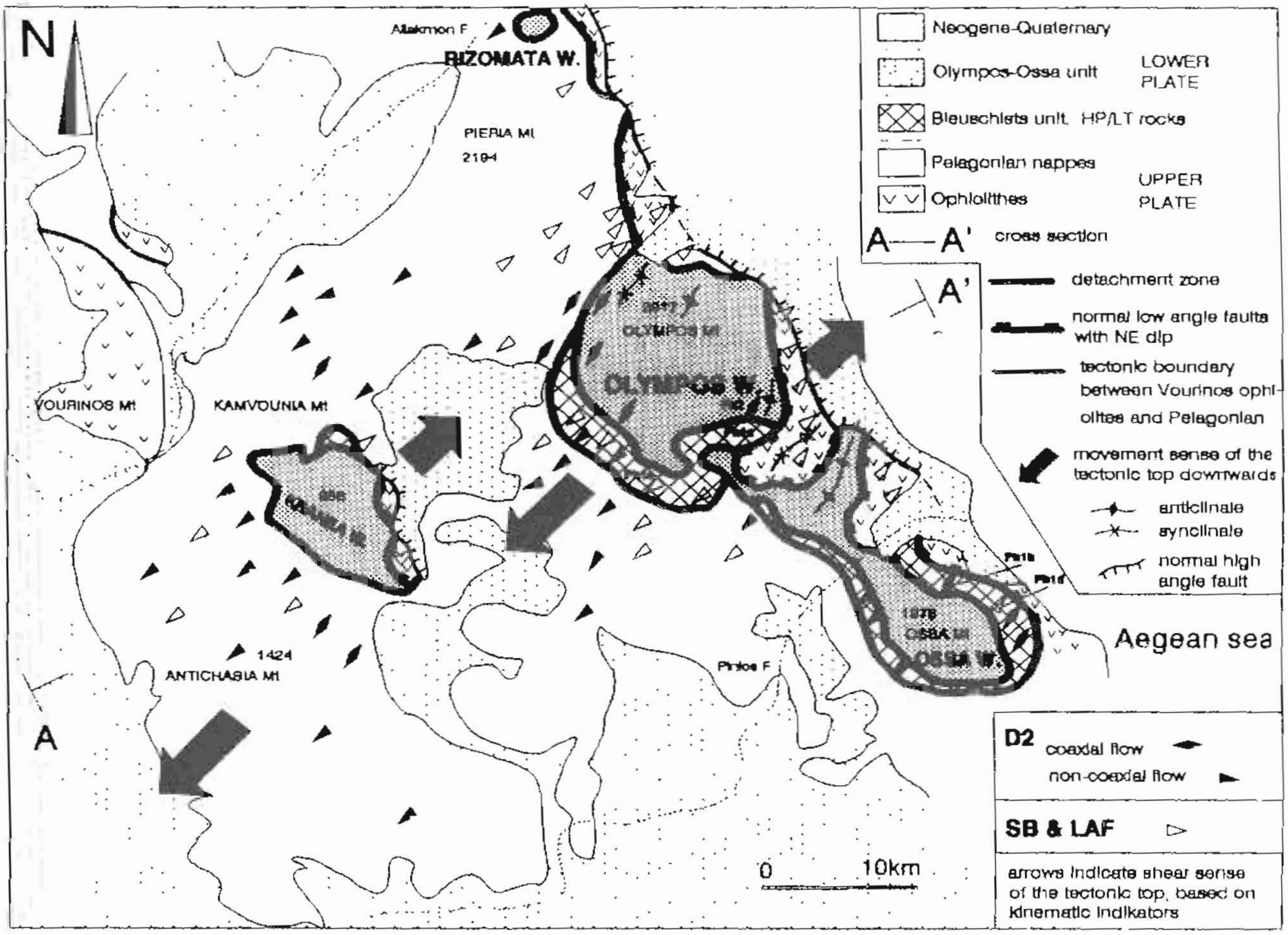

FIGURE 2: *Geological map of the Olympus-Ossa area. Compilation of shear criteria for D2 deformation. Arrows indicate the normal opposed sence of movement of the nappe pile in the central Hellenides during the Oligocene-Miocene. Geological mapping: BRUNN 1956, GODFRIAUX 1968, SCHMITT 1983, MIGIROS 1983. MIGIROS et al. 1985, KILIAS & MOUNTRAKIS 1985, 1987, 1989, SCHERMER 1990, KILIAS et al 1991a,b).*

which terminates in Eocene flysch (GODFRIAUX 1968, MERCIER; 1968, FERRIERE 1982, CLEMENT 1983), is recognized as the uppermost nappe (Fig. 2,3).

DATA AND OBSERVATIONS

Geometry and kinematics of the deformation

An S1-schistosity and B1- intrafolial isoclinal folds, as well as sheath folds, forming representative structures of the earliest D1-event are identified in the blueschist unit. A kinematic analysis of this initial stage is not possible since the D1-structures are almost entirely affected by the second D2-penetrative ductile event (Photo 1a). D2 causes an intense transposition of the S1-schistosity in S2, so that S1 and S2 develop almost parallel and they cannot often be distinguished from each other (Fig. 4, Photo 1a, b, c). The associated with the S2 fabric L2 stretching lineation, defined by elongated and ruptured minerals and mineral aggregates mainly develops with a NE-SW trend (Fig. 5). The L2-stretching lineation west of the carbonate Olympus-Ossa window plunges SW while, on the contrary, east of the window it plunges NE, following the general trend of the S2-schistosity (Fig. 3, 4). The B-axes of the isoclinal folds usually develop parallel to the L2 stretching lineatiou. (KILIAS et al. 1991a, b).

During this second D2-event all kinematic indicators and the strain analysis, register either a major component of coaxial deformation or movement of the tectonic top towards SW. In places, diplacement develops also antithetic to the overal top to SW sense of shear, due to downwards glide along steep NE dipping glide surface (Fig. 9).

A map scale evolution of the sense of shear indicators is presented in Fig. 2. Coaxial strain

