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HARIKLIA D. SKILODIMOU (*), GEORGE D. BATHRELLOS (*), HAMPIK MAROUKIAN (*)
& KALLIOPI GAKI-PAPANASTASSIOU (*)

LATE QUATERNARY EVOLUTION OF THE LOWER REACHES OF ZILIANA STREAM IN SOUTH MT. OLYMPUS, GREECE

ABSTRACT: SKILODIMOU H.D., BATHRELLOS G.D., MAROUKIAN H. & GAKI-PAPANASTASSIOU K., *Late Quaternary evolution of the lower reaches of Ziliana stream in south Mt. Olympus, Greece.* (IT ISSN 0391-9838, 2014).

It is well accepted that active tectonics directly influences the evolution of hydrographic networks. This is the case of Mount Olympus where uplift and fault tectonism control the development of its major drainage networks.

This work examines the paleogeographic evolution of the lower reaches of Lazi Griva, Ziliana and Vathyrema streams flowing at the southwestern edge of the eastern piedmont of mountain Olympus in east Central Greece. For this purpose, detailed field work and large scale geomorphological analysis and mapping, were performed. A spatial database was created, and ArcGIS 10 software was used to process the collected data.

The Late Pleistocene - Holocene uplift of Mount Olympus has led to downcutting in the upper reaches of the three streams. The Lazi Griva stream formed the southern alluvial fan of the Olympus piedmont. The reactivation of a major normal fault zone running roughly N-S along the eastern front of Mount Olympus affected the flow direction of Lazi Griva stream at its exit from the mountain mass. The three streams join immediately after the fault zone and reach the sea as a single main channel of Ziliana. Six fluvial terraces were recognized, the oldest one at 224 to 260 m, followed by the others at 124-236 m, 104-134 m, 74-104 m, 16-104 m, and the youngest at 12-100 m.

Near the apex of the inactive alluvial fan a displacement of about 11 m was observed which indicates that the most recent reactivation of the eastern major fault of Mt. Olympus occurred in Holocene.

KEY WORDS: Drainage network, Alluvial fan, Terraces, Tectonic uplift, Mt. Olympus, Greece.

Περίληψη: SKILODIMOU H.D., BATHRELLOS G.D., MAROUKIAN H. & GAKI-PAPANASTASSIOU K., *Παλαιογεωγραφική εξέλιξη του κάτω ρου του χειμάρρου Ζηλιάνα κατά το Ανώτερο Τεταρτογενές στον νότιο Όλυμπο (Ελλάδα).* (IT ISSN 0391-9838, 2014).

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Είναι ευρέως αποδεκτό, ότι η ενεργός τεκτονική επηρεάζει άμεσα την εξέλιξη των υδρογραφικών δικτύων. Αυτό παρατηρείται και στο όρος Όλυμπος, όπου η ανύψωσή του και ο ρηξιγενής τεκτονισμός ελέγχουν την ανάπτυξη των κύριων υδρογραφικών δικτύων του.

Η παρούσα εργασία εξετάζει την παλαιογεωγραφική εξέλιξη του κάτω ρου των χειμάρρων Λαζί Γρίβα, Ζηλιάνα και Βαθύρεμα, που ρέουν στο νοτιοδυτικό άκρο των ανατολικών υπωρειών του όρους Όλυμπος, στο ανατολικό τμήμα της κεντρικής Ελλάδας. Για το σκοπό αυτό πραγματοποιήθηκε λεπτομερής εργασία υπαίθρου, γεωμορφολογική ανάλυση και χαρτογράφηση. Μία χωρική βάση δεδομένων δημιουργήθηκε και το λογισμικό ArcGIS 10 χρησιμοποιήθηκε για την επεξεργασία των συλλεχθέντων δεδομένων.

