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KINEMATICS OF PELAGONIAN NAPPES IN THE KRANEA AREA NORTH THESSALY, GREECE

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ABSTRACT

Pelagonian crystalline basement overthrusts Mesozoic marbles and Lower Tertiary flysch ascribed to the Gavrovo-Tripolis Zone, forming a series of tectonic windows in the Olympos-Kranéa region. Pelagonian Permomesozoic units, in turn, overthrust the basement. Serpentinite lenses ascertain the crustal dimension of the thrust planes. A two-stage model is proposed for the Lower Tertiary orogeny: Thrusting occurred under high-pressure conditions in the first stage. Subsequent decompression and rheological softening caused uprise of domes and crustal thinning due to gravity spreading during the collapse of the orogenic wedge. A penetrative mylonitic foliation formed under falling P-T conditions during this second stage. Flow was to the SW but in a late stage reversed to the opposite direction on the northeast flank of the Olympos dome. The mylonitic fabric obliterated nearly all the older structures formed during the Eohellenic (Lower Cretaceous) and Variscan orogenies.

ΠΕΡΙΛΗΨΗ

Στήν περιοχή τῆς Κρανέας στήν Βόρεια Θεσσαλία, τό κρυσταλλοσχιστῶδες ὑπόβαθρο τῆς Πελαγονικῆς Ζώνης ἐπωθεῖται σέ μάρμαρα πιθανῆς Μεσοζωϊκῆς ἡλικίας, σχηματίζοντας τό τεκτονικό παράθυρο τῆς Κρανέας. Πάνω στό πελαγονικό κρυσταλλοσχιστῶδες ὑπόβαθρο τοποθετοῦνται μέ τή μορφή τεκτονικοῦ καλύμματος Περμομεσοζωϊκῆς ἡλικίας ἑνότητες. Φακοί ὀφειολιθικῶν πετρωμάτων, μυλωνίτες καί ζῶνες διάτμησης χαρακτηρίζουν τό ἐπίπεδο τῆς ἐπώθησης, οἱ ὁποῖες ἀναπτύσσονται ἐπίσης εὐκρινῶς στά Βαρίσκειας ἡλικίας γρανιτοειδῆ πού διεισδύουν στό ὑπόβαθρο. Ἐξακριβώθηκαν δύο φάσεις Τριτογενοῦς τεκτονικῆς. Κατά τήν ἐξέλιξη τῆς α΄ φάσης λαμβάνει χώρα ἡ ἐπώθηση τοῦ κρυσταλλοσχιστώδους ὑποβάθρου πάνω στά μάρμαρα τῆς Κρανέας καί μία HP/LT μεταμόρφωση. Στή β΄ ἔχουμε βαρυτική ροή τοῦ διογκωμένου φλοιοῦ κάτω ἀπό συνθῆκες χαμηλῆς πίεσης μέ λέπτυνση καί ἀναθόλωση τοῦ φλοιοῦ. Στό στάδιο αὐτό σχηματίζεται μία μυλωνιτική σχιστότητα κάτω ἀπό συνεχῶς ἐλαττούμενες συνθῆκες πίεσης καί θερμοκρασίας. Ἡ σχιστότητα εἶναι παράλληλη πρός τά ἐπίπεδα ἐπώθησης καί τίς ἀνεξάρτητες διατμητικές ζῶνες στό ὑπόβαθρο. Ἡ μυλωνιτική σχιστότητα καί μία σταθερῆς διεύθυνσης ENE-WSW γράμμωση ἐφελκυσμοῦ εἶναι τά κυρίαρχα τεκτονικά στοιχεῖα. Strain analysis ἔγινε μέ τίς μεθόδους Rf/Φ καί Fry. Κριτήρια διάτμησης στούς μυλωνίτες (s-c δομές, ζῶνες διάτμησης, mica fish, ἀσύμμετρες σκιές πίεσης) φενερώνουν ροή τῶν πετρωμάτων πρός τά ΝΔ. Συνεπῶς ἡ ἐπώθηση τῶν πετρωμάτων ἔλαβε χώρα πρός τά ΝΔ. Ἡ μυλωνιτική ὑφή κατέστρεψε σχεδόν κάθε παλαιότερη ὑφή τῆς Ἐοελληνικῆς φάσης καί τοῦ Βαρύσκιου ὀρογενοῦς.