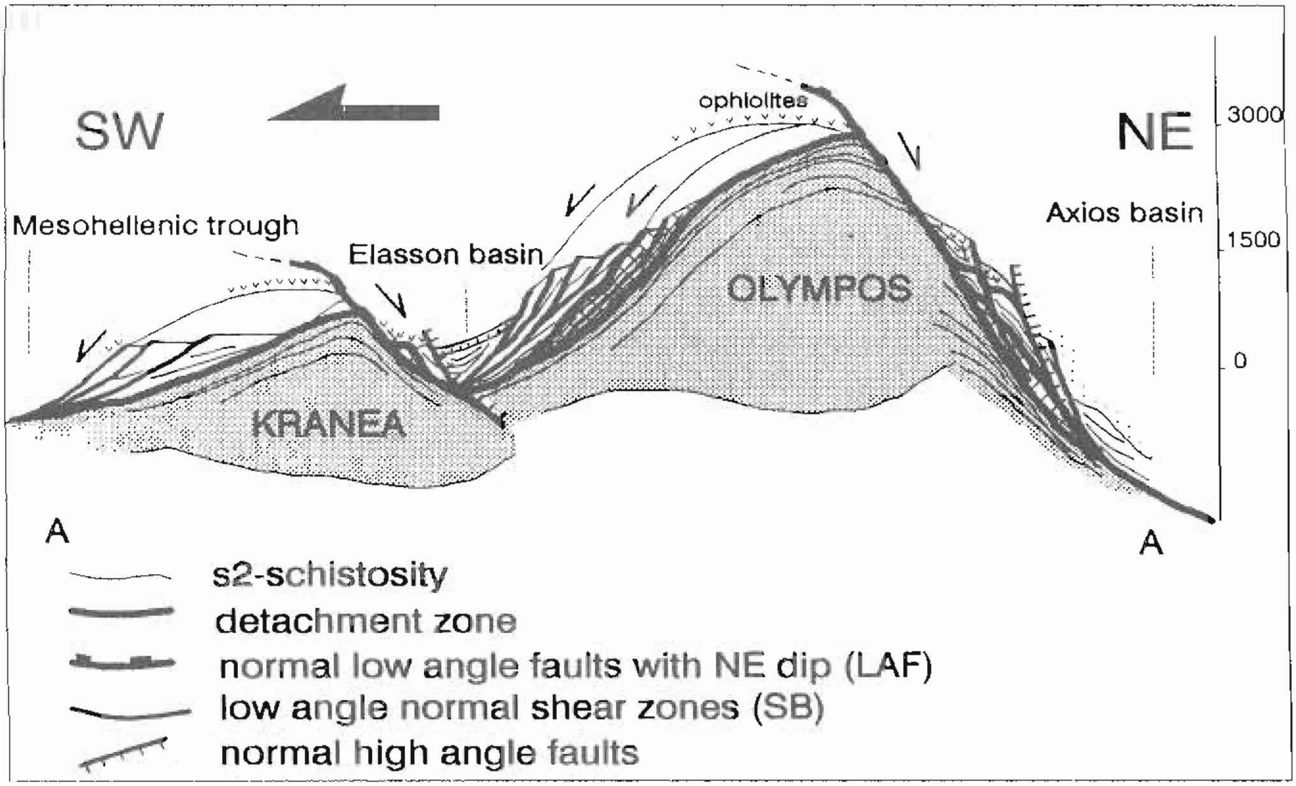

FIGURE 3: *Geological cross section along the nappes of the central Hellenides, from the Axios basin to the Mesohellenic trough. The asymmetry of the Olympus and Ossa carbonate domes (lower plate), is also shown. Symbols as in fig. 2.*

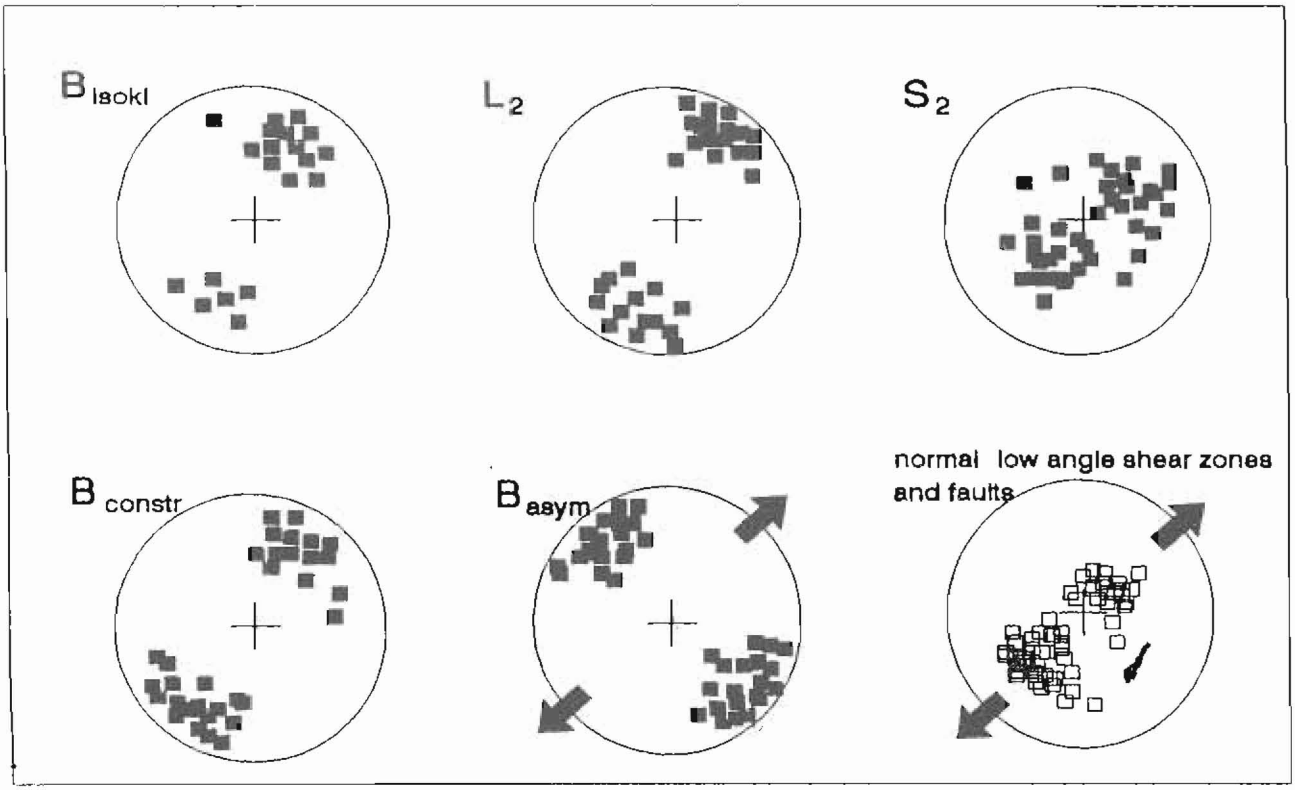

FIGURE 4: *Stereographic projection of the tectonic structures of the Olympus-Ossa area (Schmidt equal-area net, lower hemisphere).*

seems to be predominate mainly in the lower parts of the blueschist unit whereas the hanging wall parts, of the blueschists seems to have suffered non-coaxial flow.

The coaxiality of the deformation is stressed by the development .of symmetrical conjugate shear zones, associated with the main S2 foliation, with an opposite sense of shear, (Photo 1b), symmetrical boudinage of competent layers, and symmetrical elongation of clasts and mineral aggregates. (Photo 1b).