Η ανύψωση του όρους Όλυμπος από το Ανώτερο Πλειστόκαινο έως σήμερα έχει οδηγήσει στην κατά βάθος διάβρωση του άνω ρου των τριών χειμάρρων. Ο χείμαρρος Λαζί Γρίβα δημιούργησε αλλουβιακό ριπίδιο στις νοτιοανατολικές υπώρειες του Ολύμπου. Η επαναδραστηριοποίηση μίας κύριας ρηξιγενούς ζώνης, η οποία έχει διεύθυνση σχεδόν Β-Ν διατρέχοντας το ανατολικό μέτωπο του Ολύμπου, επηρέασε τη διεύθυνση ροής του Λαζί Γρίβα στην έξοδό του από τον ορεινό όγκο. Οι τρεις χείμαρροι συμβάλλουν ακριβώς μετά τη ρηξιγενή ζώνη και φτάνουν στην θάλασσα ακολουθώντας την κύρια κοίτη του χειμάρρου Ζηλιάνα. Έξι ποτάμια αναβαθμίδες αναγνωρίστηκαν, η παλαιότερη σε υψόμετρο 224-260μ., ακολουθούμενη από τις άλλες στα 124-236μ., 104-134μ., 74-104μ., 16-104μ. και η νεότερη στα 12-100μ.

Κοντά στην κορυφή του ανενεργού αλλουβιακού ριπίδιου παρατηρήθηκε μία μετατόπιση ύψους περίπου 11μ. Έτσι η πλέον πρόσφατη επαναδραστηριοποίηση του ανατολικού κύριου ρήγματος του όρους Όλυμπος τοποθετείται χρονικά στο Ολόκαινο.

Λέξεις κλειδιά: υδρογραφικό δίκτυο, αλλουβιακό ριπίδιο, αναβαθμίδες, τεκτονική ανύψωση, Όρος Όλυμπος, Ελλάδα.

INTRODUCTION

The Greek landscape has undergone significant morphological changes in the Quaternary. During this period active tectonics formed the Aegean Sea and caused considerable morphological changes in the area. Thus, the mountainous landscape of Greece reflects the recent tectonic and seismic activity of the broader area. Mount Olympus is lo-

cated in the eastern part of central Greece (fig. 1). It is the highest mountain of Greece (2,917m) and represents an uplifting mass of Mesozoic-Early Tertiary carbonate rocks.

The carbonates of Olympus massif are exposed in the form of a tectonic window, overthrust by sheets of the older granitic basement (Schermer & *alii*, 1990, 1993; Mountrakis, 2006). Uplift of the mountain massif was facilitated by Pliocene and Quaternary normal faulting. The front zone along the mountain's eastern flank consists of a main NNW-SSE trending normal fault zone and a series of subsidiary NW-SE normal faults (Nance, 1981; Smith & *alii*, 1997, 2006). According to Vergely & Mercier (1990) the opening of the Olympus tectonic window took place between Oligocene and Late Miocene. Faugeres (1975) proposed a nearly 2 km uplift and opening of the tectonic window in Pleistocene times, while Psilovikos (1981) assigned an uplift of 550-950 m during the Quaternary. Recently Nance (2010), has dealt with the eastern flank of Mount Olympus for the Late Pleistocene suggesting rates of uplift of 1.3 mm/yr in the last 210 Ka and 1.6 mm/yr in the last 125 Ka. Moreover, the geomorphological and biological evidence of a 60 cm seismic uplift along the Ossa-Mavrovouni-Pillion range, south of Olympus massif, at about 1,500 BP, suggests that this uplift is still continuing during the Holocene (Stiros & *alii*, 1994). Gaki-Papanastassiou (2010) notes for Agia-Agiokambos area, a minimum uplift rate of 0.3 mm/yr for the period starting from the Middle-Upper Pleistocene until today.

