GEOMORPHOLOGICAL EVIDENCE OF ENE-WSW PLEISTOCENE FAULTING ACROSS NORTHERN EVIA (CENTRAL GREECE)[1]

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ABSTRACT

In this paper reconnaissance geomorphological and geological observations that suggest the existence of an ENE-WSW fault zone and other probable structures with the same strike in North Evia island are presented. These discontinuities exert important control on the morphology and the drainage networks of the area, indicating that they played an important role during the Quaternary phase of tectonic activity. Probable cases of significant dextral river translations together with the direction of the discussed structures seem to provide support to recent hypotheses about a large ENE-WSW dextral shear zone crossing N. Evia.

KEYWORDS: Geomorphology, morphotectonics, neotectonics, drainage networks, North Evia island, Kechriae fault zone, Nileas river, Central Greece.

ΠΕΡΙΛΗΨΗ

Στην εργασία αυτή παρουσιάζονται αναγνωριστικές γεωμορφολογικές και γεωλογικές παρατηρήσεις σε τμήμα της Β. Εύβοιας, με βάση τις οποίες καθίσταται πιθανή η ύπαρξη μιας αρκετά μεγάλης ρηξιγενούς ζώνης διεύθυνσης ΑΒΑ-ΔΝΔ καθώς και άλλων ασυνεχειών παράλληλων με αυτήν. Οι τεκτονικές ασυνέχειες αυτές ασκούν σημαντικό έλεγχο στη μορφολογία και τα υδρογραφικά δίκτυα της περιοχής, γεγονός που υποδηλώνει οτι συμμετείχαν ενεργά στην τεκτονική παραμόρφωση κατά το Τεταρτογενές. Η ύπαρξη πιθανών σημαντικών δεξιόστροφων μεταθέσεων ποτάμιων κοιλάδων κατα μήκος τους, σε συνδυασμό με τη διεύθυνση που έχουν οι δομές αυτές, ενισχύουν πρόσφατες θεωρίες για την ύπαρξη μιας μεγάλης νεοτεκτονικής δεξιόστροφης ζώνης διάτμησης διεύθυνσης ΑΒΑ-ΔΝΔ, εγκάρσια πρός την Β. Εύβοια, η προέκταση της οποίας έχει πρόσφατα πιστοποιηθεί στην απέναντι ακτή της Στερεάς Ελλάδας.

1. INTRODUCTION

The study area is located in North Evia (Fig. 1) and belongs to the extensional province of central Greece and the Aegean. Two main phases of extension since the Miocene have been recognized, manifested in faults striking WNW-ESE to NW-SE, NE-SW and ENE-WSW to E-W, which hosted the formation of large Neogene and Quaternary basins (Mettos et al., 1989, 1991). The structures that have been active during the Quaternary, a series of WNW-ESE to NW-SE normal fault zones (e.g. Roberts & Jackson, 1991 - Fig. 1 inset) dominate the landscape evolution of the broader area of Lokris and N. Evia and are responsible for the formation of the N. Evoikos graben (e.g. Leontaris & Delibassis, 1987, Mettos et al., 1991).

1:ΓΕΩΜΟΡΦΟΛΟΓΙΚΕΣ ΕΝΔΕΙΞΕΙΣ ΓΙΑ ΤΗΝ ΥΠΑΡΞΗ ΝΕΟΤΕΚΤΟΝΙΚΩΝ ΡΗΓΜΑΤΩΝ ΑΒΑ-ΔΝΔ ΔΙΕΥΘΥΝΣΗΣ, ΕΓΚΑΡΣΙΩΝ ΠΡΟΣ ΤΗΝ Β. ΕΥΒΟΙΑ

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In this paper, there will be a discussion of reconnaissance geomorphological observations that suggest the existence of an ENE-WSW fault zone across N. Evia,