Southwestwards sense of shear of the tectonic top show: S-C structures (LISTER & SNOKE 1984), asymmetricaly rotated clasts of rigid minerals or mineral aggregates in their surrounding ductile matrix (PASSCHIER & SIMPSON 1986), extensional shear bands of high shear strain formed synchronously with the main S2-foliation (PLATT & VISSERS 1980), asymmetric mica fish (LISTER & SNOKE 1984), asymetric boudins (SIMPSON & SCHMIDT 1983, HOOPER & HATHCER 1988), S-Z-type folds in heterogeneous shear zones (VAN DEN DRIESSCHE & BRUNN 1987). A top to SW large scale movement in the Mt. Olympus region was also described by previous workers (KILIAS et al 1991, SFEIKOS et al 1991, SCHERMER 1993).

The partitioning of coaxial and non-coaxial flow cinematics is also demonstrated by comparison of quartz-c-axis fabrics. Fig. 5 schows quartz-c-axis fabrics with orthorhombic symmetry (1,2,4: coaxial) and monoclinic symmetry top to SW (3: non-coaxial).

Progressively, during the development of the D2-event there develops locally, a compression parallel to the Y-axis of the finite strain ellipsoid. Thus typical compressional structures (thrust faults and asymmetric open folds) are produced orientated parallel to the maximum stretching. (Fig. 2, 8).

The D2-deformation is also conveyed, with similar symmetry and kinematics, to the Pelagonian nappes of the upper plate, over the blueschist unit (KILIAS et al. 1991 a,b, SFEIKOS et al. 1991, SFEIKOS 1992).

A significant component of coaxial flow also prevails in the underlying Olympus-Ossa lower plate and particularly towards the boundaries with the blueschists or the overlying nappes of the upper plate. In the sediments of the Olympus-Ossa unit (Photo 2) develop two coeval sets of shear bands and abundant symmetric boudinage of competent layers. The maximum extension is NE-SW, similar to that of the bluschist unit, during the D2-event. The S2 mylonitic fabric and the boundary between upper and lower plate, are always parallel (Fig. 3).

The results obtained from the strain analysis (Rf/Φ- and Fry-methods) of the blueschists and the gneissic mylonites of the Pelagonian nappe, revealed a considerable thinning, perpendicular to the S2 schistosity, as well as a subhorizontal development of the maximum stretching (x-axis) with a NE-SW trent (KILIAS et al. 1991b, SFEIKOS et al. 1991, KILIAS 1991, SFEIKOS 1992).

The low angle (10° to 30°) conjugate shear zones (SB), with a movement of top downwards and the low angle normal faults (LAF), with a NW-SE strike, are also important tectonic structures in the blueschist unit. These structures persist with a similar intensity also in the Pelagonian and ophiolite nappes.

The geometry of these discrete extensional shear zones is illustrated in figure 3 and Photo 1c, d, e. The listric surfaces of these zones terminate in the main detachment zone of the two plates. The kinematics and geometry of these extensional shear zones exhibit a symmetry similar to that of the ductile D2-stretching. This is indicated by tbe NE-SW striations on their sliding planes. It is recognized that a top to the SW sense of shear prevails to the west of the Olympus-Ossa dome, while a NE sense of movement prevails to the east (Fig. 2, 3). Similar conditions of kinematics are also preserved in the Kranea and Rizomata tectonic windows (Fig. 2, 3) (KILIAS et al. 1991a, SFEIKOS et al. 1991). Asymmetrical open folds or kink zones with vergence sometimes NE and sometimes SW, often accompany this downward sliding of the rocks (Fig. 4).

A large scale downwards slide of rock masses along these extensional conjugate shear structures, resulted in the juxtaposition of the tectonically higher units of the nappe edifice with the lower ones (Fig. 3). Thus, we see normal displacements between the difference tectonic nappes, in places associated with an omission or intense thinning, of whole nappes. For example, we see the pelagonian basement in the western side of the Olympus carbonate dome, in direct tectonic contact with the rocks of the underlying Olympus-Ossa unit. In contrast, in the eastern side of the Olympus dome the ophiolitic nappe mouving downwards to the NE is emplaced directly on the blueschist unit or still on the lowermost Olympus-Ossa unit (Fig. 2, 3).

It is recognized that the movement of rock masses towards NE at the eastern side of the Olympus-Ossa, Kranea and Rizomata windows displays a greater throw (Fig. 2, 3). The preservation of the uppermost ophiolitic nappe in two narrow zones along the eastern sides of the Olympus-Ossa and Kranea carbonate domes, in direct tectonic contact with the rocks of the lower plate units, confirm this asymmetrical collapse of the nappes (Fig. 2, 3).

The asymmetrical distribution of these conjugate extensional shear zones on either side of the Olympus-Ossa and Kranea tectonic windows, also combined with the D2-kinematic regime previously described, produces a mega-domino structure in the nappe pile of the inner Hellenides, in the wider Olympus-Ossa area. This asymmetry is reflected also in the asymmetry of the Olympus-Ossa and Kranea carbonate domes, as demonstrated by the steeper development of their intense fractured eastern side (Fig. 2, 8, 9).

Finally, younger high angle normal fanlts, in various directions and with corresponding complicated neotectonic kinematics, fragment the rocks of the study area (CAPUTO 1990, MERCIER et al. 1989, PAVLIDES et al. 1990, CAPUTO & PAVLIDES 1993, MOUNTRAKIS et al. 1993).

Stratigraphy criteria of the syntectonic basins in the wider Olympus-Ossa area (BRUNN 1956, GODFRIAUX 1968, LALECHOS & SAVOYAT 1979, BENDA & STEFFENS 1982, MIGIROS et al. 1985, TRIANTAFILLIS et al. 1987, CAPUTO 1990) and the kinematic analysis of the brittle tectonics, showed that the older generation of these tectonic faults developed mainly with a NW-SE strike. These display a kinematic symmetry similar to that of the preceeding ductile to semiductile tectonics. Paleostress analyses by the ANGELIER (1979) and CAPUTO & CAPUTO (1988) methods yielded a finite stress ellipsoid, with an almost subhorizontal NE-SW striking axis of the minimum σ3 stress and with an almost vertical axis of the maximum σ1 stress ($\sigma1>\sigma2>\sigma3$ Fig. 6).

