

Holocene alluvium around Lefkosia (Nicosia), Cyprus: an archive of land-use, tectonic processes, and climate change

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Abstract

Excavations for modern, urban construction in the greater Lefkosia (Nicosia) area of Cyprus expose three to ten meter thick Holocene alluvium of the Pedhieos River. The Pedhieos River originates in the Trodoos Mountains, flows north to the Mesaoria Valley, then eastward to the Mediterranean. Alluvial stratigraphy presents serial flood deposits underlying river terraces and an extensive alluvial fan. Individual flood deposits include fining-upward sequences of gravel, sand, and silt. Thick, silty, fine-sand, over-bank sequences are overprinted by textural soil profiles and incipient caliche representing periods of sub-aerial, non-deposition. Artifacts from a long history of human occupation occur with ¹⁴C dates from charcoal and other organic remains that indicate the Holocene alluvial sequence has been accumulating for at least 8,000 years.

The stratigraphy and geomorphology of the alluvium can be interpreted to distinguish not only the effects of climate change, but also land-use change, and the impact of particular engineering works. Following thousands of years of floods on the aggraded Pedhieos River flood plain, the Venetians rebuilt the city of Lefkosia (Nicosia) in the mid-sixteenth century. The Pedhieos River was re-directed into a shorter, steeper channel, initiating vigorous arroyo cutting and downstream aggradation of lithically distinctive alluvium. The redistributed alluvium caused local channel migration and eventual disuse of a Roman-style bridge. In response to the upstream arroyo cutting, a new Gothic-style bridge was constructed by the Venetians; it remained in service until late in the twentieth century. This fluvial signature of a unique event is an analog for the effect of surface cutting faults that are part of the seismic risk for the Lefkosia (Nicosia) area.

Keywords: Holocene stratigraphy, alluvium, paleosol, flood plain, alluvial fan, flood history, anthropogenic activity, Cyprus.



1 Introduction

During the period 2000 to 2003 we were involved in a geologic mapping study of the neotectonics and seismic risk assessment around Lefkosia (Nicosia), Cyprus. Working with government geologists from the Greek and Turkish Cypriot communities, we produced companion bedrock and surficial geologic maps (Harrison et al. [1], Newell et al. [2]) that describe the structural and stratigraphic framework and the geomorphology and surficial deposits; much information is included on the history of surface cutting faults, changing climates, and the impact of human occupation from numerous cultures. This report is developed from data collected and analyzed during our mapping of Holocene alluvium. Studies of surficial deposits always depend on ephemeral exposures and more are always to be desired. Although our field work was brief and intense, ongoing urban expansion permitted us to compile a surprisingly comprehensive, well-calibrated stratigraphy.

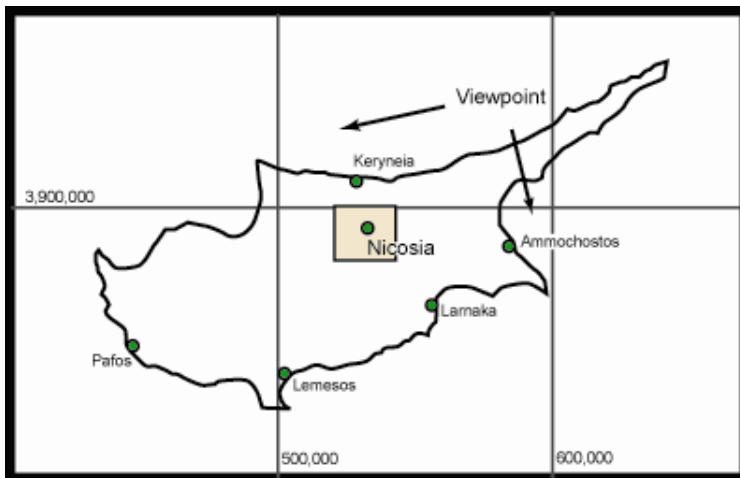


Figure 1: Index map of the greater Nicosia map area (Harrison et al. [1], Newell et al. [2]) on the island of Cyprus. “Viewpoint” indicates perspective for Figure 2.

