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*Geological Society, London, Special Publications* 2009; v. 311; p. 293-310
doi:10.1144/SP311.11



**Notes**

# The Itea–Amfissa detachment: a pre-Corinth rift Miocene extensional structure in central Greece

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**Abstract:** The Itea–Amfissa valley, separating Giona Mountain to the west from Parnassos Mountain to the east, is related to an extensional detachment observed along the eastern slopes of Giona. The detachment is traced for 30 km north of the Corinth Gulf and dips 25°–40° to the east, showing an east–west extension parallel to the Hellenic arc. The lower nappes of Pindos, Penteoria, Vardoussia and mainly the basal thrust of the Parnassos unit form part of the footwall, whereas the upper thrusts of the Parnassos unit and the Western Thessaly–Beotia nappe form part of the hanging wall. The eastern slopes of Giona are controlled by the detachment and several hundred metres of syn-tectonic breccia-conglomerates are observed at the top of the hanging wall rocks and are back-tilt towards the detachment plane. Two conglomeratic sequences are distinguished: the lower one consists of argillaceous matrix and abundant ophiolite detritus whereas the upper one bears carbonate matrix with carbonate detritus together with large olistholites of Mesozoic limestones. Based on calcareous nannofossils a middle Miocene age has been determined for the lower formation and a middle–upper Miocene age is probable for the upper. Planation surfaces cut on top of the sediments rise from south to north starting from sea level at Galaxidi to about 1400 m at Prosilio. The throw of the detachment is about 2.5–4.2 km measured mainly from the structural omission of the Alpine tectono-stratigraphic units. A contrast between the footwall and the hanging wall structure is described, with monoclinic sequence of the Parnassos nappe dipping to the west in the footwall but a complex synsedimentary horst and graben structure of sliding blocks of Alpine formations within the Miocene clastic sequences in the hanging wall. The detachment has been deformed by the east–west-trending steep normal faults that have created the Corinth rift during late Pliocene–Quaternary time showing a north–south extension. The Itea–Amfissa detachment forms the northern tip of the broader East Peloponnesus detachment, observed south of the Corinth rift structure from Feneos to Kyparissi. Similar geodynamic phenomena with large olistholites and breccia conglomerates are known from the Serravalian of Crete, related to the activity of the Cretan detachment.

The two highest mountains of Sterea Hellas in central Greece, north of the Corinth Gulf, are Giona (2507 m) in the west and Parnassos (2455 m) in the east (Fig. 1). They are separated by a narrow morphological valley, covered by alluvial deposits with famous olive groves, cropping from the Itea Gulf in the south to the city of Amfissa in the north. This prominent morphological feature trends north–south at right-angles to the east–west-trending Corinth Gulf, which is well known to be the result of neotectonic activity of east–west-trending normal faults (e.g. Armijo *et al.* 1996). Surprisingly, no tectonic structure or other geodynamic process (e.g. erosion) has ever been reported in the literature to explain this north–south-trending valley. Alpine structures might have produced this morphological feature, parallel to a thrust or a syncline in a north–south direction, which is the general Alpine tectonic trend along central and western Greece. However, both mountains on both sides of the Itea–Amfissa depression are located on the same geotectonic unit of Parnassos (Renz 1955; Papastamatiou 1960; Celet 1962) and no particular thrust or fold has been reported so far that would explain the formation of the valley (Celet 1962; Schwan 1976) (Fig. 1). Interestingly, the existence of post-Alpine clastic sediments of unknown age has been reported in the area of Aghia Efthymia village along the eastern slopes of Giona, capped by a well-developed planation surface at about 350–400 m of elevation and in the area of Prosilio at about 1000–1200 m (Papastamatiou *et al.* 1960, 1962; Celet 1962). This is the most important outcrop of post-Alpine sediments along the northern margin of the Corinth Gulf, in contrast to the southern margin, where post-Alpine sediments crop out almost everywhere along the north Peloponnesus coastline from Corinth to Patras (Fig. 1).

*From*: van Hinsbergen, D. J. J., Edwards, M. A. & Govers, R. (eds) *Collision and Collapse at the Africa–Arabia–Eurasia Subduction Zone*. The Geological Society, London, Special Publications, **311**, 293–310.
DOI: 10.1144/SP311.11 0305-8719/09/$15.00 

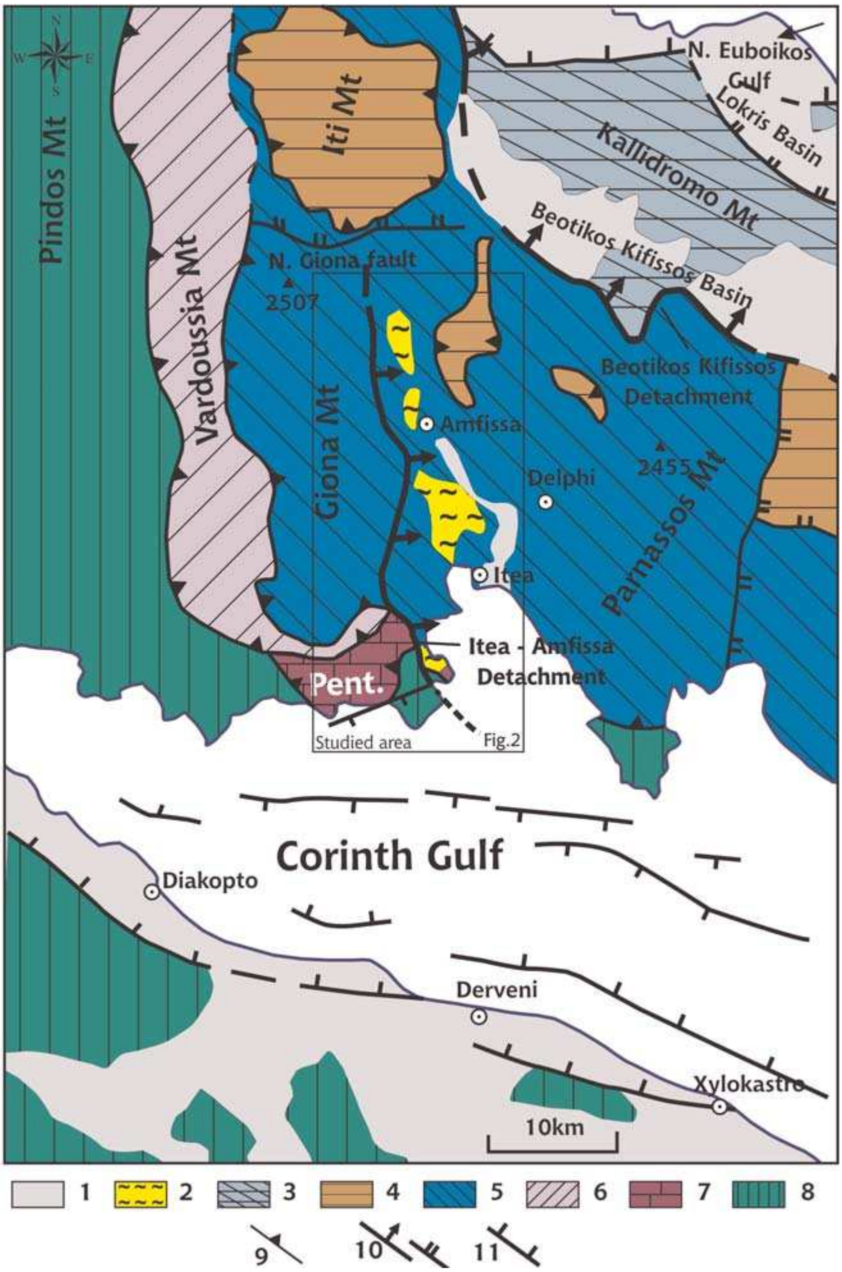


**Fig. 1.** The studied area within the geographical and geotectonic frame of central Sterea. (1) post-Alpine sediments, mainly Plio-Quaternary; (2) Miocene sediments of the Itea–Amfissa basin; (3) Tectonic units of the Internal Hellenides, mainly SubPelagonian; (4) Western Thessaly–Beotia unit; (5) Parnassos unit; (6) Vardoussia unit; (7) Penteoria unit; (8) Pindos unit; (9) Alpine overthrust; (10) Miocene detachments and normal faults; (11) Plio-Quaternary normal faults.

Our study has shown the existence of a major extensional detachment fault along the eastern slopes of the Giona Mountain, trending in the north–south direction. This Itea–Amfissa detachment has created the Itea–Amfissa depression with clastic sedimentation during Miocene, before the onset of the east–west trending faults of the modern Corinth rift structure.

## The geology of the eastern Giona Mountain and the valley of Itea–Amfissa

The Alpine structure of both Giona Mountain and Itea–Amfissa valley comprises a number of thrust units incorporating shallow-water carbonate rocks belonging to the Parnassos platform (Philippson 1898; Renz 1955; Papastamatiou 1960; Celet 1962). At the southern end of Giona Mountain on the Galaxidi peninsula some thrust sheets belonging to the lower parts of the nappe pile show differentiated stratigraphy, with rocks deposited either in slopes or in basinal environments, showing a lateral transition towards the Pindos basin, which forms the next lower nappe cropping out to the west (Celet 1960; Papastamatiou & Tataris 1963; Wiedenmayer 1963; Johns 1979).