Metamorphism-tectonics relations. Timing of deformation

Some microscopic and mesoscopic features show that D1 in the blueschist unit took place simultaneously with the HP/LT metamorphism (M1-

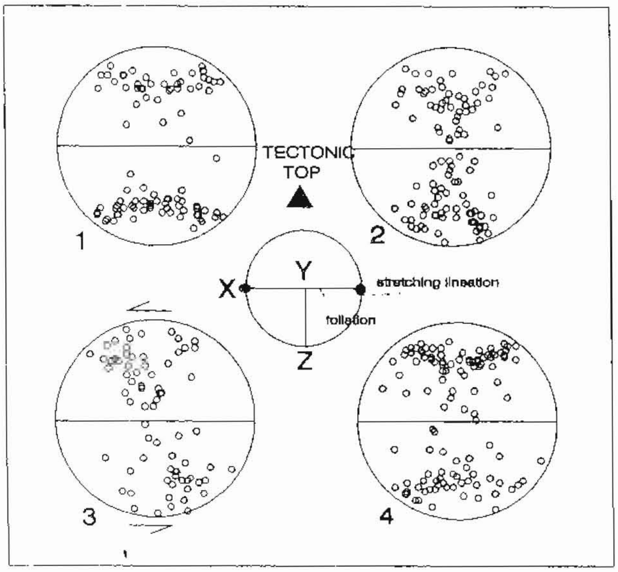

FIGURE 5: *Quartz-c-axis fabrics in samples from the blue schist unit. The distribution symmetry of the quartz c-axis plot appearing in diagrams 1, 2 & 4, indicates a coaxial deformation regime. X, Y, Z, are the finite strain ellipsoid axes, X > Y > Z.*

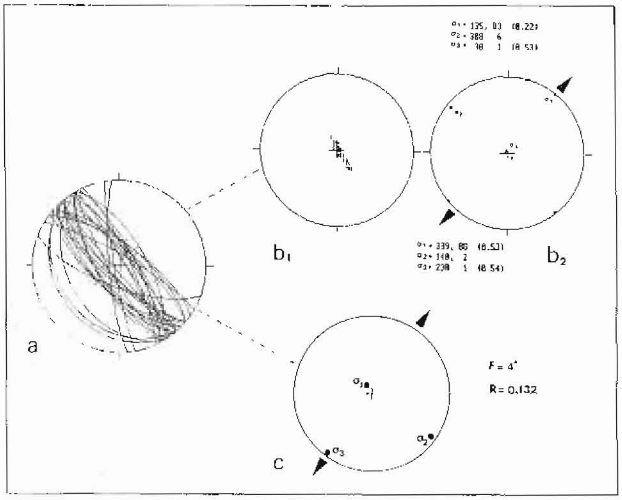

FIGURE 6: *Paleostress analysis diagrams of the older generation of neotectonic normal faults from the Olympus-Ossa area (Schmidt equal-area net, lower hemisphere).*

a. Schmidt equal-area, lower hemisphere projection of fault planes and their striations

PROGRAM FAULT (CAPUTO & CAPUTO, 1988).

b1. The results of the right-diedrons method.

b2. Orientation of the three principal axes of stress ellipsoid (s1>s2>s3)

INVERSE METHOD (ANGELIER 1979).

c. Position of the three main axes of the stress ellipsoid, R=ellipticity, F=fluctuation.

metamorphism). These are as follows: (1) S1-schistosity is defined by elongate minerals of the M1-high pressure paragenesis such as: blue amphibole, epidote, white mica, chlorite, and remnants of lawsonite (Photo 1a), (2) tension gashes, D1 microshear zones and pull apart ruptures in augite minerals, in the basic members of the unit, are filled up with blue amphibole minerals, epidote and chlorite, (3) growth of blue amphibole in the pressure shadows of pyroxene and amphibole crystals having rotated during D1 in the basic members of the unit.

Metamorphic P-T conditions derived from mineral equilibria (LIOU et al. 1985) and compositions (SCHERMER et al. 1989 and KILIAS et al. 1991b) indicate T~300°-350° C and P~5-8 kbr for the syn-D1 M1 event (Fig. 7).

The penetrative mylonitic fabric aud the L2 stretching lineation are defined by the growth of the following minerals (Photo 1a, b, c): white mica, chlorite, actinolite, stilpnomelane, albite, and dynamically recrystallized quartz, which determine a syn-D2 M2-metamorphism under conditions of a low grade greenschist phase (Fig. 7, KATSIKATSOS et al. 1982, KILIAS et al. 1991b). A sigmoidal development of the internal Si-texture in rotated albite crystals and the concordant transition of the Si-texture to the external Se=S2 texture, indicates the syntectonic nature of the M2-albite. Frequently also blue amphibole is observed reorientated within the S2-fabric, following the L2-stretching lineation (Photo 1a, b).

Comparisous of microfabrics under the microscope have shown that the greenschist phase partly overprints the high pressure M1 metamorphism. Thus M2 in places causes a decomposition of the blue amphibole into actinolite or chlorite. Furthermore, a breakdown is often observed of blue amphibole into aggregates of chlorite and stilpnomelane. Albite porphyroblasts, syntectonic with S2 fabric, were probably derived in part from breakdown of sodic amphibole.

These relations of replacement of the M1-parageneses under the conditions of the greenschist phase of M2, indicate that the syn-M2 D2 deformation took place outside the field of the high pressure M1-metamorphism (Fig. 7). The local preservatiou of the blue amphibole on the S2-foliation iudicates that at least during the early evolutiouary stages of the D2-event, the high pressure conditions were still maintained, and also that the uplift and exhumation of the blueschists occurred rapidly.

The Olympus-Ossa lower plate underlying the blueschists does not exhibit a similar tectonometamorphic process. Although tectonically it comprises a deeper tectonic unit, it completely lacks the high pressure syn D1 metamorphic fabric, while the S2-mylonitic foliation is characterized only by low pressure low temperature minerals (GODFRIAUX 1968, KATSIKATSOS et al. 1982).

White mica, chlorite, and dynamically recrystallized quartz develop along the low angle conjugate extensional shear zones (SB) and the low angle normal faults (LAF) of the blueschists unit and the overlying tectonic nappes. The local development of these extensional shear structures, their style, the syntectonic nature of the low grade minerals observed along their surfaces, as well as their symmetry in relation to the D2 mylonitic fabric (as it was described above), indicate that these extensional zones must constitute a progressive stage of the ductile D2-deformation. This stage took place at least in its initial steps, in a still hot environment (T reaching at least 250° C).

The high pressure syn-D1 M1 metamorphism evolved during the Middle-Late Eocene (55-40 million years), (GODFRIAUX 1968, KATSIKATSOS et al. 1982, SCHERMER et al. 1989). Consequently the younger syn-D2 M2 metamorphism must have taken place during or after the Late Eocene.

Ar/Ar data on microcline samples from the footwalls of the low angle normal shear zones showed that the cooliug of the metamorphic rocks,

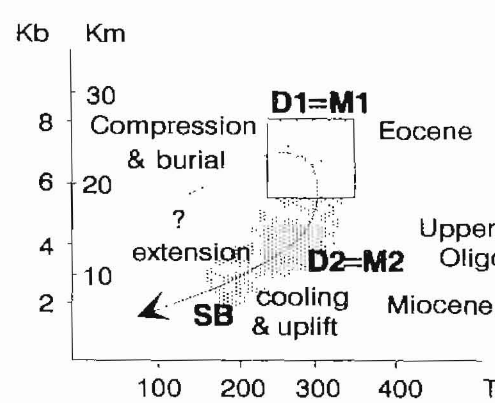

FIGURE 7: *Pressure-temperature-time-deformation relations at the blueschists unit. P-T estimates are from KATSIKATSOS et al. 1982, SCHERMER et al. 1989. SCHERMER 1990, and KILIAS et al. 1991 a.b.*

during crustal stretching and thinning, started in early to middle Miocene time (~16-23 Ma, SCHERMER et al. 1989).

