A CASE OF DRAINAGE DERANGEMENT AND REVERSAL BETWEEN THE VIOTIKOS KEFISSOS AND N. EVOIKOS BASINS (CENTRAL GREECE)[1]

H. MAROUKIAN[2], N. PALYVOS[3], G. LIVADITIS[1] AND K. GAKI-PAPANASTASSIOU[4]

ABSTRACT

This paper presents the results of a study of the Alargino Rema and Assos river drainage networks, located between the North Evoikos and Viotikos Kefissos / Kopais basins, the characteristics and anomalies of which suggest that they are relics of a large E.-M. Pleistocene drainage network flowing towards the N. Evoikos gulf. This network, that could be the ancestral Viotikos Kefissos, was deranged sometime in the M. Pleistocene and its flow was reversed towards the SW in the present-day Assos watershed area, due to tectonic uplift in the area of Alargino.

ΠΕΡΙΛΗΨΗ

Στην εργασία αυτή παρουσιάζονται τα αποτελέσματα γεωμορφολογικής μελέτης των υδρογραφικών δικτύων του Αλαργινού ρέματος και του π. Άσσου, τα οποία αναπτύσσονται ανάμεσα στα τεκτονικά βυθίσματα του Β. Ευβοϊκού κόλπου και της λεκάνης του Βοιωτικού Κηφισσού π. / Κωπαϊδας. Τα χαρακτηριστικά των δικτύων αυτών και οι ανωμαλίες που διαπιστώνονται, υποδηλώνουν οτι πρόκειται για υπολείμματα ενός μεγάλου κ.-μ. πλειστοκαινικού δικτύου το οποίο κατέληγε στον Β. Ευβοϊκό κόλπο και θα μπορούσε να θεωρηθεί πρόγονος του Β. Κηφισσού (ο οποίος σήμερα καταλήγει στην Κωπαϊδα). Το παλαιό μεγάλο δίκτυο υπέστη διαταραχή κάποτε στο Μ. Πλειστόκαινο και η ροή του αναστράφηκε πρός ΝΔ στην περιοχή του σημερινού π. Άσσου, κατά πάσα πιθανότητα λόγω τεκτονικής ανύψωσης του κάτω τμήματος του (στην περιοχή του σημερινού Αλαργινού ρέματος).

KEYWORDS: Geomorphology, drainage networks, drainage reversal, Viotikos Kefissos river, Hyambolis fault zone, Atalanti Fault zone, Lokris basin, Central Greece.

1. INTRODUCTION

This paper is concerned with the characteristics and anomalies of the Alargino Rema and Assos river drainage networks (Fig. 1), located between the North Evoikos and Viotikos Kefissos / Kopais basins, largely along a fault zone transverse to the WNW-ESE trending active ones of Lokris. Alargino Rema flows towards the N. Evoikos gulf, whereas Assos river towards the SW, being presently a tributary of the Viotikos Kefissos river. The discussion that follows, aims at demonstrating that the present day Alargino Rema and Assos river are relics of a quite large Early-Middle Pleistocene drainage network that was flowing towards the N. Evoikos gulf and was deranged sometime in the M. Pleistocene.

2. THE DRAINAGE NETWORKS OF ALARGINO REMA AND PLATYREMA

The trunk stream of the Alargino Rema drainage network - Fig. 1 - follows a SW-NE course at the SE flank of the Neogene Lokris basin (or Renginion basin, or Kallidromon-Knemis basin – Philip, 1974, Rondogianni, 1984, Ioakim & Rondogianni, 1988, Mettos et al., 1992, Kranis, 1999), directed towards the North Evoikos gulf. The position of Alargino was dictated by the presence of the NE-SW trending Hyambolis fault zone (1 in Fig. 1 inset), which constitutes the boundary between the Chlomon mountain and the Lokris basin (Kranis et al., 2001, Pa-

---

1:Μια περίπτωση διαταραχής και αναστροφής υδρογραφικού δικτύου μεταξύ των βυθισμάτων του Βοιωτικού Κηφισσού και του Β. Ευβοϊκού κόλπου

2:Associate Professor, University of Athens, Faculty of Geology, Geography-Climatology Department, Panepistimioupoli, 157 84, Zografou, Athens.
3:Geologist, PhD, Navarinou 21, 152 32 Halanthri, Athens.
4:Assistant Professor, University of Athens, Faculty of Geology, Geography-Climatology Department, Panepistimioupoli, 157 84, Zografou, Athens.

lyvos, 2001), juxtaposing soft Neogene and Quaternary deposits against the alpine basement. The drainage pattern of Alargino is quite asymmetric, with the main stream close to its NW divide and major tributaries mostly at the SE part of the watershed (NW-SE to N-S trending drainages, that developed on the uplifting footwalls of the Hyambolis zone faults).