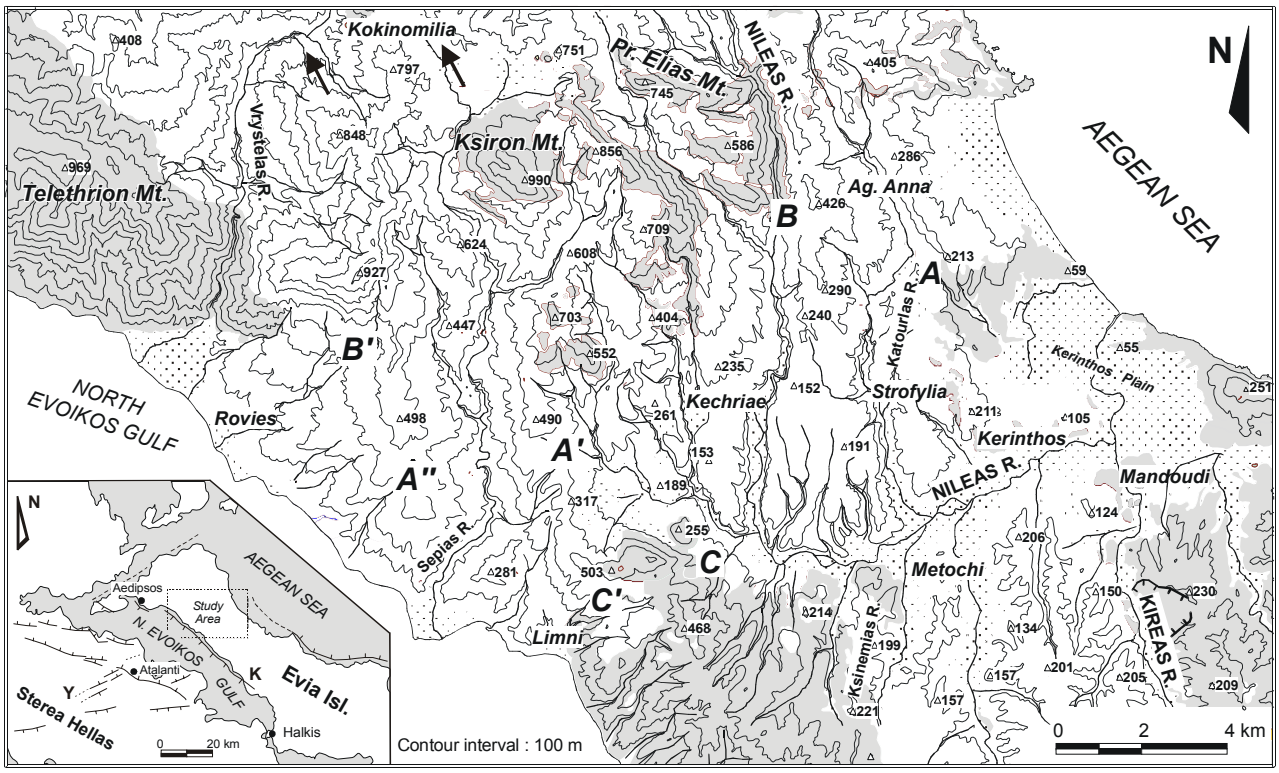

Fig. 1. Topography, lithology and drainage networks of the broader area of interest. Contours from 1:50.000 maps of the Hellenic Army Geographical Service, lithology from Katsikatsos et al. (1980, 1984). Dotted pattern : Late Quaternary deposits, White: Neogene, Grey: alpine formations. Fault zones in inset location map from Roberts & Jackson (1991), Mettos et al. (1989, 1991), Galanakis et al. (1998), Kranis (1999) and Kranis et al. (2001).

as well as other probable structures with the same strike. These structures exert important control on the morphological characteristics and the drainage networks of the studied area, indicating that they also played a significant role in the tectonic evolution during the Quaternary (and not only the NW-SE zones). Apart from their local interest, the probable faults that will be discussed are quite interesting in the context of the regional tectonic framework.

2. GEOMORPHOLOGICAL CHARACTERISTICS OF THE BROADER STUDY AREA

The broader area of interest extends between the Telethrion-Ksiron-Profitis Elias mountain range and the large WSW-ENE directed valley of the Nileas river between Limni and the Kerinthos plain (Fig. 1). The easternmost part of the Telethrion Mt. (969 m) and its eastward continuation, Mt. Ksiron (990 m) and Mt. Profitis Ilias (745 m), constitute a landstrip of high terrain where alpine basement formations surface in increased extent (or entirely, in Telethrion - Fig. 1). This is due to significant Quaternary uplift of this area, which was once part of the Limni-Histiaia basin, filled by Mio-Pliocene fluvio-lacustrine deposits (Guernet, 1971, Katsikatsos et al., 1984, 1980, Mettos et al., 1991, 1992) that are still the dominant lithology.