Consequently there remains an interval within the Upper Eocene to Oligocene, during which the syn-D2 M2 metamorphism of the low greenschist phase must have taken place.

The age of the younger normal faults, which may be still active, is characterized by the syntectonic basins filled with Miocene and younger sediments (BRUNN 1956, GODFRIAUX 1968, LALECHOS & SAVOYAT 1979, BENDA & STEFFENS 1982, MIGIROS et al 1985, TRIANTAFILLIS et al. 1987, CAPUTO 1990) and bounded, to the west and east of the Olympus-Ossa window, by these high angle normal faults.

EVIDENCE FOR CRUSTAL EXTENSION

The geometry and style of structural and map relations as well as the metamorphism-tectonics relations described here, indicate that during the D2 tectonics and its progressive stage of the low angle normal shear zones the blueschists unit and the overlying nappes are simultaneously subjected to a total thinning in the vertical sense, and to a subhorizontal stretching. Some of the criteria are summarized below:

(1) Progression of the ductile D2-structures overprinted by brittle structnres with similar summetry, and thus decreasing pressure conditions (Fig. 7). (2) The mylonitic rocks exhibit a normal sense of shear relative to the present orientation of the mylonitic foliation, (3) A significant

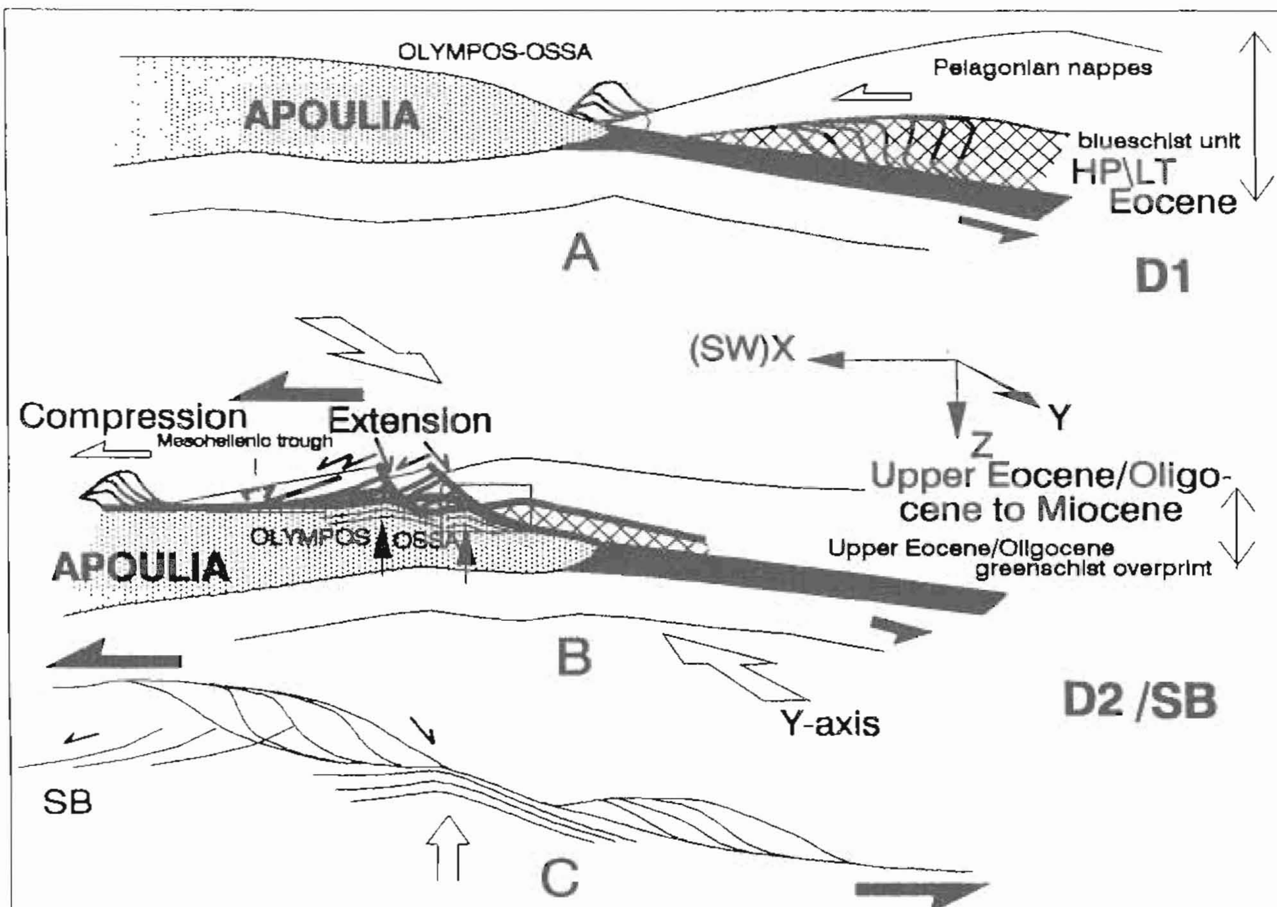

FIGURE 8: *Illustration of the Tertiary tectonic evolution, of the eastern Thessaly blueschist unit and of the adjacent underlying (Olympus-Ossa unit) and overlying (Pelagonian and Ophiolitic nappes) units. A. Nappe stacking and crustal overthickening. Development of the HP/LT metamorphism in the subducted materials, B. Emplacement of the blueschist unit and the overlying nappe pile, simultaneously with a subhorizontal stretching and vertical thinning of the overthickened pile nappe, which took place under a regional plate convergence regime. Compression subparallel to the Y-axis of the finite strain ellipsoid also develops. C. Opposed downwards nappe sliding and exhumation of the blueschist rocks and the Olympus Ossa carbonate dome.*