2 Geographic setting and geologic framework

Lefkosia (Nicosia) is sited at the head of an alluvial fan complex deposited by the Pedhios River. The Pedhios River drains north from the central Troodos Mountains to the east-west trending Mesaoria Plain that separates the north coastal Kyrenia Mountains from the Troodos Mountains. The intervening lowlands are underlain by Pliocene marine marls. Sediments shed from the rising mountains produced Plio-Pleistocene deltas and alluvial fans into and across the marine deposits. Subsequently, the Pedhios and other rivers incised these

deposits, producing terrace sequences and alluvial fans across the lower slopes of the Mesaoria valley. Faulting and climate change events are recorded in the fluvial deposits.

3 Geomorphology

The headwaters of the Pedhios River are short, narrow, and steep. The upper watershed in the regolith landscape of the Troodos Mountains ophiolite sequence (diabase, gabbro, see, Malpas, et al. [3]) is about 10 km long by 5 km wide; the channel way has an average slope for much of its upper reaches of about 9 degrees. Where the river cuts across the upper Mesozoic and Cenozoic formations, its gradient flattens, and the flood plain aggrades with many anastomosing channels. The narrow headwaters, the middle reaches, and the broad but linear valley occupied by F1 and F2 deposits (Figure 2) are bounded and underlain by a system of NE to SW transform faults (Harrison, et al. [1]).

Topographic details of the Pedhios River alluvial fan (F2) reveal many channels and flood plains diverted around faulted bedrock remnants of the Nicosia (Pliocene) Formation. The last alluvial fan deposits of map unit F3 are juxtaposed against the easternmost bedrock buttress of Nicosia Formation. Tilting from west to east is implied.

The oldest ¹⁴C age on charcoal (8230±60ybp) from the basal Jinar River gravel (a tributary from the west, see Figure 2,6) is consistent with common speculation that across Cyprus the upland source areas were stripped of forests for charcoal used in smelting copper beginning in the bronze age (Knapp [4]). Rapid denudation of hill and mountain slope soils provided the thick 2-10 m blanket of fine-grained alluvial mud that accumulated on the Mesaoria Plain from the Pedhios River for the succeeding 7,000+ years. Arroyo cut and fill cycles probably prevailed from place to place, initiated by climate change, change in forest cover, and stimulated locally by surface cutting faults that created steep gradients and initiated cycles of arroyo cutting and downstream alluviation.

4 Surficial deposits and stratigraphy

The oblique shaded relief view of figure 2 is developed from the Surficial Geologic Map of the Nicosia area (Newell et al. [2]). The map units of Figure 2 include: F1, Cemented alluvium under high terraces; F2, Un-cemented alluvium under low terraces and alluvial fan; F3, Alluvium of abandoned channel and alluvial fan; Fm, Modern alluvium; af, Artificial Fill: (includes NW, Nicosia wall, and Mf, moat fill). (Bridge icons show Venetian bridge to west and Roman style bridge downstream to east.). Surficial deposits shown by the map units include a sequence of ancient to modern alluvium and areas of extensive artificial fill. Alluvial channel, floodplain, and alluvial fan deposits include sand and gravel, sandy, silty mud, and cobbles and boulders. Old units are oxidized red to orange and are extensively cemented at the surface by caliche. Younger deposits are olive gray to brown or yellowish brown and include caliche horizons



