Fluvial Terrace Evolution and Landscape Change; Potamia, Grevena Province, Northern Greece

Julianne M. Williams
Carleton College
Northfield, MN 55057

Introduction

The site of Potamia is located in a mid-catchment area. The Potamia Valley is drained by a small, effluent stream that is a tributary to the Haliakmon. Bedrock in the area is fine-grained Miocene sandstone with inter-bedded marls. In most places it is overlain by Vourinos-derived conglomerates that are Plio-Pleistocene in age.

The Potamia Valley contains Late-Pleistocene and Holocene fill-terraces and some cut-fill terraces. These terraces reflect changes that have occurred in the valley in recent geologic time. The main problem I address is the nature and chronology of terrace evolution in a small reach of the valley. The main method for reconstructing terrace development is sedimentary stratigraphic analysis of the sediments underlying the terraces. Although C^{14} dates are still outstanding, paleomagnetic data and development of modern soil profiles have allowed me to develop a tentative chronology. This information can then be compared to that from other catchments in the area, as well as climatological studies to determine the causes of changes.

Site and Terrace Description

My field area covers approximately $1km^2$. It is located in a transition zone where the physiography of the valley changes significantly. In the upstream section of my field area, the modern stream flows virtually north-south and is confined to narrow valley, with a flood plain approximately thirteen meters wide. (see Figure 1) Downstream, the stream converges with another from the south, and they are both re-directed west. At this point, the valley changes from a closed gorge to a broader plain.

The Potamia stream is currently incised approximately sixty meters below the level of the upland landscape. On the eastern side of the valley, an erosive scarp separates this surface from the terrace plain below it. A number of landslides have originated from this scarp, some of which have extended as far as the current stream valley. Of particular interest, is a large landslide dividing my study area from fellow Keck participant Bob Wilson's. In Bob's area, upstream of the landslide, the stream runs NE-SW, the terraces are narrow, and the topography is steep. Colluvial fill is a significant stratigraphic component of the terrace sequences in his area.

Along my reach of the stream, stratigraphy is predominantly alluvial, with a distinct absence of colluvial input. Here, the topography below the scarp is more gradual, the main feature being an extensive terrace of approximately one-hundred meters width. This is the highest described terrace on the eastern side, and stands nine to fourteen meters above the modern stream channel. Approximately five meters below this terrace, slope wash and slump blocks create a somewhat level surface. From there, the valley steeply slopes to a small terrace 0.6 meters above the stream. (see Figure 1)

On the west side, the highest observed terrace detailed is six meters above stream level. The work conducted by Julia Daly, Katie Donelly and Mary Greene was conducted on slopes above this surface. One and a half meters below this terrace is an intermediate terrace that is about six meters wide, and bisected by a large gully. From this level, a concave slope grades into a small terrace 0.4 meters above the stream. (see Figure 1)

Stratigraphy

I studied the stratigraphy below the main terrace on the east side and the intermediate terrace on the west side. These two terraces were chosen due to exceptional exposure, on the east side by stream incision (and subsequent slumping), and on the west side by gullying.

Stratigraphic analysis reveals that the two terraces were deposited at different times, under distinct fluvial regimes. The stratigraphic sections differ in 1) grain size, shape, and composition, and 2) anthropogenic material.

The stratigraphy of the eastern terrace is primarily fine-grained, containing some gravel deposits. The fine-grained alluvium is well sorted, very fine sand and silt. The gravel deposits show a range from large, laterally extensive boulder deposits to lenticular deposits of imbricated gravels, and isolated pebble lenses. All of the gravels are rounded, and most are bladed to oblate. Their composition is predominantly limestone and igneous lithologies, with some quartz. Overall, fine-grained alluvium dominates the section, comprising 75% of the observed alluvium (by thickness).