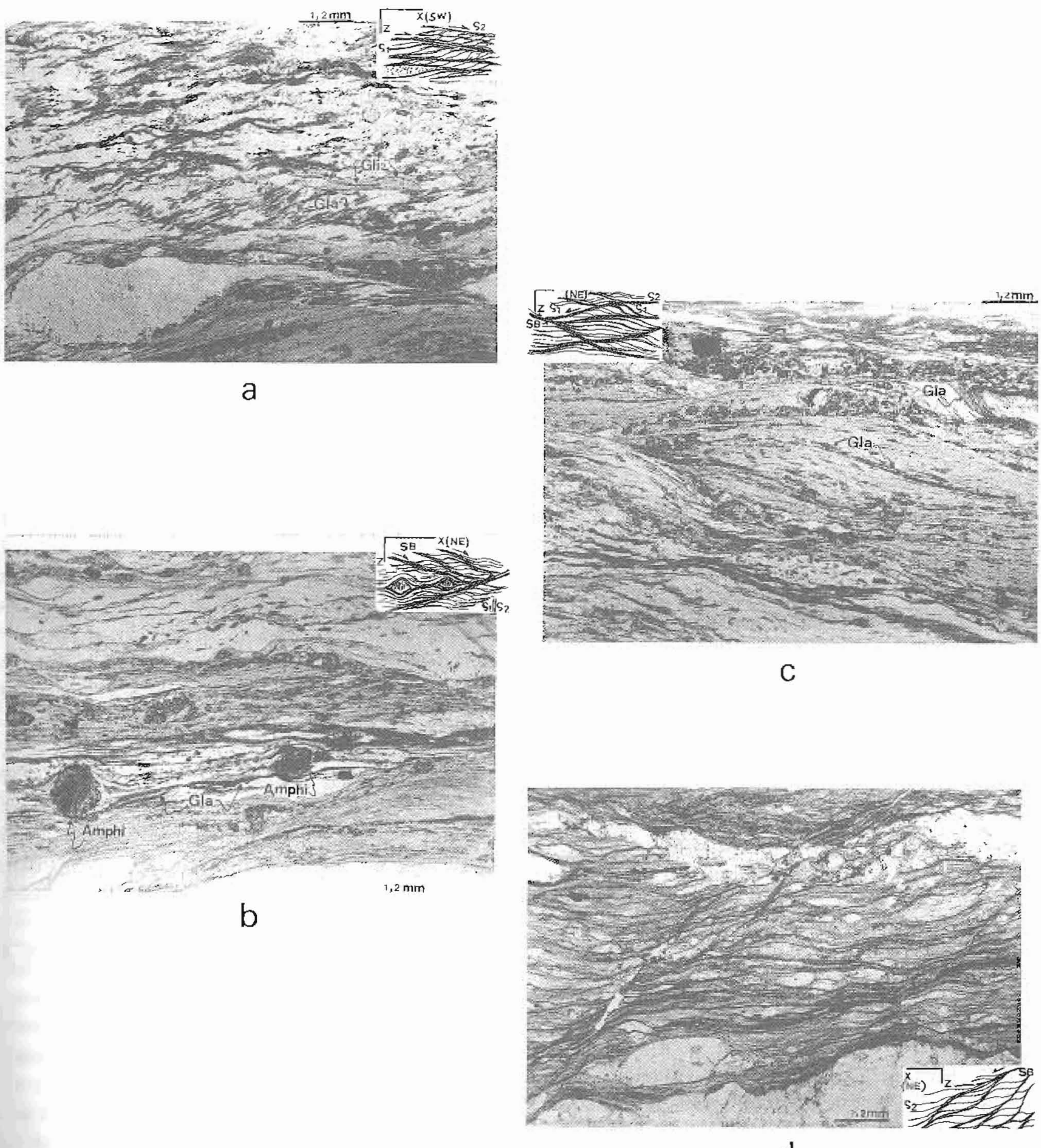

PHOTO 1: *Thin sections illustrating the main tectonic structures and the symmetry of deformation of the blueschists unit in eartern Thessaly (location of the samples in Fig. 2, Ph 1a): a. S1 and S2 mylonitic fabric. S1 is defined by elongated blue amphibole (Gla). Blue amphibolė deformed during D2 and reorientated along the S2. Here, top to SW-movement. Gli-white mica. b. Conjugate shear bands and symmetrical development during D2 of amphibole clasts (Amphi). Significant component of coaxial deformation. S1 lie parallel to S2 fabric due transposition. c. S1 schistosity with blue amphibole (Gla) development oblique to S2 fabric. Top to SW sense of shear. NE dipping low angle, extensional shear bands. d. Low angle, asymmetric, NE dipping, shear bands, indicating normal northeastwards sense of shear.*

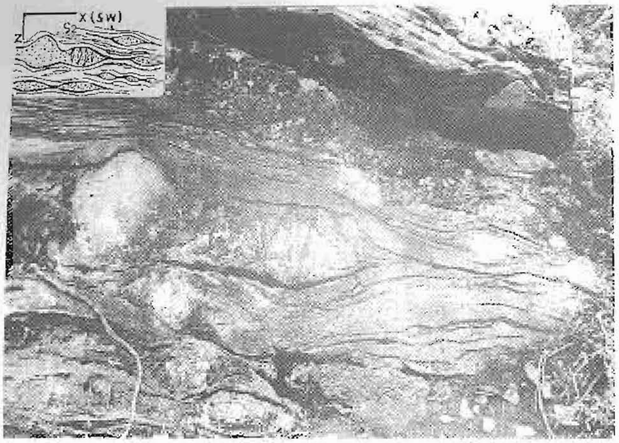

PHOTO 2: *Symmetric boudinage of competent layers, produced during D2 in the carbonate rocks of Olympus-Ossa unit. Tension gashes in the competent boudins bodys develop perpendicular to the S2-mylonitic fabric. Coaxial deformation. Tectonic contact between blueschists and Olympus-Osse Unit at the SE side of the Olympus dome (exactly location of the sample in Fig. 2).*

component of coaxial extension subparallel to the layering with associated S2 mylouitic fabric nearly parallel to the boundaries of the nappes as well as to the main detachment zone between the blueschists and the lower plate. (4) The subhorizontal development of the maximum stretching (X-axis) and the correspondiug almost vertical development of the maximum thinuing (Z-axis) of the D2 final strain ellipsoid in the whole pile of mylonitic rocks. (5) The justaposition, after the peak of the M2 metamorphism, of the uppermost nappes over the HP/LT blueschist unit or directly over the lower Olympus-Ossa plate, by sliding along the semiductile low angle extensional shear zones. (6) The normal low angle shear zones exhibit a southwest-directed down-dip sense of shear to the west of the Olympus-Ossa dome and a northeast-directed down-dip sense of shear to the east of the dome. (7) Parallelism between the mylonitic L2 elongarion lineation and the striation on the sliding plane of the low angle extensional shear zones. (8) The possible connection of the ductile D2 deep tectonics, with its relatively contemporary syntectonic basins of the upper plate at the higher tectonic levels, which exhibit a similar symmetry with a maximum extension of a NE-SW direction (e.g. the Mesohellenic trough BRUNN 1956, PAPANIKOLAOU et al. 1988).

In this way during the D2 tectonics and its progressive stage of the low angle normal shear zones, the blueschists unit and the overlying nappes are simultaneously subjected to a total thinning in the vertical sense, and to a subhorizontal stretching. Combining these with the results of the strain-analysis (KILIAS et al. 1991b, SFEIKOS et al. 1991, SFEIKOS 1992), it was found that the structure of the upper plate nappes underwent a vertical thinning by half or even more of its initial thickness, during the D2-deformation and its progressive stages.

DISCUSSION

Emplacement during extension

The initial D1-tectonics and its contemporary high pressure M1-metamorphism, should be interpreted as having evolved in the period of the middle-upper Eocene, during the subduction of the blueschist unit, under the Pelagonian continental block. This event took place in a regime of plate convergence and compression. Thus during this Eocene period the stacking of the nappes and the overthickening of the continental crust, must have been combined with the burial of the blueschist unit under the Pelagoniau (Fig. 8A).