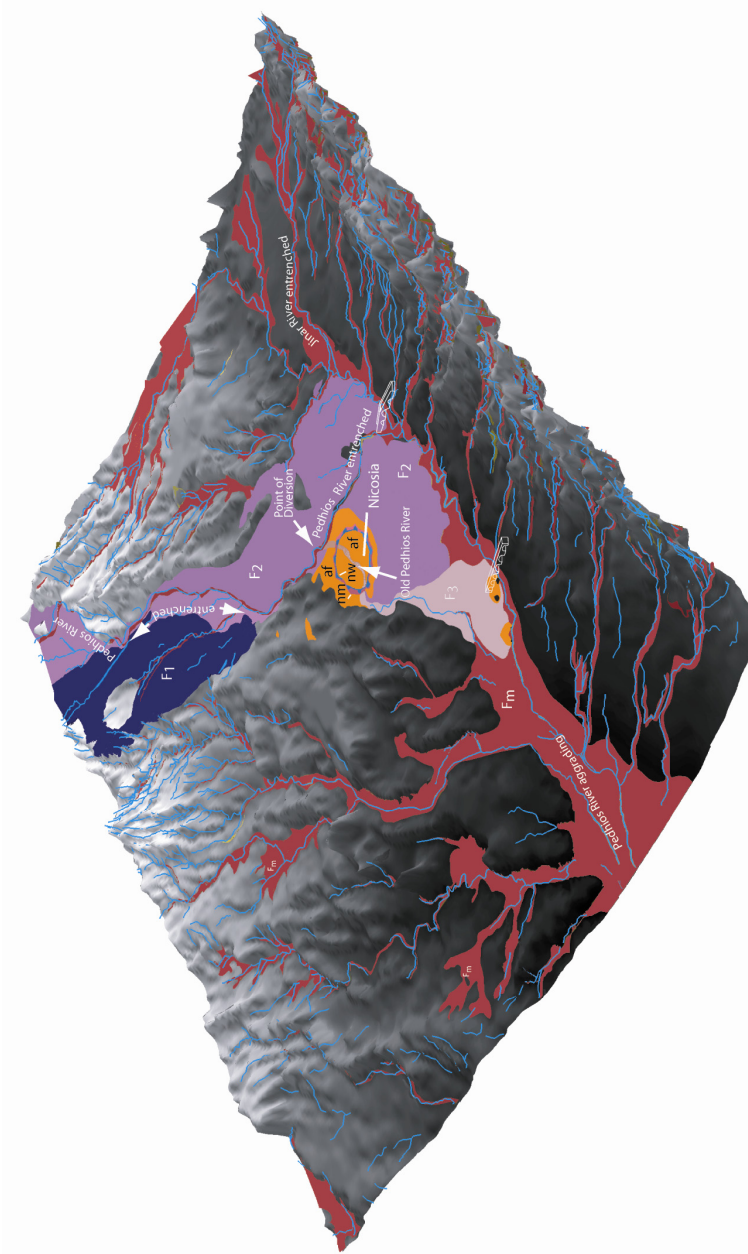


Figure 2: Southwest oblique map view. Area is 10 x 12 km.



that indicate soil-forming periods. The alluvium is commonly 1 to 4 meters thick and reaches 10 meters on the alluvial fans. Artificial fill includes unsorted debris of variable size and compaction. The artificial fill defines the footprint of the pre-Venetian city of Nicosia. The “nw (the wall)” unit defines the footprint of the walled city later built by the Venetians.

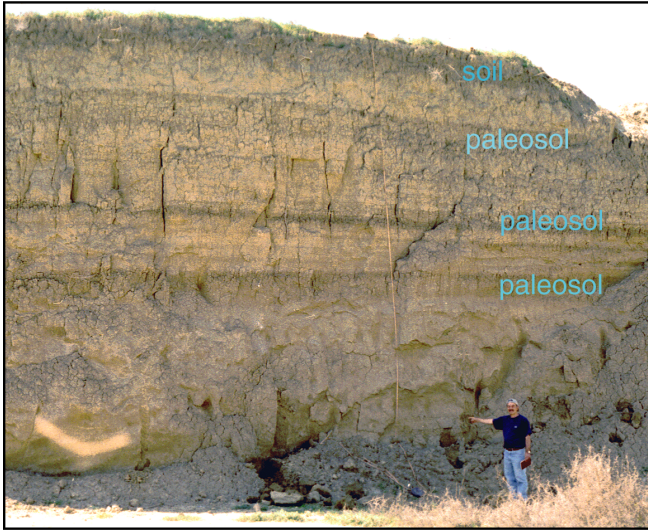


Figure 3: Photo of multiple paleosols exposed in the high wall of the Hespoldt brick pits.