Our mapping distinguished four nappes along the southern Giona section (Fig. 2) with: (i) the Pindos nappe at the base, containing Cretaceous pelagic carbonates and Paleocene flysch; (ii) the Penteoria nappe on top of the Pindos, consisting of upper Triassic–middle Jurassic shallow water carbonates overlain by upper Jurassic–Cretaceous pelagic sequences and Paleocene–Eocene flysch; (iii) the Vardoussia nappe overlying the Penteoria nappe, featured by transitional slope facies from the upper Triassic to the Cretaceous and Paleocene–Eocene flysch; and (iv) the Parnassos nappe on top of the previous nappes, containing carbonate platform strata from the upper Triassic to the upper Cretaceous, interrupted by three main bauxite horizons ($b_1$ in the upper Jurassic, $b_2$ in the lower Cretaceous and $b_3$ in the upper Cretaceous) and covered by Paleocene–Eocene flysch deposits.

Internal thrusts are present within each nappe. For example, in the northern part of the Itea–Amfissa valley in the area east of Prosilio, there are two thrust sheets present in the upper part of the Parnassos nappe (Figs 2 and 3, profile A–A′). The highest nappe in this area, the nappe of Western Thessaly–Beotia, lies with a subhorizontal contact above the Parnassos thrust sheets at the western end of the Parnassos Mountain, known as Gerolekas (Fig. 2). This upper nappe is of more internal origin and belongs to the transitional units between the Parnassos platform and the Internal Hellenides (Celet *et al.* 1976; Papanikolaou & Sideris 1979; Papanikolaou 1986). Its main characteristic is that the stratigraphic column is continuous from the Triassic–Jurassic to the Cretaceous–Eocene, with the upper Jurassic–lower Cretaceous flysch type sediments bearing abundant ophiolite detritus marking the vertical transition. In contrast, the units of the Internal Hellenides, like the Subpelagonian, are characterized by a prominent orogenic unconformity in the upper Cretaceous, which covers both the Triassic–Jurassic sediments and the previously emplaced ophiolite nappe. These more internal nappes crop out north of the Parnassos Mountain in the area between the Beotikos Kifisos Basin and Kalidromon Mountain up to the Northern Evoikos Gulf (Fig. 1). The subsidence of the higher nappes and the formation of the Beotikos Kifisos and Lokris post-Alpine basins are due to the activity of the NE-dipping Beotikos Kifisos extensional detachment (Kranis & Papanikolaou 2001) (Fig. 1). Another normal fault trending east–west marks the tectonic boundary of Giona Mountain with Iti Mountain to the north. This fault has subsided the block of Iti Mountain to the north of Giona Mt by more than 1 km of throw. This activity has resulted in the preservation of the outcrops of the Western Thessaly–Beotia nappe in Iti Mt, whereas in Giona Mt this nappe has been eroded.

The Itea–Amfissa north–south-trending extensional detachment system, reported here for the first time, is developed along the eastern slopes of Giona Mountain (Fig. 2). This detachment is first exposed from the south in the area of Galaxidi and can be traced northwards, east of Penteoria and Vounichora villages to further north in the area west of Amfissa and Prosilio.

The overall tectonic structure of the Eastern Giona and the Itea–Amfissa valley is shown in three NE–SW tectonic profiles (Fig. 3). The central and the northern profile (Fig. 3, A–A′, B–B′) show that the footwall of the detachment is made from the lower thrust sheet of the Parnassos nappe, whose carbonate sequence generally dips $15^\circ$–$30^\circ$ to the west. This is in agreement with the fact that all along the detachment surface the age of footwall rocks of the platform carbonates is upper Triassic–lower Jurassic and only along the western part of Giona Mountain do the Cretaceous formations crop out. At the southern profile (Fig. 3, C–C′) the upper Triassic base of the Penteoria nappe occurs at the footwall. Small tectonic wedges of the Vardoussia nappe occur along the detachment and below the lower thrust unit of the Parnassos nappe, forming the hanging wall.

In contrast, the structure within the hanging wall of the detachment is complex with a number of thrust sheets belonging to the upper part of the Parnassos nappe, cropping out together with the upper nappe of Western Thessaly–Beotia and the post-Alpine sediments of Aghia Efthymia and Prosilio. The general dip of the thrust sheets in the hanging wall is towards the east, with two distinct thrust sheets of Parnassos unit dipping below the Western Thessaly–Beotia nappe along the Gerolekas slopes. It is noteworthy that only the Ailias tectonic block (Fig. 3, profile C–C′) is made of the lower part of the stratigraphic sequence of Parnassos, incorporating mainly the upper Triassic–middle Jurassic formations, whereas the other blocks of

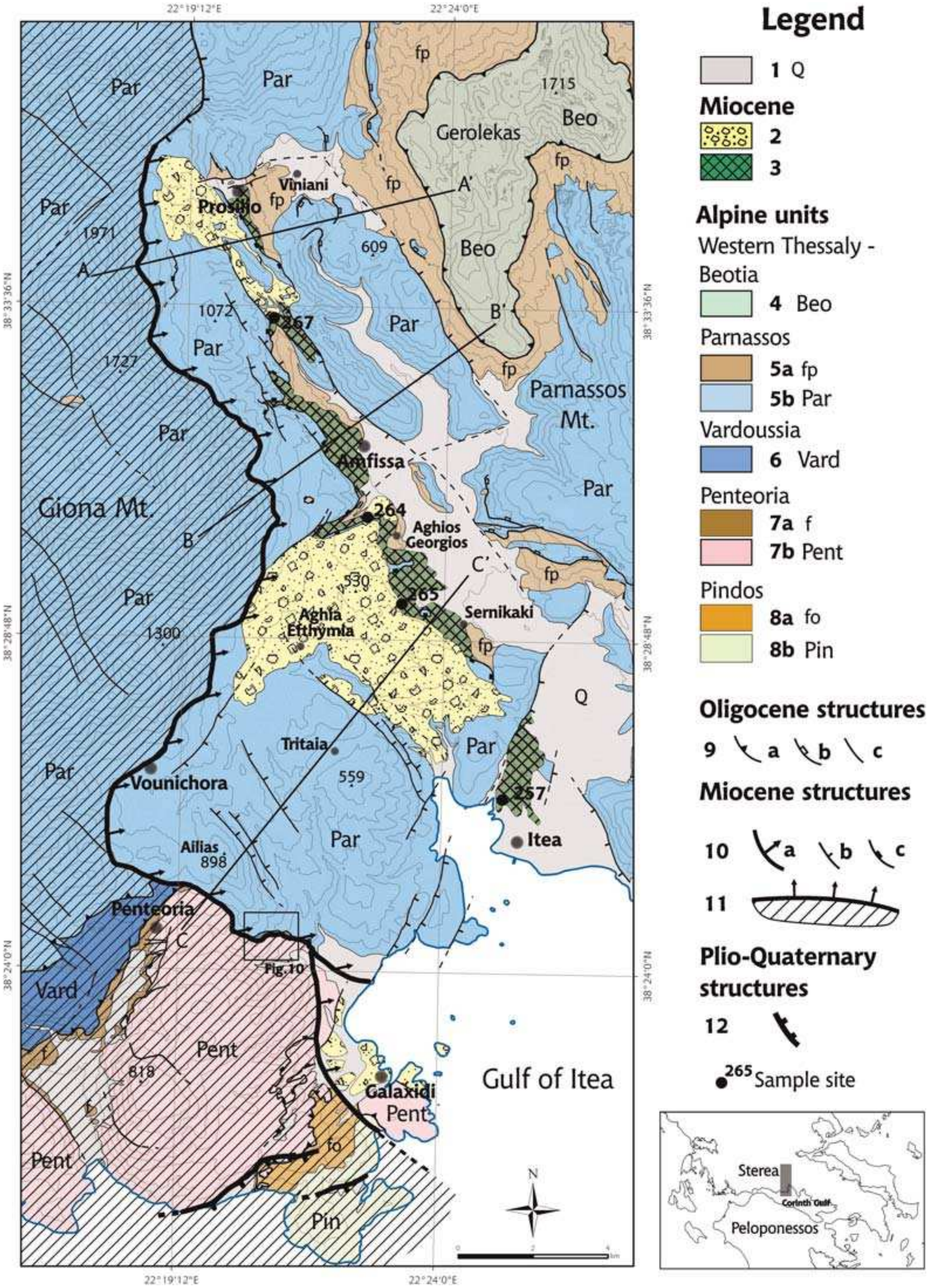


**Fig. 2.** Simplified geological map of the studied area in the Eastern Giona Mountain and the Itea–Amfissa Valley (based on the maps of Papastamatiou *et al.* 1960, 1962 at scale 1:50 000 and our own mapping at scale 1:10 000). (1) Quaternary deposits; (2) Upper sequence of sediments, middle–upper ?Miocene; (3) Lower sequence of sediments, lower–middle Miocene; (4) Western Thessaly–Beotia nappe; (5a) Parnassos flysch, Paleocene–Eocene; (5b) Parnassos carbonate platform, upper Triassic–upper Cretaceous; (6) Vardoussia nappe; (7a) Penteoria flysch,