From Ksiron and Pr. Elias towards the SSE, systematically lower-altitude areas constitute a WSW-ENE directed zone of morphological transition between the mountains and the WSW-ENE stretch of the large valley of Nileas river, on the NW and SE side of which an extensive area of low elevations can be recognised. This

area was occupied during the (late) Middle Pleistocene by an erosional surface, remains of which can be found in 1:5.000 HAGS topographic maps (4m contour interval) at 180-195 m SSE, SW and N of the village of Strofylia, after which it will also be named ('Strofylia surface' – although the village is not located on it). The existence of the Strofylia surface is betrayed by the fact that in the area where it extended the topography is consistently lower than 180-210m (the elevations of the valley divides – Fig. 1).

The area is today intensely dissected by the tributaries of Nileas (especially SE of the Nileas WSW-ENE valley), and successive generations of younger erosional surfaces (wide and flat valley floors) can be recognised in the 1:5.000 maps. Fytrolakis et al. (1988) mention 4 groups, and comment that the area of the Strofylia surface has probably been subjected to small vertical dislocations by faults.

3. THE GEOMORPHIC DISCONTINUITY OF KECHRIAE – A FAULT ZONE ?

The transition between the area where the Strofylia surface extended and the progressively higher terrain towards Ksiron and Pr. Elias Mts., corresponds to a quite linear geomorphic discontinuity of ENE-WSW direction, that will be called 'discontinuity of Kechriae' in the discussion that follows (line A-A' in Fig. 1, more evident in the 20 m HAGS topographic map given in Fig. 2). Due to intense dissection and the easily erodible Neogene lithologies, steep morphology along