Figures 3, 4, 5 and 6 show vertical assemblages of flood sequences from a variety of locations around the flood plains and alluvial fans of the Pedhios and Jinar Rivers. Each sequence is defined by fining upwards flood deposits capped by a paleosol that represents a long hiatus of exposure between depositional events. Textures, thickness, and the number of sequences within each exposure are spatially and temporally variable. Although every exposure shows multiple flood sequences and paleosols, it is unlikely that any one of these deposits is broadly distributed. Although ^{14}C dates of charcoal have provided good upper and lower control of the Holocene alluvial package, there are not enough dates to correlate sequences from place to place. Nevertheless, some interpretation of the rates of aggradation and soil forming processes can be made. At the site of the buried oven (Figure 5), aggradation ceased after the Pedhios River entrenched its channel below the surface of the floodplain/alluvial fan. The oven site accumulated 2m of mud between 1220AD, date of the oven, and 1567AD, the time of Venetian channel diversion. Subsequently, the site has been exposed for more than 400 years. Soil with caliche (10 to 20 cm thick) is common under the surface of map unit F2 that also contains the oven. The soil-forming period of each buried paleosol 10 to 20+ cm thick may represent 0.5 to 1.0 millennia

in duration. This is consistent with the interpreted age from land snails at the Hespoldt Brick pit (Figure 4). The age date at 3.5m depth is 6,135 (+/- 35) years BP. If 3,000 years are discounted because today's land snails date at 3,000 years, the remaining time interval of 3,500 years is congruent with three cycles of deposition and interposed soil forming intervals of roughly 1,000 years each. Two of the soil intervals are up to .5 m thick and may represent most of the 1,000 years of a flood sequence/soil forming period; 0.5 to 1m of fluvial deposits on the distal margin of an alluvial fan can be accumulated in as little as a few years to tens of years. The time and space scales are appropriate. Without wide spread chronological markers, the variability in sequences from place to place must be explained by random events in time and space. Compatible with this assumption is the probability that much of the alluvial material and caliche deposits is recycled from place to place within the fluvial system.

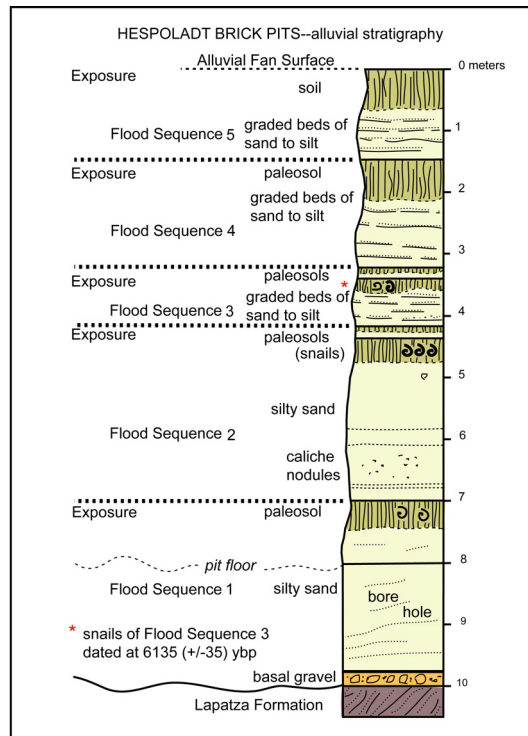


Figure 4: Measured section of ten meters of alluvial fan stratigraphy in the high wall of the Hespoldt brick pits. Note that land snails of flood sequence 3 have been dated (^{14}C) at 6135 +/- 35 ybp. This date may be as much as 3,000 years too old because modern land snails collected nearby in 2002 AD yielded a ^{14}C age of 2975 +/- 35 ybp. (Lapatz Formation at base is Miocene gypsum evaporite deposit.)