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INTRODUCTION

The Pelagonian Zone of the Olympos region encompasses several tectonic windows (Fig. 1) which are correlated with the Gavrovo-Tripolis Zone further west (Godfriaux, 1962). The Pelagonian Zone represents a Cimmerian continental fragment which separated the Paleo-Tethys from the Neo-Tethys ocean (Mountrakis, 1986). The closure of the two oceans caused the Pelagonian Zone to develop into a thrust system consisting of a Variscan crystalline basement and a Permomesozoic cover sequence (Barton 1976; Yarwood and Aftalion 1976; Nance 1981; Mountrakis 1983, 1986).

Godfriaux (1962, 1968) described the Olympos Window as Pelagonian basement thrust over both Mesozoic marbles and Lower Tertiary flysch of the Gavrovo-Tripolis Zone. The Rizomata Window to the north, the Kranéa Window to the west, and the Ossa Window to the south are analogous to the Olympos Window (Derycke and Godfriaux, 1976 1979; Katsikatsos et al., 1986; Kilias and Mountrakis, 1987). The windows form circular or elongate domes. Based on lithostratigraphic correlation between the rocks of the Olympos Window and the unmetamorphosed rocks of the Gavrovo-Tripolis Zone in western Greece, Godfriaux (1968) proposed overthrusting of the Pelagonian Zone toward the SW.

Barton (1975) concluded from linear structures, asymmetric folds, thrust plane dips, and reverse faults that thrusting of the Pelagonian basement over the sediments exposed in the Olympos Window was directed to the NE. Barton (1976) proposed a Late Eocene age for the thrusting event due to a 40 Ma K/Ar age of glaucophane in metabasalts of the Ambelakia Nappe (Fig. 1) sandwiched between the window and the Pelagonian basement.

This paper presents results of a structural and kinematic analysis of the widespread mylonites in the Pelagonian basement in the Kranéa-Sarantáporo area (Fig. 2). Displacements were deduced from a combination of strain and flow criteria.

GEOLOGIC SETTING

The lithostratigraphy of the Kranéa Window encompasses a sequence of marbles with an exposed thickness of 1500 m. The lower part is made up of white, thick-bedded marble changing upward to grey thin-bedded marble with thin phyllite intercalations. The age of this sequence is inferred to be Triassic to Jurassic according to lithostratigraphic correlation (Godfriaux, 1962). The thrust plane exhibits small serpentinite lenses on the eastern margin of the window (Fig.2).

Two lithologic units that suffered pre-Alpine metamorphism are discerned in the basement of the Pelagonian Zone (Kilias and Mountrakis, 1987). The lower Elassóna unit predominantly consists of orthogneiss with intercalations of banded amphibolite-paragneiss sequences. The higher Kefalóvriso unit encompasses micaschist and paragneiss with marble intercalations and concordant amphibolite sheets.