In tectonically active areas, the evolution of hydrographic networks is influenced by the interaction between the earth's surface and recent tectonic processes (Schumm, 1986; Burbank & Anderson, 2001; Firpo & Spagnolo, 2001). In Greece, several studies have reported the effect of active tectonism on the evolution of drainage networks (e.g. Bathrellos & *alii*, 2009a, 2009b, 2012, 2013; Gaki-Papanastassiou & *alii*, 2008; Kamberis & *alii*, 2012; Migiros & *alii*, 2011; Panagopoulos & *alii*, 2012; Papadopoulou & *alii*, 2013; Rozos & *alii*, 2011, 2013; Skilodimou & *alii*, 2003). This is the case of Mt. Olympus, where recent tectonism directly controls the development of its major drainage networks.

To examine this aspect, a drainage system debouching eastwards from the southern flank of Mount Olympus to the Aegean Sea was studied. For this purpose, detailed field work, large scale geomorphological analysis and mapping, were performed.

STUDY AREA

The study area is located at the southern end of the eastern piedmont of Olympus massif and includes the lower reaches of Lazi Griva, Ziliana and Vathyrema streams having a total drainage area of 141 km² (fig. 2).

The piedmont comprises three well formed east looking alluvial fans of Quaternary age with a thickness of 1,100 m that are inactive and eroding today. The southern alluvial fan (Lazi Griva) is located in the study area.

The geologic formations from Olympus Unit and Pelagonian zone participate in the geological structure of the study area. The Olympus Unit formations outcropping in the study area are Cretaceous grey, medium to thick-bedded crystalline limestones with dolomitic intercalations. The overthrust Pelagonian zone formations include an ophiolitic complex consisting of serpentinites (Migiros, 1983; IGME, 1985).

The Pleistocene alluvial fan deposits consist of cohesive calcareous conglomerates with elements of red beds (fig. 3).

Previous researchers (Faugères, 1977; Psilovikos, 1981, 1984) proposed that the sediments of Olympus alluvial fans, record the following sequence of events:

- (1) deposition of the oldest unit in an arid-semiarid climate with humid intervals during early Villafranchian to early Pleistocene time (total thickness > 600 m),
- (2) deposition of the intermediate unit under periglacial conditions during the early to middle Pleistocene (total thickness < 200 m), and
- (3) deposition of the youngest unit in a glacial period during the middle to late Pleistocene (total thickness 300 m).



FIG. 1 - Location map of the south Mount Olympus with the main channels of the hydrographic network of Ziliana river and elevations.

FIG. 2 - The drainage networks and their basins of the three important rivers along with the downstream location of the study area.