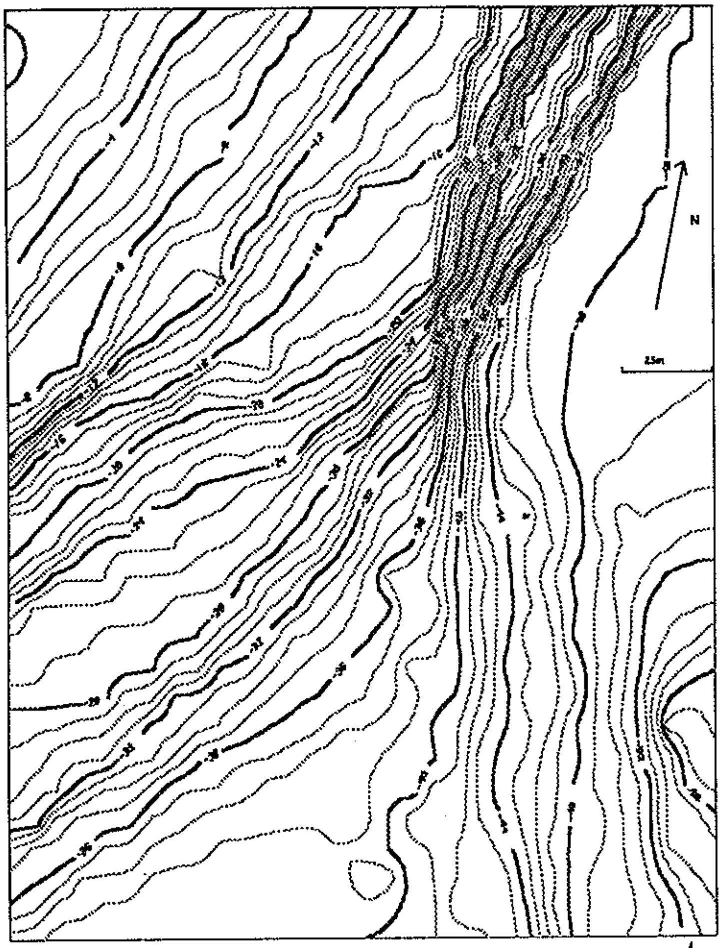

Figure 4. Topographic map of the present day Potamia site.

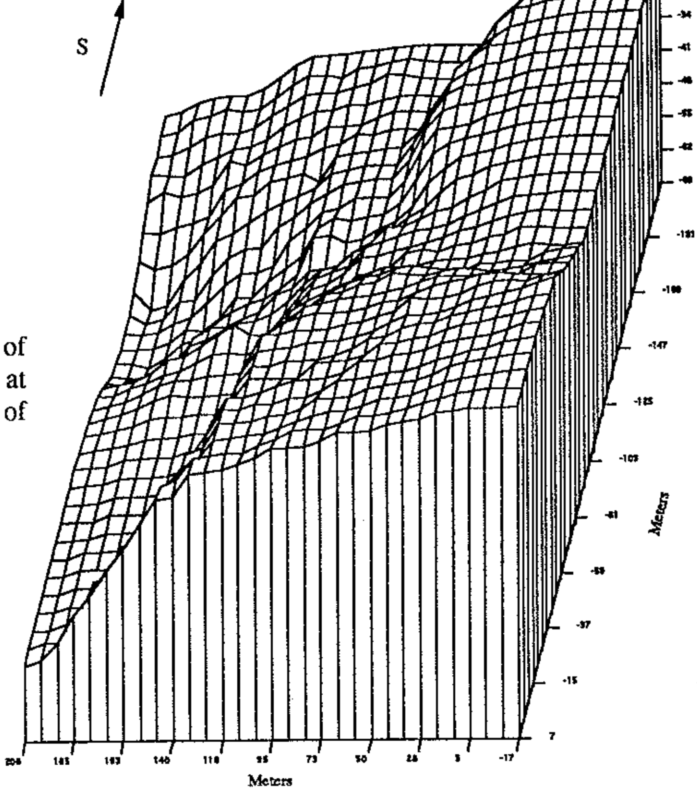

Figure 5. Three-dimensional representation of one possible restoration of the landscape at Potamia created by adding equal amounts of material to all points in the source area.

The alluvium on the eastern side overlies a highly irregular Miocene bedrock surface observed in one outcrop. No bedrock was observed on the western side of the stream valley. The Miocene bedrock has a highly irregular erosion surface, both on the small and large scale. The only observed exposure of bedrock was on the Eastern side of the valley under the highest terrace, in the narrow reaches of the gorge. At this site, the bedrock varied in height by approximately 2-3 meters within a ten meter section. The fact that the bedrock did not outcrop anywhere else reveals that the depth of the bedrock beneath the alluviation surface also is extremely variable on the larger scale.

The West-side stratigraphy is coarser-grained. The majority of the section is composed of coarse-grained gravel deposits. Unlike the east side, individual gravels are often sub-rounded to subangular, with the largest particles being nearly flat. Large (maximum 20x7x4cm), rectangular pieces of sandstone were present. Anthropogenic material, such as small pieces of mud brick and pottery were present below 160 centimeters.

