Journal of Archaeological Science 34 (2007) 1932–1952

Journal of Archaeological SCIENCE

http://www.elsevier.com/locate/jas

Geoarchaeological approaches to the environmental history of Cyprus: explication and critical evaluation

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Accepted 29 January 2007

Abstract

Geoarchaeology represents crossdisciplinary research focused on environmental issues and human activities, and directed primarily to social scientists. Site micro-studies are central to the enterprise, emphasizing cultural sediments and the taphonomic record of site formation, preservation, or destruction. But when expanded to include off-site investigation and watershed studies, geoarchaeology can go well beyond stratigraphy and context, to address human impacts on the environment or long-term sustainability. This paper articulates a research agenda to evaluate the largely anecdotal premise that the island of Cyprus has been degraded by millennia of improvident land use. First, it outlines Holocene settlement, land use and forest histories, as a differentiated model against which to apply specific types of investigation, and in conjunction with other archaeological sciences. Second, it applies Quaternary-style watershed study to confront commonplace misunderstandings about possible degradation, to show that most of the slope and stream deposits on Cyprus are of Pleistocene age. Third, it switches to examples of site micro-geoarchaeology to illustrate the possibilities of understanding detailed change. The purpose is heuristic, in the absence of many more site and off-site studies that incorporate bioarchaeology. Provisional inferences suggest that environmental damage may be limited, that even with heavy land-use stress, climatic triggers were critical to inaugurate change, and that the system may be more resilient than anticipated. Such caveats may encourage greater attention to environmental research design in ongoing and future excavation projects.

Keywords: Geoarchaeological micro-study; Land use and degradation; Watershed response; Colonial stereotypes; Cyprus

1. Focusing on the environmental history of Cyprus

1.1. Introduction

Located at the eastern end of the Mediterranean Sea (Fig. 1), the island of Cyprus is relatively large (9250 km^3) and ecologically complex. Settlement has always been concentrated on the semiarid lowland plains, but the hallmark of Cyprus remains its more humid, forested mountains. Just within sight of the Anatolian and Levantine skylines, and as a nexus of shipping routes, travelers have visited the island since Classical times. Archaeological, geological and biological exploration or research were initiated during the mid-1800s and there is a substantial record of incidental environmental information. But it is fragmentary and inchoate, and an environmental history cannot yet be assembled.

Given the fundamental interest of Mediterranean island ecosystems (see Patton, 1996), this is unfortunate, because misconceptions abound. From the earliest times the 'accepted wisdom' is that the environment of Cyprus has been impacted or degraded by centuries of improvident timber-cutting or land use. In part this was a consequence of a dubious comment attributed to Eratosthenes, that the entire island had once been covered by dense forest (Oberhummer, 1903, pp. 247–249). Medieval and Renaissance visitors commonly came during the hot, dry summer months, when little or no rain may fall for four months, leaving the arable lands parched and dusty. More recent observers from northwestern Europe, conditioned

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0305-4403/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.jas.2007.01.013

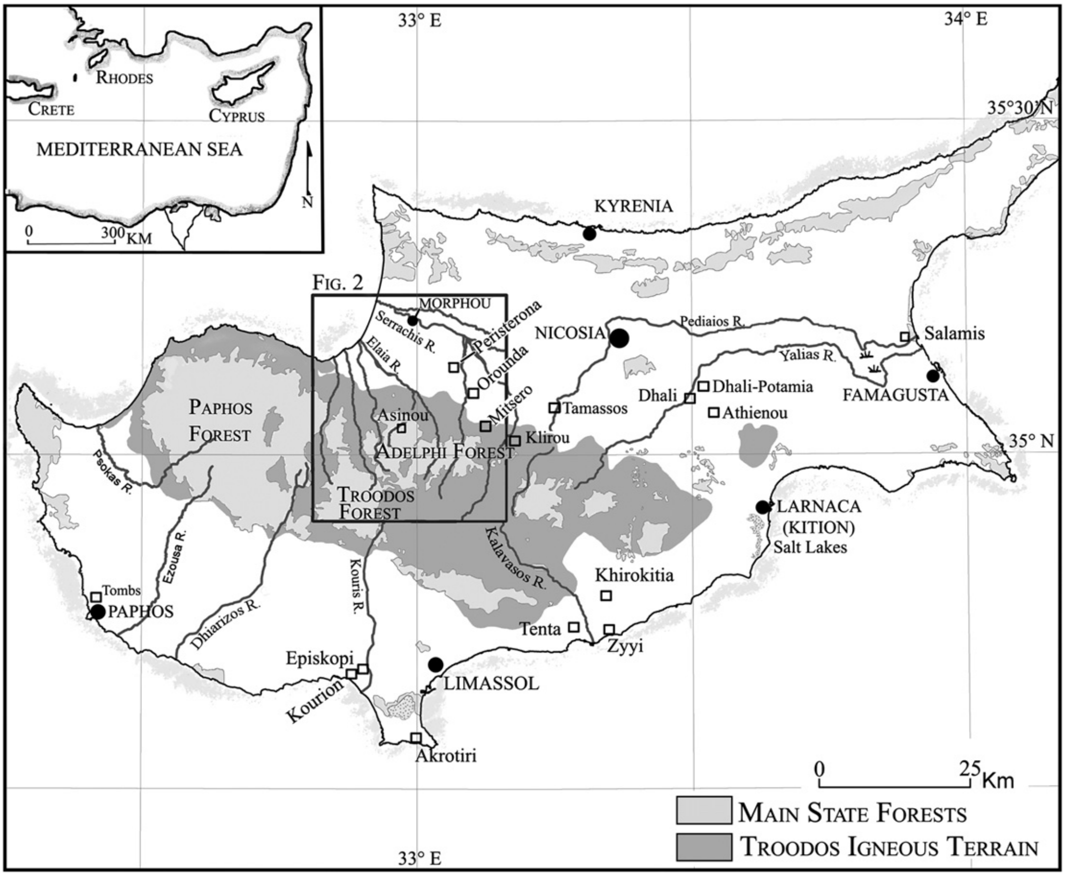

Fig. 1. Cyprus location map. Based in part on Forest Map of Cyprus (1946) and Geological Map of Cyprus (1995).

to moister environments, were disturbed by the open nature of woodlands and that streams were intermittent. And in the contemporary wisdom, degradation is assumed unless the opposite is demonstrated.

For outsiders, the cultural perception of forest condition readily became a proxy for either environmental health or degradation. These are not identical measures, but both do reflect complementary aspects of land use change. Whether or not the older evaluations are valid, the association between forest history, soil attrition, and land use is a productive starting point—if we focus on the processes and connectivities, without assuming identical outcomes. That basic premise underlies the organization of our presentation.