The lower reach of Alargino -before entering the Atalanti plain-, as well as its tributaries, have been in a state of rejuvenation in the Late Pleistocene, with intense downcutting that has resulted in the formation of quite deep V-shaped valleys (Fig. 1). This rejuvenation is the result of uplift of the lower part of the network by the Atalanti fault zone (no. 2 in Fig. 1 inset). Even though the cumulative uplift that has been produced by the Atalanti fault zone is dramatically reduced upon its intersection with the Hyambolis fault zone (Pantosti et al., 2001, Palyvos, 2001, Kranis et al., 2001), there has been nevertheless appreciable uplift at the NW tip of the former zone inside the Lokris basin.

It seems that this has not been the case during the M. Pleistocene, when subsidence produced by the NE part of the Hyambolis zone resulted in the deposition of alluvial fans (area 1 in Fig. 1) in front of the escarpment of the NE part of the zone (Palyvos, 2001). These fans pushed the Alargino channel away from the fault escarpment, close to its NW divide where it still remains today.

The trunk stream of the Platyrema network (Fig. 1) is also controlled by the Hyambolis fault zone and is located at the prolongation of Alargino towards the SW, having the same general direction. Although the drainage pattern suggests that Platyrema was the upper part of Alargino in the recent geological past - a fact also made obvious by the observed continuity between the valleys they are occupying -, today it makes a sharp turn in the area of point 2 (Fig. 1 and 2), and attains a N-S direction flowing to the area of Loutsa.

South-West of the head of the Late Pleistocene rejuvenation of its lower reach, Alargino flows through a quite wide valley with flat bottom (Fig. 1 and Fig. 2). At point 2, the valley floor of Alargino is interrupted, and a wind gap can be observed today (Fig. 2). This is interpreted to be the result of stream capture of the once upper (SW) part of the river (Platyrema), by a small drainage flowing to the area of Loutsa. Loutsa is at a lower level than the wind gap and judging from the fact that it is a depression that has been accepting sediments during the Late Pleistocene - Holocene, its level was probably even lower at the time of the capture. At the point of capture a small reverse stream has formed, indicating that the capture of Platyrema is not a very recent event, although it could be as young as a few tens of thousands of years, judging from the size of the valley the reverse stream has created and the fact that it is developed on easily erodible lithology. Since its capture, Platyrema has formed a small alluvial cone inside Loutsa (Fig. 2).

It will be discussed later, that in the area of capture was the junction between Alargino–Platyrema and the large river that flowed through the valley of Hyambolis. Their derangement, it should be stressed, is an older event than the capture discussed above.