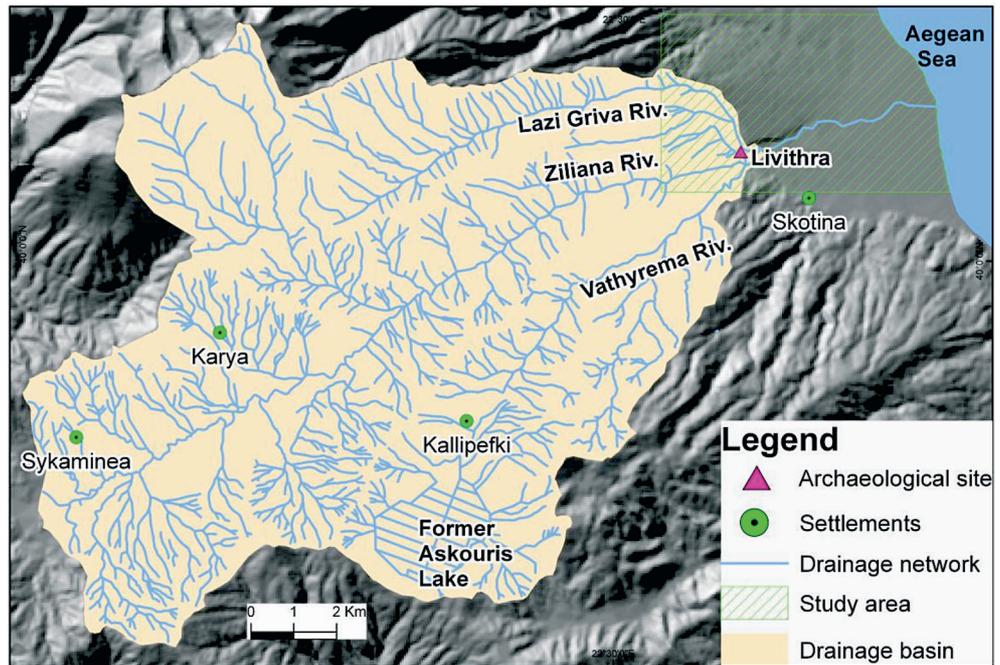


FIG. 3 - The Pleistocene alluvial fan of Lazi Griva stream extending W to E (left to right) from its apex towards the apron to the sea. In the middle foreground the 32 m erosional scarp of Lazi Griva alluvial fan is seen (fig. 5).

Smith & alii (1997, 2006) and Nance (2010) recorded on piedmont sediments east and west of Mount Olympus three discrete stages of deposition, each of which can be related to glacial activity on the mountain. They proposed that the oldest unit of sediments on the Olympus piedmont is predominantly glacial diamictons, with a minor proglacial component that corresponds to the Mindel glaciation (marine isotope stage (MIS) 8 at ca. 260,000 BP years). The intermediate unit on the piedmont is consid-

ered to have been deposited in a fluvial or glaciofluvial setting during the Riss (MIS 6) glaciation at ca. 160,000 years BP. The youngest unit is generally similar to the intermediate one and comprises glaciofluvial and alluvial fan deposits. This unit corresponds to the Würm (MIS 4-2) glaciation between 70,000 and 20,000 years B.P.

The Holocene deposits are composed of unconsolidated materials such as sandy clays, sands, gravels, pebbles of various sizes and coastal sediments.

At the confluence of Lazi Griva, Ziliana and Vathyrema streams, next to a fault on a terrace, there is the ancient settlement of Livithra. It flourished from 11th to 1st BC centuries and was thought to be the burial place of mythic musician Orpheus. It is also believed to have been destroyed by an earthquake and/or a heavy flood by Ziliana (ancient Syn) torrent (Poulaki-Pantermali and Klinaki, 2007).

MATERIALS AND METHODS

The following sources and data were used in the context of the current research:

- Topographic maps and diagrams of the Hellenic Military Geographical Service at scales of 1:50,000 and 1:5,000,
- The geological map of Greece at scales of 1:500,000 and 1:50,000, Sheet Kontariotissa-Litochoro, of the Institute of Geology and Mineral Exploration-IGME (IGME, 1985),
- Air photos at a scale 1:15,000 (1965),
- The detailed fieldwork of this study was carried out during 2011-2013.

A spatial database was created, and ArcGIS 10 software was used to process the collected data.

Geomorphological mapping was undertaken at a scale of 1: 5,000 in the lower reaches of Lazi Griva, Ziliana and Vathyrema streams. It involves the determination of elements such as streams, gorges, alluvial fans, abandoned river beds, knick points, and fluvial terraces. For the purpose of the present work, morphological profiles of the alluvial fan and terraces were produced.

GEOMORPHOLOGICAL ANALYSIS - DISCUSSION

The drainage basin of Lazi Griva, covers an area about 22.5 km², is elongated with a main WSW-ENE orientation reaching an elevation of 2,380 m at its western part. The length of its main stream channel is 11.8 km and has a SW-NE flow direction for 7.8 km and then follows a W-E direction for about 1.6 km. Its flow changes to NW-SE for about 2.4 km before reaching the confluence of Ziliana and Vathyrema streams. Its mountain exit is at 280 m.

The Ziliana hydrographic network drains an area of about 96.2 km², is elongated with a SW-NE orientation reaching an elevation of 2,690 m at its northern end. The main stream channel has a length of 18.1 km and follows a SW-NE flow direction, while its mountain exit is at 120 m.