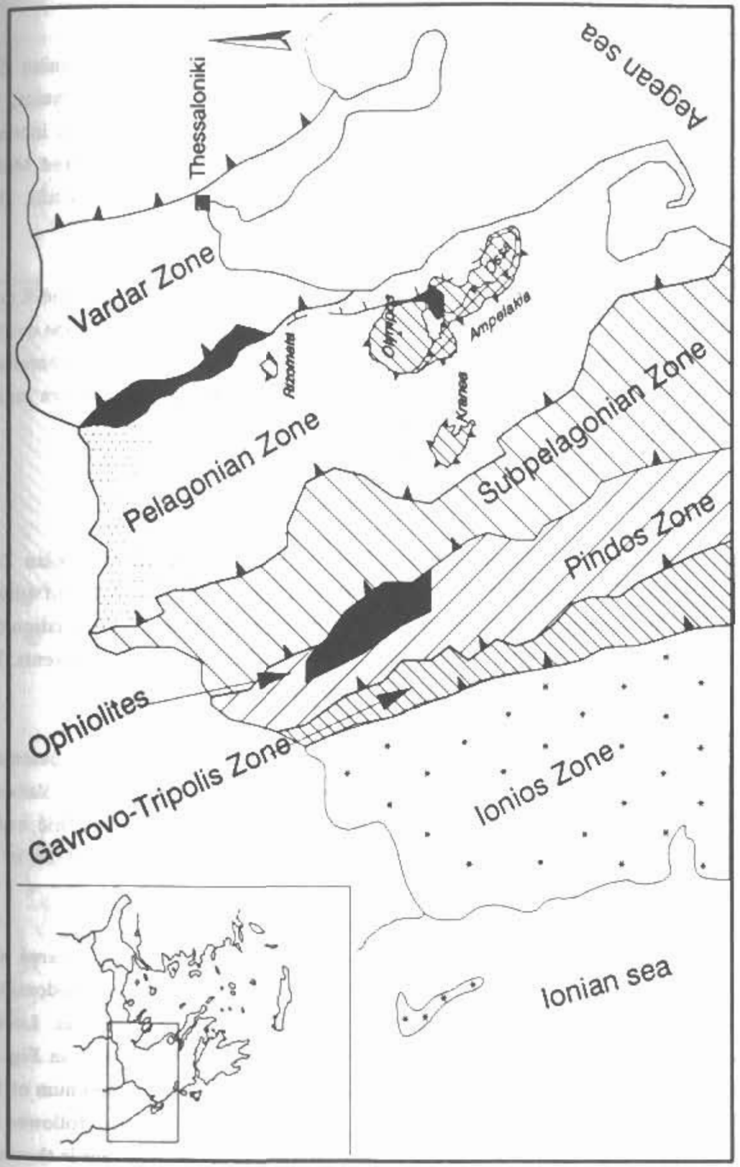

Fig. 1. Tectonic map of northern Greece showing position of tectonic windows in the Olympos-Kranéa area of the Pelagonian Zone (modified after Jacobshagen, 1976).

A series of granodiorite and granite, the Deskáti series, intruded into the basement rocks. The contacts are in part migmatitic. Granites similar to those of the Deskáti series in areas further north and east yielded radiometric ages around 300 Ma (Yarwood and Aftalion, 1976; Schermer et al., 1988). The age of the Deskáti intrusives in the Kranéa area is therefore inferred to be Late Carboniferous.

Permoscythian metaclastics exposed along the western margin of the Pelagonian Zone (Mountrakis et al., 1983) cover the basement. They consist of phyllite, metavolcanics, and metaconglomerate. The phyllite is in part carbonatic. The carbonate content generally increases upsection. The clastic sequence is overlain by a carbonate sequence with an inferred Middle Triassic to Jurassic range in age (compare Kelepertzis, 1974; Baumgartner and Bernoulli, 1976; Clement, 1983).

The Pelagonian Zone forms a thrust system. The Sarantáporo thrust north of the Kranéa Window separates basement in the footwall and cover in the hanging wall by a shear zone decorated with lenses of ultramafic rocks (Fig. 2) . Similar shear zones also occur within the basement. A slice of the Kefalóvriso unit is found beneath the Elassóna unit on the southwestern margin of the Kranéa Window.

METAMORPHISM

Pre-Alpine and Alpine metamorphism and deformation affected the Pelagonian Zone (Kilias and Mountrakis, 1987). A pre-Alpine, probably Variscan, event (M1) attained amphibolite facies grade. The accompanying deformation (D1) is represented by a first foliation (S1) preserved in parts of the basement which were less intensely affected by the Alpine events. The event did not affect the Deskáti series and the cover sequence.

Alpine metamorphism and deformation affected the rocks of the Pelagonian basement, the Deskáti series, and the cover sequence. Radiometric evidence exists (Barton, 1976; Yarwood and Dixon, 1977; Maluski et al., 1981; Schermer, 1988) of two Alpine metamorphic events accompanied by deformation, one in the Early Cretaceous (M2, D2; 120-130 Ma) and one in the Early Tertiary (M3, D3; 50-40 Ma). A strong mylonitic D3 deformation in the Kranéa-Sarantáporo area with penetrative cleavage (S3) and well developed NE-SW stretching lineation (L3) is the predominant structural feature obliterating most of the older structures and mineral parageneses. Locally preserved glaucophane in Permoscythian rocks near the Kranéa thrust (location G in Fig. 2.) formed on the prograde branches of the M2 and M3 events. The temperature maximum of M3 was in the middle to upper greenschist facies grade (T_{max} 450-500°C). It was followed by retrograde mineral transformations. The approximate P-T path during the M3 event is shown in the inset of Fig. 3 (cp. P-T path for Ambelakia rocks around Olympos Window; Kilias et. al. 1990).