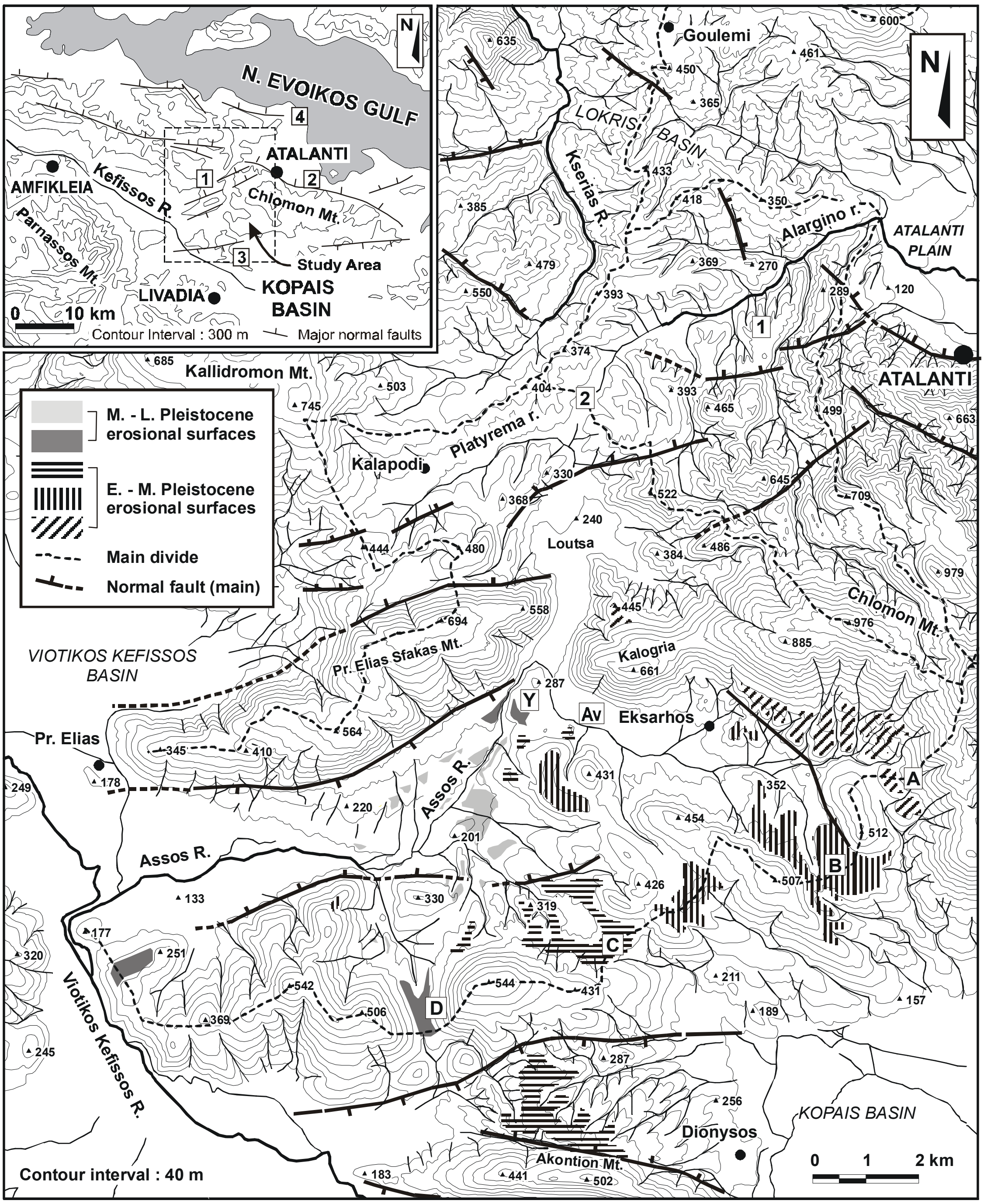

Fig. 1. Topographic map of the study area (40 m contours, from HAGS 1:50.000 maps), with erosional surfaces and terraces s.s. in the Assos watershed. Letters and numbers are locations and features referred to in the text. Location map and main fault zones in inset (faults drawn after Maratos et al., 1967, Philip, 1974, Rondogianni, 1984, Sideris, 1988, Roberts & Jackson, 1991, Kranis, 1999, Kranis et al. 2001 and Palyvos, 2001).

3. THE DRAINAGE NETWORK OF ASSOS RIVER

The drainage network of Assos (Bogdanos)river – a stream, strictly speaking -, flows today towards the Viotikos Kefissos basin. Its trunk stream has a general NE-SW direction, paralleling the elongate Pr. Elias Mt., a horst of Triassic – Jurassic carbonates created by the Hyambolis fault zone (Kranis et al., 2001, Palyvos, 2001).

The younger branches of the Assos network as well as Assos river itself south of the hill of ancient Hyambolis (area Y in Fig. 1), occupy young V-shaped valleys they have created in the M.-L. Pleistocene, e.g. those on Pr. Elias Sfakas Mt., or those at the eastern part of the watershed. Taken as a whole though, the network is clearly underfit, flowing through wide valleys, that were created by a significantly larger network in the past. Four generations of erosional surfaces can be identified in the Assos watershed, which correspond to successive levels of flow of the drainage network (A-D in Fig. 1), D –and A, to a lesser extent- being the floor of a valley with well preserved morphology.

Levels B and C are not related to distinct valley morphology, due to lithological variations (ophiolites/melange – carbonates) largely created by tectonic discontinuities. It should be noted that only major faults, most of them with known Pleistocene activity are drawn in Fig. 1, but even from the topographic map alone, a NW-SE structural grain is evident in the SE part of the Assos watershed. The very broad old valley on the floor of which Assos river has created successive terraces and incised in the recent past (creating the quite narrow small valley it is presently flowing through), owes its morphological characteristics to the fact that it is a 'corridor' of easily erodible rocks (ophiolites, melange and Plio-Pleistocene deposits) between resistant carbonates, bounded by faults of the Hyambolis zone to the NW and by a N-dipping fault to the S (Palyvos, 2001). Assos was flowing along this 'corridor' sometime in the E.-M. Pleistocene and during a period of base-level stability it was able to create a flat valley floor belonging to valley floor generation C. Remains of surface C are not drawn inside the wide valley of Assos –except for two small ones south of point Y in Fig. 1-, because this old valley floor has been subsequently lowered and younger terraces have formed in its place; still, its previous existence is betrayed by the fact that the topography on ophiolites, melange and Plio-Pleistocene deposits that composed the valley floor never exceeds the 280 m contour in elevation.