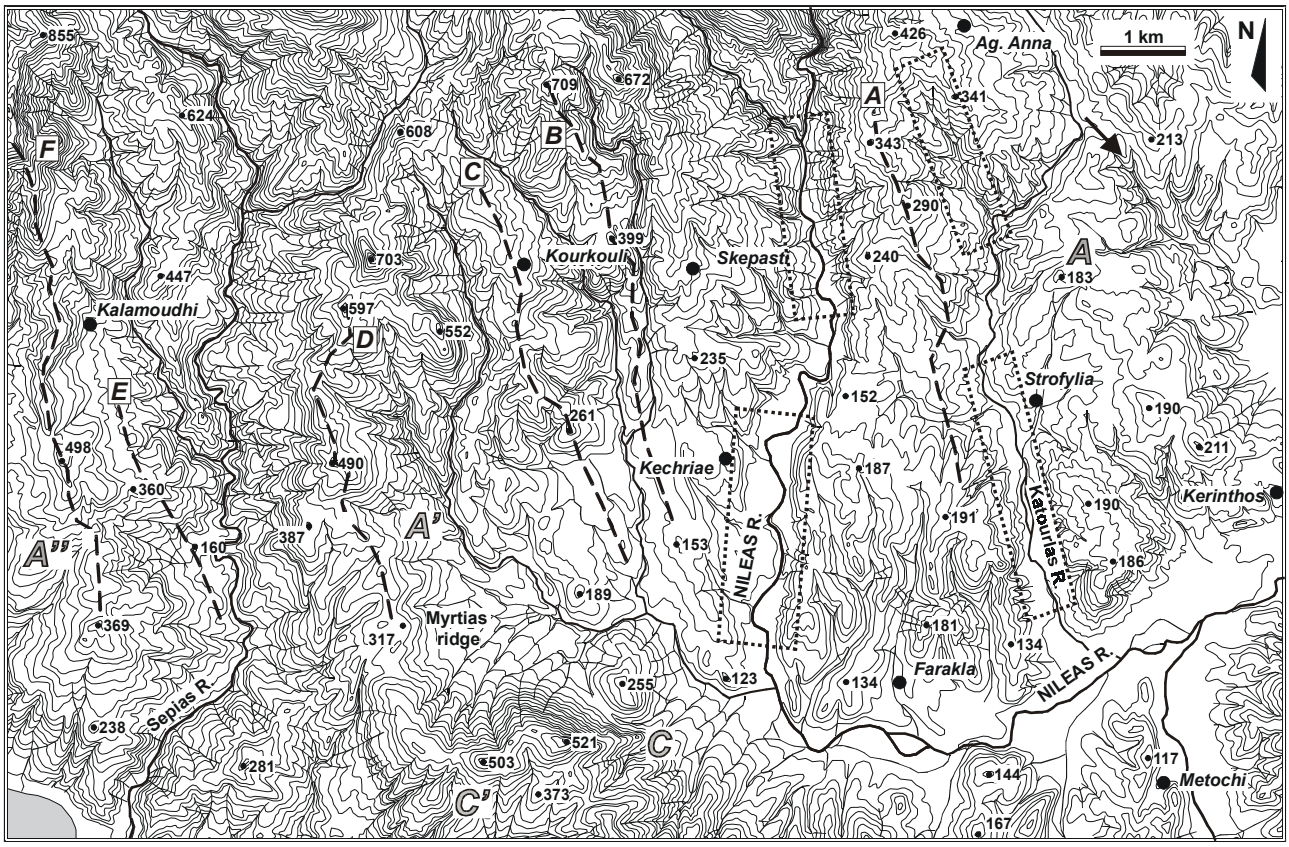

Fig. 2. Topographic map of the geomorphic discontinuity of Kechriae and surrounding areas (20 m contours from the 1:50.000 HAGS map, 'Limni' sheet). Dashed lines labeled A to F are the profile lines of Fig. 3.

line A-A' can be discerned at very few places and only for short distances. Still, the identification of an ENE-WSW lineament across which a geomorphic step exists -smoothed to a greater or lesser extent-, is facilitated if the modification caused by the drainages that traverse it is 'removed' by drawing

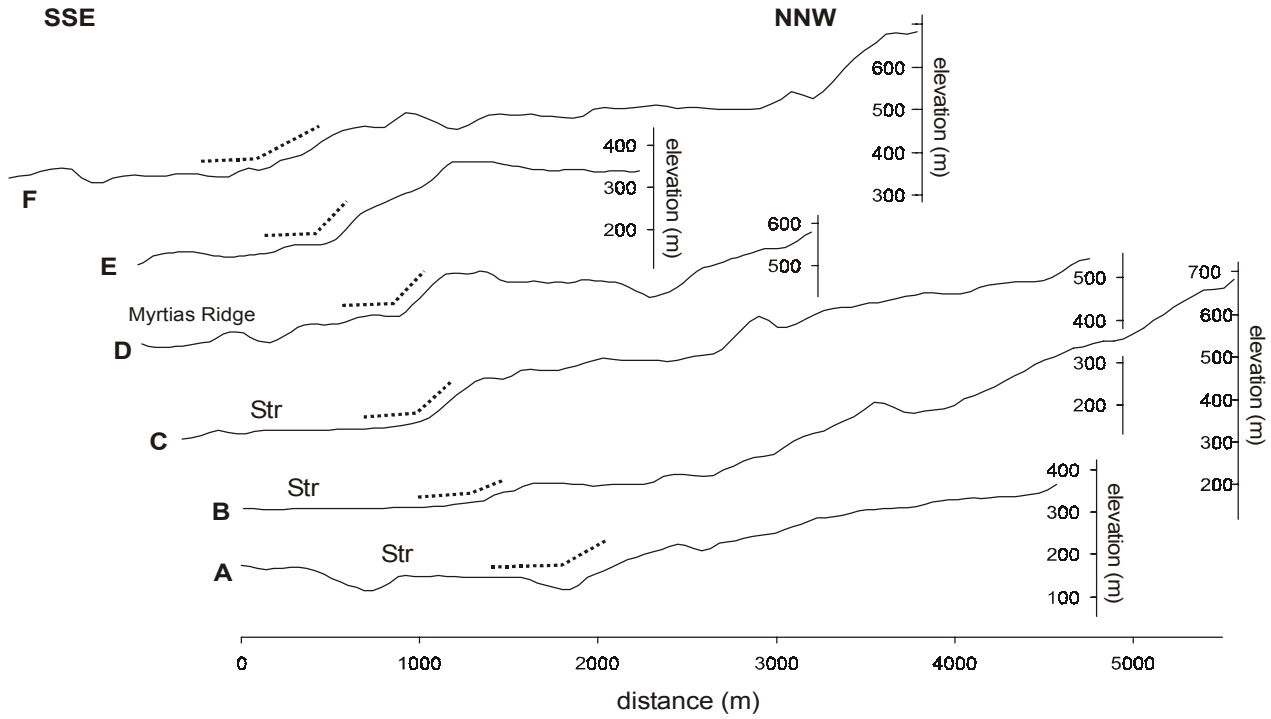

Fig. 3. Topographic profiles directed NNE-SSE, across the geomorphic discontinuity of Kechriae (vertical exaggeration more than 2). The dashed lines mark the relief disruption associated with the discontinuity at the boundary between the Ksiron – Pr. Elias foothills and the area of the 'Strofylia surface'. Str: areas occupied by the Strofylia surface (the surface was at a higher level – what is depicted in the particular profiles is somewhat lower and younger surfaces).

generalised contours (ignoring valleys and taking into account only the spurs in-between them - see e.g. Sparks, 1986).