Table 1 offers a framework to organize and overview what is known about forest history, settlement expansion and contraction, and changing land use, across ten millennia of Holocene time. It is distilled from a wide range of recent archaeological studies (Croft, 1991; Fejfer and Hayes, 1995; Given, 2000; Guilaine and LeBrun, 2003; Harris, n.d.; Held, 1992; Horwitz et al., 2004; Knapp et al., 1994; McClellan and Rautman, 1995; Peltenburg et al., 2001; Rautman, 2003; Simmons et al., 1999; Steel, 2004; Stylianou and Stylianou, 2001; Toumazou et al., 1998). Historical landscape detail can be consulted in the classic 1:63,360 topographic and land use map series of Kitchener and Grant (1885), while satellite imagery is readily available through a variety of sources. Topographic map series for the island at 1:50,000 are available starting in the 1940s, although the most recent editions have limited access. Aerial photos of select areas can be obtained through the Department of Lands and Surveys (Cyprus). The geography of Cyprus by Christodoulou (1959) is dated but remains indispensable.

1.2. Discussion of the historical framework

In some ways Table 1 represents a non-traditional model to test hypotheses about human settlement and its possible feedbacks and impacts for Cyprus. The subsequent discussion explicates how demography, settlement, land use, forest history, and ecological health are interconnected. The following interpretation is partly based on arguments developed in Butzer (2005).

(a) There appear to be repeated settlement discontinuities during the early prehistoric (Neolithic) record (around ~7000, ~5000, and ~4000 BC), suggesting that site clusters remained localized and landscape adaptation incomplete. Even if there were agropastoral damage to the environment, it would have been restricted to circumscribed areas, without leaving fluvial evidence in many or most lowland catchments.

(b) Basic settlement continuity marked the Chalcolithic and Bronze ages (perhaps 3800–1100 BC), with settlement expansion and population growth underway by ~2000 BC.

Table 1
Programmatic historical structure of forests, archaeology, settlement and demography on Cyprus

1960–Present	The Department of Forests of the Republic of Cyprus continues to build upon a framework set in place by the British. Increasing rural emigration to urban centers
1878–1960	British colonial government, following then prevailing forest science, instituted a forest policy favoring conservation and eliminating goat browsing in the forests. Limited woodland exploitation, with importation of most timber and fuel; steady population growth from 186,000 in 1881 to 578,000 in 1960
1571–1878	Ottoman Era. Administered in collaboration with the Orthodox church. Chronic insecurity and increasing oppression during 17th and 18th centuries, leading to emigration and depopulation; demographic growth during the final 50 years. Unsupervised 'traditional' forest exploitation (cutting, coppicing, resin tapping, goat browsing), but no reliable evidence for significant deforestation or government-organized timber extraction; condition and limits of forests reported 1726–1736 almost identical to those reported or mapped during British era
1489–1571	Venetian Era. Systematic exploitation of human and natural resources; population grows to perhaps 197,000 in 1570. Controlled timber-cutting for shipbuilding inferred, but not archivally documented
1192–1489	Era of the Crusader kingdom, ruled by French Lusignan dynasty. Continuation of Byzantine servile oppression of rural population. Inferred but undocumented timber-cutting for shipbuilding, but major investment in cathedral and monastery construction into the 1350s; limited resumption of copper mining uncertain. Followed by economic and population decline, in part reflecting outbreaks of the Black Death (1348–1438), and pillaging by Genoese and Egyptians
649–1191	Mid-Byzantine Period. Arab raids (849–911 AD) destroyed or depopulated many towns, accelerating urban decay and the ruralization already underway, especially in coastal areas; tribute extraction by both Arabs and Byzantines, until the latter assumed control in 964. Construction of new churches since the 11th century indicates a gradual recovery, strongest in the Troodos and the hill country behind Paphos. Building of the 'painted' monasteries in the mountains required timber-cutting
365–649 AD	Late Roman/Early Byzantine. After devastating earthquake of 365, renewed urban and rural growth until severe outbreaks of Justinian's plague (beginning 542). Urban decline (Paphos) and ruralization apparent by 600. Forest history obscure
58 BC to 365 AD	Early Roman. Flourishing urban civilization centered on commercial entrepots of Kourion and Salamis. Decline after civil war 115–116 AD; Hadrian's plague ~167–172; and the Roman anarchy of the 3rd century. Nothing substantive known about forest history or the chronology of declining copper production
312–58 BC	Under Ptolemies of Egypt, urban wealth concentrated in Paphos after Kition destroyed. Timber-cutting for shipbuilding (Egyptian navy) and copper-smelting probable
~750–312 BC	Consolidation of new, Archaic population and power centers; urban growth in several city kingdoms, based on copper extraction and export. Despite foreign hegemony (Assyria, Egypt, Persia) over long periods, Cyprus populous and wealthy. A large navy and continuing copper production presuppose much timber-cutting, supported by comments of Theophrastus (~320 BC?) about shipbuilding, the difficulty of timber hauling, and an interdict against felling cedars
~1050–750 BC	Inadequate archaeological resolution (Iron Age); inauguration of new settlement patterns
~1200–1050 BC	Presumed demographic and economic decline during uncertain times, following depredations of the 'Sea Peoples,' immigration of new settlers, and possible natural disasters; destruction or abandonment of Bronze Age cities
~2400–1200 BC	Bronze Age. Emergence of town life, social complexity, mining and copper production Cattle reintroduced as plow animals, with donkeys for transport. Settlement numbers and sizes increase strongly (Early and Middle Bronze Age, before 1650 BC). Late Bronze urban-rural complementarity, and integration within economic system of Eastern Mediterranean, suggesting demand for Cypriot timber
~3800–2400 BC	Chalcolithic. Use of copper in a similar, mixed economy, but again site disjunctions suggesting settlement discontinuity. Olive cultivation and winemaking. Prominence of deer and adult male goats raises questions about hunting and pastoral practices, now shifting in favor of pig
~5000–3800 BC	Ceramic Neolithic. Introduction of ceramic technology from abroad, in conjunction with previous economy, but with deer important; new site locations imply discontinuity
~7000–5500 BC	Agricultural settlement (Aceramic Neolithic), in a number of prominent and permanent villages scattered near edge of coastal plain. A mixed agricultural, pastoral and hunting economy; but cattle phased out. Followed by settlement disjunction
~8800–7000 BC	Early Pre-Pottery Neolithic. Initial agropastoral settlement from mainland, with introduction of pig, goat/sheep, cattle and, surprisingly, fallow deer; hamlets scattered in foothills, with emphasis on hunting and herding. Followed by settlement disjunction
~11th millennium BC	Relict Pleistocene fauna (mainly pygmy hippos) in Akrotiri coastal cave, with ephemeral human occupation; followed by midden(s) with exploitation of marine resources

Olive and grape cultivation and processing were established, with pig a central part of the livestock economy. In that light the Chalcolithic may have been a period of agricultural experimentation and 'settling in.' During the Late Bronze there were some large towns, either trading or mining centers, that presumably stimulated the intensification of rural production with a typical Mediterranean agrosystem. The environment surrounding most site clusters may well have been modified, and in some cases, damaged by cultivation and cutting of timber or fuel wood.

