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# TECTONIC EVOLUTION AND STRESS FIELD OF THE KYMI-ALIVERI BASIN, EVIA ISLAND, GREECE

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## ABSTRACT

Stress and strain analysis has been used to reconstruct the post-Oligocene geodynamics of the Kymi-Aliveri basin: The Kymi-Aliveri basin occupies the footwall of the Kymi-Thrust, which formed during the Middle Miocene as a large transpressional structure in the late orogenic stages of the Hellenides. Subsequently, in the Upper Miocene the shape of the basin was strongly modified by an orthogonal system of NE and NW trending normal faults as a result of post orogenic collapse. In the Pliocene and Pleistocene time the basin is a part of the back arc basin, which developed behind the Hellenic Arc. WNW trending normal faults and reactivated faults characterized this tectonic phase.

**KEY WORDS:** fault-slip data analysis, palaeostress field, transpression, back arc extension, Kymi-Aliveri basin, Evia.

## 1.GEOLOGICAL SETTING

In Evia island, outcrops of three tectonic units are exposed: the Pelagonian plate, the Attico-Cycladic Massif and the sedimentary cover of post-Oligocene deposits.

### 1.1 THE PELAGONIAN PLATE

The northern part of the study area, occupies the southeastern margin of the Pelagonian plate, which runs parallel to the structural grain of the Hellenides (Fig. 1). A nappe pile of two structural units was established mainly during the Eohellenic orogeny: The lower unit consists of a rift sequence of (?) Permian low-grade metasedimentary and metavolcanic rocks overlain by Triassic-Jurassic marbles (Pelagonian marbles) with a composite structural thickness of 1.2 Km (Fig.1:1). The basement of the sequence consists of orthogneisses and paragneisses, that reaches a composite structural thickness of 8 Km. The upper structural unit called "Eohellenic nappe" consists of 500 m of ophiolites and volcanosedimentary rocks (Jacobshagen et al 1978) obducted in a precollisional stage at 150 Ma above the eastern Pelagonian margin (Spray et al 1984). Late Cretaceous limestones are deposited transgressively above them and passes upwards to a Palaeocene-early Eocene flysch (Bignot et al 1973; Katsikatsos et al. 1976 ; Robertson 1990) (Fig.1:1).

### *1.2 THE ATTICO-CYCLADIC MASSIF*

The southern part of the study area occupies the northwestern part of the Attico-Cycladic massif and is separated from the Pelagonian plate by a major tectonic contact, called here as Pelagonian Fault (PF) (Fig.1:A-A'). The Aliveri thrust (AF) separates the Attico-Cycladic Massif into two structural units: a) the lower unit named the Almyropotamos unit (Katsikatsos et al. 1981), consists of Triassic to late Eocene limestones with schists intercalations, and a 1200m thick flysch sequence deposited during the lower Oligocene (Dubois & Bignot 1979). b) The upper unit, called here the "Mesohellenic nappe", is about 2000m thick and comprises marbles with mica schist intercalations which pass upwards to metapelites, black quartzites, metabasites and metatuffs. Thick ultra-mafic lenses are included in the lower parts of this unit. The upper part of the marbles gave a late Cretaceous age and suggest a Mesozoic age for the whole unit is suggested (Tembra et al 1975). The paragenesis of glaucophane, lawsonite and epidote found within mica schists from the unit indicate an origin in the low temperature blueschists facies at 300° °C and 8 kbars (Bonneau & Kienast 1982). 40Ar/39Ar age determinations on glaucophanes and phengites yielded metamorphic ages of 45-50 Ma (M1 metamorphic event, Bavay et al 1980).

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### *1.3 THE KYMI BASIN*

In the Early Miocene, after a sedimentation break in the Oligocene time, the Kymi-Aliveri basin was formed (Fig.1). This basin was filled by 500m thick conglomerates and marls with lignitic intercalations (Katsikatsos et al. 1977), which was later intruded by volacnic rocks at 13Ma (Fig.1:2) (Katsikatsos et al. 1976, Pe-Piper & Piper 1994). In the southern margin of the Kymi-Aliveri basin c.1000m of late Miocene conglomerates were accumulated (Katsikatsos et al. 1981).

The aim of this paper is to describe stress and strain in the Kymi-Aliveri basin (Figs. 2,3) and to present the post-Oligocene geodynamic evolution of the area (Fig.5).