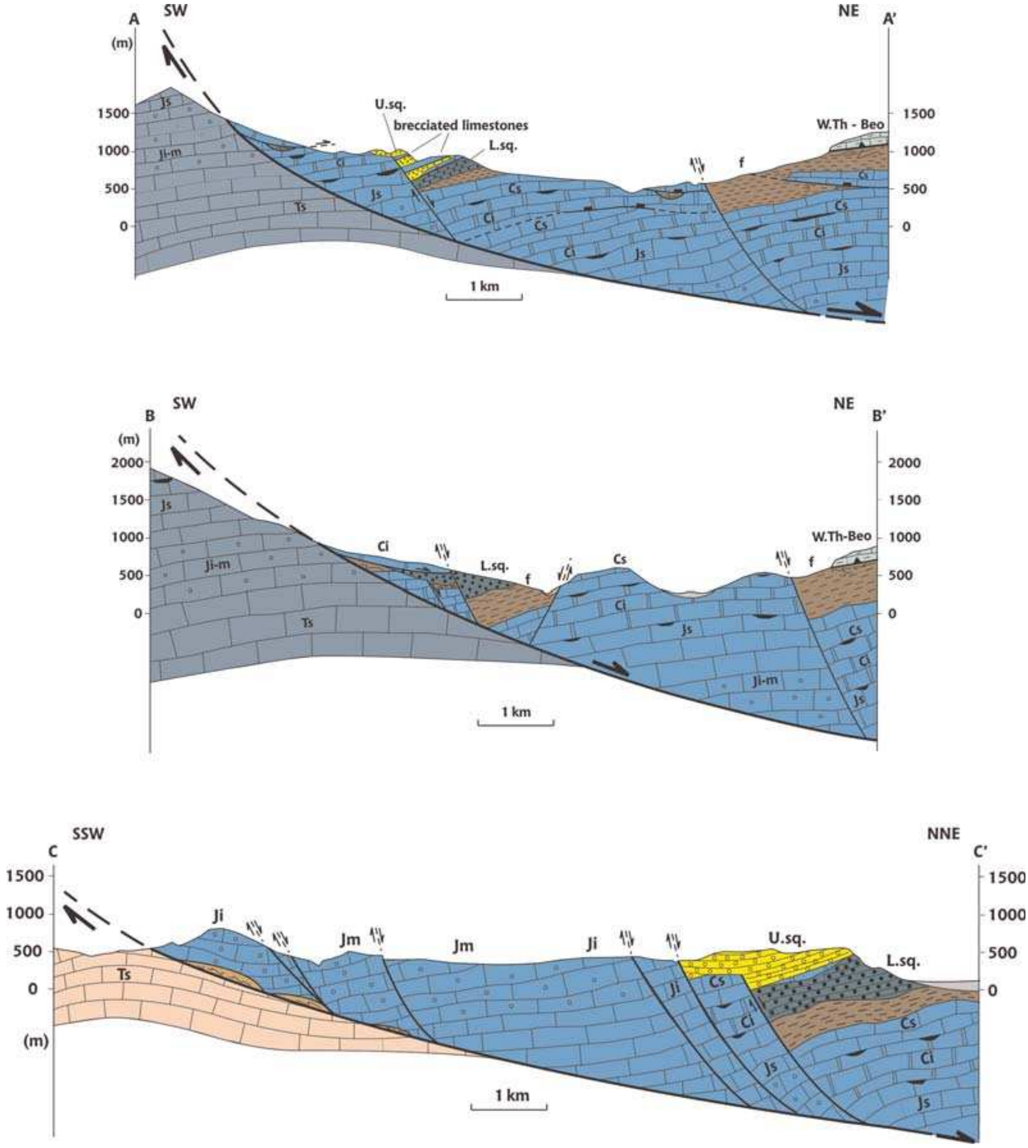


**Fig. 3.** Tectonic profiles across the Itea–Amfissa detachment. Their location is given on the geological map of Figure 2.

the hanging wall incorporate thrust sheets with upper Jurassic–Eocene formations. The dip of the Aghia Efthymia and Prosilio clastic sediments is usually 10°–30° to the west into the detachment surface. Some steep North–NE–South–SW-trending normal faults are present within the hanging wall rocks close to the detachment.

No other post-Alpine sediments are observed in the area with the exception of some Quaternary scree and alluvium.

**Fig. 2.** (*Continued*) Paleocene–Eocene; (7b) Penteoria carbonate sequence, upper Triassic–upper Cretaceous; (8a) Pindos flysch, Paleocene–Eocene, (8b) Pindos pelagic sequence, upper Cretaceous; (9) Alpine structures, Oligocene; (9a) overthrust, (9b) thrust, (9c) fault; (10) Miocene structures, (10a) extensional detachment, (10b) normal fault, (10c) gravity nappe, (11) shaded area marks the geological formations of the detachment's footwall; (12) normal faults of the Corinth rift system.

## The Itea–Amfissa sedimentary deposits: Tectonostratigraphy and age assessment

Several hundred metres of coarse clastic sediments are observed at the top of the hanging wall succession along the detachment. They generally consist of breccia and conglomerates alternating with sandy and clay layers including smaller pebbles. These sediments represent the remnants of the Itea–Amfissa basin that was formed during the Miocene at the hanging wall of the detachment. The present day Itea–Amfissa valley has been uplifted and incised the Miocene sedimentary basin. Present-day alluvial deposits are observed at altitudes from sea level to 200 m along the valley, whereas the top of the Miocene sedimentary succession is observed several hundred metres higher along the eastern slopes of Giona Mt Outcrops of sediments are traced in Galaxidi, Aghia Efthymia and Prosilio with progressively increasing altitude northwards. Thus, the southern outcrops around Galaxidi are observed at about 0–50 m, the outcrops at the central part around Aghia Efthymia at about 350–500 m and the outcrops at the northern part of the study area around Prosilio at about 800–1300 m (Fig. 2).

Two stratigraphic sequences can de distinguished in the sedimentary deposits of the Itea–Amfissa basin. The lower sequence crops out: (a) on the hillside north of Itea; (b) along the slopes of the cliff separating the Aghia Efthymia planation surface from the alluvial plane of Amfissa in the area of villages Sernikaki, Aghios Konstantinos and Aghios Georgios; (c) in the area of Prosilio; and (d) in narrow outcrops at the base of the limestone cliffs in the area west of Amfissa (Fig. 2). The upper sequence extends over large areas forming a subhorizontal relief in the planation surfaces of Aghia Efthymia and Prosilio (Fig. 2). The main difference of the two sequences is the lithological composition of the clasts in the pebbles and breccia of the conglomerates and the matrix. In particular, the lower sequence comprises mainly sandstones, pelites, ophiolites and radiolarites with minor carbonate rocks within an argillaceous matrix, whereas the upper sequence comprises clasts mainly of dolomite and limestone within a sandy–carbonate matrix. The majority of the carbonate clasts in the upper sequence are of Parnassian origin. On the other hand, the clasts of the ophiolites and the pelagic siliceous sediments characterizing the lower sequence are most likely debris from the upper nappes of the Western Thessaly–Beotia and the more internal ophiolites bearing nappe units. This major difference in the lithological composition of the two sequences indicates that during the deposition of the lower sequence the main sediment supply source was from the upper nappes of Western Thessaly–Beotia and the Internal Hellenides, whereas during the deposition of the upper sequence the carbonate platform of the Parnassos unit was the main supply source.

The transition from the lower to the upper sequence differs significantly from locality to locality along the Itea–Amfissa basin. In the south, in the area of Aghia Efthymia–Sernikaki there is an angular unconformity between the upper and the lower sequence observed along the base of the Aghia Efthymia cliff for more than 4 km. The lower sequence dips 30°–35° to the NW whereas the upper sequence dips 20°–30° to the SW. This is nicely revealed in the area of Portes, near Aghios Nikolaos, where the conglomerate beds of the lower sequence are truncated by the basal conglomerate beds of the upper sequence. The base of the unconformity is marked in the morphology by the cliff, due to the differential erosion of the softer argillaceous lower conglomerate sequence and the much stiffer upper conglomerate sequence, which resembles to a carbonate formation (Fig. 4). The dip of the lower sequence immediately south of Sernikaki is similar to the dip of the basal contact of the lower sequence over its Alpine basement and to the overall dip of the Alpine formations. Thus, the lower sequence forms a triangular outcrop between the Alpine basement in the south and the unconformity of the upper sequence, which in the NW–SE oriented section looks subhorizontal (apparent dip because of the strike-parallel direction; Fig. 5a). The maximum thickness of the lower sequence in the Sernikaki–Aghios Georgios area is estimated to almost 1 km. However, north of Aghios Georgios its thickness decreases abruptly to only a few tens of metres. Herein, it is observed below the subhorizontal

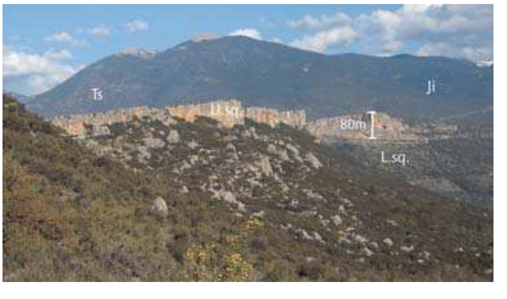


**Fig. 4.** The cliff of the Aghia Efthymia planation surface on top of the clastic sediments of the upper sequence (U.sq) seen from S–SE. The lower sequence (L.sq) forms the slopes below the cliff. At the back scene the eastern Giona slopes following the detachment plane are also observed with outcrops of upper Triassic (Ts) and lower Jurassic (Ji) limestones.