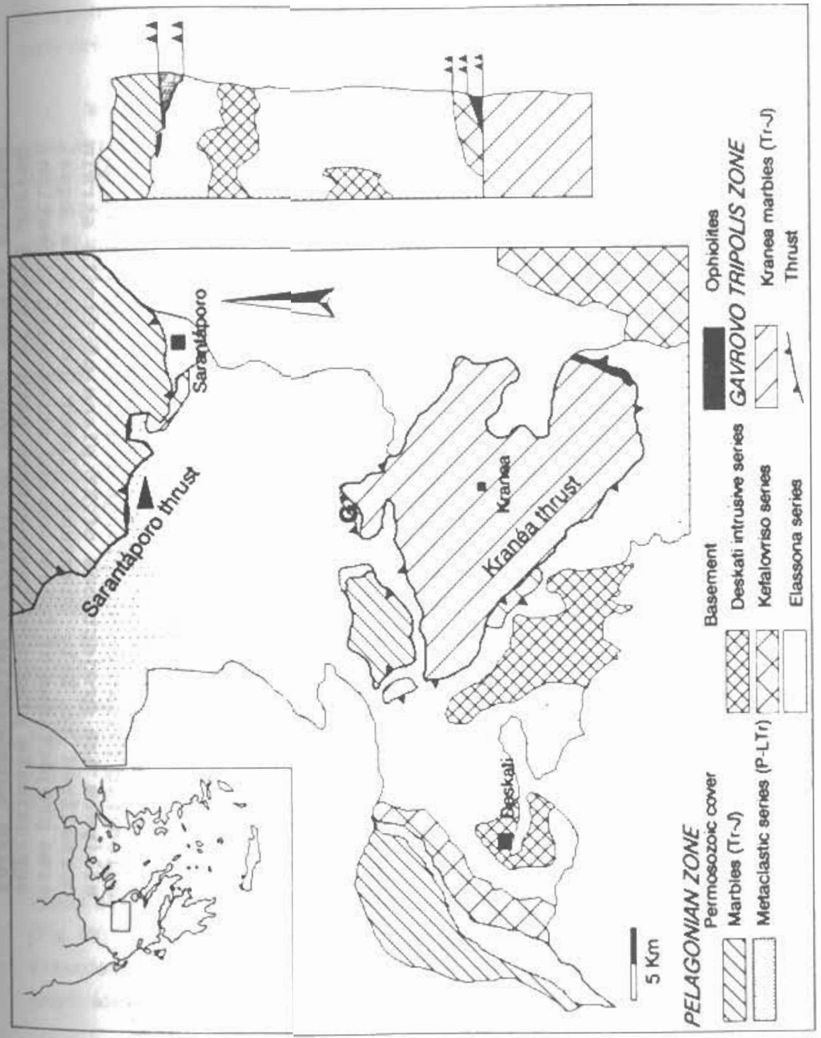

Fig. 2. Geologic map of the Kranéa-Sarantáporo area. Barbed bold lines are thrusts. G: outcrop with glaucophane assemblage. Column shows tectonic succession.