The drainage basin of Vathyrema has an area of about 42.4 km², is elongated with a main SW-NE orientation reaching an elevation of 1,580 m at its western end. Its main stream has a length of about 8.5 km and it flows in a SW-NE direction. The exit of the stream from the mountain is at 120 m.

The three streams, immediately after their exit from the mountain, join and reach the sea as a single main channel of Ziliana. It has a total length of 4.6 km and follows an almost W-E flow direction.

Downcutting in the upper reaches of the three streams is particularly intense forming a 300 m deep steep-sided V-shaped valley. It is characterized by high sedimentation rates and occasional heavy floods in the lower reaches. The uplift of Mount Olympus has led to active downcutting in the upper reaches of the three streams and the different elevations at their exit from the mountain.

The most characteristic geomorphological feature of the lower reaches of Ziliana stream is the existence of the southern alluvial fan (area of 9.3 km²) of the Olympus piedmont reaching an elevation of 400m at its apex. The morphological profile of the alluvial fan is markedly concave (fig. 4).

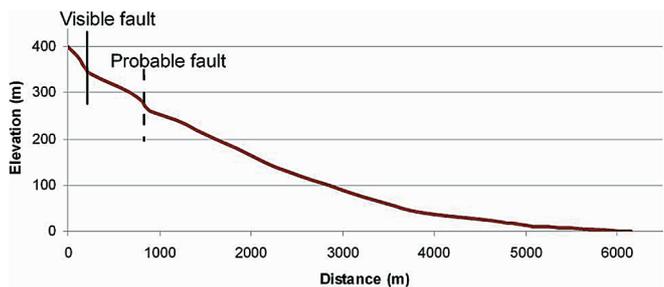


FIG. 4 - The morphological profile of the abandoned alluvial fan surface of Lazi Griva.

The sediments present three facies of deposition relating with the glacial periods of the Pleistocene. The alluvial fan was formed by the depositions of Lazi Griva stream (fig. 5). The existence of Askouris lake on the upper reaches of Vathyrema stream, which was drained in 1911 to create cultivable land, reduced its sediment discharge leading to the lack of alluvial fan on its lower reaches. Similarly, the terrestrial and lacustrine deposits in the upper reaches of Ziliana stream indicate the probable existence of a lake during Late Pleistocene. So, favorable conditions



FIG. 5 - Erosional scarp due to intense downcutting of the abandoned Pleistocene alluvial fan of Lazi Griva stream. The height of this section is about 32 m (Photo was taken from west to east).

did not exist for the formation of an alluvial fan. Consequently, from the three streams, only Lazi Griva had a continuous flow during Quaternary.

The former abandoned river bed of Lazi Griva stream was located on the alluvial fan surface reaching a height of 360m (fig. 6). The previous main channel of Lazi Griva

had a SW-NE flow direction and emptied into the sea. The presence of a major normal fault zone running NNW-SSE along the eastern front of Mount Olympus caused the change of the stream flow direction to the SE. The fault zone that has affected the fan deposits resulted in a Late Pleistocene - Holocene reactivation and displacement of