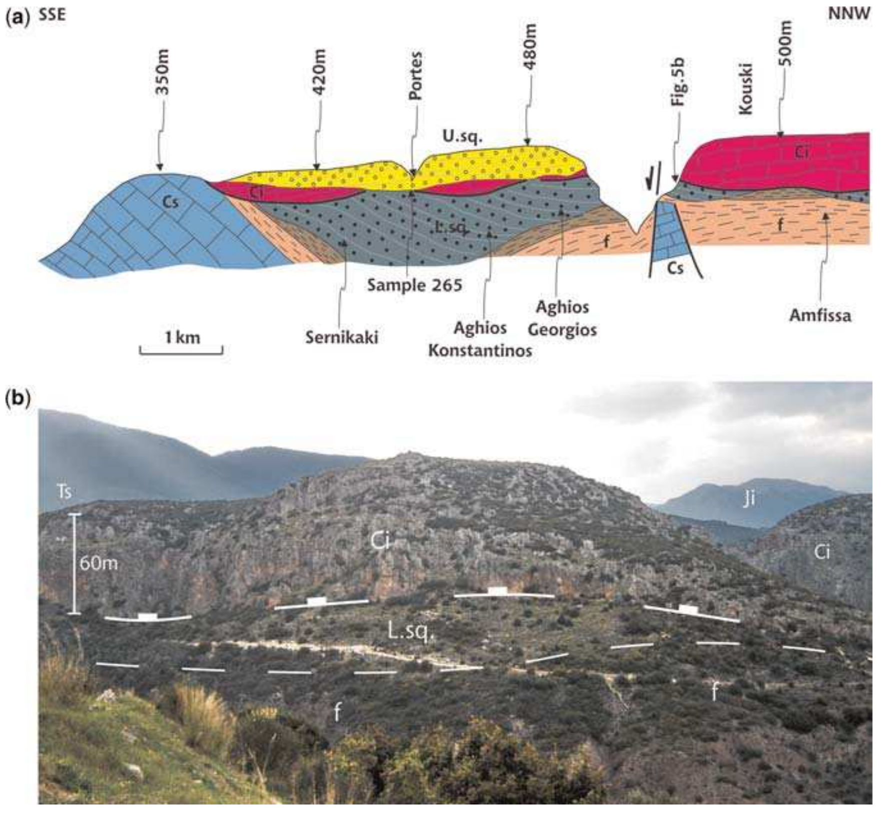


**Fig. 5.** (**a**) Tectonic sketch showing the angular unconformity between the lower and the upper sequence along the section Sernikaki–Aghios Georgios–Amfissa. Allochthonous Mesozoic limestones are observed at the base of the upper sequence, (**b**) The tectonic block of Cretaceous limestones (Ci) of the Parnassos nappe forming the Kouski hill, on top of the lower sequence sediments (L.sq) and the underlying flysch (f) of the Parnassos nappe between the chapels of Aghia Marina and Aghios Nikolaos.

block of the Mesozoic limestone and above the Eocene flysch (Figs 2 & 5b). Along strike the valley between Aghios Georgios and Amfissa there is a NE–SW trending fault zone, which crosses through the Panaghia, Aghios Nikolaos and Aghia Marina chapels. This fault zone separates the massive limestone klippen unit of Kouski hill to the west of Amfissa resting above the lower sedimentary sequence (Fig. 5b), from the upper sequence cropping out in the southern block all over the planation surface of Aghia Efthymia (Fig. 2). The fault is an oblique-slip normal fault as shown by the slickensides observed in several localities. Subsidence occurred to the southeast as implied by the thickness of the lower sequence. For example, its thickness in the hanging wall is estimated into several hundred metres in contrast to only a few tens of metres in the footwall northwards. A dextral strike-slip component is also traced, but its significance cannot be quantitatively determined. It is remarkable that the altitude of the subhorizontal planation surface of Aghia Efthymia is similar on both sides of the valley following the fault, even though the geological formations are different with outcrops of the upper sequence in the south and block of Mesozoic limestone in the north (Fig. 5a). Additionally, the unconformity of the upper sequence in the south is placed at about the same level with the base of the allochthonous limestone block in the north. Thus, the offset of the basal unconformity of the lower sequence over the Alpine basement on both sides of the NE–SW fault zone along the valley corresponds to the throw of the NE–SW fault zone during the deposition of the lower sequence. An additional throw of 20–30 m was formed during the arrival of the material of the upper sequence and of the emplacement of the allochthonous limestone block. The overall structure indicates a syn-depositional tectonism of the clastic sequences accompanied by the emplacement of olistholites, blocks and small extensional gravity nappes of Mesozoic limestones,


**Fig. 6.** A characteristic outcrop of the alternation of beds of compact carbonate breccia-conglomerates with loose sandstones-conglomerates marking the transition from the lower to the upper sequence within the Miocene sediments near Prosilio. Sample 267 was taken from the lower soft formation along the level of the road.

sliding from the Itea–Amfissa detachment footwall along the eastern Giona slopes. The upper sequence is 300 m thick, as measured along the Portes–Aghia Efthymia direction, which is perpendicular to the average 30° dip to the SW of the conglomerates (see also Fig. 8b).

On the contrary, no unconformity is traced at the outcrops near Prosilio. Instead, the conglomerates of the lower sequence progressively grade up to those of the upper sequence (Fig. 6). This transition is best observed in the area of Aghios Nikolaos on the road to Prosilio (approaching from the south) where an 8–10 metres thick compact conglomerate bed is formed, marking for the first time the arrival of the carbonate material. A spring (known as Krya Vrisi, which means ‘cold spring’) is observed at the base of the compact conglomerate bed due to the permeable conglomerates and the underlying impermeable argillaceous matrix. A second compact conglomerate bed with carbonate rocks is observed after an intercalation of several metres of soft conglomerates with sandstones and ophiolites within argillaceous material, similar to the beds of the lower sequence. This soft interval between the two carbonate beds shows an increase to about 40–50% in the content of carbonate clasts from 10–20% at the lower sequence. The following upper conglomerates above the second limestone conglomerate bed turn almost entirely carbonatic with 80–90% of carbonate clasts. The thickness of the two sequences in Prosilio is about 150 m for the lower sequence and 250–300 m for the upper sequence.

Large blocks and olistholites of carbonate rocks are common within the base of the coarse clastic formations of the upper sequence. This is observed almost everywhere even if there is an unconformity between the two sequences or not. Thus, large blocks of limestone are observed at the base of the upper sequence above the villages of Aghios Konstantinos and Aghios Georgios (Fig. 5a) as well as above the village of Prosilio. More spectacular phenomena are observed in the area west of Amfissa, where very large blocks of limestone are emplaced on top of the lower sequence (Fig. 5b). As a result, small-scale nappes are formed, that were emplaced during the sedimentation of the lower sequence and the transition from the lower to the upper sequence. A characteristic outcrop occurs 1 km south of Panaghia, built in the Panaghiorema gorge, where the lower sequence is observed between two blocks of limestone (Fig. 7a). The underlying limestone is of upper Cretaceous age whereas the overlying limestone is of upper Jurassic–lower Cretaceous age. The thickness of the lower sequence conglomerates separating the two limestone units ranges between 20–30 m. In this area the upper conglomerate sequence has not been traced, suggesting that the emplaced limestone blocks are substituting laterally the conglomerates of the upper sequence. The lower sequence conglomerates are deposited in a NW–SE tectonic graben in the area of Koromilies and Papa Lakkos south of Prosilio. This graben structure is filled both by the transitional conglomerate beds from the lower to the upper sequence and by olistholites of Mesozoic limestone in the area towards Prosilio in the north (Fig. 7b). These observations indicate a syn-tectonic sedimentation of the conglomerates with a pronounced activity during the transition from the lower to the upper conglomerate sequence, characterized by the emplacement of allochthonous limestone blocks. Their origin from the footwall carbonate formations of the Itea–Amfissa detachment, demonstrates the genetic relation of the sediments to the detachment. Similar synsedimentary tectonic graben structures occur also within the Aghia Efthymia conglomerates of the upper sequence as observed in a ravine draining the planar area to the SE (Fig. 8a). The synsedimentary character of the normal fault is nicely illustrated by the dragging of the stratification of the conglomerates adjacent to the fault surface and by the gradual overstep sequence which covers the top of the faulted block with the lower Jurassic limestones. This synsedimentary structure corresponds to the southwestern boundary of the tilted block of Aghia Efthymia, whose northeastern boundary is observed in the area of Portes (Fig. 8b). Here, along the Portes–Sernikaki slopes the base of the upper sequence is observed with angular unconformity on top of the lower sequence as described previously (see also Figs 4 and 5a).