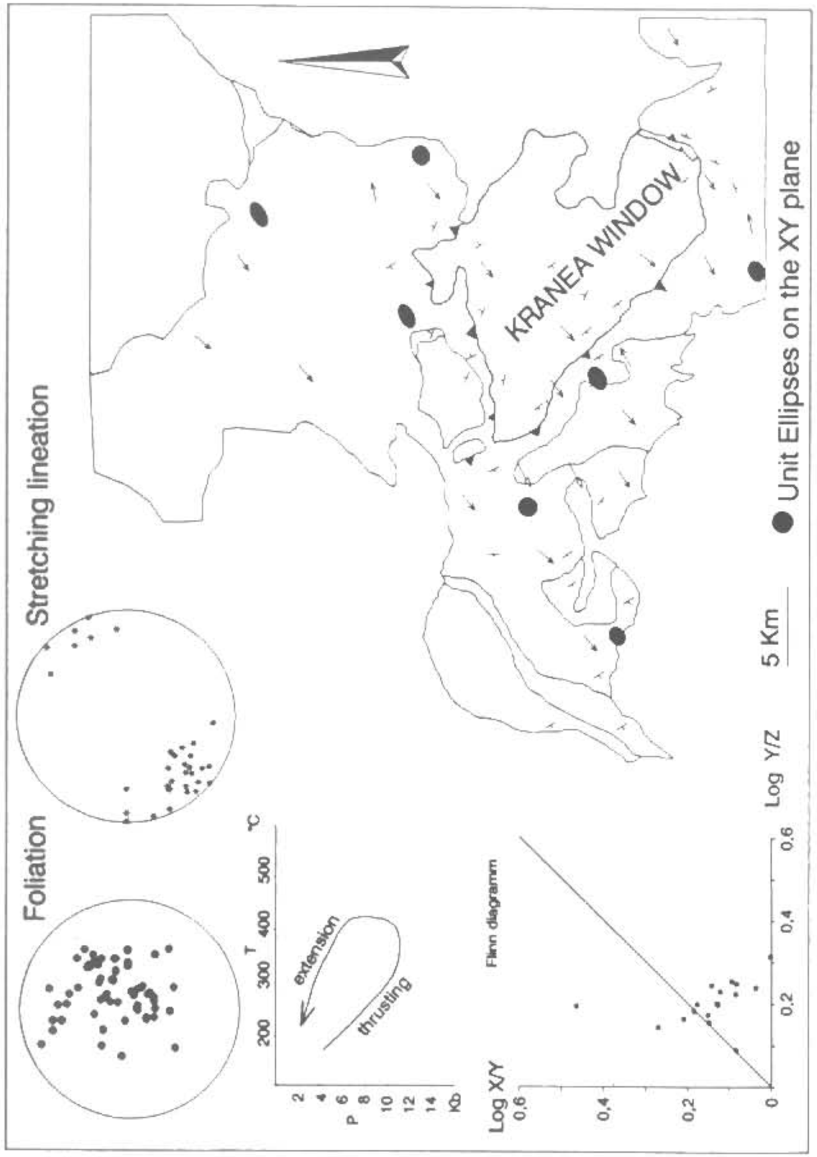

Fig. 3. Strain in the Kranéa-Sarantáporo area. Map: dip of mylonitic foliation and plunge of stretching lineation; ellipses are projections of XY plane of finite strain normalized to Z=1. Diagrams: lower hemisphere equal area projections of foliation and stretching lineation; approximate pressure-temperature path of rocks during **third metamorphism/deformation cycle; strain plotted on Flinn diagram.**

STRAIN AND KINEMATIC ANALYSIS

The D3 mylonitic foliation (S3) of the Kranéa-Sarantaporo area runs subparallel to the Kranéa thrust bounding the Kranea Window, the Sarantaporo thrust, and other low-angle shear zones within the Pelagonian Zone. The L3 stretching lineation, consistently trending NE-SW (Fig 3), is portrayed by elongated minerals and preferred mineral orientation. S3 and L3 are analogously developed both in the Pelagonian units and in the Kranea marbles.

We assume that L3 represents the maximum extension axis X, and S3 the XY plane of the finite strain ellipsoid of the D3 event. To quantify the strain, the R_f/ϕ method (Ramsay and Huber, 1983; Lisle, 1984) was applied to feldspar porphyroclasts in orthogneisses. We measured two principal sections (XZ and YZ) of the strain ellipsoid. The strain values (Fig. 3) give only part of the total strain due to strain partitioning between the rigid porphyroclasts and the ductile matrix. The matrix is dominated by well recrystallized quartz and mica. Feldspar shows no or very weak recrystallization. Most strain data plot in the flattening field (Fig 3: Flinn diagram). The scatter of the data may be due to pre-deformational (magmatic) preferred orientation of the feldspar crystals.

The sense of shear during non-coaxial deformation was determined in sections perpendicular to the foliation and parallel to the stretching lineation (XZ plane of finite strain ellipsoid). Fig. 4 shows the displacement directions obtained from various shear criteria.

Fig. 5a shows a minor shear zone in undeformed granite of the Deskati series. S-C fabrics (Berthé et al., 1979) are common in the mylonitic gneisses and are particularly well developed along distinct shear zones such as the Kranea and the Sarantáporo thrusts. The well developed C surfaces are the dominant mesoscopic foliation and are marked by layers rich in recrystallized mica. Quartz microlithons limited by the C surfaces show dynamically recrystallized quartz grains with elongation oblique to the C surfaces (Fig. 6a: type II S-C mylonites after Lister & Snoke, 1984). The oblique elongation marks the S surfaces. The S-C fabrics consistently show a top to SW or WSW sense of shear.

Sets of extensional crenulation cleavage (ecc; e.g., Platt and Vissers, 1980) are widespread and indicate extension with a shear sense in most cases consistent with the S-C fabrics (Fig. 6b). Conjugate ecc sets on the north margin of the Kranéa Window indicate coaxial flow. Extensional crenulation cleavage is accompanied and followed by normal faulting on a mesoscopic scale (Fig. 5b). The kinematics of the faults is consistent with that of the ecc.

On the northeast flank of the Olympos dome structure, S-C fabrics and extensional crenulation cleavage show the opposite sense of shear, i.e. top to NE or ENE.