Apart from the important passive control of structure, the extent to which the morphology of the wide Assos valley is due to exogenetic or endogenetic processes (Pleistocene fault activity that is) is not precisely known. The fault at the NW side of the wide old valley of Assos has been active in the Pleistocene (the Hyambolis fault s.s. – Palyvos, 2001, Kranis et al., 2001), but it is not clear whether the Hyambolis escarpment (the SE slope of Pr. Elias) is the product of Pleistocene fault activity only (a fault escarpment), or also of differential erosion. It could be that differential erosion along the fault –which exists since the Miocene- is mainly responsible for the formation of the escarpment, with Pleistocene fault activity involved in a lesser extent. The observed continuity between the Hyambolis escarpment and the south-facing slope of nearby Kalogria (see Fig.1), the base of which also coincides with another carbonates / ophiolites-melange contact, suggests that this scenario is quite probable. Similarly for the SW side of the Assos valley -which is also controlled by a fault zone juxtaposing ophiolites/ melange on carbonates-, the extent to which the bounding fault contributed actively to the shaping of the observed relief is not constrained with the available data (here no evidence of Pleistocene activity is known of).

As far as the age of the discussed valley floors is concerned, C can be placed sometime in the E.-M. Pleistocene, since it has developed (partly) on Plio-Pleistocene deposits (Palyvos, 2001). Valley floor D is of a younger generation than C, its period of formation being sometime during the M.-L. Pleistocene. Valley floor B, which is the one immediately older than C, is considered to be also of Pleistocene age (Early – Middle), on the grounds of its hypsometric correlation with Pleistocene surfaces farther to the east (Palyvos, 2001). Given the lack of absolute dating, this does not conflict with the Latest Pliocene – Early Pleistocene age proposed earlier by Papadopoulou (1990) for the same erosional surface and could be true also for the oldest one (D).

At the SE side of the watershed, surfaces A to D are truncated and large wind gaps can be observed today (where the letters A, B, C, and D are located in Fig. 1 – successively older valley floors from A to D). The formation of the Kopais basin (formerly a lake – Papadopoulou, 1990), offers an explanation for the derangement of the SE part of the Assos network, that was captured by drainages directed towards Kopais. The existence of the ENE-WSW striking tectonic discontinuity of Aspledon (no. 3 in Fig. 1 inset) guided the SE directed drainage networks and resulted in the observed -more or less- linear arrangement of the discussed wind gaps. The fact that the discontinuity of Aspledon juxtaposes easily erodible Eeocene flysch against hard Cretaceous carbonates in the area of wind gap D, is responsible for it having the most characteristic morphology, although A also is quite distinct, despite the fact that it has formed exclusively on carbonates. According to our present knowledge, the role of the Aspledon zone in the derangement of the SE part of the Assos network was only passive (no substantial movements involved).

No fluvial deposits are preserved at the wind gaps or along the old valley floors (where they are developed on bedrock), whereas in valley floors developed on the Plio-Pleistocene fluvio-lacustrine deposits that can be found in the Assos area, discerning younger fluvial deposits would demand detailed studies (wherever suitable outcrops are available). Thus, no direct evidence of the direction of flow of the older generations of the network are available, except for those corresponding to the terrace generations drawn in light grey in Fig. 1 (more than two), the distribution of which unequivocally speaks of a network