The age of the sediments in the Itea–Amfissa depression remained highly controversial, with ages ranging from Neogene to Quaternary

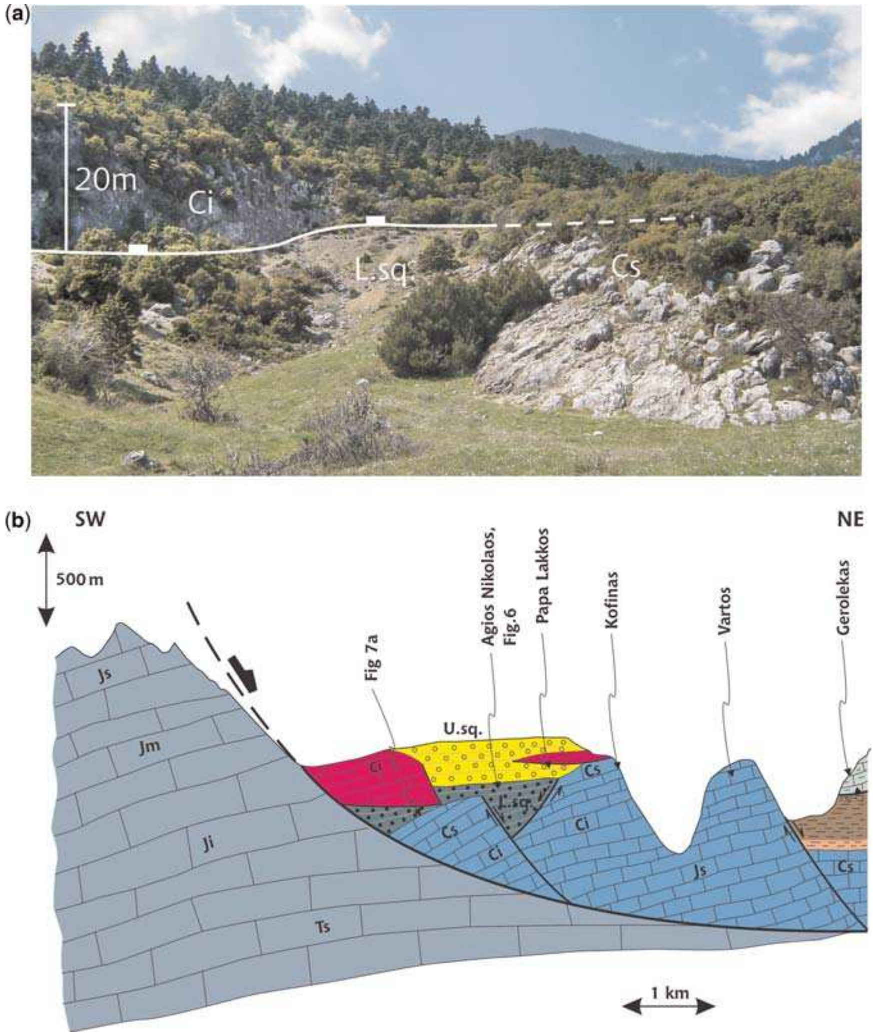


**Fig. 7.** (**a**) The occurrence of the lower sequence (L.sq) between two limestone blocks of upper Cretaceous (Cs) and upper Jurassic–lower Cretaceous (Ci) in the area southwest of Panaghiorema. (**b**) Schematic representation of the synsedimentary graben of Papa Lakkos south of Prosilio within the hanging wall of the Itea–Amfissa detachment.

without any stratigraphic evidence (Celet 1962; Papastamatiou *et al.* 1960, 1962). This is due to the lack of fossils within the breccia–conglomeratic sediments and the sandy matrix particularly of the upper sequence. In order to resolve this key parameter we sampled from several localities, so as to obtain some age constraints. The material has in general barren, but four sites proved successful in the calcareous nannofossil analysis (their location is indicated on Fig. 2).

The methodology comprised the following: smear slides for calcareous nannofossil analysis have been prepared following the standard preparation technique of Perch-Nielsen (1985). The smear slides preparation in terrigenous material can dilute the concentration of nannofossils that in fact are often only present or rare. In our study area however, we have chosen the simple smear slide preparation technique instead of preparing concentrated samples through settling techniques, which require ultrasonic bath treatment, in order to ensure that the smaller and more delicate forms will remain unbroken. In order to tackle the problem of dilution and search thoroughly for the maker species in the studied clastic deposits, more than one smear slides using different concentrations have been prepared from the same sample. To obtain accurate biostratigraphic estimations, up

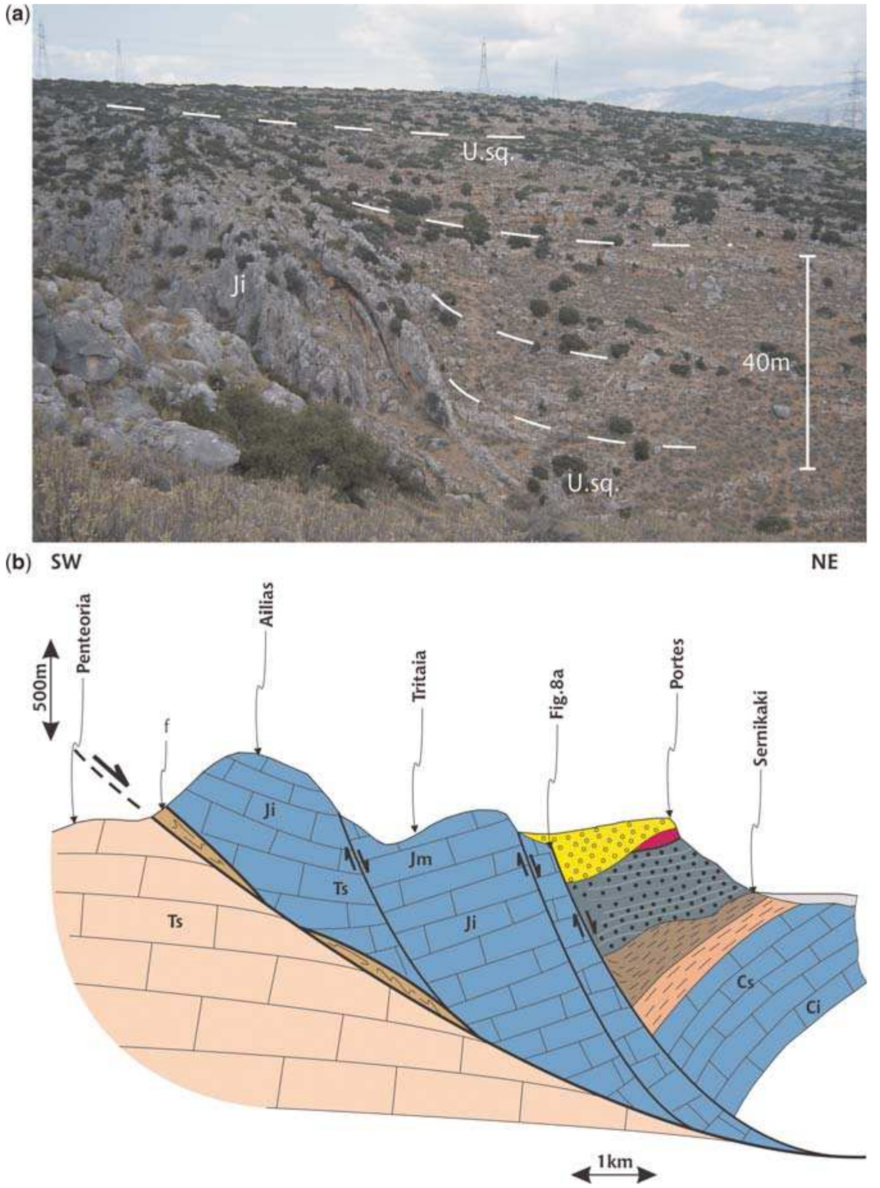


**Fig. 8.** (**a**) The upper sequence conglomerates (U.sq) overstepping a synsedimentary normal fault in the area east of Aghia Efthymia. Lower Jurassic limestones (Ji) dipping to the NE are observed at the footwall of the fault. (**b**) Back tilt of the upper sequence of Agia Efthymia to the SW from Portes to the detachment.

to 1500 fields of view haven been investigated per slide in longitudinal traverses randomly distributed (15 traverses; 100 fields of view per traverse), counting at least 500 specimens, with a Leica DMLSP optical polarizing light microscope at $\times 1250$. Nannofossil state of preservation is fair, showing evidence of dissolution and/or overgrowth in some specimens, but this did not hinder identifications. Semiquantitative abundances of the taxa encountered were recorded as follows: C, common: 1 specimen/10 fields of view; R, rare: 1 specimen/10–100 fields of view; P, present: 1 specimen/ >100 fields of view; RW, reworked specimens.

The nannofossil biostratigraphic results are based on the biozonal schemes of Martini (1971) and Fornaciari *et al.* (1996), as they have been incorporated in the magnetobiochronological framework of Berggren *et al.* (1995) and revised by Lourens *et al.* (2004). On this basis NN4 and NN6 biozones (Martini 1971) and MNN6b (Fornaciari *et al.* 1996) have been recognized. Numerical ages of biozone boundaries are given according to Lourens *et al*. (2004).

The obtained results are the following:

*(a) Sample 265.3 (Fig. 2).* The calcareous nannofossil analysis revealed the presence of common *Reticulofenestra pseudoumbilicus* (apart from isolated coccoliths several intact coccospheres have also been observed), *Discoaster variabilis* and *Cyclicargolithus floridanus* along with the absence of *Sphenolithus heteromorphus*, *Discoaster kugleri*, *Calcidiscus macintyrei*, *Helicosphaera stalis* and any trace of Late Oligocene or Pliocene biostratigraphic indices. Rare Cretaceous, common Eocene and Early Miocene reworked species are also present. Some small pennate and concentric diatoms have been detected.

The definition of *R. pseudoumbilicus* is restricted to reticulofenestrids $>7$ m, following Raffi & Rio (1979). The common and continuous presence of the species is concomitant with the LO of *S. heteromorphus* at the top of NN5 biozone (Fornaciari *et al.* 1996; Raffi *et al.* 1995; Maiorano & Monechi 1998).

Therefore, the nannofossil assemblage of the studied sample implies the presence of NN6 biozone (Martini 1971) or MNN6b (Fornaciari *et al.* 1996) pointing to Serravallian age, ranging between 13.4–11.8 ma.

*(b) Sample 264.2 (Fig. 2).* The calcareous nannofossil analysis revealed the presence of common *Cyclicargolithus abisectus*, rare forms of *Sphenolithus* cf. *Sphenolithus heteromorphus* and presence of *Helicosphaera ampliaperta*.