Flow resistant feldspar pophyroclasts in mylonitic basement gneisses show asymmetric strain shadows (Simpson and Schmid, 1983). The shadows formed by dynamic recrystallization

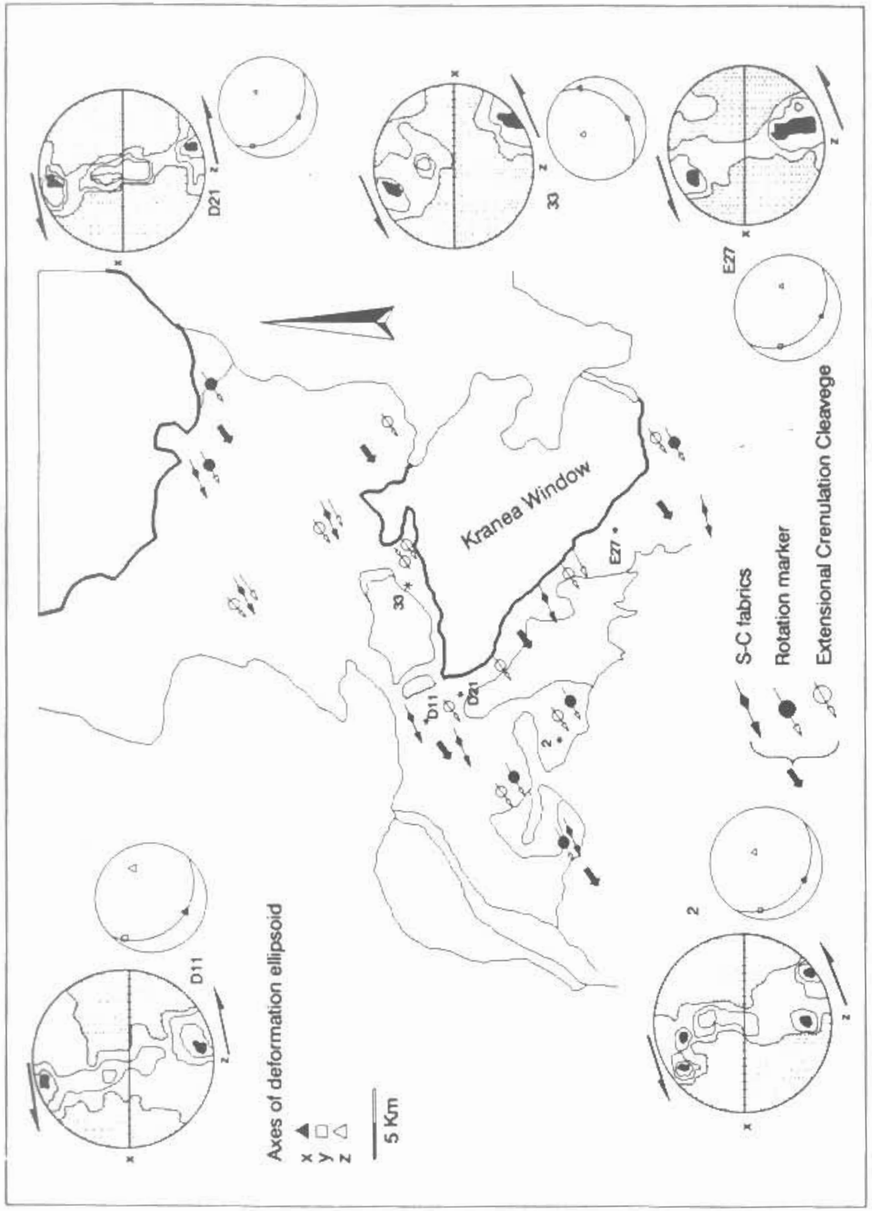

Fig. 4. Kinematic data of the Kranéa-Sarantáporo area. Arrows indicate sense of shear. Stars show location of samples used for quartz c-axis fabric measurements. Diagrams, lower hemisphere equal area projection, plot of quartz c-axes. Small diagrams show projection of principal strain and foliation.

Fig. 5. Kinematic indicators of the Kranéa-Sarantáporo area.

(a) Shear zone in undeformed Deskati granite. Coin is 2.5 cm in diameter.
(b) Extensional crenulation cleavege and normal faulting in mylonite in the vicinity of the Kranéa thrust. Line represents 20 cm.