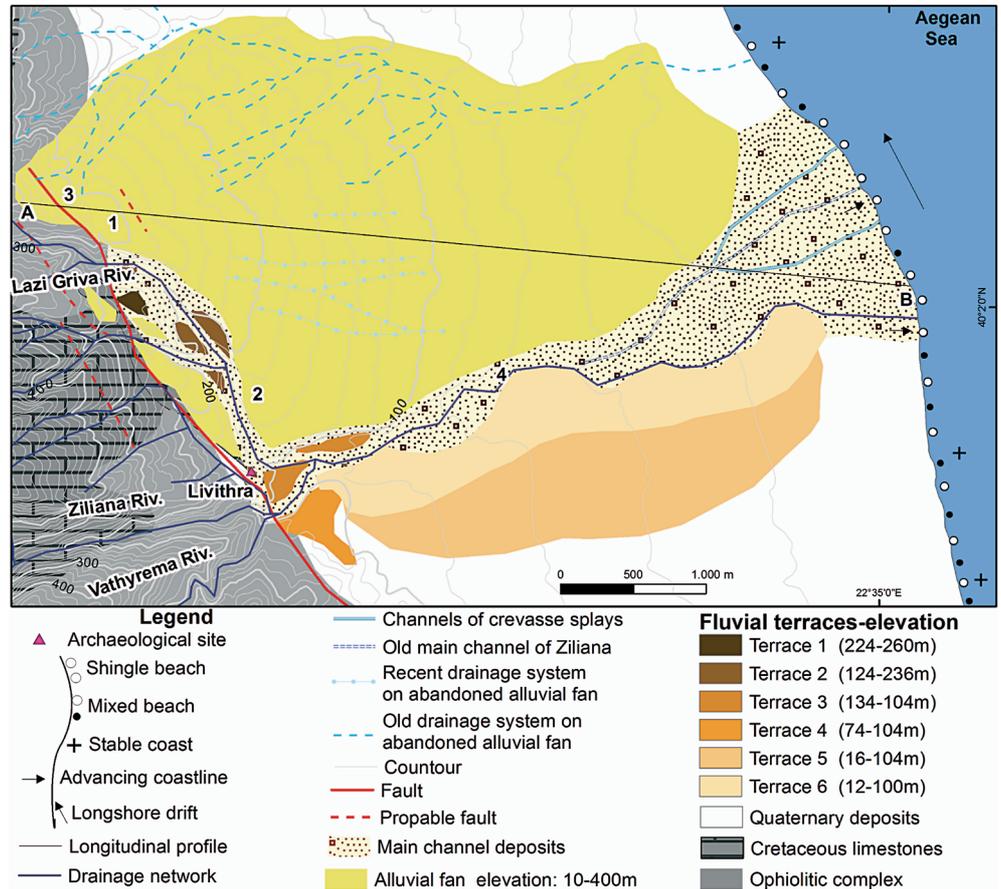


FIG. 6 - Simplified geomorphological map of the study area. Line AB and numbers 1-4 refer to morphological profile of alluvial fan and photos respectively, included in this study.

about 11 m (fig. 7). It seems to be ending a little after the confluence of Ziliana and Vathyrema streams. The reactivation of the fault has created a graded knickpoint which has moved upstream by about 160 m and today has formed a step-like channel for a distance of nearly 20 m. The distance of the knickpoint from the location of the fault implies the reactivation did not occur in the very recent past but several thousand years ago.

Several fluvial terraces have been identified in the eastern front of Mount Olympus (Psilovikos, 1981). In the study area six (6) Late Pleistocene-Holocene fluvial terraces were mapped (fig. 6). The highest and oldest one, Terrace 1, is found at elevations ranging from 224 to 260 m. The second (Terrace 2) is not continuous due to intense downcutting and located at elevations: 210-236 m, 180-208 m, 160-200 m, 146-176 and 124-136 m. These two fluvial terraces are composed from Lazi Griva stream deposits. The third (Terrace 3) and fourth (Terrace 4) have



FIG. 7 - The fault scarp created by the fault zone along the eastern flank of Mount Olympus running from left to right behind the trees, affecting the Pleistocene alluvial fan deposits.

been recorded at elevations between 104-134 m and 74-104 m, respectively. The third terrace has been deposited by Ziliana and Vathyrema streams while the fourth one seems to have formed by Ziliana and Lazi Griva streams. The fifth (Terrace 5) is developed at elevations of 16-104 m. The lower and younger one, Terrace 6 has been recognized at elevations of 12-100 m. Deposits of Lazi Griva, Ziliana and Vathyrema streams formed the last four fluvial terraces.

A remnant alluvial fan severed from the main body of the alluvial fan has formed at elevations of 146-300 m. The upper section (264-300 m) has been cut off by the major fault of Mount Olympus and is situated about 10 m higher than the old fan surface. The uplift of Olympus has resulted in the intense downcutting of the alluvial fan. The morphological profiles of the six terraces along with remnant alluvial fan are presented in fig. 8.