These differences in grain size, shape, and composition, as well as the presence of anthropogenic material in the western terrace and not in the east, points toward distinct events of stratigraphic aggradation.

Soils

Soil profiles were conducted for the modern soils on the highest terraces on either side of the valley, and for buried soils within each profile. The soils confirm different developmental histories and chronologies for the two terraces.

First of all, the modern soils is less developed on the western terrace in comparison to that of the eastern terrace, as calculated by the mean Profile Development Index (PDI) (this is the PDI divided by total profile depth; Harden, 1982 and Birkeland, 1991). Using parameters of color paling, rubification, carbonate development, structure, and texture, the mean PDI is 0.19 for the western terrace and 0.25 for the soil on the eastern terrace. This suggests that the soil on the eastern terrace is older than that of the western terrace.

Additionally, paleosols beneath the two terraces do not correlate. Near the top of the section on the eastern side, there were two weakly developed paleosols, one at 42cm and the other at 85cm.

In contrast, the western side there were at least three buried soils, which appear to be more developed than those on the eastern side. These paleosols were thick, and high in clay content.

Aggradation, Degradation, and Terrace Development Through Time

Depth to Miocene bedrock varies extensively laterally in the study area. In the surrounding uplands, the bedrock is composed of Plio-Pleistocene alluvial deposits. These deposits create a plain that is coincident in elevation (600m) with the Mersina surface, explained by Doyle as an aggradational level covering and areal extent of 200+km^2 throughout the central Nomos. (Doyle, 1990) The Plio-Pleistocene material rests unconformably on the Miocene bedrock, indicative of an extensive period of erosion and a change in the tectonic regime from Miocene to Pliocene deposition.

The deposition of Plio-Pleistocene conglomerates was followed by a period of incision. This incision extended either to the broad terrace level tens of meters below it, or incised all the way to the Miocene bedrock surface.

First Alluviation

The eastern terrace may be a strath terrace cut across the same Plio-Pleistocene material as is found beneath the Mersina surface. Another possibility is that it is a fill terrace composed of re-mobilized Plio-Pleistocene material. Whichever is the case, the deposit indicates an extensive period of aggradation. The alluvium rests on the highly irregular Miocene surface unconformably. As indicated by the extent of the terrace surface, alluviation occurred across a significant area.

The described sequence on the eastern side consists of alternating gravel and fine-grained alluvial deposits. It is interpreted as channel deposits juxtaposed with suspended load deposition. The lack of medium-sized grains, such as sand, may be explained by 1) a lack of sand in the source material (as would be the case if the alluvium was composed of re-mobilized Plio-Pleistocene conglomerates), or 2) a factor dependent on high discharge variation (in which channeled water was initially competent enough to carry sand further down drainage, but then was significantly reduced, dropping its suspended load. A similar sequence of fines and gravels is described by William and Rust as a braided stream facies, and by Boothroyd and Ashley as a distal alluvial fan facies. Therefore, these sediments were probably deposited on a distal alluvial fan in which the predominant mechanism of transport was braided streams.

The aggradation was interrupted at least twice by brief periods of relative stability in which weakly developed soils formed. Stream incision followed this extensive aggradational period to at least the current floodplain level. Incision may have found the path of least resistance in a structural weakness in the Miocene bedrock. This incision led to the abandonment of the former flood plain, creating the broad eastern terrace.

The east side terrace is tentatively dated as Late Pleistocene. Surely it predates human occupation, since archaeological remnants are found only on its surface. The clasts of limestone and igneous lithologies are derived from the Vourinos mountain range. Due to the distance of transport, these lithologies suggest deposition in a tectonic regime different from the present. Paleomagnetic analysis indicates that the fine-grained sediments are normally magnetized, and therefore likely deposited within the last 730,000 years. A C^{14} date from the same stratigraphic level as the paleomagnetic sample will further constrain the time of deposition.

The maximum carbonate development stage for the modern soil of the eastern terrace is II+ (after Birkeland, 1991). If this is compared to soil chronosequences developed for similar climatic conditions in the Southwestern United States, the terrace surfaces may date to 15,000-25,000 BP. (Machette, 1985)

A Late Pleistocene-Early Holocene date for this terrace would make it coincident with the Syndendron Terraces of a nearby catchment, as described by Richard Doyle. (1990) According to Doyle, stream aggradation occurred in many areas throughout the world at this time, and had a climatic control. Change from a cold-dry glacial climate (14,000-10,000BP) to a warm-wetter post glacial one (Early Holocene), created erosion in the uplands and deposition in the valleys as precipitation increased before vegetation could compensate and stabilize the landscape.