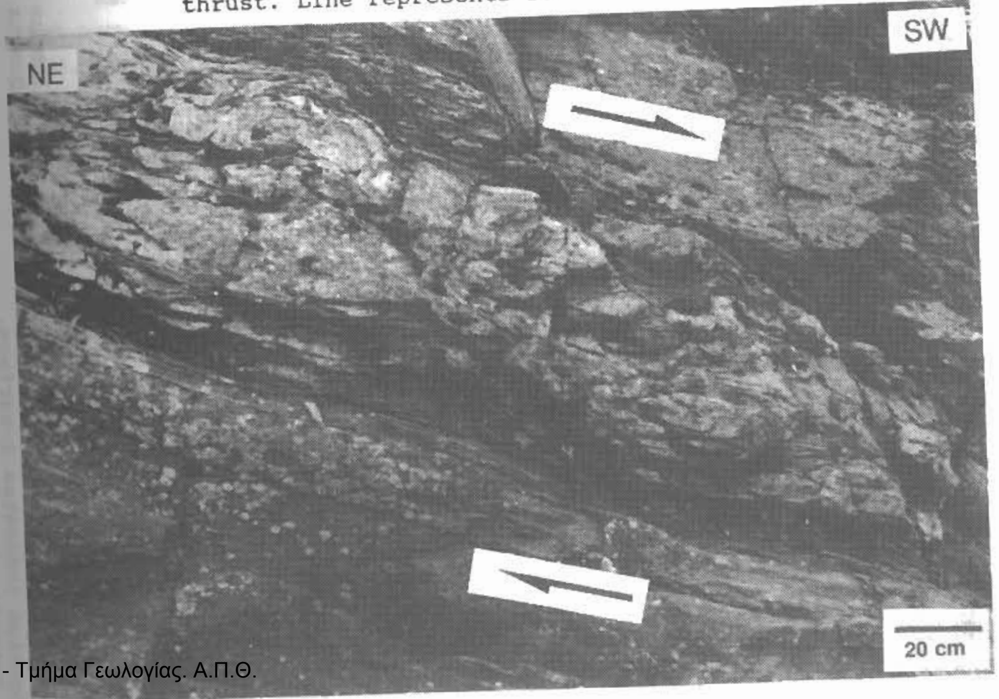

Fig.

Kinematic data of the Kranéa-Sarantáporo area.
(a) Dynamically recrystallised quartz in microlithons bound by C-surfaces in granite mylonite. Quartz elongation indicates S-surface.
(b) Extensional crenulation cleavage in orthogneiss mylonite of Elassóna series.
(c) Asymmetric strain shadow around feldspar porphyroclast (σ-clast). Same sample as (b).
(d) Antithetic slipped mica fish in granite mylonite. **Same sample as (a).**

of matrix quartz and mica. The general shape of the shadows is of the σ-type, indicating that porphyroclast rotation was slower than recrystallization of the quartz (Passchier and Simpson, 1986). The asymmetry of the shadows consistently indicates top to SW or WSW flow (Fig. 6b,c).

Large igneous mica flakes in orthogneiss (basement and Deskáti series) behave rigidly during ductile flow of the matrix and form mica fish with antithetic slip on the (001) crystallographic plane (Fig. 6d). The sense of displacement derived from the obliquity of the (001) planes to the foliation is again top to SW (WSW).

Quartz-<c>-axis textures measured in quartzitic rocks and quartz bands of mylonitic gneiss show asymmetric type I cross-girdle patterns (Lister et. al. 1978) (Fig. 4) indicating non-coaxial flow towards the SW (WSW).

DISCUSSION AND CONCLUSIONS

In the area of the Kranéa Window in northern Thessaly, pre-Alpine crystalline basement of the Pelagonian Zone overthrusts the Kranéa marbles of probably Mesozoic protolith age. Another major thrust plane, the Sarantáporo thrust, separates the Pelagonian basement from its Permomesozoic cover. Both thrusts contain lenses of ultramafic rocks indicating crustal-scale thrusting. Several minor thrusts occur within the basement. The thrusting process is inferred to be Late Eocene from radiometric and stratigraphic evidence from elsewhere in the Pelagonian Zone (Baumgartner and Bernoulli, 1976; Maluski et al., 1981; Clement, 1983; Schermer et al., 1988). Consequently the entire thrust system was affected by ductile rock flow subparallel to the thrust planes and bedding (M3, D3 event). This process obliterated most of the older structures.

Radiometric and structural evidence from other regions exists of an older event with high-pressure metamorphism around 130-120 Ma ("Eohellenic phase"; Barton, 1976; Jacobshagen et al., 1977; Yarwood and Dixon, 1977; Maluski et al., 1981; Schermer, 1988; Kilias et al., this volume), which we interpret as a first Alpine accretionary and crustal thickening event (M2, D2). We found only little evidence in the Kranéa-Sarantáporo area of such an event: a relictic foliation in Permotriassic rocks with a coeval northwest-trending stretching lineation. This relictic structural pattern may correlate with the older deformational event in the Ambelákia unit framing the Olympos Window (Kilias, this volume).