Given the aforementioned lack of laterally extensive escarpment morphology, in order to illustrate the existence of a morphological step successive topographic profiles were constructed (Fig. 3), based on a 20m DEM interpolated from 20 m contours of the HAGS 1:50.000 map. The profile lines are oriented transverse to line A-A' and follow interfluves (except profile E - see Fig. 2 for locations). In all profiles but the north-easternmost one (A), a distinct slope break can be observed along line A-A' (it is marked with dotted lines in Fig. 3). In profile A the slope base of the Kechriae degraded escarpment has been modified by a small stream, but if its valley is ignored a –smoothed- geomorphic step can still be recognised. Profile E exhibits the largest step, due to the fact that it runs along the valley of Sepias river and the observed elevation difference across line A-A' is in part due to erosion.

Profiles D and F are important in that they exhibit the existence of a distinct morphological step ESE of point A', indicating that the geomorphic discontinuity of Kechriae is longer than line A-A', and extends between A and A'' (Figs. 1 and 2). The fact that the relief disruption associated with the discontinuity of Kechriae is shown not to be restricted along the Strofylia surface boundary only but also to traverse the ridge that constitutes the N. Evoikos – Aegean sea divide, together with its straightness, indicates that it is a geomorphic feature that could be fault-controlled, rather than erosional. More specifically, the aforementioned relationship of the Kechriae discontinuity with its surrounding relief suggests that it could be the degraded escarpment of a fault zone, that is, the product of Quaternary fault activity. A hypothesis of a fault-line scarp is considered unlikely, due to the absence of lithological contrast across line A-A'' (Neogene deposits are found on either side - Katsikatsos et al., 1980), although it is possible that there has been significant erosional modification of the escarpment base in some places in its NE part (e.g. between Katourlas and Nileas rivers).

In view of the above discussion, line A-A'' (13 km long - Fig. 2) can be viewed as the crude trace of a probable fault zone striking ENE-WSW, the 'Kechriae fault zone'. It should be stressed, that in this reconnaissance the existence of this fault zone is proposed on the basis of geomorphological (indirect) observations, the natural next step being to verify this hypothesis by geological study. Given the fact though that the area along the zone trace is mostly forested and in general lacks suitable cross sections, direct geological verification might not be readily facilitated along most of its length.

Arguments favouring the hypothesis of a fault zone along the Kechriae geomorphic discontinuity could also be drawn from the drainage pattern. The value of drainage networks in studies of active faulting is well recognized (e.g. Leeder & Jackson, 1993) and it becomes even more significant in areas of soft Neogene lithologies where fault-controlled landscape features may be subdued by erosion (e.g. Goldsworthy & Jackson, 2000), as the case at hand could be. In the area of interest, indirect support to the degraded fault escarpment scenario is provided by the general orientation of drainages perpendicular to line A-A' (from Katourlas at the eastern part, to Sepias at the western – see Fig. 1 and 2) and their more or less regular spacing (the trunk streams are spaced 2-2.6 km apart). Fytrolakis et al. (1988) and Leontaris & Gournellos (1991) mention fault control of NNW-SSE drainages in the area, and indeed the Nileas river is most probably fault controlled from the latitude of Ag. Anna to the NNW, probably also the upper part of Katourlas (captured from the drainage network east of point A in Fig 2). Still, these cases correspond only to a small portion of the drainage network, whose general disposition in relation to the Kechriae discontinuity remains quite distinct, as described above.