The nannofossil assemblage implies the tentative assignment to NN4 biozone (Martini 1971) pointing to Burdigalian-Langhian age, ranging between 18–15 ma.

*(c) Sample 257.1 (Fig. 2).* Rare overgrown specimens of *Coccolithus pelagicus*, *C. floridanus*, *Ericsonia formosa*, *Sphenolithus heteromorphus*, *Sphenolithus moriformis* have been detected, considered as reworked species. The assemblage does not bear any clear *in-situ* nannofossil index species pointing to an age younger than Langhian.

*(d) Sample 267.1 (Fig. 2).* Similar nannofossil assemblage with sample 257.1 has been detected, including rare and overgrown specimens of *Coccolithus pelagicus*, *C. floridanus*, *Ericsonia formosa*, *Sphenolithus heteromorphus*, *Sphenolithus belemnos*, *Sphenolithus moriformis*, which are considered as reworked. The assemblage does not bear any clear *in situ* nannofossil index species, pointing to an age younger than Langhian.

In conclusion, the age of the Itea–Amfissa sedimentary deposits is Early to Middle Miocene and more precisely late Burdigalian–Serravalian. Considering that the dated specimens are only extracted from the stratigraphic horizons of the lower sequence a Tortonian age is probable for the upper sequence. Thus, the entire sedimentary history of the Itea–Amfissa basin may comprise the period Late Burdigalian–Tortonian (*c.* 18–8 ma).

## The Itea–Amfissa detachment

The Itea–Amfissa detachment is traced for 30 km from the Corinth Gulf in the south to Prosilio and Northern Giona Mountain in the north. It separates the eastern part of the Giona Mountain with altitudes between 1500–2200 m from the Itea–Amfissa valley with altitudes between 0–200 m. Thus, the average difference in topography observed across the detachment in east–west profiles is about 2 km. This difference in altitude is mainly observed within a narrow zone along the eastern slopes of Giona, expressed by a sub-plannar slope dipping to the east with an average dip of 30°. This sub-plannar slope is controlled by the detachment surface that passes below the hanging wall rocks, where it creates a first major break in the slope morphology of about 1200 m topographic difference. A secondary zone of steep morphological slope is developed within the hanging wall formations from the top of the hanging wall to the present day lower level of the Itea–Amfissa valley. This forms a further decrease of topography of several hundred metres expressed by well-defined morphological cliffs (Figs 4 & 9). However, the topographic difference in the Aghia Efthymia cliff is about 350–400 m (Fig. 4) whereas in Prosilio it is about 900–1000 m (Fig. 9). This second step in the Giona slopes is formed by erosional incision of the planation surface at the top of the Miocene clastic deposits occurring in Aghia Efthymia and Prosilio. Considering the difference of elevation of about 1400 m within 30 km distance between the Prosilio, Aghia Efthymia and Galaxidi outcrops of the Miocene clastic formations a general southward tilt of *c.* 3° of the planation surfaces on top of the clastic sediments can be inferred.

The detachment fault plane is exposed in several localities. The best preserved outcrop occurs at the southern part of the detachment in the area east of Penteoria as shown on the detailed geological map of the area (Fig. 10). In this area the fault plane is marked by the existence of some tectonic lenses between the carbonate rocks of the Penteoria nappe in the footwall and those of the Parnassos

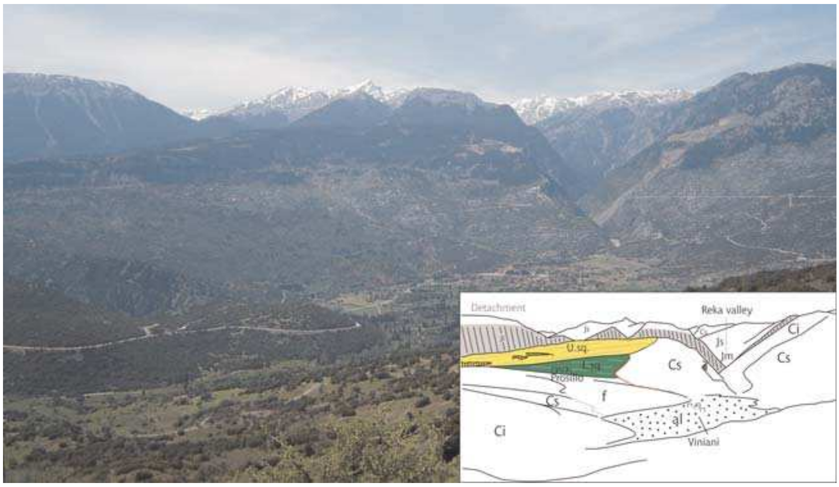


**Fig. 9.** The planation surface above Prosilio on top of the upper sequence (U.sq) as seen from the east and simplified geological sketch. The sediments of the upper sequence are marked by the cliff formed by the erosional incision right above the level of Prosilio village. Below the cliff a triangular outcrop of the lower sequence (L.sq) is formed, bounded to the north by a NE–SW transverse normal fault. Behind the Prosilio planation surface the geometrical eastern slopes of Giona Mountain (shaded in grey) delineate the Itea–Amfissa detachment up to the Reka valley. Note the gradual decrease of the morphological expression of the detachment from left (south) to right (north) along the Giona slopes (indicated by vertical lines).

nappe in the hanging wall. The rocks within the tectonic wedges along the detachment belong to the Eocene flysch (probably belonging to the Penteoria unit) and to the Upper Triassic–Upper Jurassic pelagic carbonates of the Vardoussia unit. The best outcrop of the detachment is observed along the contact of the underlying Upper Triassic carbonates of the Penteoria unit and the overlying Eocene flysch (Fig. 11). This planar contact can be observed for about 500 m length and locally it has a width of about 25–40 m. The dip of the detachment is 30° to N 45° E and the slip direction as deduced from kinematic indicators is slightly oblique in an N 60° E direction.

The throw across the detachment cannot be accurately constrained because there are no outcrops of the same tectono-stratigraphic units on either side of the detachment. As shown in the description of the geological structure of the area there are several thrust sheets within the Parnassos nappe therefore no correlation is feasible on either side of the detachment. Along the southern part of the detachment east of Penteoria the throw incorporates the structural omission of the Jurassic and Cretaceous part of the Penteoria sequence (several hundred metres thick), the whole stratigraphic column of the Vardoussia nappe (exceeding 1 km of thickness) and unknown number of thrust sheets of the Parnassos nappe. The minimum calculated throw, where no thrust sheets of the Parnassos unit are considered, is estimated at several hundred metres, which represents the structural omission of the Upper Triassic platform carbonates of Parnassos. Taking into account the throw inferred from the topography between the Jurassic formations on either side of the detachment, that is more than 800 m, then the overall minimum throw is 2500–2800 m. On the other hand along the northern part of the detachment around Prosilio the minimum throw is 4400 m incorporating: (i) the thickness of the upper thrust sheets of Parnassos (more than 2200 m in thickness); (ii) the overlying nappe of Western Thessaly–Beotia (more than 400 m thick); (iii) the missing Jurassic part of the Parnassos platform (about 800 m thick); and (iv) the topographic difference between the footwall carbonates of Parnassos and the nappe of Western Thessaly–Beotia in Gerolekas at the hanging wall (about 900–1000 m).

Considering an average dip of 30° for the detachment the total displacement in the E–NE direction is more than 9 km. This value is very close to the present width of the Itea–Amfissa Valley measured at the 1000 m contour level between the Eastern Giona and Western Parnassos slopes.

The contrast between the footwall and the hanging wall structure of the detachment is impressive. Thus, a rather rigid structure can be observed all along the footwall with the lower stratigraphic levels of the Parnassos unit (Upper Triassic–Middle Jurassic) dipping 20°–30° to the west. In contrast, the hanging wall is made of a complex

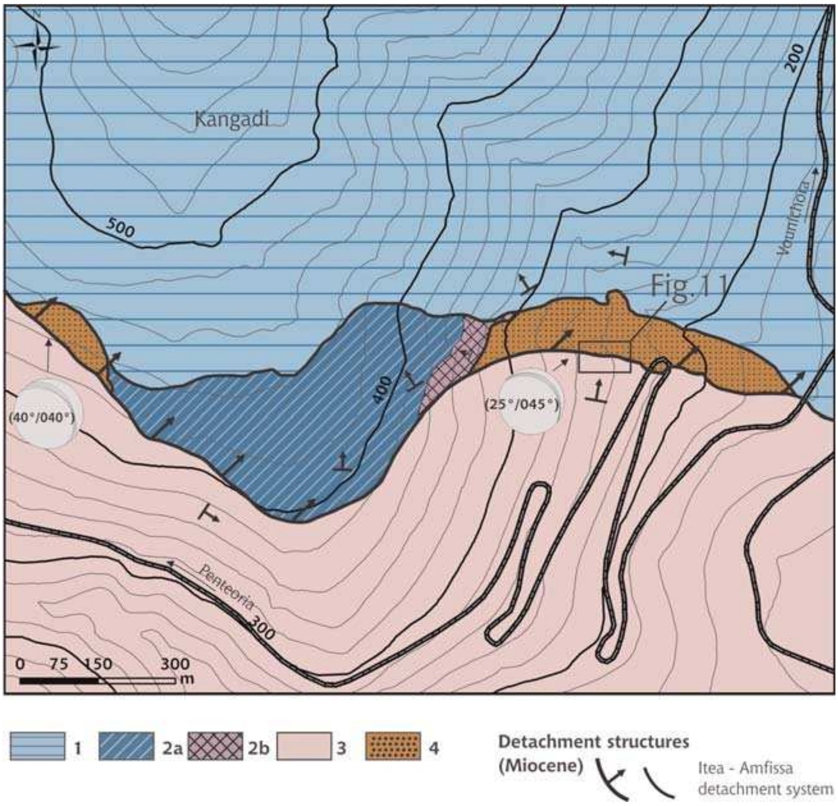


**Fig. 10.** Detailed geological map of the area on both sides of the detachment at southern Giona between Galaxidi and Penteoria. For location see geological map of Figure 2. (1) Lower Jurassic carbonate rocks of Parnassos nappe; (2a) Jurassic pelagic limestones of Vardoussia nappe, (2b) Upper Triassic pelagic limestones of Vardoussia nappe; (3) Upper Triassic neritic limestones of Penteoria nappe; (4) Eocene flysch of Penteoria nappe.

structure of small-scale blocks of Mesozoic limestones and early Tertiary flysch, which have slided to the E–NE during the sedimentation of the Itea–Amfissa sedimentary deposits (Fig. 12a). The interfingering of the conglomerates with the olistholites and the small gravity nappes along the hanging wall provide a characteristic view of it. This is accentuated during the sedimentation of the upper conglomeratic formation with the carbonate rocks, which are traced both in front and above the sliding blocks.