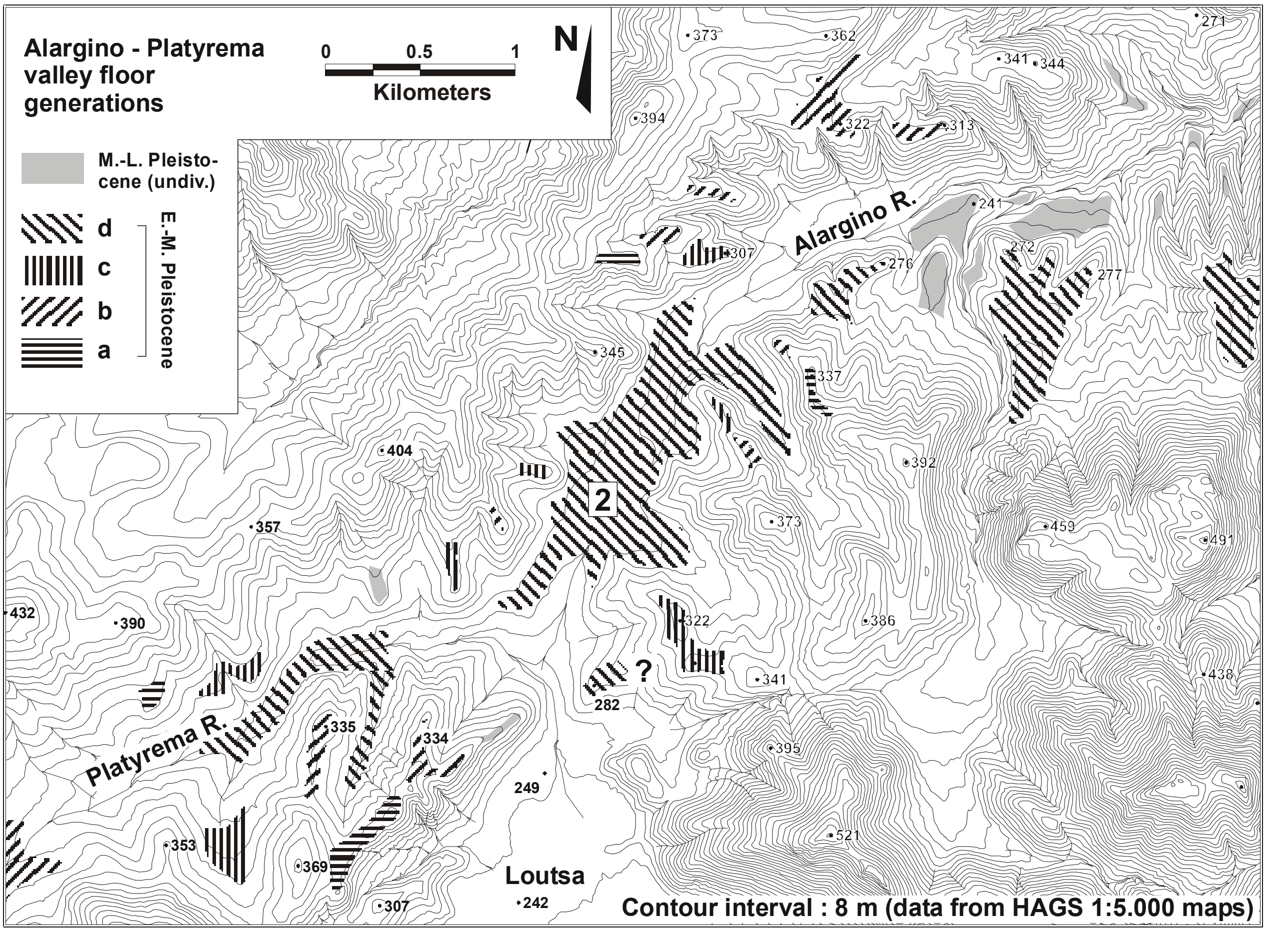

Fig. 2. Detailed topographic map of the Alargino-Platyrema valley (8 m contours from 1:5.000 HAGS maps). Surfaces (valley floor generations) are discussed in the text.

flowing towards the Viotikos Kefissos, as modern Assos does.

In view of the lack of direct evidence, from the drainage pattern, as it is implied by the most characteristic old valley remains (those in the vicinity of wind-gaps D, A and B), it is inferred that the NW-SE directed branches of the network were probably flowing towards the old valley of the Assos river (let it be noted that the bifurcation observed in valley D towards Assos, is taken to be the result of piracy in earlier periods).

Based on –indirect- geomorphological observations, an attempt can be made to determine the direction of flow of Assos itself in the past, that is, before the formation of its present valley SW of Hyambolis and the M. – L. Pleistocene terraces inside it (those drawn with light gray in Fig. 1). In the area of the ancient fortress of Hyambolis ('Y' in Fig. 1), two erosional surfaces (remains of an Assos valley floor generation) can be identified at an elevation of around 240 m, on either side of the river. These are developed on bedrock, reddish-coloured M. Pleistocene alluvial cone deposits and Plio-Pleistocene fluvio-lacustrine deposits – they are drawn in dark grey in Fig. 1. In the same area, surfaces belonging to valley floor generation C have been recognised exactly above the valley floor at Hyambolis (Fig. 1). These remains are close to the main one farther SE, so their correlation based on elevation is justified. Also, the elevation of the hilltop of the fortified hill of Hyambolis, allows its correlation with valley floor level C, the same being true for the hill the fortress of ancient Avai was built on (site 'Av' in Fig. 1). This implies that the valley floor at 240 m can be correlated with valley floor D, which is immediately younger than C and also close in elevation (at around 220 m) – always keeping in mind that the 'flat' valley floors were not level but gently sloping.