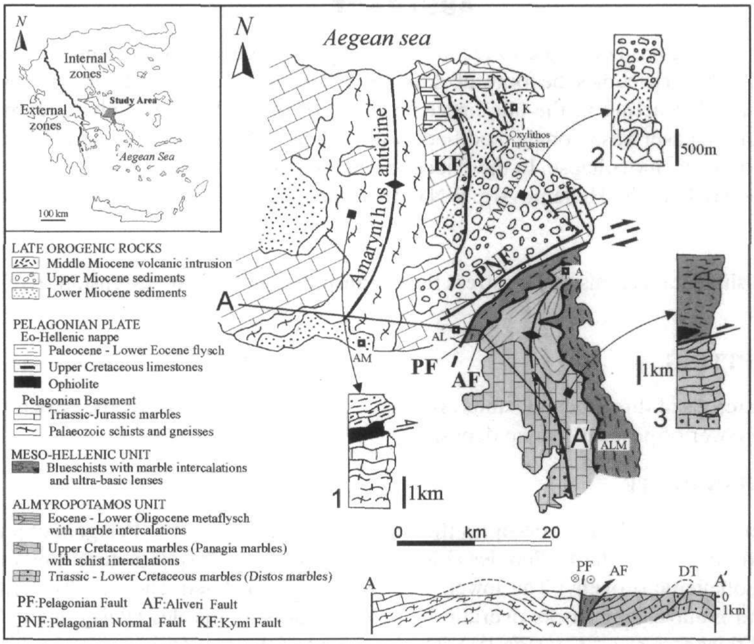


***Figure 1. Geological map, tectonostratigraphic columns (1-3) and schematic tectonic cross-section (AA') in the Central Evia. Inset shows the study area.***

## 2. FAULT-SLIP DATA ANALYSIS

Field data used to reconstruct the tectonic evolution and stress field of the post-orogenic sediments were taken from marginal and intrabasinal faults within the Kymi-Aliveri basin. The slip sense was inferred from several kinematic indicators along the fault plane summarized by Hancock (1985) and Petit (1987). In each site, subsets of fault-slip data consistent with different stress directions were separated, on the basis of both the orientation/type of the stress regime and the chronological constraints. The latter were obtained in the field mainly by using criteria such as succesive striations on a fault plane, cross-cutting relationship etc. The scatter of the fault movements and a second calculation of the kinematic axes were obtained using the P-T axes method (Turner 1953). The average contractional (P) and extensional (T) kinematic axes (strain axes) represent a good estimation of the calculated maximal and minimal stresses respectively (Fig.4:nets).

A computer program (Delvaux, 1993) was used for fault data analysis. Inversion of slip direction deduced from kinematic indicators starts with the right dihedron method (Angelier and Mechler, 1977) in order to fit the best reduced stress tensor to the data set. This led to the definition of the principal stress axes (s1>s2>s3) and the value of the ratio R=(s2-s3)/(s1-s3) between principal stress magnitudes. In some cases, where polyphase faulting occurred, the Mohr-diagram (Fig.4) guided the separation of fault data into subsets and the selection of the best-fitting stress tensor. The program checks the ability of the tensor to activate or not activate pre-existing fractures. For the definition of the palaeostress field we took into account the nature of the (sub)vertical stress axis and the value of the ratio R (Delvaux et al. 1997).

The kinematic analysis of faults reveals the presence of two successive stages controlled by compression and tension respectively.