(c) After ~1200 BC the Late Bronze cities were battered or destroyed, with new site locations and hierarchies emerging during the 'dark' Iron Age. Urban decline spells rural depopulation, perhaps leading to a greater pastoral emphasis that may have retarded reconstitution of the biotic landscape.

(d) From the eighth century BC to the seventh century AD, settlement patterns on Cyprus remained stable, including trading emporia at the coast and mining towns near copper sources of the interior. There were periodic downturns of population and prosperity—archaeologically verified during mid-Roman times (after ~170 AD)—that may have allowed ecological recovery in stressed environmental sectors. At other times, mining and lumbering probably kept ecological pressures at the Late Bronze level, and local damage is possible.

(e) The plague of Justinian and the demands of constant war explain urban decay and ruralization towards 600 AD, even before the devastating Arab raids after 649 AD. Continuing insecurity would have led to retraction of settlement into the interior of the island, with growth indicated in the fastness of the Troodos valleys and ridgetops at 600–1100 m elevation. At the time of Turkish occupation the mountaineers were described as healthy and warlike (G. Diedo in Cobham, 1908, p. 89). Considerable ecological reconstitution is possible in the low, as opposed to high, country during these five centuries, but pastoralism may have expanded in areas of agricultural retraction.

(f) The Lusignan and Venetian eras saw a return to urban growth, intensification, and economic prosperity within the Mediterranean commercial network. The landmark churches of the mountains continued to be built and painted into the early 1500s. Renewed pressures on the land and the forests are plausible, perhaps modulated during the downturn of ~1350–1500 AD.

(g) The Ottoman Era is enigmatic, with insecurity and political constraints to prosperity possibly crippling the rural sector and leading to urban stagnation, exacerbated by large-scale emigration and reduced productivity ~1650–1750 AD. Despite the prominent role of pastoralism, some ecological recovery could be expected, at least locally.

(h) The British colonial administration attempted to document an environment stressed by traditional land use, but this was to some degree a cultural interpretation. In any event, the forests were protected, pastoralism largely eliminated within the forests, and the population exploded. Except for areas of urban sprawl, the current environmental health of the island is in the eye of the beholder.

This may seem like an overly elaborate scenario. But it is not. With adequate archaeological resolution, an equally differentiated record could be retrieved from many parts of the Mediterranean world. The problem for environmental history is that such an analysis is almost never attempted, thereby oversimplifying the conceptual frame of investigation. What springs out here is: (1) the prominence of demographic cycles; (2) the discontiguous footprint of Neolithic settlement; (3) the probability that the impacts of intensification and pastoralism are not synchronous; (4) the dependence of rural growth on urbanism; (5) the linkages of urbanization, mining, and possible deforestation to regional economic integration; and (6) *the striking cyclical rhythm of human occupation of the land*, with its logical implications for selected windows during which ecological damage or recovery might be most likely. There also is the potential role of pandemics in reversing growth trends, information that only is accessible for later historical times. Finally, the important history of climatic oscillations or change is a *tabula rasa* unless empirical data are generated by appropriate forms of inductive research.

2. Geoarchaeology and environmental history

2.1. Different geoarchaeologies

Geoarchaeology is a cross-disciplinary endeavor, in which most practitioners have strong attachments to their traditional disciplines in the geosciences, and there is little articulation of common goals or related strategies. For an increasing number of geoarchaeologists the focus has turned to an environmental history that emphasizes the same themes of nature and society addressed in contemporary environmental studies (see Walsh, 2004; also Butzer, 1964, p. vii). Such an approach would be interdisciplinary in spirit (for example, Butzer, 1982; Rapp and Hill, 2006), in distinction to the preoccupation with analytical methods of an 'archaeological geology' (for example, Goldberg and Macphail, 2006). The point is not about semantics, but a recognition that we all approach our goals in different ways, that priorities vary, and that the ends need not be identical.

Most geoarchaeologists are Quaternary specialists by training, and give priority to issues of landscape history, human activities, and their interrelations. That dictates a shifting selection of methodologies, and the resulting questions or answers are now commonly addressed to social scientists, rather than mainstream geoscientists (see Van Andel et al., 1990; Butzer, 2005; Walsh, 2004).

At a finer scale, site micro-studies are not concerned with micro-depositional environments, but also with mixed cultural and environmental products, and the taphonomic record of site formation, preservation, and potential destruction (Butzer, 1982, chapters 6, 7). Other geoarcheologists go beyond the site to examine the temporal and spatial parameters of human impact on environmental transformation or degradation, or monitor the processes and feedbacks of 'historical' change. Such contributions can inform larger synchronic questions integral to global change and sustainability (Butzer, 2005). The common thread is that many 'cultural' or 'landscape' geoarchaeologists now apply their technical methodologies within new conceptual frameworks, that seek to better understand human–environment interactions, and not as an afterthought.

2.2. Devising a geoarchaeological strategy for Cyprus

The forests of Cyprus have attracted scientific attention since about 1860. During the British colonial period (1878–1960) they formed the centerpiece of environmental policy, to generate a popular narrative of deforestation, destructive traditional land use via goat grazing, and resulting biological degradation (for example Thirgood, 1987). In a longer frame, the Ottoman occupation (1571–1878) or the preceding Venetian interlude (1489–1571) have been variously blamed for poor governance or systematic timber-cutting, but without empirical evidence. Sarah Harris, who comes to these issues with many years of archaeological experience and intensive archival research, is skeptical of the 'accepted wisdom' about forest degradation (Harris, n.d.). These problems are embedded in a larger narrative of land use and environmental stress, which plays out with competing politico-ecological constraints, and that cannot ignore what happened before the time of the archival record. Consequently Karl Butzer joined Harris in the field in 2004 to examine whether and how a complementary, geoarchaeological strategy could be implemented, in order to place the forest history of the British period into a productive historical context.

The forests in question are situated in rough, igneous mountains, the Troodos (Fig. 1), with few archaeological sites other than medieval churches. That requires testing of high-relief watersheds for environmental change across long time spans, by Quaternary-style investigation of slope deposits, alluvial fills, and soil stratigraphies. But the archaeological record of Cyprus is concentrated within the Cenozoic lowlands, often in coastal proximity. That in turn calls for detailed geoachaeological examination of individual sites to search for possible evidence of human activity, at particular times. But isolating the roles of high-magnitude rains and excessive land use stress is difficult, so that it is important to closely compare montane watershed evidence with that from sites that commonly lie outside that catchment. The practical difficulties of integrating and reconciling these different but complementary kinds of evidence are the central challenge for this essay. It calls for more scale-switching, between the features recorded in an excavation profile, to the imprints immediately around a site, and to the potential response of the whole watershed. The role of site-specific geoarchaeology and watershed studies is analogous to that of excavation and survey in archaeology. Their combination is essential to addressing larger issues effectively.