Accepting the aforementioned hypothesis that the stream of valley D was flowing towards Assos, the valley floor of Assos during period D should have been lower than 220 m at their confluence (220 m is the elevation of valley floor D at the wind gap in Fig. 1). Since valley floor D is found at 240 m in the area of Hyambolis (Y), this implies that the valley floor of Assos during this period (M.-L. Pleistocene) was sloping towards the SW and the river was flowing in this direction, being a tributary of the Viotikos Kefissos as is the case today. In the next section, arguments favouring the probability of a NE-flowing Assos river in earlier periods (when valley floors C?, B and A were formed, sometime in the E.-M. Pleistocene) will be discussed.

4. THE VALLEY OF HYAMBOLIS

The valley of Hyambolis belongs to the old valley system of the Assos river and it is a quite large valley in carbonates (360 m visible depth) extending from the fortress of Hyambolis ('Y' in Fig. 1) up to Loutsa. Together with valley D (which is of comparable morphology) it is the relatively narrowest and steepest of the old valleys of the Assos network. These morphological characteristics of the Hyambolis valley (significantly narrower than the other old valleys of the Assos watershed) can be interpreted as the result of relatively fast downcutting of an antecedent river that was keeping up with tectonic uplift by the NW-dipping Hyambolis zone faults, faults that have been active in the E. – M. Pleistocene (Palyvos, 2001, Kranis et al., 2001). Of course, the valley has been subsequently modified, attaining its present –less steep- morphology.

On the other hand, given the fact that the Hyambolis zone exists since the Miocene (exhibiting intermittent activity – Palyvos, 2001 and Kranis et al. 2001), it is probable that the river that created the Hyambolis valley was superposed on a partly pre-existing horst buried by Neogene deposits – a horst not as high as it became after the E.-M. Pleistocene phase of tectonic activity. In support of this scenario comes the discussion in the previous section, that the Hyambolis escarpment (the SE side of Pr. Elias Sfakas, corresponding to a SE-facing fault of the Hyambolis zone) is probably a landform shaped to a significant extent by differential erosion of the horst carbonates and the ophiolites/melange in the Assos valley.

The Hyambolis valley is judged to be very important in this study, since it connects the drainage network of Assos river with that of Platyrema and Alargino farther N. **The position and morphological characteristics of the Hyambolis val-**

ley suggest that the two drainage networks are parts of what was once one larger network, with a quite large trunk stream flowing through it. Having discussed that the available data so far point to an Assos river flowing towards the SW at least as early as valley floor generation D (sometime in the M. Pleistocene), an important question rises : **was the Assos network flowing towards the SW also in earlier times ? or, did it have a direction of flow towards the N /NE, that was for some reason reversed in its SW part (the area of modern Assos) sometime in the late Early - Middle Pleistocene ?**

Inside the valley of Hyambolis neither terraces nor fluvial deposits are preserved, and only slope wash and alluvial cone deposits can be seen, exposed in roadcuts at the bases of the valley slopes. The valley floor is covered by a dark brown soil developed on fine grained Holocene deposits (possibly marsh deposits; in the recent past, there has been no natural channel in the valley, and several decades ago an artificial channel was excavated to drain the stagnating water). Thus, here also there is no direct evidence of the direction of flow of the river that flowed through the valley.

In order to determine the direction of flow of the old Assos-Alargino network indirectly, it can be argued in favour of the second hypothesis (N-flowing network) that the drainage pattern in the Lokris basin, north of the Hyambolis valley, does not seem to retain any characteristics that imply flow of earlier generations of streams towards the S. The strength of this argument should of course be evaluated in the context of the soft lithologies and the intense dissection of the basin fill by present-day drainage networks during the M.-L. Pleistocene, factors not favouring the preservation of such features in the drainage pattern, but on the other hand, it is considered unlikely that these would have been entirely eliminated. The angle of confluence between the Hyambolis valley and the valley of Platyrema – Alargino, also suggests that the direction of flow of the trunk stream of this old network was in all probability towards the N or NE (the N. Evoikos Gulf). Further arguments to substantiate this hypothesis were sought in the distribution of terraces (previous valley floors) in the Platyrema – Alargino Valley in the vicinity of its junction with the valley of Hyambolis.