The NNE-SSW general direction of the rivers N of the Kechriae discontinuity persists all the way to the Telethrion – Pr. Elias range (excluding cases of stream capture), N of the ridgeline of which striking drainage anomalies can be seen (black arrows at the N limits of Fig. 1, other cases also outside it). The Eastern Telethrion-Ksiron-Pr. Elias range has a general ENE-WSW direction that parallels the Kechriae discontinuity and in between them staircase morphology can be identified in interfluve areas. These characteristics could be suggesting that there was earlier uplift of the Eastern Telethrion-Pr. Elias range by faults of the same general direction as the proposed Kechriae zone (along line B-B' in Fig. 1), uplift that caused the development of consequent drainages on the fault footwalls and derangement of pre-existing networks (hence the drainage anomalies N of the range) and, subsequently migration of the fault activity farther SSE towards the Kechriae discontinuity. The intense dissection of the area though, makes the task of delineating probable fault traces N of the Kechriae discontinuity based on geomorphic signature alone a difficult one, plus, such ENE-WSW faults are not documented in the bibliography (Katsikatsos et al., 1980, Mettos et al., 1989, 1991), indicating that further geological study is needed to substantiate the interpretation proposed above.

4. RECONNAISSANCE INFORMATION ABOUT THE PROBABLE KECHRIAE FAULT ZONE BASED ON GEOMORPHOLOGICAL OBSERVATIONS

The intense dissection of the probable escarpment of Kechriae, the significant reduction of its slope gradient in most places where relics of the original slope can be seen, indicates that if it indeed corresponds to a fault zone, this fault zone has been either inactive or characterised by a very low rate of vertical displacement during the Late Quaternary. The latter hypothesis is preferable, because the geomorphic expression of the zone should be evaluated at all times in the context of easily erodible Neogene lithologies (fluvial and lacustrine deposits), and the –large- size of the drainage networks that dissect it. In the area the escarpment is crossed by profile C for example (west of Kechriae, Fig. 2), an escarpment facet retains an increased slope gradient of 36 %, as well as the knickpoint caused by the zone in the interfluve followed by profile D (31 %).

The geomorphic discontinuity of Kechriae can be followed westwards up to the Sepias – North Evoikos gulf divide (point A'' in Figs 1 and 2). This divide exhibits a step 150 m high upon intersecting line A-A'' (Profile F in Fig. 3), but, from that point to the west no morphology that could be fault-related can

be identified. The general direction and morphology of the coast at the western end of the Kechriae geomorphic discontinuity, suggests that at least throughout the Late Pleistocene - Holocene the dominant factor in the evolution of the relief has been the NW-SE Kandili fault zone (K in Fig. 1 inset), which uplifts a quite long stretch of the N. Evoikos coastline of Evia. This zone is responsible for a succession of uplifted marine terraces NW and SE of Limni (identified in this preliminary study, to be discussed in a forthcoming paper), which so far have not been found to be substantially affected by a prolongation of the geomorphic discontinuity of Kechriae to the west of A''. In a similar fashion, the eastern part of the discontinuity of Kechriae ceases to be recognizable after crossing the valley of Katourlas river at the longitude of point A (Figs 1 and 2). As mentioned previously, the northern part of the Katourlas river is probably controlled by a NNW-SSE fault zone passing from point A.

A very interesting observation with important implications pertaining to the kinematics of the proposed Kechriae fault zone (and also an argument augmenting the probability of its existence), is the possible horizontal translation of the Nileas river that can be observed at its intersection with the proposed zone trace (rectangles drawn with dotted lines in Fig. 2), which indicates a dextral horizontal dislocation of about 700 to 900 m. Similar behaviour can also be observed in the adjacent valley of Katourlas river, which exhibits about 500 m of dextral translation (rectangles in Fig. 2). It should be reminded that the large right step Katourlas exhibits at the longitude of point A (Fig. 1) is due to stream capture along a probable NE-SW splay of the Kechriae zone and not related to the cases of translation discussed above.

An alternative explanation for the 'bends' of Nileas and Katourlas could involve WSW tilting of the area S of the Kechriae discontinuity, but, there is no such evidence from the disposition of erosional surfaces identified there in 1:5.000 maps. Also, in both cases the lithology consists of Neogene formations, the inhomogeneities inside of which are unlikely to have produced an anomaly of this scale, especially on rivers of this size.

West of the Nileas valley, analogous cases of offset streams cannot be identified along the Kechriae discontinuity, but, quite distinct dextral translocations can be found south of the large ENE-WSW part of the Nileas valley, S and SE of Metochi (outside Fig. 2, evident in a 20 m contour map, not in Fig. 1). There, in the valleys of Ksinemias and Makryrema rivers the horizontal displacement ranges from 700 to 900 m. The Kireas river also exhibits a similar anomaly SSW of Mantoudi (also outside Fig. 2), which together with the others mentioned above should be studied in more detail to verify or discard the interpretation proposed in this reconnaissance. These probable cases of river translations suggest that the proposed Kechriae fault zone as well as other structures yet unmapped, are characterised by a significant dextral horizontal component of displacement, which could be larger than the vertical one (judging from the height of the degraded Kechriae escarpment and the amount of horizontal dislocation of Nileas and Katourlas).