The primary goal of this paper is heuristic. It aims to illustrate how Quaternary watershed studies can be integrated with (a) site-specific geoarchaeological analyses and (b) an archaeological/historical model such as Table 1 to gain a better understanding of human impacts on the environment of Cyprus. Archaeologists and environmental historians are the primary intended audience. It is they who need to be most aware of the difficulties and ambiguities of making a solid case for degradation, or the intricacies of environmental response to human impacts. And it is at the level of archaeological projects that improved geoarchaeological—and bioarchaeological—strategies need to be implemented, until there are sufficient 'building components' to elaborate a comprehensive environmental history of Cyprus.

This project advances our understanding of environmental transformation, but until there is considerably more empirical information, it remains a work in progress. Given the constraints of time and resources, the authors had to make strategic choices. Four contiguous watersheds were selected on the north slope of the Troodos (Fig. 2). They were chosen according to the presence of extensive and exposed alluvial sediments linking the highlands and lowlands; no single one had a 'complete' record, and each offered special perspectives to achieve a larger picture. Unfortunately, the lowermost valleys are difficult to access owing to the current political divisions of the island.

There are innumerable excavated sites on Cyprus, but except for the western part of the island, few major projects are active. Most large Neolithic and Bronze Age sites are partly backfilled or artificially 'preserved' and unavailable for study, although many were visited. Eventually we chose three sites for closer analysis. These span a period of about 2700 years, equivalent to the late Holocene, and include Archaic, Classical, Byzantine and later components. For a more representative picture, this phase of our agenda could and should be supported by many more, comparable or better studies.

3. An interdisciplinary menu of research avenues

'Doing' geoarchaeology on Cyprus is not just about geoscience methods and their application. In seeking to understand environmental history it is important for goals and procedures to be modified or shaped in a larger conceptual context, that includes contributions and advances from parallel investigations that range from archaeology to land use and biology. The geoarchaeologist needs more than technical proficiency and experience, and must read about and listen to other voices and perspectives. Rather than work in isolation, it is more stimulating to share questions and hypotheses in a genuinely interdisciplinary exchange among equals. In the ideal case the geoarchaeologist would in fact develop some ethnographic facility in order to appreciate the logic of what country people do and how (Butzer, 2005). Consequently this section presents an unconventional menu that highlights the interdisciplinary links and components of current environmental research on Cyprus, identifying aspects that require more attention, above all in excavation research design.

3.1. Paleobotany and zooarchaeology

Land use studies in Cypriot archaeology have focused on paleobotanical evidence for cultivars and their frequency, but give little attention to the charcoal record of indigenous trees and shrubs. A stronger focus on zooarchaeology (both livestock and game) has opened a productive discussion of animal management by Croft (1991). But hard intrasite information as to how domesticated or 'controlled' animals were herded, 'followed', or simply hunted continues to be scarce. Pastoral impacts on off-site land cover will depend on just how animal management, hunting, or mixed herding and hunting were practiced, and by which kind of short-term or seasonal foraging schedules and movements. This will require a massive expansion of off-site archaeology, as well as in the scale and diversity of biological investigations. Given the special circumstances of island biogeographies, it would also be important to know whether overall biodiversity has been reduced since human occupation (see McGlade, 1995).

3.2. Palynology

Although an obvious resource, palynology has only been marginally successful on Cyprus. Studies of pollen in archaeological sediments of the island usually have poor results. Comprehensive studies at Neolithic and Chalcolithic excavations show that 40–90% of the counts represent the tough-shelled grains of a single weedy family (the Cichoriae). This implies serious degradation and selective preservation of pollen, which is confirmed by the

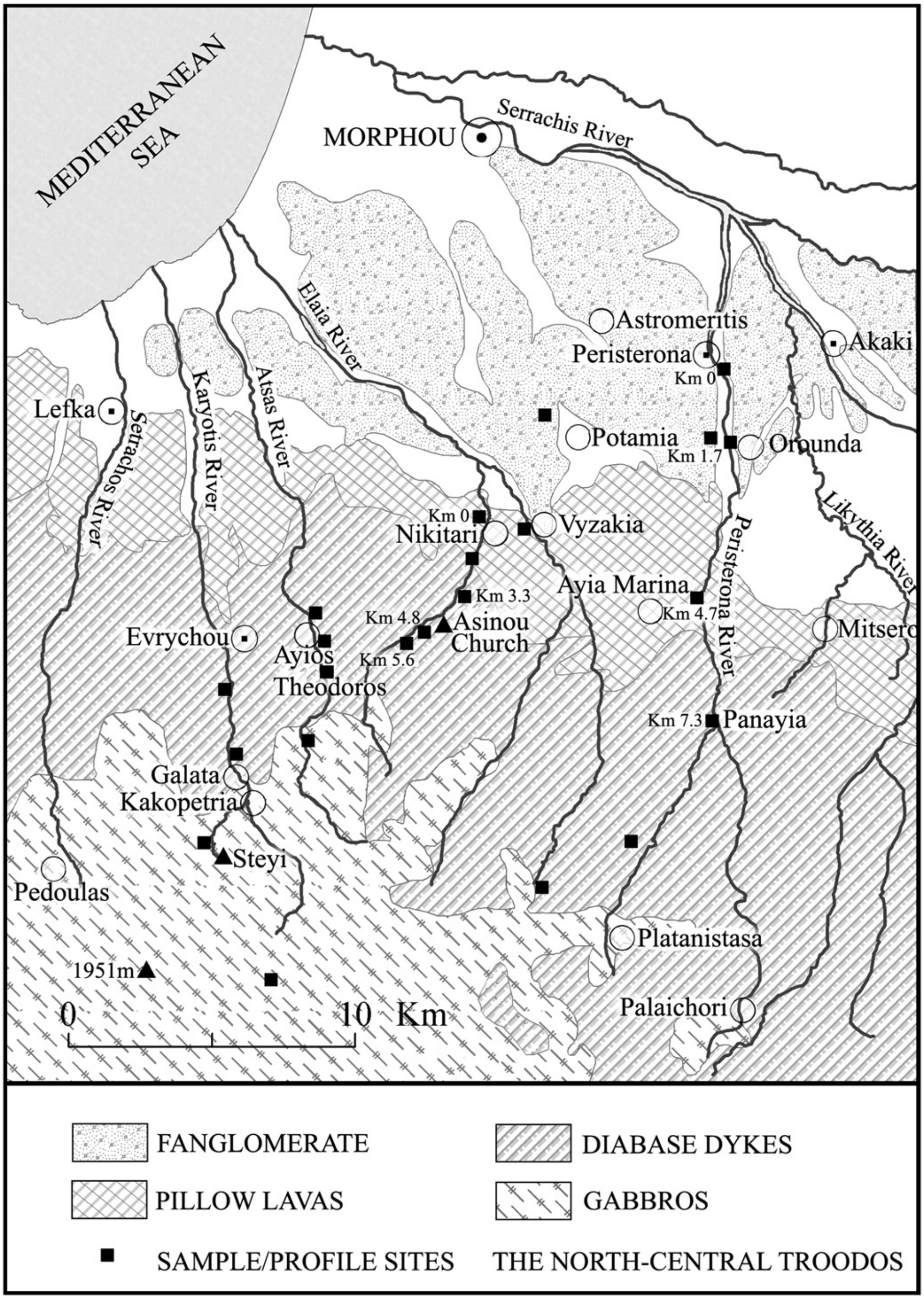

Fig. 2. The north-central Troodos showing main study or profile sites. Geology based in part on Geological Map of Cyprus (1995).

more diverse arboreal charcoals. Phytolith analysis should also be tested. Gifford (1978) obtained better pollen results from estuarine and lagoonal sediments near Larnaca. Although productivity was low and many samples unproductive, the range of taxa recorded in the better spectra inspire confidence that a renewed study program could be rewarding. It would be important to know at least whether the pollen influx of upland or montane trees was variable during the course of the Holocene.