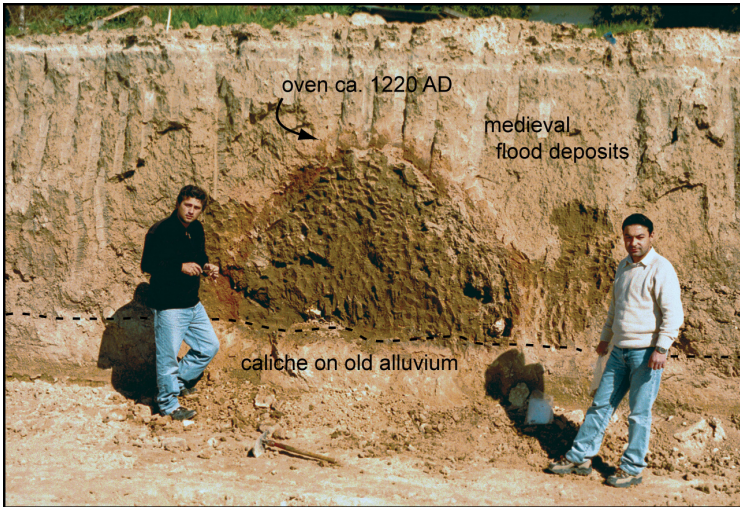


Figure 5: North wall of foundation excavation near Ayios Nicolas west of Engomi reveals an oven of burned mud approximately 2m in basal diameter. The oven has been buried by more than 2m of flood plain deposits. Sediments inside oven preserve terra cotta pottery fragments, bones and teeth of sheep or goats, and charcoal that has been dated at 1220 AD +/- 35years. Widespread aggradation of the flood plain and alluvial fan surface of map unit F2 has not occurred since the diversion of the Pedieos River.

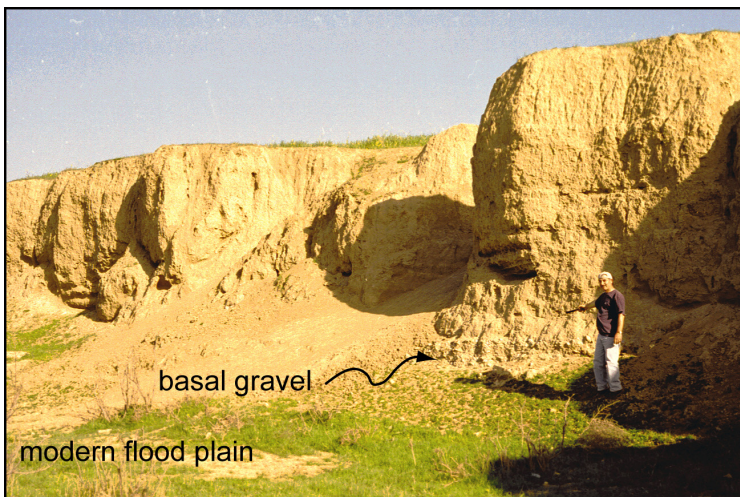


Figure 6: Typical fluvial sequence of the Jinar River with numerous flood sequences and soil forming intervals similar to the Pedhieos River deposits. Basal gravels yielded primitive pottery shards and charcoal that was dated by ^{14}C at 8230 +/-60ybp.

The floodplain/alluvial fan deposits that underlie map unit F1 are distinguished from deposits of map units F2 and F3 by red-orange oxidized colors of the matrix, some weathered rinds on mafic clasts, and by extensive durable caliche at the surface. Excavations that expose the base of the F2 flood sequences commonly show similar, coarse, oxidized and cemented gravel and cobble to boulder gravel that is probably the stratigraphic equivalent of the exposed F1 deposits. Compared to the gray brown to light yellowish gray colors of the un-oxidized, un-cemented Holocene muds of F2 and F3, these deposits have been exposed for much longer periods, back into the Pleistocene. Perhaps they are as old as the last interglacial warm period (Sangamon/Stage 5E)

5 History

Arroyo cutting following a long history of aggradation was triggered in about 1567 AD by Venetian engineers who rebuilt Nicosia as a walled city with a moat and a smaller footprint on top of the preceding city built by the Lausinian French. The Pedhios River was diverted from the center of the old city back into a north directed arroyo within the alluvial fan deposits (F2) graded to the Jinar/Almyros River system. As a result, active erosion and deposition on the alluvial fan deposits of map unit F3 ceased. More importantly, the new reach of the Pedhios River had a steeper gradient. This resulted in rapid arroyo cutting and the headward migration of a nick point up stream. The upstream limit of the nick point has presently migrated 10 km. Above the nick point, the Pedhios River is aggrading. Down stream, the river bed is entrenched three to five meters below the F2 surface. Over-the-bank flood plain deposits on the F2 floodplain/alluvial fan surface apparently have not occurred for more than four centuries.