The ancient settlement of Livithra is located on Terrace 2 at an elevation of 126-134 m (fig. 6).

The main channel of Ziliana is braided with a maximum width of 114 m (Photo 4). The deposits of the Ziliana river bed are very coarse, clastic materials with various lithologic compositions. They consist of sands, gravels and boulders reaching diameters larger than 1 m (fig. 9).

Regarding the coastal landforms of the study area, an extensive beach has developed. It is composed of loose mixed phase materials and coarse grained at the mouth of Ziliana river. The coast is characterized as stable.

It seems that the actual fan apex of Lazi Griva stream is not at today's exit of the stream from the mountain, but at least 560 m to the northwest where the highest elevation (400 m) of the fan deposits are. This displacement of the main channel of Lazi Griva to the southeast is owed to the activation of the main fault along the eastern front of

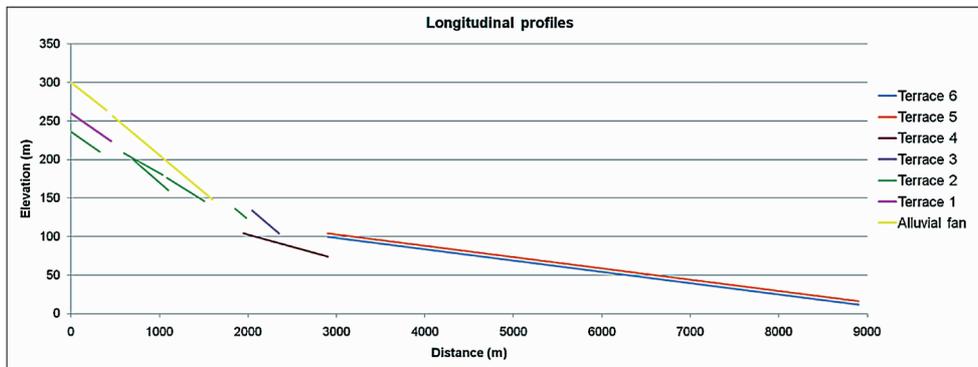


FIG. 8 - The morphological profiles of the six terraces and the remnant alluvial fan.



FIG. 9 - Braided main channel of Ziliana stream, downstream of the confluence of Lazi Griva, Ziliana and Vathyrema looking west towards mountain Olympus.

Mount Olympus. As previously mentioned this activation has also resulted to an elevation difference of a small part of the old alluvial fan near the mountain which was cut off from the main body of the fan. The severed part is located on the uplifting block of Mount Olympus and is found about 10-12 m higher than the surface of the alluvial fan.

Given that the uplift of Mt. Olympus is 1.6 m/k.y. for the Late Pleistocene - Holocene (Smith & alii, 1997) an average uplift of about 11m corresponds to 6,875 years happened during the Holocene.

CONCLUSIONS

The lower reaches of Lazi Griva, Ziliana and Vathyrema streams were affected by Quaternary active tectonism. The uplift of Mount Olympus has led to downcutting in the upper reaches of the three streams. The Lazi Griva stream formed the southern alluvial fan of the Olympus piedmont. The reactivation of a major normal fault zone running roughly N-S along the eastern front of Mount Olympus affected the flow direction of Lazi Griva stream at its exit from the mountain mass. The three streams join immediately after the fault zone and reach the sea as a single main channel of Ziliana. Six fluvial terraces were recognized, the oldest one at 224 to 260 m, followed by the others at 124-236 m, 104-134 m, 74-104 m, 16-104 m, and the youngest at 12-100 m.

The displacement of about 11m near the apex of the inactive Lazi Griva alluvial fan implies that the most recent reactivation of the eastern major fault of Mt. Olympus had a starting age of 6,875 years B.P.

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