The background problem for Cyprus is that there are neither peat bogs nor montane lakes in which sediment could accumulate slowly. The only major sediment trap is the marshland of the Pediaios River, west of Famagusta; but these clay silts are impregnated with sodium salts. Whether deep cores would be productive for palynology is uncertain.

3.3. Dendrochronology

Given the extent of forest on Cyprus (see Tsintides et al., 2002, for tree taxonomy and ecology), with almost exclusive stands of mature black pine (*Pinus nigra pallasiana*) at ∼1250–1950 m elevation, tree ring studies are very promising. Carol Griggs (personal communication) drilled black pine cores in the Troodos during 1978, including a 385-year sequence, before focusing her dissertation on the Northern Aegean. Her data

> "indicate two main periods of forest regeneration, in the late 16th to early 17th centuries, and again in the late 18th; between these two periods the forest was mainly mature. The juvenile rings of the late 16th to early 17th century cohort indicate a degree of deforestation in the area, but there still was some forest competition, evident in the juvenile ring growth. The mid to late 18th century deforestation was greater, with larger juvenile rings indicating less competition. Comparison with pine cores from southern Anatolia shows that the ring growth of these two periods do not have a similar signature, pointing to a local, Troodos phenomenon" (Griggs, personal communication).

With the help of Byzantine monastery timbers, as has been done in Greece and Turkey (Griggs, 2006), it may eventually be possible to identify periods of major cutting or forest regeneration in the Troodos far back into Medieval times. Dendrochronological work on Cyprus has been resumed by Sturt Manning, in collaboration with the Department of Forests of Cyprus.

3.4. Historical accounts of vegetation

Historical reports on vegetation vary greatly in terms of reliability and quality. Classical allusions are rarely scientific, as opposed to metaphorical or allegorical. The exception for Cyprus is Theophrastus, a pioneer botanist, who seems to imply that cedar was never abundant, but that dragging timber down to the coast posed a challenge (Theophrastus, 1916, Books 5, 7.1. and 8.1).

If the specific taxa or isotopic tracing of timbers used in Egyptian boats (see Gale et al., 2000) will allow identification of Cyprus, as opposed to Lebanon or Cilicia, as a source area, there would be a promising line of investigation. A strong Cypriot or Egyptian navy at the battles of Salamis or Actium supports the idea of timber-cutting for shipbuilding (see Meiggs, 1982, chapter 5; Hauben, 1987), and could be applied to estimate the number of prime timbers required to build a certain number of triremes, with an expected use for a given number of years, depending on the specific kinds of wood used.

Karl Appuhn (2000, and personal communication), who is particularly familiar with Venetian forestry and shipbuilding archives, knows of no records for Venetian timber exploitation on Cyprus. He also notes that galleys would have been constructed under close supervision in the military shipyards of that city, probably using timber from the surrounding mountains. Particularly before 1489, Venetians did control sugar production in the Limassol–Paphos area, but this did not require timber, as opposed to lower-grade fuelwood or woody shrubs, as is verified from charcoal remains (von Wartburg, 1992). From Ottoman sources of the 1570s we know of requests of timber from Anatolia for ship masts and boards (Jennings, 1993, p. 325). This suggests either ecological or organizational issues in obtaining local timber. Such examples imply that further archival research could directly complement a new effort in dendrochronology.

Study of mining and smelting for copper is well underway (Given and Knapp, 2003; also Fox et al., 1987) and the goal now would be to model the mass of fuel required to stoke the fires that allowed a flow of copper across various periods. Would the necessary cutting of wood exceed the natural rate of regrowth? Mid-Bronze Age mining towns were apparently founded and abandoned within a generation, which could reflect exhaustion of the local wood-supply (Peter Kuniholm, personal communication).

Travel itineraries with snippets of biotic information begin during the late Middle Ages. But about 1576, Tommaso Porcacchi (in Cobham, 1908, p. 164) specifically describes the Troodos, with a circumference of 18 *leguas* (∼75 km), as very high, replete with trees of all kinds, and harboring many Orthodox monasteries. That has the ring of empirical observation, and would appear to document the existence of a wooded massif. It finds confirmation in the detailed itineraries of the Russian monk, Vasyl Barsky, who traveled widely during four extended visits 1726–1736 (Grishin, 1996). Comparison of his corpus of descriptions with the contemporary state of land cover at specific locations strongly suggests that there has been little change in the delimitation of the Troodos forests. He repeatedly refers to dense forests covering the high mountains, except for the summit; he also mentions huge pines and non-ornamental cypress (Grishin, 1996, pp. 34, 44, 50, 63, 69, 76, 83).

In 1787, the botanist J. Sibthorpe (in Cobham, 1908, pp. 329–31) described the Troodos as steep and well wooded, with black pine, live oak and arbutus, whereas its valleys harbored maple, poplar, willow, alder, and plane trees. For the lowland plains, William Turner in 1815 (Cobham, 1908, pp. 433, 436, 444) identified great tracts of brushwood, heath, and thistles (maquis or phrygana); but in the mountains he found that foliage darkened the road, despite many burnt logs testifying to intensive charcoaling (see Cobham, 1908, pp. 439–440). The modern era of observation began in 1859 with the research of Kotschy (1862), who noted a somewhat abused condition of the Troodos Forest, introducing a dialectic of conservation versus 'traditional' forest use that later dominated the discourse of British forest policy.

The impression obtains that there was little or no large-scale deforestation during the Ottoman period. A larger perspective is offered by Samuel Baker (Baker, 1879, pp. 324–342) who cogently argued that the plains had never been forested, and that in the high country "ancient forests must have existed where their vestiges remain to the present day" (Baker, 1879, p. 341); but in some areas former woodland had been cleared to plant vineyards (also Barsky, in Grishin, 1996, p. 44). Forest mutilation was due to reckless cutting of fuel wood, resin tapping, and fire, rather than the depredation of goats, which were tended and shunned eating pine saplings (Baker, 1879, pp. 317–326, 336). Even so, fire scars today are very rare in the old-growth, black pine forest. Baker did observe foreign fuel exploitation on the northeastern peninsula, and implicated timber cutting for the deforestation of the coastal, western Troodos (Baker, 1879, pp. 44, 227–228).