Use of the very detailed 1:5.000 HAGS topographic maps (4m contours) permits the identification of successive valley floor levels inside the Alargino-Platyrema valley (Fig. 2). This can be done in considerable detail, by utilizing terraces, or -where terraces are not preserved- distinct slope gradient changes in the valley cross profile (low-gradient parts of ridgelines between the valleys of the tributary streams of Alargino, well expressed in the 1:5.000 topographic maps). The correlation of the preserved terraces -and the terraces implied by ridgeline profiles- proposed in Fig. 2, was based on the elevations of their outer edges, 'outer edge' referring to the edge towards the valley centerline.

The remains of the valley floor level that can be recognised at around 330m in the Alargino-Platyrema –former- confluence area –level 'b' in Fig. 2-, are found at progressively lower elevations towards the ENE (down to 316 m or less), suggesting that river flow was towards this direction. The same is true for valley floor level c, which is the next younger one. The fact that valley floor b and all the older ones extend across the watershed between Platyrema-Alargino and Loutsa (Fig. 2), is implying that as late as the period during which valley floors b and c were formed (sometime in the E-M. Pleistocene), there was a confluent of Alargino from the south, flowing across the present-day watershed. This confluent is logically assumed to have been flowing through the valley of Hyambolis, indicating that the Assos-Alargino unified network existed as late as the period of formation of b and c, flowing towards the Atalanti plain and the N. Evoikos gulf (as the elevation trend of the valley floor remains suggests).

In Fig. 2, a possible remain of valley floor level d is drawn with a question mark between Loutsa and the Alargino-Platyrema valley, based on the existence of a low gradient part in the –former- divide (breached today by modern Platyrema). If this interpretation is indeed correct, it would suggest that a wind gap existed along the Loutsa / Alargino-Platyrema divide and that the unified Assos-Alargino network existed as late as valley floor period d.

The lack of terraces inside the Hyambolis valley, does not permit a safe correlation between the valley floors in the Platyrema – Alargino valley with those in the Assos drainage basin. Based on its elevation, it can be stated as a generalisation that level B in the Assos watershed could be roughly correlated with either level a or level b in the Alargino-Platyrema valley (it is higher than the latter, as would be expected in a network flowing to the N/NE).

5. DISCUSSION

Accepting that present-day Alargino and Assos are parts of one and the same older network that was flowing to the N/NE sometime during the Early – early Middle Pleistocene, it can be assumed that the trunk stream of this network could have been the ancestral Viotikos Kefissos, that was flowing during this period towards the N. Evoikos gulf along the Hyambolis fault zone. It would be of interest to identify the reasons that caused reversal of the old Assos-Alargino drainage network in the area of the present-day Assos watershed. In general, the evolution of the old network was affected by the pattern of regional tectonic movements (uplift/subsidence) and the evolution of the basins of Kopais and Viotikos Kefissos.

A working hypothesis that can be put forward is that of reversal due to tectonic uplift of the NE part of the network. This hypothesis is favoured by the fact that, in general, the SW flanks of the N. Evoikos gulf are uplifting by fault zones like the Atalanti f.z. or the Arkitsa – Kammena Vourla f.z. (2 and 4 in Fig. 1 inset, respectively), even though uplift rates, at least as far as the Atalanti fault zone is concerned), are not as high as those in Northern Peloponnesos (e.g. Ganas, 1997, Pantosti et al., 2001), where classic examples of drainage reversals have been documented (Dufaure, 1975).

In a more detailed view of the arrangement of the fault zones, an important point that should be taken into account is that Alargino (the NE part of the old network) occupied the particular position because of the existence of the Hyambolis zone, which, apart from producing lithological contrast and subsidence along the NW flank of Chlomon Mt., constitutes also a barrier for the Atalanti fault zone (Pantosti et al., 2001, Kranis et al., 2001, Palyvos, 2001). The large amount of total uplift produced by the NW part of the Atalanti fault zone at Chlomon Mt. (Ganas, 1997, Pantosti et al., 2001, Palyvos, 2001) that has also caused marked backtilting of Miocene paleosurfaces, abruptly decreases when the Atalanti f.z. intersects the Hyambolis f.z. In a first approach, this implies that with this specific course, the Assos-Alargino network would not be expected to be prone to reversal due to tectonic uplift, since it was here exactly because of a substantial deficit in cumulative uplift, in-between the footwalls of the Atalanti and Arkitsa-Kammena Vourla fault zones (2 and 4 in Fig. 1 inset, respectively), as a transfer zone drainage (Gawthorpe & Hurst, 1993, in Collier & Gawthorpe, 1995). On the other hand, the geomorphological characteristics in the area between the Atalanti fault zone and the Arkitsa fault zone, seem to suggest that homogeneous uplift has been occurring instead in the area of Alargino and Goulemi - excluding relatively small displacements by faults inside the Lokris basin and localised SSE tilting in the Arkitsa Livanates area farther E.