We propose a two-stage model for the Lower Tertiary deformation (D3) in northern Thessaly. During a first stage, an orogenic wedge formed in the Middle to Late Eocene stacking oceanic and continental rocks (accretion-collision stage). Deformation occurred in a low temperature, initially probably high pressure, environment restricting deformation structures to narrow thrust planes (compare deformation structures in recent accretionary wedges; e.g., Moore, 1986; Behrmann et al., 1988). Rheological softening during decompression in the Oligocene triggers the second, crustal thinning deformation stage by the collapse of the orogenic wedge. We interpret the domal structures of the Rizomata-Olympos-Ossa and Kranéa windows as metamorphic core complexes. They either formed due to uplift along crustal ramps during stacking or as rollover structures within a crustal extensional shear zone during wedge collap-

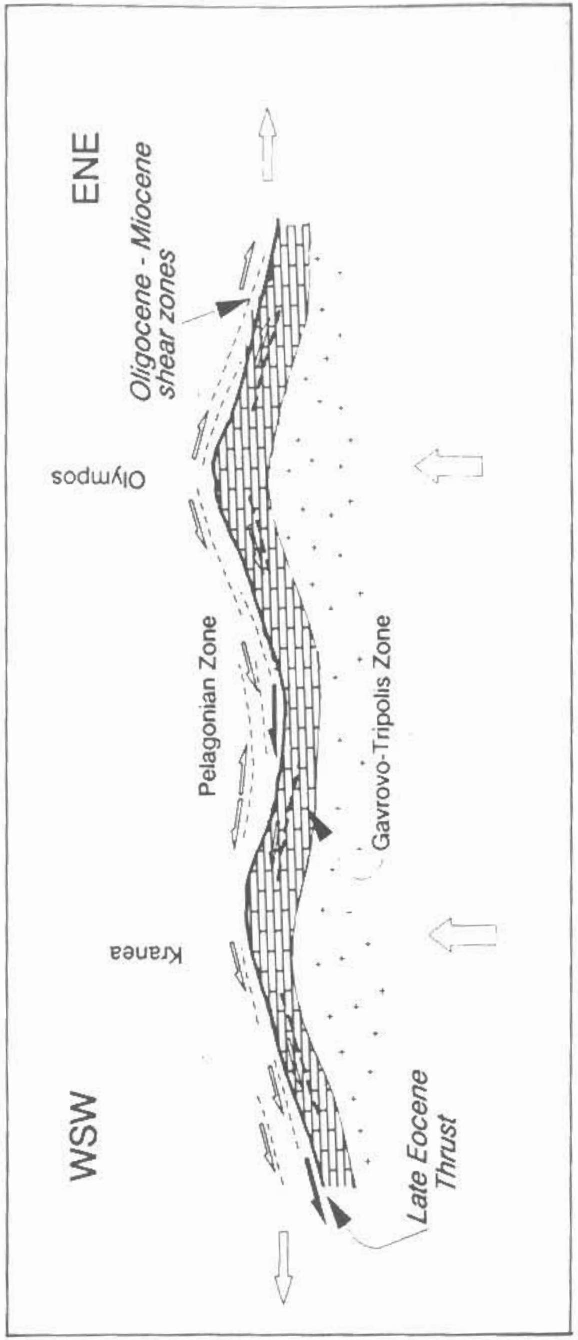

Fig. 7. Figure showing the proposed model for the structural evolution in the Tertiary of the tectonic windows in the Kranéa Olympos area. The accretionary stage of the orogenic wedge is represented by the Late Eocene thrust. Rheological softenig forms the shear zones.

se. The mylonitic foliation of this stage largely obliterated the accretion-collision related structures.

We attribute the second stage D3 deformation structures to extensional, crustal thinning based on the following:

(1) Deformation occurred along the cooling branch of the P-T path and is thus coeval with the uplift. This is indicated by retrograde mineral transformations (e.g. biotite to chlorite) and by the lack of statical recrystallization and grain growth of quartz. Moreover, the mylonitic deformation initiated in a ductile stage and subsequently continued into brittle states of the quartz-mica matrix as indicated by extensional crenulation cleavage overprinted by mesoscopic normal faulting. Rocks subjected to high-pressure metamorphism during Eocene subduction (glaucophane being stable) are thus rapidly uplifted and preserved from thermal overprint.

(2) The mylonitic foliation of the second stage of D3 is subparallel to the subhorizontal bedding and the thrust planes formed during the first stage of D3. Therefore, this deformation resulted in overall thinning of the crust. Strain is of the flattening type in most analyzed samples. This is interpreted in terms of late stage spreading of material during gravitational flow.

During the incipient stages of updoming rock flow was non-coaxial and SW-directed. In an advanced stage of updoming, SW-directed flow continued on the west flanks of the domes. However, flow was in part coaxial, as on the northeast flank of the Kranéa Window, or reversed to the opposite direction, as on the northeast flank of the Olympos dome (Fig. 7). This reflects accommodation of the late-stage uplift centered within the present dome structures.

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