The sum of these early qualitative reports would not seem to support systematic timber cutting under the Ottomans, and perhaps not under the Venetians either. But the unpublished dendrochronology suggests a more complex picture. It may be that indigenous forest exploitation was destructive in detail, rather than the big picture. Contrary to the stereotype of improvident land use, Baker admits that farmers in the northern mountain ranges went to extraordinary pains to protect soil from erosion by building terraces and check dams (Baker, 1879, pp. 194–196). Non-functional check dams are still commonplace on hillsides. The ethnocultural overtones to this 'colonial' debate are evident (also Grove and Rackham, 2001).

3.5. Soils and paleosols

Major constraints on soil development in Cyprus are set by lithology, relief, and a precipitation gradient from 300 to 1100 mm, between the lowland plains and the high Troodos ranges. Most of the lower country is dominated by Tertiary marls and limestones that are mainly permeable and calcimorphic; soils tend to be pale in color, low in organic matter, but base-saturated. On the other hand, the igneous terrain of basic to ultrabasic rocks of the Troodos is impervious, although jointed and fissured. Given the rough topography, soils tend to be thin, stony, and pale brown, except for slopes and valley floors mantled with reddish Quaternary sediments. Such surficial deposits display the greatest variability of soil types and colors, not only within the mountains but across the sheets of Pleistocene deposits that mantle Tertiary limestones, or follow through-rivers down to the sea.

Our study of the Quaternary record reveals a progression of weathering intensity from younger to older surficial sediments that is consistent among slope screes, valley alluvia, and pediment fanglomerates. Applying the systematic soil taxonomy of USDA (1999), we were able to identify a progression of soil types with respect to relative age, so that field criteria of profile thickness, textural distribution, structure, and (dry) Munsell colors became stratigraphic aids. For soils and sediments, textures below are given in standard pedological nomenclature, with field identifications controlled by laboratory micro-study of cube-samples. Although the rationale of USDA (1999) would attribute this progression of weathering intensity to increasing age, it is equally affected by cycles of soil stability or instability and climatic change. In this way soils and paleosols help diagnose change and stability in a watershed. Soils are a dynamic part of the environment and should be integral to the geoarchaeologist's skills. Soil is not a static but a vulnerable 'resource.'

3.6. Surficial sediments

Away from the coasts, where there may be eolian or marine deposits, the Quaternary sediments of Cyprus consist primarily of slope and alluvial materials. An essential part of geoarchaeological research, they fit into a three-dimensional landscape. Sediments are part of an 'operational chain' that links land cover and surface water to a system of interdependent processes that create the features to be studied. Geoarchaeology cannot be limited to a site and its immediate environs—a sticky point for some excavation projects.

Slope deposits are almost ubiquitous above 500 m elevation in the Troodos, and can be well over 5 m thick. The domed, central plutonic core (1951 m maximum elevation) exposes Inceptisols or eroded Alfisols, buried or at the surface. The lower, mountain circumference of sheeted diabase dykes is dissected by steep-sided valleys where crude rubble is abundant. Extensive talus accumulations grade into distal screes, particularly on north-facing slopes. Some of these rubbles are active or have been reactivated, while others are finer-grade and stable, with modest Entisols. Downvalley, loamy screes are thickest on lower slopes. These are derived from deeply weathered deposits (Alfisol-grade) and may be partly buried by younger, fresher screes.

This complex record argues for a cyclic alternation between stability, with protracted soil formation, on the one hand, and instability, with accelerated slope erosion and sediment mobilization, on the other. The bulk of the slope debris now in storage was a product of deep weathering (Alfisols on top of saprolite). Bedding inclinations of 10–25° are most characteristic, and transfer involved a mix of gravity and water-assisted movements, under an incomplete biotic groundcover. Although the 19th century and more recent snowpack on the mountains lasted up to 6 months (Oberhummer, 1903, pp. 205–206; Schmidt, 1959), characteristic cold-climate ('periglacial') features of Pleistocene or younger age (see Butzer and Mateu, 1999) are not apparent. Yet the sheer bulk of the slope deposits of the northern Troodos, where hard frosts remain common today, suggests that frost-weathering and ancillary soil–frost movements have played a significant if indirect role.

Alluvial deposits in the Troodos fall into several categories. The most striking are densely packed, coarse gravel (2–6 cm length), cobbles (6–25 cm), and occasional boulders (larger than 25 cm). Such coarse/cobble gravel is poorly sorted and stratified, clast-supported, and with a limited matrix of sand/loam in the interstices. Larger clasts in alluvial fills may be of greater mass than any of those exposed in talus or slope screes, and imply a lag of deposits from anomalously wild spates, from which finer materials were periodically winnowed. Observation of channel beds indicated that cobbles are too heavy to be moved by modern floods, except by rolling and some saltation. Mainly found in valley bottoms of the foothills, or on piedmont plains, such highly concentrated clasts are of great age and now in indefinite channel storage ('lag facies').

There also are matrix-dominated alluvial deposits, with long lenses or dispersed zones of clasts. Although roughly sorted and stratified, crossbedding is rare. They imply short bursts of torrential flow, with highly turbid waters approaching debris-flow thresholds; any suspended sediments appear to have been flushed out during subsequent remobilization ('torrential facies'). Both the lag and torrential facies represent palimpsests that are highly selected and unrepresentative of former flood dynamics. Without contemporary data on channel flow, it is not possible to model former sediment budgets.

Less common but of great agricultural import are flood loams, deposited on top of lag facies by overbank discharge. Flood loams are ephemeral in that they will be removed when a new cycle of high peak-discharge begins. They are correspondingly rare in the older alluvial record. Thick accumulations of flood silts are only present along the lower Pediaios River.

3.7. Observations of fluvial activity

Travelers' reports are consistent about the seasonal or episodic nature of stream flow on Cyprus, punctuated with occasional, catastrophic floods. Porcacchi in 1576 (Oberhummer, 1903, p. 216, n. 12) reports that "the island has no rivers, but only streams that do great damage when they do flow, but then rapidly diminish." Such a flood in early November 1330 attained a depth of ∼4.5 m inside the city of Nicosia, where some 3000 people reportedly died in the destruction of residential quarters (Oberhummer, 1903, pp. 210–211, 217–218); other but less destructive floods of the Pediaios River are dated to 1567, 1859, and 1888; they also took place at the beginning of the Mediterranean rainy season (late September to mid-November) and were associated with brief but phenomenal rains, that affected the south coast as well. Although not quite devoid of ponds with water during the summer dry season, the Pediaios rarely flowed for more than 6 weeks of the year, and almost never reached the sea.