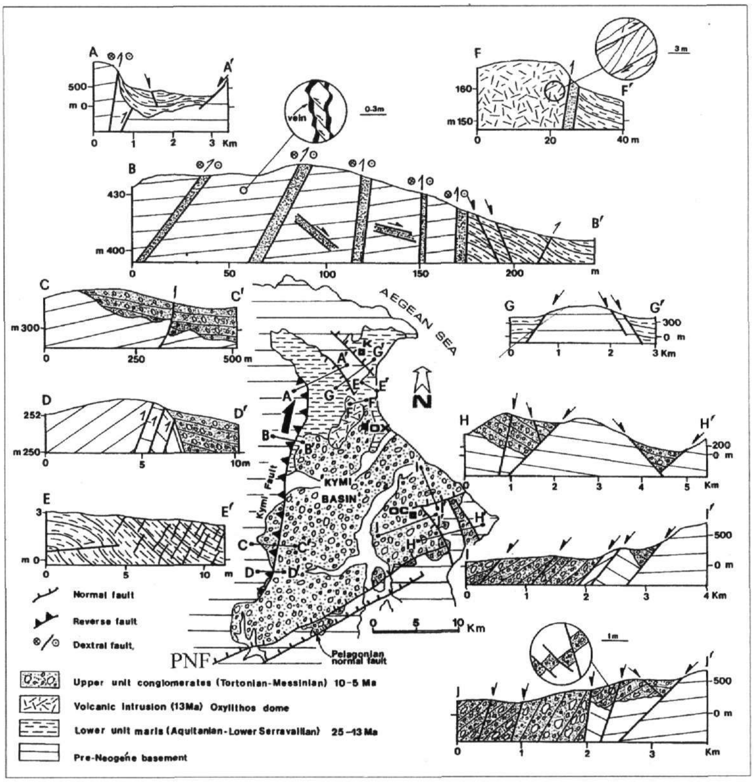

*Figure 2. Cross sections along the compressional (AA', BB',CC', DD') and the extensional margins (JJ', II', HH', GG') of the Kymi basin. Cross sections EE' and FF' show the internal deformation of the basin*

## 3. THE COMPRESSIONAL STAGE

The Kymi-Aliveri basin is an intramontane basin, 40km long and 10km wide, which are filled with Early Miocene sediments (Katsikatsos et al. 1981). The basin trends NNE and is asymmetric in cross section deepening towards the mountain front in the west. The northern part of the basin contains up to 500m of syntectonic sediments (Fig.2:A-A') that were eroded from the Amarynthos anticline to the west and deposited in alluvial fan, fluvial and lacustrine depositional settings. These sediments are getting thicker and coarser towards the mountain front due to higher rates of subsidence and closer proximity to the uplifted source terrane.

The western margin of the Kymi basin is marked by an arcuate fault, the Kymi Thrust, resulting in a vertical structural relief of more than 1300m (Fig.2:A-A'). The progressive increase of sendiments thickness toward the west implies a synsendimentary origin for this fault. Internal deformation in the hangingwall of the Kymi Trust is represented by 50m spaced synthetic faults with oblique reversal character (Fig.2:B-B', D-D') as well as abundant calcite veins (Fig.2 inset in B-B') and stylolitic cleavages. Mutual cross-cutting relations between the veins and the stylolitic cleavage suggest that they are coeval. The fault dips steeply ('70-80°) to the west, shows a dextral reverse character and is associated with up to 10m thick cataclasites and calcite cemented breccias (Fig.2:B-B'). Slip data on mesoscopic faults (Fig.3:$T_2$) are consistent with transpression (principal stress axes s1 and s3 are nearly horizontal) with a NE-SW direction of compression.

Internal shortening in the sedimentary infill of the Kymi basin is characterized by large open folds that are tens to hundreds of meter across with limbs that dip less than 20°. Mesoscale NE-SW trending open folds are often associated with low angle thrusts (Fig.2: E-E'). Although some of these structures are clearly due to soft-sediment slumping the majority of these are of tectonic origin and an axial planar spaced cleavage is developed (Fig.2: E-E' and Fig.3: $T_1$). The presence of insoluble residues on the cleavage surfaces and the offset of bedding at bedding-cleavage intersection shows that removal of the $CaCO_3$ through dissolution took place along the cleavage surfaces. Taking this interval shortening of the beds into account, the total shortening of the sediments does not exceed 10% (sensu Alvarez et al 1978). The cleavage seams are orthogonal to calcite fibers in veins and