6. CONCLUSIONS

- The drainage networks of Platyrema-Alargino and Assos are parts of one single older (E.-M. Pleistocene) network, the trunk stream of which flowed through the valley of Hyambolis
- The direction of flow of the E.-M. Pleistocene Assos-Platyrema-Alargino network was in all probability towards the N/NE
- The trunk stream of the old Assos-Platyrema-Alargino network could have been the ancestral Viotikos Kefissos, that was initially flowing towards the N. Evoikos gulf, along the Hyambolis fault zone
- The old network was subjected to reversal in the area of modern Assos, due to tectonic uplift of its NE part (Alargino area)

7. ACKNOWLEDGEMENTS

We would like to thank the reviewers of this paper for their useful comments. The PhD work of N.P. was funded by the State Scholarship Foundation (I.K.Y.).

8. REFERENCES

[1]COLLIER, R. and GAWTHORPE, R., 1995, Neotectonics, drainage and sedimentation in central Greece: insights into coastal reservoir geometries in syn-rift sequences, *Journal of the Geological Society, London*, Sp. Publ. no. 80, 165-181.

[2]DUFAURE, J.-J., 1975, Le relief du Peloponnese, Paris, Universite Paris XI.

[3]GANAS, A., 1997. Fault segmentation and seismic hazard assessment in the gulf of Evia rift, Central Greece, PhD thesis, Univ. of Reading, 368 pp.

[4]KRANIS, H., PALYVOS, N., LIVATIDIS, G. and MAROUKIAN, H., 2001, The Hyambolis zone : Geomorphological and tectonic evidence of a transverse structure in Lokris, *Bull. Geol. Soc. Greece*, XXXIV (1), 251-257.

[5]KRANIS, H., 1999, Neotectonic activity of fault zones in Central - Eastern Sterea Hellas (Lokris), PhD Thesis, Univ. Athens, Dep. of Geology, 234 pp. (in Greek).

[6]MARATOS, G., RIGOPOULOS, K. and ATHANASSIOU, A., 1967, Geological map of Greece in 1:50.000 : Elateia sheet, IGME, Athens.

[7]MARATOS, G., RIGOPOULOS, K. and ATHANASSIOU, A., 1965, Geological map of Greece in 1:50.000 : Atalanti sheet, IGME, Athens.

[8]METTOS, A., RONDOGIANNI, TH., IOAKIM, CH. et PAPADAKIS, I., 1992, Evolution geodynamique et reconstruction paleoenvironnementale des basins neogenes-quaternaires de la Grece centrale, *Paleontologia i Evolucio*, 24-25, 393-402.

[9]PALYVOS, N., 2001, Geomorphological study of the broader Atalanti area (Fthiotis, Central Greece), PhD Thesis, Univ. Athens, Dep. of Geology, 233 pp. (in Greek).

[10]PANTOSTI, D., DEMARTINI, P.-M., PAPANASTASSIOU, D., PALYVOS, N., LEMEILLE, F. and STAVRAKAKIS, G., 2001, A re-appraisal of the 1894 Atalanti earthquake ruptures, central Greece, *Bull. of the Seism. Soc. of America*, 91 (4), 760-780.

[11]PAPADOPOULOU-VRYNIOTI, K., 1990, Geomorphological study of the Kopais area (Boeotia), PhD Thesis, Univ. Athens, Dep. of Geology, 145 pp. (in Greek).

[12]PHILIP, H., 1974, Etude neotectonique des rivages egeens en Locride et en Eubee nord orientale, These de 3eme cycle, Acad. de Montpellier, Univ. de Lanquedoc, 86 pp.

[13]ROBERTS, S. and JACKSON, J.A., 1991, Active normal faulting in central Greece: an overview, Geological society, London, sp. publ., 56, 125-142.

[14]RONDOGIANNI, TH., 1984, Etude neotectonique des rivages occidentaux du canal d' Atalanti (Grece centrale), These de 3eme cycle, Univ. Paris XI, 190 pp.

[15]SIDERIS, CH., 1988, The Triassic volcano-sedimentary sequence of Atalanti, *Ann. Geol. de Pays Helleniques*, XXXIII/II, 353-369(in Greek).

[16]SPARKS, B. W., 1986, Geomorphology, Longman, 3rd ed., 561 pp.