The faults observed on the hanging wall trend either parallel to the detachment or transverse. In both cases they do not penetrate the footwall rocks, but they are synchronous to the sedimentation of the lower sequence and die out during the sedimentation of the upper sequence. The transverse faults have a general NE–SW direction and they form three distinct fault zones (Fig. 12b). The southern fault zone passes north of Itea, the middle passes south of Amfissa and the northern one passes north of Prosilio (Figs 2 & 12b). These ENE–WSW trending faults have produced a syn-sedimentary tilt to the NW of the lower sequence during middle Miocene and at the same time they bound to the north the outcrops of the upper sequence. The faults parallel to the detachment are forming back tilted blocks within the Alpine formations and syn-sedimentary tectonic grabens filled with clastic sediments similar with the lithologies of the sliding limestone blocks (Fig. 12a). The most characteristic structure is observed in the area of Aghia Efthymia, where the upper sequence dips 30° to the SW against the NW–SE trending fault passing from the Itea harbor and the village of Aghia Efthymia (Figs 2 & 8b). The same tilt to the SW is observed in the sediments of the upper sequence in Prosilio against the detachment surface at 1300 m of altitude (Figs 2 & 7b).

The overall structure within the hanging wall of the Itea detachment is illustrated in two schematic profiles; one across the hanging wall in an east–west direction and the other longitudinal in a north–south direction (Fig. 12). These profiles


**Fig. 11.** The outcrop of the detachment in the area between Galaxidi and Penteoria. Its location is shown in the geological map of Figure 10. The cliff above the detachment is made of the Vardoussia pelagic Jurassic sediments (2) found in tectonic wedge between the upper Triassic neritic limestones of the Penteoria nappe (1) in the footwall and the lower Jurassic neritic limestones of the Parnassos nappe (3) in the hanging wall. The flat area with the olive trees corresponds to the Eocene flysch (4).

provide the relationship between the sliding of the carbonate units above the detachment together with the sedimentation of the two sequences of breccia–conglomerates. The role of the parallel faults creating the sliding blocks and the resulting horsts and grabens in the north–south trend is illustrated by the transverse section (Fig. 12a), whereas the longitudinal section demonstrates the role of the transverse NE–SW faults that dissect the hanging wall structure in successive blocks along strike (Fig. 12b).

Northwards the detachment can be traced up to the Reka Valley that has an east–west orientation and starts from the area of the Giona summit (2507 m) and ends at the Viniani depression, which occurs below Prosilio at about 7 km north of the Amfissa depression. North of the Reka Valley there is no morphological expression of the detachment but a high-angle normal fault (50°–60° dip to the E–NE) separates the footwall Jurassic carbonates dipping to the west from the hanging wall Cretaceous carbonates dipping to the east (Fig. 13). This fault has a throw exceeding 1200 m, based only from the missing stratigraphic horizons between the footwall and the hanging

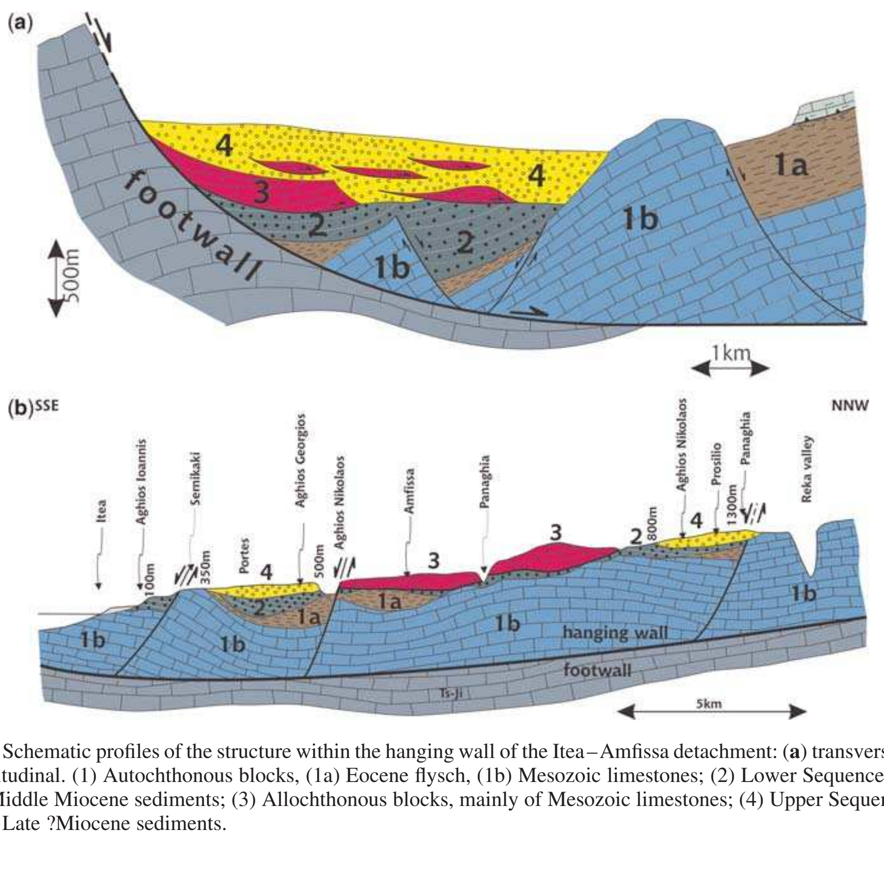


**Fig. 12.** Schematic profiles of the structure within the hanging wall of the Itea–Amfissa detachment: (**a**) transverse and (**b**) longitudinal. (1) Autochthonous blocks, (1a) Eocene flysch, (1b) Mesozoic limestones; (2) Lower Sequence of Early–Middle Miocene sediments; (3) Allochthonous blocks, mainly of Mesozoic limestones; (4) Upper Sequence of Middle–Late ?Miocene sediments.

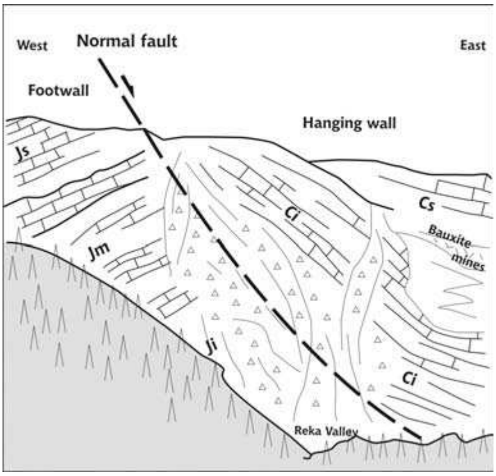


**Fig. 13.** Panoramatic sketch of the tectonic structure on the northern side of the Reka Valley in Northern Giona as seen from the south in 1400 m of altitude. The Jurassic carbonate rocks in the footwall dip to the west whereas the Cretaceous carbonate rocks in the hanging wall dip to the east. North of the Reka Valley the morphological expression of the extensional structure becomes insignificant, the dip of the normal fault is steep, between $50^{\circ}–60^{\circ}$, and the throw becomes minimum (a little more than 1 km).

wall. Thus, the extension of the Itea–Amfissa detachment to the north of the Reka Valley is expressed as a high angle normal fault, which terminates along the northern slope of the Giona Mountain that is controlled by a major east–west-trending normal fault – the Northern Giona fault (Fig. 1).

The age of the detachment is indicated by the age of the syntectonic sedimentation of the Itea–Amfissa basin, which is dated as Burdigalian–Serravalian. The probable extension of the upper part of the conglomerates in the Tortonian indicates the most probable time range for the tectonic activity between the late Burdigalian and the Tortonian, which is ranging between 18–8 ma.