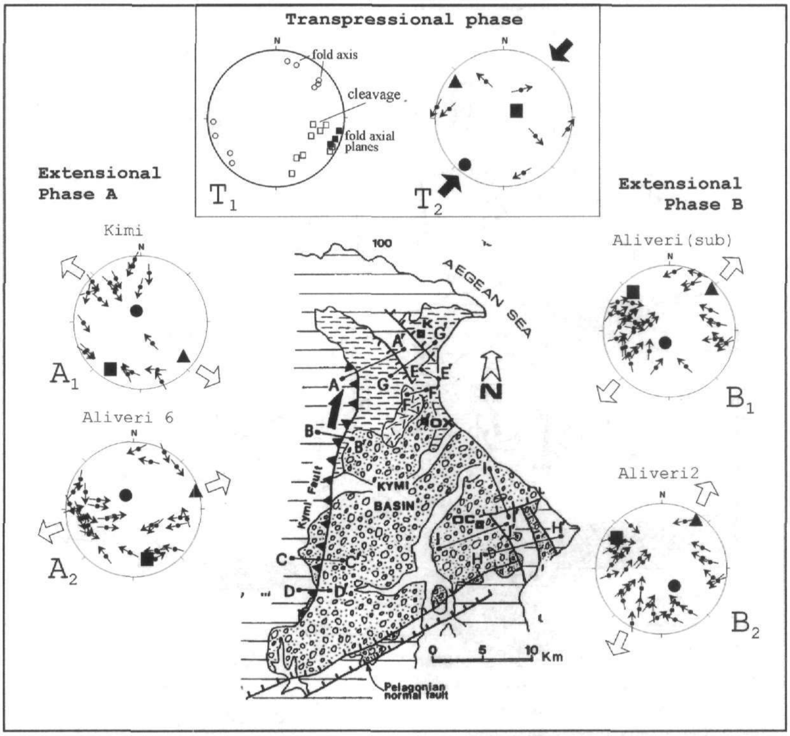


*Figure 3. Geological map of the Kymi basin and equal-area, lower hemisphere stereonets with fault planes shown as poles and striae as arrows onto the poles. In stereonets the filled cycle indicates the position of s1 stress axes, the rectangular the position of s2 and the triangle the position of s3.*

pressure shadows, indicating that the veins formed subperpendicular to the principal shortening direction. In addition pits on irregular stylolite surfaces show the same direction. However this shortening results from transpression as is suggested by analysis of slip data on mesoscopic strike-slip faults within the basin (Fig.3 :$T_2$).

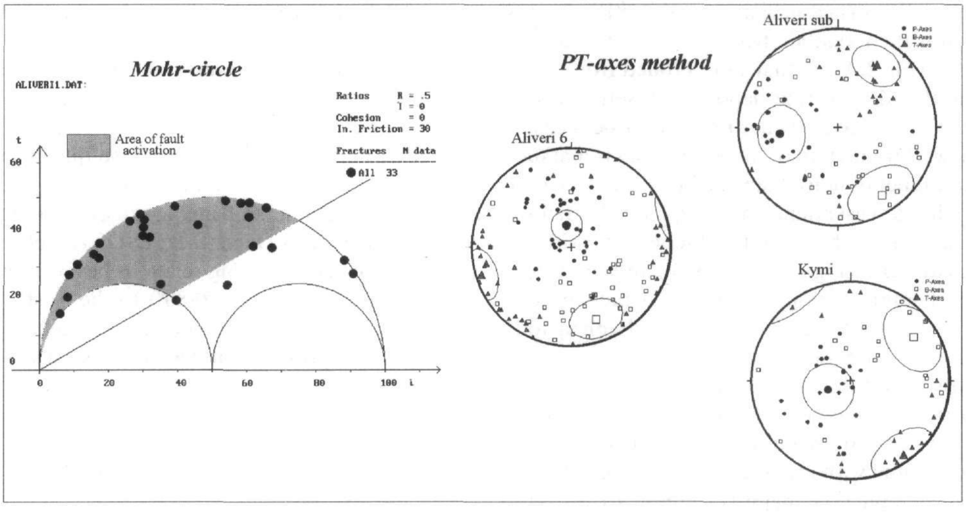


*Figure 4. The P-T axes method of Turner (1953)was used in order to obtain both the scatter of the fault movements and a second calculation of the kinematic axes. The application of Mohr-circle method guided the separation the fault data in subsets and checks the ability of the tensor to activate or not activate pre-existing fractures.*

*THE OXYLITHOS INTRUSION.* In the Middle Miocene (13 Ma) porphyritic dacite and andesite occurs in a NNE- trending dome or sub-volcanic complex, 5 km long and 1 km wide (Fig.2). These volcanic rocks were intruded as phreatomagmatic eruptions concomitant with rhyolithic pyroclastic surge deposits in the central parts of Kymi basin(Pe-Piper & Piper 1994). Volcanic rocks containing lacustrine clasts as xenoliths and pyroclastic rocks alternating with lacustrine marls show that sedimentation and volcanic activity were coeval. The eastern margin of the intrusion is a 60 m high fault (reverse) scarp, at the base of which 3 m thick cataclasites have been observed (Fig.2: F-F′). The phreatomagmatic character of volcanism suggest that this fault is a true magmatic conduit. A 6m thick fault zone within the volcanic rocks adjacent to the margin fault displays c-s structures indicating top up-to-the-east reverse movement (inset of F-F′ in Fig. 2). Finally, some smaller synthetic faults adjacent to the margin fault display nearly horizontal slickensides indicating a transpressional setting.