Second Alluviation

A second major alluvial fill is represented by Holocene fill terraces on the West side. The coarse-grained deposits are interpreted as bar and channel deposits. It may represent an alluvial fan facies proximal to the region of uplift. (Boothroyd and Ashley, 1975) This would indicate fan progradation between the time of the first and second alluviations.

Anthropogenic material at the base of the section confirms that aggradation was coincident with, or followed human occupation. This would place a maximum age of alluviation at around 8,000 BP. At the base of the west terrace, there are at least two buried soils that are high in clay content, with moderately developed soil structure. These paleosols indicate that the alluviation period was not continuous, but occurred in intervals. This alluviation may correlate with the fill beneath the Sirini set terraces described by Doyle (1990).

Modern soil development reveals a maximum carbonate development stage of I+ for the western terrace, which may date the surface to <8,000 BP. (Machette, 1985)

Recent Fluvial History

Following this second major alluviation, the stream once again incised to the current stream level. During incision, the stream likely migrated eastward, temporarily stabilizing to create the cut-fill terrace that is the intermediate terrace on the west side.

Today, the stream continues to incise. However, the <1m high terraces on either side of the modern stream probably represent very recent aggradation. Episodic sediment overload created by upland landslides and erosion may be the cause of this seeming contradiction.

Conclusions

The Potamia Valley contains significant evidence of the landscape changes that have occurred. This history can be read in the terraces that have recorded the changes in their stratigraphy, soils, and anthropogenic remnants. Chronology of landscape changes can be constrained by paleomagnetic studies and soil development indices.
The depositional/erosional regime in the valley has significantly changed since the Late Pleistocene. The predominant mechanism for landscape evolution has been valley incision, as evidenced by the current stream level over sixty meters below the Mersina surface. This general trend of incision has been interrupted by at least two major aggradation periods, one of which formed the extensive alluvial fill on the eastern side of the valley. This aggradation probably occurred in a distal alluvial fan environment during the Late Pleistocene. A later alluviation (Holocene) of a proximal fan facies created the fill beneath the terraces on the west side. The change in facies may indicate progradation of the alluvial fan.

Preliminary analysis reveals that these terraces may show some correlation to those found in other catchments. Changes in the valley were likely climtically induced in the Late Pleistocene, and may have been affected by humans in the Holocene.

Further study will focus on constraining the chronology of terrace evolution by C^{14} analysis and more detailed soils interpretation.

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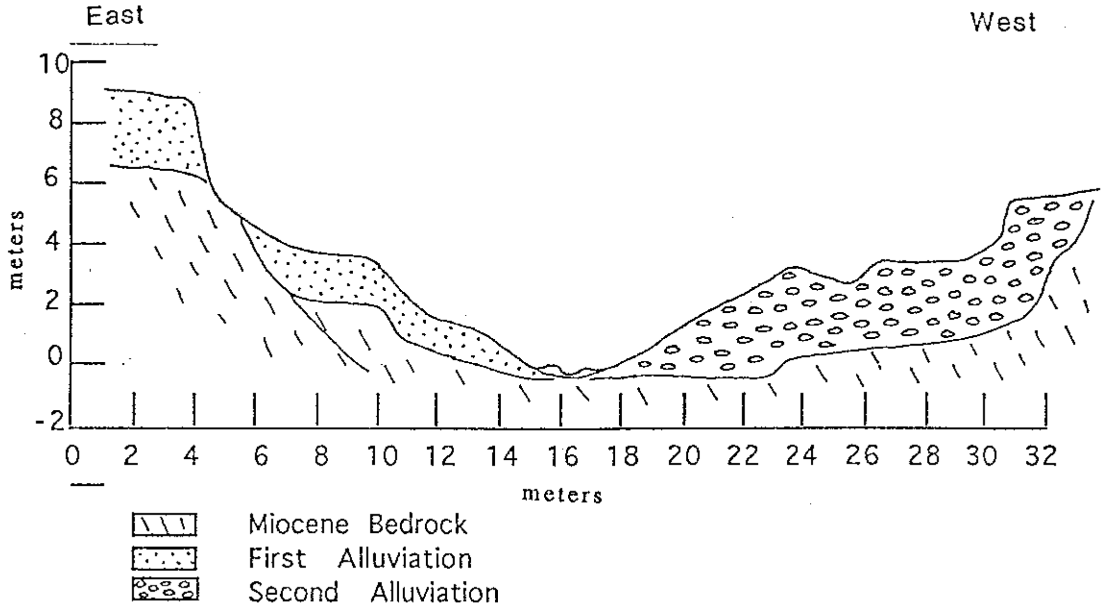
Figure 1. Cross Section of Valley
(Surface Levels Actual, Below Surface Hypothetical)