5. DISCUSSION

The geomorphic discontinuity of Kechriae and the fault zone that is proposed to exist along it, conspicuously parallels a major tectonic discontinuity located 4 km to the SE, which according to Katsikatsos et al. (1980) traverses the island of Evia in a ENE-WSW direction and controls the large valley of Nileas between Limni and Mantoudi (Katsikatsos et al., 1980). This discontinuity, that will be called 'the discontinuity of Nileas' in the discussion that follows, is a boundary between ophiolites and schist-chert melange on its SE side and carbonates of the Sub-Pelagonian zone to its NW (Katsikatsos et al., 1980). In the IGME map (Katsikatsos et al., 1980), the discontinuity of Nileas is considered to be an Heo-alpine thrust dipping towards the SE. On the other hand, Fytrolakis et al. (1988) proposed the existence of a neotectonic structure along the valley of Nileas, based on geomorphological evidence (namely, the existence of terraces in the Nileas tributary valleys NW of the discontinuity only).

It should be noted that the discontinuity of Nileas is drawn in the IGME map as a contact buried along most of its length by the Late Pleistocene - Holocene valley fill of Nileas. Its characterization as an alpine thrust is based on two surface occurrences of the ophiolites / carbonates contact -spaced ~13 km apart-, one SE of Myrtias (Misopetri Mt., line C-C′ in Fig. 1) and one ENE of Mantoudi. During field reconnaissance, the contact in Misopetri (line C-C′) was found exposed in an adequately large roadcut, which was probably constructed later than the IGME field mapping. The measurements taken showed that the contact is in fact vertical or dipping at a very high angle (>85°) to the S. Distinct evidence of it affecting Late Pleistocene -and perhaps Holocene- colluvium and limestone scree was also found (minor movements on a discontinuity otherwise inactive during the Holocene and Late Pleistocene). The dip of the contact together with the fact that no structures typically encountered in thrusts were observed in the cross section, indicates that a detailed re-examination of the Heo-Alpine thrust scenario is called for, at least as far as the contact at Misopetri is concerned, where the existence of a neotectonic discontinuity seems to be favored instead.

Studying in detail the Kechriae discontinuity and other probable ENE-WSW structures mentioned herein becomes very attractive when placed in the context of a model recently proposed by Kranis (1999), in which the area of interest in this study is traversed by a large-scale dextral shear zone of the same ENE-WSW direction (e.g. the possible right-lateral translations of river valleys discussed in the previous section, come very interestingly into play in this scenario). This zone is proposed as the SE boundary of a broader shear zone hosting rigid to semi-rigid block rotations around horizontal and vertical axes (blocks bounded by the WNW-ESE to NW-SE active fault zones of the area), that could be related to the prolongation of the North Anatolian fault zone into the Hellenic mainland. The crude trace of the SE boundary zone as proposed by Kranis (1999) was verified on the other side of the N. Evoikos gulf -in Lokris-, where it was found to coincide with a previously unmapped fault zone (the Hyambolis fault zone, discussed in Kranis et al., 2001, and Palyvos, 2001 – Y in Fig. 1 inset). In Evia, the zone trace proposed by Kranis (1999) roughly coincides with the Kechriae discontinuity, but, given the fact that at the exact prolongation of the mainland Hyambolis fault zone across N. Evoikos the discontinuity of Misopetri and the ENE-WSW ‘lineament’ of the Nileas valley is found, we would propose them instead as candidates.

Mettos et al. (1989, 1991) document sinistral strike-slip faults directed NNE-SSW and suggest that they probably belong to a Late Pliocene – Early Pleistocene tectonic phase of transition between the two main extensional ones affecting the area. Strike-slip faulting in the area of Rovies-Limni is mentioned also in Kranis (1999), plus, during field reconnaissance several strike slip faults were measured in large roadcuts on the road from Mantoudi to Limni, striking NNE-SSW ENE-WSW and ESE-WNW. In view of the model of Kranis (1999) and the new data presented in this preliminary study, these faults need to be systematically studied in order to clarify if they may be 2nd order faults inside a wide dextral shear zone in between 1st order faults such as the Misopetri-Nileas discontinuity and the proposed Kechriae fault zone.

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