The absence of HP/LT mineral parageneses from the Olympus-Ossa, Kranea, and Rizomata units of the lower plate, suggests that these units have never participated in the high pressure compressional deep tectonics of the blueschists. This means that, although the Olympus-Ossa, Kranea, and Rizomata units comprise the lower tectonic units of the inner Hellenides, they have not been snbducted to a great depth.

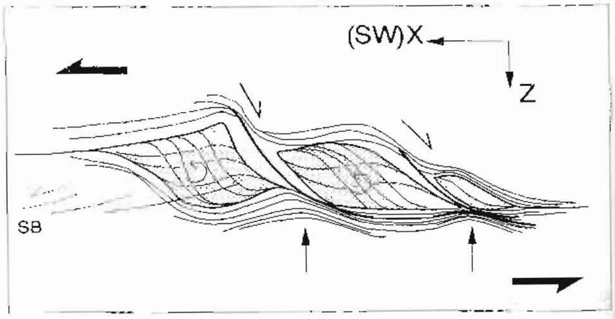

FIGURE 9: *Reconstruction of the initial domino-structure development of the nappes in the Olympus-Ossa region, during the nappe emplacement. Progressively, the gradual uplift of the underlying lower plate of Olympus-Ossa was the result of the opposed escape of the overlying nappes.*

Moreover, we should assume that the emplacement of the nappes with the blueschists at their base, over the nonmetamorphosed rocks of the lower plate, occurred during or after the Late Eocene, after the peak of the high pressure metamorphism.

The problem is: how these deep crustal high pressure rocks have been emplaced over the sediments of the nonmetamorphosed foreland at higher tectonic levels, without any significant change of the high pressure mineral parageneses.

An emplacement mechanism of the high pressure rocks, according to the model of "buoyant uprise", by return flow in the subduction zone (ENGLAND & HOLLAND 1979, CLOOS 1982, ERNST 1984) does not seem well supported: the blueschist unit is not a well defined unit with an opposite sense of shear at its upper and lower boundaries and the stretching lineations are nearly subhorizontal throughont the study area. Furthermore, the surroundings of the blueschists have been intensely deformed during the D2-deformation, so that the possiblity of motion of the rising blueschist body through an otherwise static medium is also rejected. Density contrasts between the blueschist unit and the country rocks cannot be regarded as a driviug force for the buoyant uprise, it relative proportions of metabasites and metasediments are taken into account.

Low angle or horizontal stretching lineation on steep foliation planes as required by the "wrench faulting model" for emplacemeut of high pressure rocks at higher tectonic levels (KARIG 1980), are not often observed in the field. Steep S2 foliation patterns with NE-SW trending subhorizontal stretching lineation, as for example along the NW boundary of the Olympus carbonate dome, should be regarded as the result of the late updoming of the Olympus carbonate dome or the perpendicular to the maximum stretching compression (Fig. 2 & 8B).

On the other hand, the geometry of the kinematics and the deformation regime of the D2-tectonics, sufficiently warrant the emplacement of the blueschists and the overlying pile of nappes over the foreland, as a result of the subhorizontal stretching of an overthickened accretional wedge, according to the "underplating and extension" model (PLATT 1986).

Thus, we suggest that during the initial stages of the D2-deformation, at the Upper Eocene-Oligocene, right after the compression stage and the deep tectonics, the unit of the blueschists and the overlying pile nappes were emplaced over the sediments of the Olympus-Ossa, Kranea, and Rizomata units, in a regime of subhorizontal ductile stretching and simultaneous subvertical thinning of the crust, covering the cold foreland units outwards (Fig. 8B). This proposal is in contrast to the previous works by SCHERMER et al. 1989, SCHERMER 1990, which interpret the emplacement mechanism of the blueschists as the result of thrust tectonics after the peak of the high pressure metamorphism.

The stretching regime during the emplacement of the nappes also warrants, to a large extent, the lack of high pressure parageneses in the rocks of the lower Olympus-Ossa, Kranea, and Rizomata units since, according to this pattern these do not participate in the deep underthrusting tectonics during the nappe stacking. On the contrary, if the emplacement of the blueschists and the overlying unit had developed simultaneously with the nappe stacking, the lower unit should have normally undergone the most intense high pressure deep tectonics.

However, due to the contiuuing convergence of the plates compression and nappe stacking migrate further out at the front of the stretching masses. Thus, the Upper Eocene-Oligocene thrust tectonics of the external Hellenides (BRUNN 1956) develops simultaneously with the crustal stretching and thiuuing in the inner Hellenides (Fig. 8B).

In DAVIS et al. 1983, PLATT 1986 it is mentioned that the slowing down of the plate convergence rate, the change of direction of the plate convergence, or even a roll-back of the subduction zone, may cause the stretching of the overthickened wedge and its emplacement over the cold orogenic foreland.

Such changes in the kinematics of the plate convergence in the Alpine orogenic system have been described by many investigators (DEWEY et al. 1973, SAVOSTIN et al. 1986, MEULENKAMP et al. 1988) so that shape adjustments of the scheme of the Alpine orogenic wedge are likely, resulting in the stretching of the Eocene nappe pile and its emplacement over the foreland.

Exhumation of the blueschists and the lower plate

The continuous underplating of cold sialic material of the foreland under the stretching wedge, combined with the considerable slide downwards of masses along the low angle extensional shear zones with an opposite sense of shear are the cause of the rapid upward rebound of the blueschists and the lower plate dnring the Oligocene-Miocene. At the same time, a further thiuning and collapse of the nappe pile takes place, finally resulting in the uplift and exhumation of the lower plate in the form of the Olympus-Ossa, Kranea, and Rizomata tectonic windows in the inner Hellenides as is proposed also by SCHERMER 1990, 1993, and KILIAS et al. 1991 a,b (Fig. 8C, 9).

This Oligocene-Miocene stretching and thinning of the inner Hellenides in a NE-SW direction is also supported by the simultaneous evolution and filling of the Mesohellenic trough with Oligocene-Miocene sediments. (BRUNN 1956, PAPANIKOLAOU et al. 1988). Therefore, this trough initially formed at the tectonically higher levels of the Eocene nappe pile simultaneously with the ductile D2-deformation at depth, east and behind of the simultaneous (Oligocene-Miocene) imbrication of the external Hellenides (Fig. 8B).

Moreover, considerable ophiolitic masses of the upper tectonic units during the same Oligocene-Miocene period moving dowuwards to SW are emplaced over the Oligocene imbricated flysch of the external Hellenides (MOUNTRAKIS et al. 1992 a, b).

The syn-D2 uplift of the blueschists was not accompanied by any major reheating of the system. This is an uncommon case of the P-T-t paths evolution that is proposed from SPEAR & SELVERSTONE 1983, and ENGLAND & THOMPSON 1984.