Down stream from the point of diversion at old Nicosia, the full discharge of the Pedhios River carried floodwater and the huge volume of sediment from the entrenching river down the valley of the former Jinar/Almyros River. As a result, the modern river is entrenched below the old Jinar/Almyros River flood plain. The river has built a new flood plain and channel of distinctive, ophiolite rich sediments from the Troodos Mountains inset within and below the old quartz and carbonate rich sediments from flysch and limestones of the Kyrenia Range to the north.

Near Hespoldat the post diversion alluvium aggraded across the old Jinar/Almyros River valley. At the site of a Roman-style arch bridge (Figures 2, 8), the old channels under the bridge were filled with sediment and the new Pedhios River cut around the bridge abutment on the north side, eroding older deposits and bedrock along the bank of the channel. Some of the remnant details of the bridge architecture suggest that remedial construction of one arched span on the north end was attempted but eventually, it too was lost as the River continued to erode and migrate northward around the bridge.

To the west, at the confluence of the Jinar with the Pedhios River, the Venetian engineers built a bridge that was maintained and in use until recently.





Figure 7: The Mintzeli or “Venetian Bridge” was constructed for commerce to Kyrenia across the arroyo of the Jinar/Almyros River north of Orta Keyu. Modern sediment against the bridge piers suggests that the flood plain deposits are at least 2m thick.



Figure 8: Ruins of a Roman-style arch bridge near Hespodadt. The bridge originally spanned the Jinar/Almyros River. Sediment from the Pedhieos River buried the old channel under the bridge and deflected the river to the north (outside of meander bend) until the north end of the bridge was destroyed and the bridge abandoned.

Most likely, this bridge was built to cross the Jinar River after the arroyo cutting event triggered by the Pedhios diversion; the Jinar River is in an arroyo that extends more than 6 km west beyond the bridge site (Figures 2, 7). Dates (^{14}C) of charcoal within cement indicate that the Roman-style bridge is only about 250 years old and was built during the time of the Ottoman Turks. Although post-dating both the Romans and the Venetians, the bridge indicates continuing effects of flood plain dynamics long after the channel diversion.

6 Discussion: application of engineering history of fluvial system to interpreting neotectonic effects

The entire sequence of initiating a steeper channel gradient, triggering arroyo cutting, and re-establishment of equilibrium gradients probably occurred within a few decades. These rapid transitions from an aggrading alluvial system to an entrenched system as a result of changing the gradient of a river segment can provide an interesting proxy for the effects that might be triggered by surface cutting faults changing the gradient of a river system in equilibrium. The scale of surface deformation in time and space is directly analogous. Understanding the temporal and spatial constraints of flood sequence histories within the alluvial deposits also provides a framework for constraining the ages of surface cutting fault events. Finally, details of the physical properties of the flood deposit sequences and paleosols can contribute to modeling various geophysical and engineering properties and in predicting response to vertical acceleration during earthquakes.

References

- [1] Harrison, R.W., Newell, W.L., Tsiolakis, E., Necdet, M., Panayides, I., Batihanli, H., Ozur, A., Bersoy, O., Stone, B.D., Zomeni, Z., and Lord, A.R., *Bedrock geologic map of the Nicosia, Cyprus area*. Geological Survey Department of Cyprus, 1 sheet, scale 1:25,000, in press
- [2] Newell, W.L., Stone, B.D., Harrison, R.W., Tsiolakis, E., Necdet, M., Panayides, I., Batihanli, H., Ozur, A., Bersoy, O., Zomeni, Z., and Lord, A.R., *Surficial geologic map of the Nicosia, Cyprus area*. Geological Survey Department of Cyprus, 1 sheet, scale 1:25,000, in press
- [3] Malpas, J., Moores, E.M., Panayiotou, A., and Xenophonots, C, eds., *Ophiolites, Oceanic Crustal Analogues*, In: *Proceedings of the Symposium "Troodos 1987"*, Geological Survey Department, Ministry of Agriculture and Natural Resources, Nicosia, Cyprus, 733p., 1990
- [4] Knapp, A.B., *The Archeology of Late Bronze Age Cypriot Society: study of settlement, survey and landscape*. University of Glasgow, Department of Archeology, 108 p., 1997