## 4. THE TENSIONAL STAGE

After the volcanic activity in the study area began a period of "basin and range" type of deformation including accumulation of post-middle Miocene sediments as well as uplift and extension of metamorphic rocks. Based on the stress distribution this period can be divided into phases: a late Miocene extensional phase and a Plio-Pleistocene extensional phase.

### *4.1. LATE MIOCENE EXTENSIONAL PHASE*

Stress tensor determinations from fault slip data of the first extensional phase are in agreement with pure extensive stress regime which is characterized by a variance in $s_3$ orientation between NW-SE and SW-NE (Fig.3: $A_1$ and $A_2$). The magnitude of extension in this area is strongly heterogeneous partitioned between a more "stable block" to the southeast which comprises the Median crystalline belt and a high extended domain to the northwest which comprises the Amarynthos anticline and the southern part of the Kymi basin. These two block represents the footwall and the hanging-wall of the «Pelagonian Normal Fault» (PNF in Figs 1-3). Very probably PN merges downward into the PF.

Synextensional subsidence and deposition are the main characteristics of this area. During this extension the Kymi basin was widened to the south by a 30 km long and 10 km wide rift belt, which trend parallel to the PF. Cumulative vertical displacements along northwest dipping normal faults have caused a structural relief in excess 1000 m (Fig.2: I-I′). Synrift sediments include a 800 m thick sequence of alluvial fan delta and alluvial fan. They consist of late Miocene conglomerates of a lower monomictic sequence of Pelagonian fragments and an upper polymict sequence of blueschist and metaflysch detritus and Pelagonian limestone pebbles. In the rifted margins gravity slide breccias, boulders within the conglomerates, stratal dips up to 50 (much of the dip may be primary) and rotated synsedimentary faults indicate a high relief area to the south. Basinward, Gilbert type fan delta accumulated above marls because of increasing subsidence. The extension along the NW dipping faults is calculated to lie within a range of 30-40%, using the formulas of Wernicke and Burchfiel (1982). The duration of extension has been estimated about 7 Ma, that is the time between the end of the Oxylithos intrusion at 13 Ma and the beginning of the Pliocene deposition at 6 Ma.

Movements along the strike of NW trending faults are transferred to the northeast (near Octhonia village) by a NW horst (Fig.2: H-H′ and J-J′). The faults which formed this horst divide the area into a series of 300-500m spaced blocks, showing mainly antithetic rotations. Another NW trending tectonic horst marks the northern end of the Kymi-Aliveri basin (Fig.2:G-G′).

### *4.2. PLIO-PLEISTOCENE EXTENSIONAL PHASE*

Faulting during this extensional phase has occurred within a tectonic stress field characterizes by a subvertical $s_1$ direction and $s_3$ in the NNE to NE-SW direction (Fig.3: $B_1$ and $B_2$). Mesoscopic and mapable normal faults within Plio-Pleistocene along the eastern coast of the study area display young fault scarps suggesting a recent activity. During this extensional phase older ENE trending normal faults have been reactivated into oblique normal faults (s. Fig.3: $B_1$ and $B_2$).

## 5. TECTONIC IMPLICATION-SYNTHESIS

As blueschists were overthrusted above the Lower Oligocene flysch of the Almyropotamos unit (Fig.1: A-A'), it seems that contractional movements between the Pelagonian plate and the Attico-Cycladic Massif continued in the Evia until this time. Our results revealed that contraction in this area lasted until the Middle

Miocene time as it is the further south in the Cycladic islands (Boronkay & Doutsos 1994).

On the basis of the above geometric-kinematic analysis we interpret the deformation in the Kymi basin to be a result of right-lateral strike slip faulting in a transpressive setting (Fig.5). A structural relief of more than 1300 m achieved along the Kymi oblique thrust in the time interval between 25 Ma and 13 Ma resulted in synclinal downward of the Kymi basin and a transpressional push-up on its western margin. Taking into account that Kymi fault is situated in the hangingwall of the PF that was active during the Late Oligocene, we interpret this fault as a "break back fault" (Butler 1987). The end of the contractional subphase is marked by the emplacement of andesitic magmas along a major crustal scale shear zone of transpressional origin.