This event can indeed be interpreted if we take into account a tectonic sceuario where the blueschists are detached from a relatively hot (~350°C) substratum to be emplaced onto colder crust that has not suffered deep burial and heating.

Thus, the preservation of the high pressure parageneses of the blueschists and the presence of nonmetamorphosed to slightly metamorphosed foreland units, under the intensely metamorphosed rocks of the nappes of the inner Hellenides, can also be accounted for.

The Oligocene-Miocene annealing (ATHER et al. 1982, BUICK 1991), of the Cyclades blueschists, whose HP/LT metamorphism also dates to the Eocene (ANDRIESSEN et al. 1979), as well as the preseuce of metamorphosed units below the blueschists (DURR 1975, DURR et al. 1978) must be associated with the development of a new subduction cycle. A significant crustal thinning aud stretching accompanying this Oligocene-Miocene thermal overprint of the Cycladic Massif (LISTER et al 1984, BUICK 1991, FAURE et al. 1991). The HP/LT phyllite-quartzite unit of Mani and Creta offers clear evidence of the existence of this new orogenic cycle of Oligocene-Miocene age (Fig. 1, WACHENDORF et al. 1980, SEIDEL et al. 1982, MEULENKAMP et al. 1988, KILIAS et al. 1992, FASOULAS et al. 1993). This event, however, did not take place further north in the mainland of Greece, where the orogenic process was definitely concluded with the emplacement of the blueschists and the overlying nappe pile over the cold foreland and its subsequent uplift and exhumation.

CONCLUSIONS

Structures, kinematic analysis, strain analysis and metamorphism-tectonics relations of the Olympus-Ossa blueschists, show that their tectonic evolution began in the Eocene with a rapid subduction and burial under the Pelagonian with the result that they were metamorphosed under high pressure low temperature couditions. Nappes stacking and crustal thickening takes place during this period.

The postburial history of the blueschists is characterized by an Upper Eocene-Oligocene ductile deformation under conditions of lower greenschist facies metamorphism. During this event the blueschists together with the overlying nappe pile of the Pelagonian stretchends, and thinnends cover the cold sediments of the Olympus-Ossa unit of the foreland.

The underplating of the cold plate beneath the nappe pile and the continuous supply of cold foreland materials to the subduction zone, progressively causes the uplift and further tectonic thinning of the whole nappe pile, with no significant reheating, during the Oligocene-Miocene. As a result of the significant opposite escape of nappe masses during this upward isostatic movement, the Olympus-Ossa unit is revealed in the form of an extensional dome.

The stretching and emplacement of the blueschists and the overlying nappe pile over the foreland in a total compression regime, due to the continuing convergence of the plates, can be attributed either to a retardation of the rate of convergence of the plates, during the Oligocene.

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ΠΕΡΙΛΗΨΗ

ΤΕΚΤΟΝΙΚΗ ΕΞΕΛΙΞΗ ΤΗΣ ΟΡΟΣΕΙΡΑΣ ΟΛΥΜΠΟΥ-ΟΣΣΑΣ: ΑΝΟΔΟΣ/ΤΟΠΟΘΕΤΗΣΗ ΤΩΝ ΚΥΑΝΟΣΧΙΣΤΟΛΙΘΩΝ ΤΗΣ ΑΝΑΤΟΛΙΚΗΣ ΘΕΣΣΑΛΙΑΣ ΚΑΙ ΑΠΟΚΑΛΥΨΗ ΤΟΥ ΑΝΘΡΑΚΙΚΟΥ ΔΟΜΟΥ ΟΛΥΜΠΟΥ-ΟΣΣΑΣ ΩΣ ΑΠΟΤΕΛΕΣΜΑ ΕΦΕΑΚΥΣΜΟΥ ΚΑΤΑ ΤΟ ΤΡΙΤΟΓΕΝΕΣ

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Τα πετρώματα της ενότητας των κυανοσχιστόλιθων στην περιοχή Ολύμπου-Όσσας στην ανατολική Θεσσαλία, βυθίστηκαν κατά το Ηώκαινο, στη ζώνη υποβύθισης της Απούλιας πλάκας κάτω από το ηπειρωτικό τέμαχος της Πελαγονικής, σ' ένα βάθος >20 km, με αποτέλεσμα να μεταμορφωθούν σε συνθήκες υψηλής πίεσης-χαμηλής θερμοκρασίας (P=6-9 kb και T=300-350°C). Καθεστώς συμπίεσης, συσσώρευση τεκτονικών καλυμμάτων και υπερπάχυνση του φλοιού χαρακτηρίζουν την περίοδο αυτή σύγκλισης των πλακών κατά το Ηώκαινο. Η άνοδος και η επιστροφή προς το βασικό επίπεδο των κυανοσχιστόλιθων ξεκίνησε τέλος Ηωκαίνου-αρχές Ολιγοκαίνου και συνοδεύθηκε από χαμηλού βαθμού πρασινοσχιστολιθικής φάσης μεταμόρφωση.

Ανάλυση της παραμόρφωσης και κινηματικής των κυανοσχιστόλιθων και των περιβαλλόντων τεκτονικών ενοτήτων έδειξε, ότι η άνοδος και τοποθέτηση αυτών των υψηλής πίεσης πετρωμάτων, συνδέονται με μια σημαντική έκταση και λέπτυνση της προηγουμένως, κατά το Ηώκαινο, υπερπαχυμένης ορογενετικής σφήνας επαύξησης. Η έκταση έλαβε χώρα σε δύο στάδια: Το πρώτο στάδιο συνδέεται με την τοποθέτηση των υψηλής πίεσης πετρωμάτων και της υπερκείμενης στήλης καλυμμάτων πάνω στην αμεταμόρφωτη έως ελαφρά μεταμορφωμένη ενότητα Ολύμπου-Όσσας της εμπροοθοχώρας και οφείλεται πιθανόν στην αλλαγή του ρυθμού, ή της διεύθυνσης σύγκλισης των λιθοσφαιρικών πλακών. Κατά το δεύτερο στάδιο έλαβε χώρα σημαντική αντιθετική διαφυγή μαζών των τεκτονικών καλυμμάτων προς τα ΒΑ και ΝΔ, με αποτέλεσμα την ισοστατική εκτίναξη της κατώτερης πλάκας, της εμπροσθοχώρας και τη σταδιακή αποκάλυψη των κυανοοχιστολίθων και των ιζημάτων της εμπροσθοχώρας με τη μορφή τεκτονικού παράθυρου κατά τις αρχές Μειοκαίνου.

Η έκταση συνδέεται με μεγάλης κλίμακας συσσώρευση ψυχρού ηπειρωτικού φλοιού της εμπροσθοχώρας, κάτω από την εκτεινόμενη στήλη τεκτονικών καλυμμάτων της ανώτερης πλάκας, κατά τη διάρκεια σύγκλισης ακόμη των πλακών και την ανάπτυξη των τεκτονικών καλυμμάτων και των ανάστροφων ζωνών, εξωτερικότερα στο χώρο των εξωτερικών ελληνίδων.

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