## The Corinth rift structures

The continuation of the Itea–Amfissa detachment to the south is disrupted by east–west trending steep normal faults present in the area west of Galaxidi (Fig. 14). These faults form part of the Corinth rift system and their throw is in the order of several tens of metres with subsidence occurring of the southern blocks towards the Corinth Gulf. These onshore normal faults are an exception along the southern coast of Sterea Hellas, because the major faults forming the northern margin of

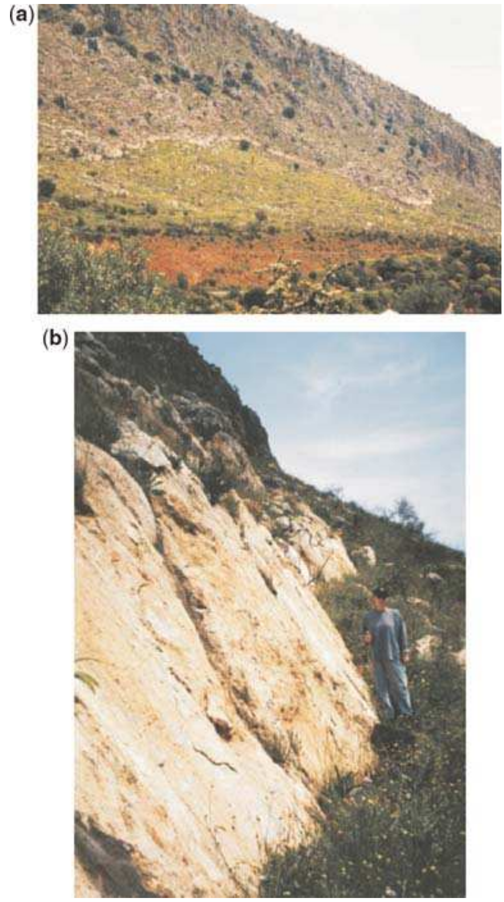

**Fig. 14.** (**a**) East–ENE–trending normal fault in the area west of Galaxidi near the Corinth coast, alongside the main road Itea–Nafpaktos. (**b**) Close view of the same fault with the Holocene fault scarp, which exceeds 3–4 m in height.

the Corinth Gulf and the rift structure are located offshore several km to the south (Moretti *et al.* 2003). Nevertheless, the characteristics of these faults near Galaxidi show recent activity in the Holocene, as the well-developed post-glacial scarps exceeding 3–4 m of height indicate (e.g. Stewart & Hancock 1991; Roberts 1996). The Itea–Amfissa detachment is expected to continue southwards below the sea bottom of the Corinth Gulf, which has been formed in the late Pliocene–Quaternary, much later than the detachment.

The only east–west fault occurring in the broader area of Parnassos and Giona mountains is the Delphi fault, which runs parallel to the Delphi Valley. However, this fault is a questionable structure, because from one side it shows some recent activity by affecting consolidated scree and slope debris of the Parnassos slopes, but it also exhibits similar geometry to the Alpine structures of the Parnassos unit in the other. Thus, the overall geometry of thrusting and folding from the Parnassos summit to the north up to the Corinth Gulf in the south consists of a number of east–west trending tectonic units-thrusts, incorporating the carbonate platform and the flysch. Especially at the archaeological site of Delphi there is an overturned stratigraphic section placing the Eocene flysch below the upper Cretaceous limestones, resulting in the formation of the famous from the antiquity Kastalia spring. Overall, the Delphi Valley is not a graben-like neotectonic structure and it cannot be explained solely by the activity of the Delphi fault.

## Discussion and conclusions

The Itea–Amfissa detachment trending NNW–SSE is a major Miocene extensional structure that followed the co-parallel compressive deformation, which created the nappes, the internal thrusting and the folding of the Alpine units of the area. Thus, the older Alpine deformation of east–west compression was followed by east–west extension. The parallel trend of the detachment with that of the previous compressive structures shows the fundamental change in position of the Giona–Parnassos area from the frontal compressive zone of the evolving orogenic arc of the Hellenides during the Oligocene period, to the co-parallel extensional zone in its backarc area during the Miocene. Thus, when the Itea–Amfissa detachment was formed, the zone of east–west compression had migrated westwards along the Gavrovo and Ionian units of the External Hellenides.

The age of the detachment is Middle–Late Miocene as the dated syn-tectonic sediments of the Itea–Amfissa basin indicates. The end of the east–west extensional phase that produced the detachment cannot be accurately determined, because the higher stratigraphic beds of the upper sequence have not been dated. Thus, the only age constraint can be pre-Late Pliocene that is pre-dating the fossiliferous Late Pliocene and Pleistocene sediments of the Corinth rift structure. Considering the above, the east–west extensional activity occurred in the Middle–Late Miocene, even though a possible extension also into the Early Pliocene cannot be excluded.

Similar geodynamic phenomena with impressive tectono-stratigraphic formations comprising olistholites of Alpine rocks mixed with breccia and conglomerates in the Middle Miocene are known also from the Cyclades and Crete (Fortuin 1978; Dermitzakis & Papanikolaou 1981; Fortuin & Peters 1984). More recently, these formations like the Prina Complex in eastern Crete (Fortuin 1978; Fortuin & Peters 1984) have been related to the activity of the Cretan detachment (van Hinsbergen & Meulenkamp 2006).

The Itea–Amfissa detachment can be traced for about 30 km from the coast of Itea to Prosilio and dies out to the north within the Northern Giona Mountain, where it is substituted by a high angle normal fault with kilometric order of throw. The whole extensional structure does not continue north of the east–west-trending Northern Giona normal fault. In contrast, it expands southwards crossing the Corinth Gulf and is probably linked to the East Peloponnesus detachment, whose length exceeds 150 km from the area of Feneos in Northern Peloponnesus to the area of Kyparissi to the southeast (Papanikolaou & Royden 2007). The age of the East Peloponnesus detachment is not well constrained, but on the basis of the Tortonian sediments on Kythera Island, in the Cretan Basin and on Spetses Island, a Late Miocene–Early Pliocene age has been proposed (Papanikolaou & Royden 2007). Now, in view of the new age constraints in the Itea–Amfissa basin, an older age may be accepted for the East Peloponnesus detachment incorporating also the Middle Miocene.

The throw of the East Peloponnesus detachment has been determined based on the tectono-stratigraphic structural omission of the nappes of the Hellenides on top of the relative autochthon unit of Mani (or metamorphic Ionian). The diagram showing the structural omission along the East Peloponnesus detachment indicates a gradual decrease of the throw towards the north in the area of Itea–Amfissa, where it dies out in the northern Giona area (Fig. 15). Thus, the Itea–Amfissa detachment represents the northern end of the East Peloponnesus detachment.

The disruption of the arc parallel extensional structures, like the Itea–Amfissa detachment, by the transverse extensional structures, such as those of the Corinth rift system, occur within the Central Hellenic Shear Zone (CHSZ), which has been defined on the basis of present day GPS data (Papanikolaou & Royden 2007), but can be probably traced back to initiation in the Late Pliocene. The northern boundary of the CHSZ coincides with the North Aegean Basin, which is interpreted as the western prolongation of the North Anatolian Fault (e.g. Armijo *et al.* 1999). It is remarkable that the timing of the westward propagation of the North Anatolian Fault into the North Aegean Basin is Late Pliocene and this is related to the onset of the recent and active Aegean extension in the north–south direction (Armijo *et al.* 1999; Flerit *et al.* 2004; Papanikolaou *et al.* 2002, 2006). However, the initiation of the CHSZ is probably also related to the change from a former continuous

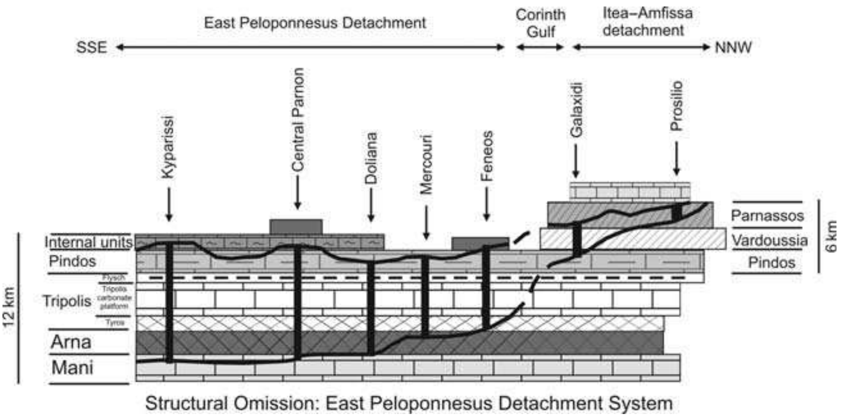


**Fig. 15.** Diagram of the structural omission along the East Peloponnesus Detachment System based on Papanikolaou & Royden (2007). Units between the upper and lower black lines are missing across the detachment surface; missing sequences at specific localities are indicated by the vertical black bars. The Itea–Amfissa Detachment corresponds to the northern end of the system north of the Corinth rift structure.

Hellenic arc structure until Middle–Late Miocene to the present day Hellenic arc and trench system, which is restricted to the Preveza area by the Kefalonia transform fault (Papanikolaou & Dermitzakis 1981). This younger structure of the Hellenic arc does not extend north of the Kefalonia transform and is related to the onset of the rapid subduction of the oceanic crust of the East Mediterranean Basin that occurred between Late Miocene–Early Pliocene.

In conclusion, the deformation of the Parnassos–Giona area of central Sterea Hellas is characterized by three deformational phases; the first two are arc parallel structures of east–west compression during Oligocene and east–west extension during Miocene, followed by the third deformational phase of north–south extension, which has disrupted the arc since Late Pliocene time.

This is a contribution to the MEDUSA project, funded by the NSF Continental Dynamics Program, grant EAR-0409373. The University of Athens has contributed to some of the field expenses. Constructive comments by M. Edwards, F. Flerit and I. Papanikolaou have significantly improved the manuscript.

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