In the valleys of the Troodos, various travelers of the 18th and 19th centuries encountered rushing streams during autumn or the spring snow-melt. The Serrachis, the third largest river, drains the Troodos, but was mainly dry and apparently had a cobble channel up to 900 m wide during the 1880s (Oberhummer, 1903, pp. 164, 220–221). The major streams of the island 125 years ago were intermittent, 'flashy', and had little or no base flow, no different than they are today.

Hydrological observations during the British period and until partition of the island in 1974 were primarily designed to evaluate reservoir function and are of limited use for paleohydrological purposes. Beyond such problems of missing process information, synoptic climatology in the Mediterranean Basin is overly compartmentalized by national services. A key question about high-magnitude rains on Cyprus is how and why some storms form or deepen over the eastern Mediterranean in relation to troughs of the upper westerlies over Anatolia, or in response to anomalous pulses of the North Atlantic Oscillation (see Meeker and Mayewski, 2002; also Alastair Dawson, personal communication).

3.8. Isotopic dating

A major drawback for this project has been the difficulty of obtaining radiometric dates. Charcoal is rare outside of archaeological sites, and accelerator dating of soil humate samples proved disappointing. Of seven samples submitted to the University of Arizona, two had insufficient humates and three yielded essentially modern ages. The latter imply contamination by post-nuclear humic acids, penetrating buried sediments from which the original organic matter has been rapidly decomposed and leached out.

For the interim, this has placed greater emphasis on soil stratigraphy and its linkage to glacioeustatic sea-level fluctuations. For the longer term, it will require more general application of a technique based on different assumptions, namely OSL dating of finer-grained slope, alluvial or colluvial sediments, a technique successfully tested in Greek prehistory (Fuchs and Wagner, 2005) and elsewhere.

4. Troodos watershed studies: a quaternary approach

To gauge the scale and response of the Troodos landscape to climatic and possible human inputs, four adjacent watersheds of similar order but different size and relief were studied (Fig. 2). Collectively they clarify particular issues, such as bedrock channels, fluvial lag deposits, relationships of slope debris to stream 'terraces,' the age of braided channels, and the significance of ancient fanglomerates. The soils bring such features into a stratigraphic perspective, to allow identification of what fits into a late prehistoric or historical time range. Archaeological inspection might suggest that the Troodos is an intensely disturbed and eroded landscape, but almost all the visible sediments and related forms are Pleistocene.

4.1. The Karyotis and Atsas Valleys

Since Medieval times the Karyotis or Karkotis Valley (Fig. 2) has been densely settled and highly productive. As a consequence, alluvial fills are poorly exposed on account of irrigation works, intricate terracing, subdivision by walls, and recent tourist development. We therefore single out only one feature, a 6–8 m cobble fill, capped by a gray brown (10 YR), clay loam. The surface is littered with large, unweathered clasts, and the soil is developed in a mantle of flood loam. But cobble or boulder-sized rocks are not found on the local diabase hillsides, and the lithology of the fill is dominated by rocks from the upper catchment, 5–10 km away: 40% are gabbros and another 40% are ultramafic clasts from the Troodos core (Poole and Robertson, 1991, Figs. 4–5). This tectonic valley once was a major channelway from the heart of the mountains to the sea, mainly transporting heavy clasts from a distance. It epitomizes the notion of a 'lag facies,' presumably brought together in early Pleistocene times.

Further downstream, Given et al. (2002) and Wells (2001) indicate the presence of multiple fills, of which their "flood chutes and bars" recall the braidplain features of the Peristerona River (see Section 4.3.). In the upper valley we could not confirm flood deposits attributed to a 17th or 18th century abandonment of terracing.

Separated from the Karyotis by a fault block, the Atsas or Kourdhali River does not extend as far south. Instead it is incised 10 m or more into bedrock along much of its course. Cobble lag and alluvial fills are absent in the upper catchment, even though a few scree cones with gabbro clasts project to the

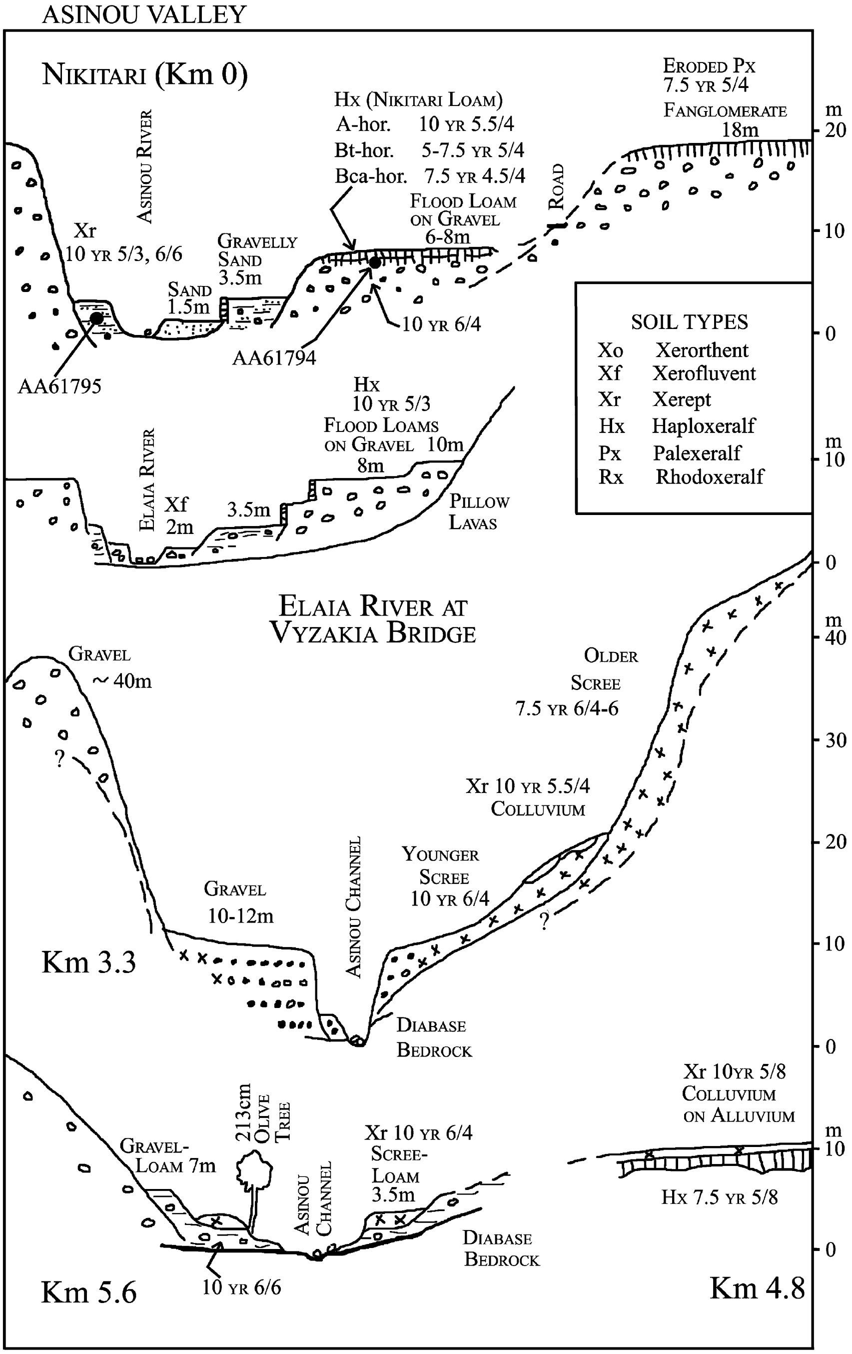

Fig. 3. Schematic cross-section of the Asinou Valley (this study). No horizontal scale. Vertical scale is identical on Figs. 3 and 4, and 'west' is always to the left. Munsell soil colors are 'dry,' with USDA soil types identified in box. Olive trees or orchards are shown, with mean girth at 1.5 m above ground. Coarse-to-cobble gravels are shown by open ovals, screes by ×. AA numbers indicate University of Arizona AMS samples.