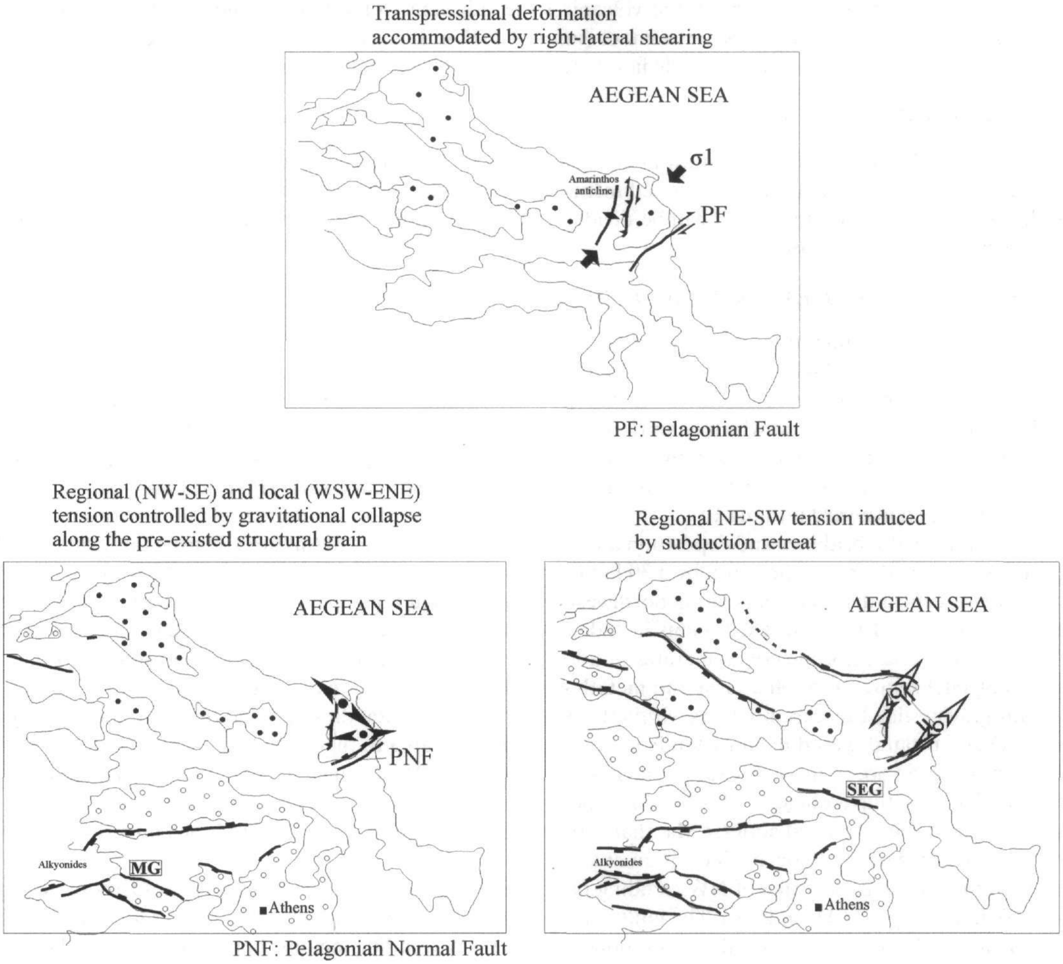


***Figure 5. The geodynamics evolution of the Kymi basin in three stages.***

Large scale extensional collapse of thickened continental crust (sensu Dewey 1988) may be the mechanism causing the NW and NE directed normal faults of the first extensional phase in the upper Miocene time. It is important to note that erosional rates during extension in the Pelagonian margins may be small because Late Miocene sediments were not deposited in the western part of the Kymi basin. Two types of faults was formed in the Kymi basin during the Plio-Pleistocene time: a)young WNW trending normal faults and b)oblique normal faults, which are reactived preexisting faults. They are the result of NNE extension induced very probably by two first order geotectonic structures: the back arc basin behind the Hellenic arc and the North Anatolian transform Fault (s. Doutsos & Kokkalas 2001).

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