Soil Development and Stream Terrace Genesis in the Potamia Stream Valley, Grevena, Greece

Robert Wilson
The Colorado College
Department of Geology
Colorado Springs, CO 80903

Introduction

The Potamia stream valley runs NE to SW and is located near the Vourinos Mountains in eastern Grevena. Many of the streams in the nomos are incised into the underlying bedrock, which is Plio-Pleistocene conglomerates in this section of the nomos. Periods of aggradation and deposition have also occurred in the nomos during the Holocene. The result of these processes has been the formation of fill terraces throughout valleys such as the Potamia. In my project area, there are three unpaired fill terraces on the western side of the valley. The terraces contain ancient soils (paleosols) as well as modern ones. An archaeological site of Hellenistic and Roman age lies on the hill above the three terraces, and pottery sherds are present in the highest of the three terraces.

Bull (1990) and Knuepfer (1988) have successfully used stream terrace soils to aid in dating times of stream incision. The amount of pedogenic clay and $CaCO_3$ accumulated in the B horizons tend to increase through time. The aim of this project is to use properties like these, and soil development in general , as tools to date stream incision and terrace formation within the Potamia valley. In addition, this project should aid archaeologists trying to determine if colluvial and alluvial events during the Holocene occurred simultaneously with settlement in the region.

Field and Laboratory Methods

Field work entailed completing soil descriptions for both modern soils and paleosols, as well as noting the stratigraphic relationship of soils to alluvial and colluvial fills. Soil properties were recorded using soil description cars designed by the New Zealand Division of Land Resources. The properties recorded are similar to the ones suggested by the United States Soil Conservation Service and Birkeland (1984). Soil horizons were identified, field textures noted, and samples collected for further study in the United States. One charcoal sample was removed from a paleosol on the eastern side of the valley, but a radiocarbon date was unavailable at the time of this writing.

Laboratory work was conducted to supplement data obtained in the field. The percentage $CaCO_3$ was determined for each soil horizon using a Chittick device. The parent material for all modern soil is carbonate rich, so $CaCO_3$ amounts reflect both pedogenic accumulations and the $CaCO_3$ that was already present at the time of deposition. Particle size distribution was also determined for each soil horizon. Most A horizons were treated with hydrogen peroxide to remove organic matter and a deflocculent (sodium hexametaphosphate) was added to all samples. Every sample was then sieved to remove sands and the silt/clay fraction was allowed to settle in a column of distilled water. Pipetting was done at specified intervals to obtain draws of the silt and clay. Numerous problems were encountered using this method of analysis and are discussed in the Results section of this paper.

The stream terraces were noticeably lacking in organic materials suitable for radiocarbon dating, so the Harden profile index and maximum profile index was used to evaluate the relative ages of the terraces (Harden, 1982; Harden and Taylor, 1983). The indices provided a means of quantifying soil properties and proved to be very useful in my attempt to understand the formation of the terraces. An accurate measure of the true thickness of most of the paleosols was impossible to obtain, either due to erosion of the A horizon, inadequate outcrop exposure, or both. Therefore, paleosols were compared to modern soils using the maximum horizon index instead of the Harden profile index. Using this method enabled me to compare soils on the basis of horizon, not profile, properties.

Results

The three terraces in the study area display a complex arrangement of colluvial deposits, alluvial deposits, modern soils, and paleosols. The paleosols are particularly significant because they represent a time of stability in the landscape (soils tend not to form if their parent material is being intensely eroded or covered with new sediment). The middle terrace in the sequence contains two well-developed paleosols beneath a thick colluvial deposit. One of the buried soils, referred to as the dark-gray paleosol (profile 1) has peds 3-4cm in diameter and slickenslides on the ped faces, a sign of movement within the soil profile due to shrinking or swelling of clays. $CaCO_3$ covers most ped faces and carbonate nodules are present in the lower 30cm of the profile. This paleosol is cut by lenticular deposits of alluvium, indicating stream channel incision in this buried soil. A later soil with firm, subangular blocky peds has formed on this deposit of alluvium and $CaCO_3$ coats the surface of the peds, but carbonate nodules are absent.