channel. The surface soil is a pale brown (10 YR), Typic Xerept. Further downstream, with altered diabase bedrock, there is a discontinuous fill of some 8–12 m that may reach up onto a rock-cut bench at 10–15 m, where it is locally masked by a younger colluvium from the adjacent, rocky hillsides. Such colluvium is again weathered to a Typic Xerept, and partly buries a striking paleosol of light reddish brown (5 YR), stony silt loam with columnar structure. Downvalley this Bt-horizon thickens from 30 to 100 cm and becomes redder (yellowish red to reddish yellow, 5 YR); it is a Typic Palexeralf or mature Mediterranean soil.

At the village of Ayios Theodoros, the 8–12 m fill increases in thickness to 18 m as it descends down a deep bedrock knickpoint; this is a stratified coarse gravel with abundant matrix of buff ('very pale brown,' 10 YR) sandy loam and scattered boulders near the base. A fragment of a second alluvium is embanked directly against it, to 13 m relative elevation; this deposit is distinctive, with a light yellowish brown (10 YR) flood

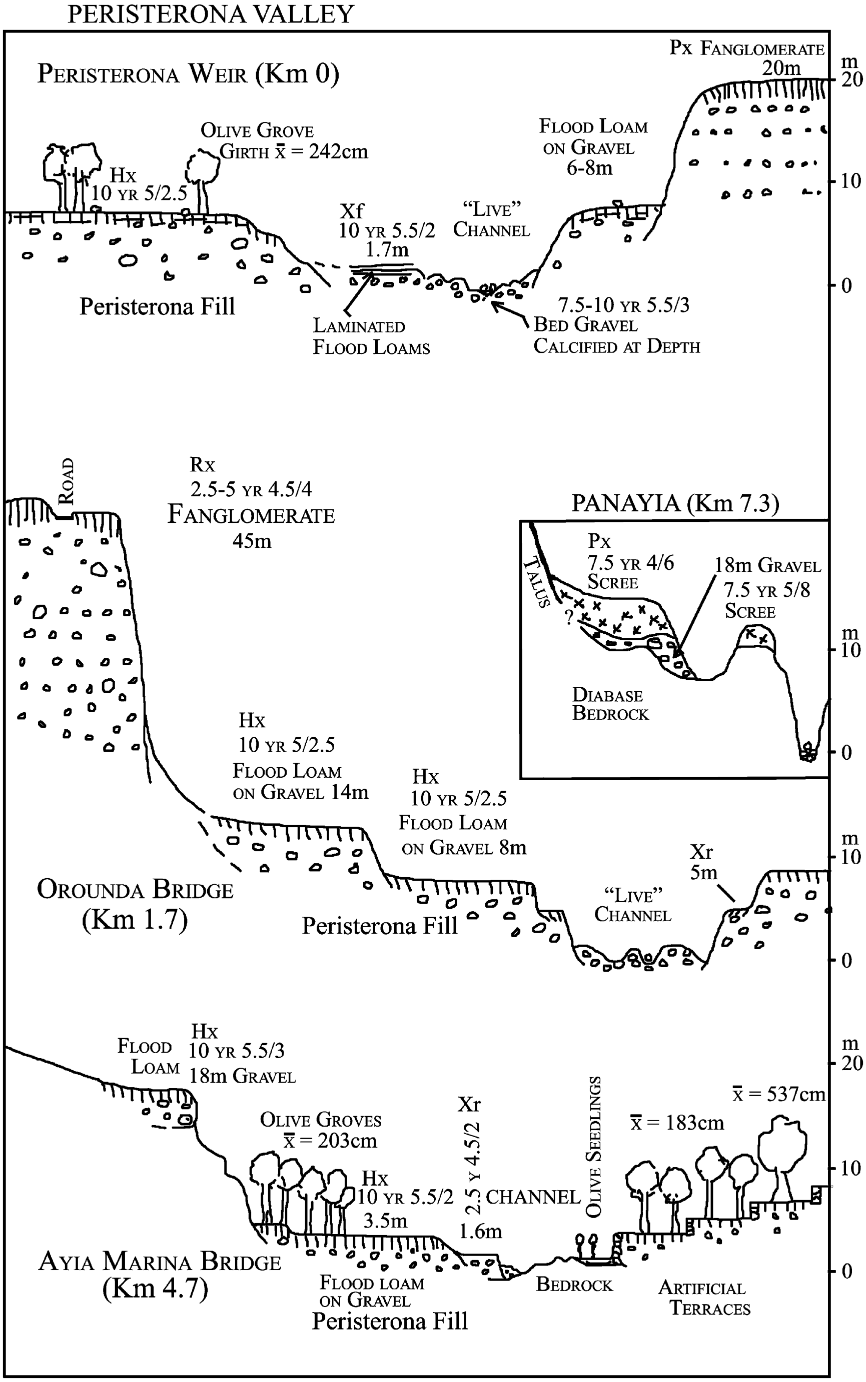

Fig. 4. Schematic cross-section of the Peristerona Valley (this study). Explanation as for Fig. 3.

loam on top of a lens of cobble gravels. Downstream the clay fraction continues to increase, with a Typic Palexeralf developed on diabase bedrock. There are two generations of fill in the Atsas Valley, one with a Haploxeralf soil and cobbles, the other with a Palexeralf and finer alluvium.

Several points merit emphasis. First, shorter lateral valleys may lack the ancient lag facies, and are not choked with alluvial detritus. Second, the streams flow in sinuous, entrenched bedrock channels of great age that change their configurations only very slowly. Third, the dominant alluvial material lies under buried Haploxeralf or Palexeralf soils. And fourth, younger deposits are relatively poorly developed, incorporating stony colluvium or screes, with modest surface soils of Xerept-grade that have distinctive, humic A-horizons.

4.2. Linked slope deposits and alluvia of the Asinou drainage

The catchment of the Asinou River has similar dimensions to that of the Atsas, but displays thick aprons or lobes of stony

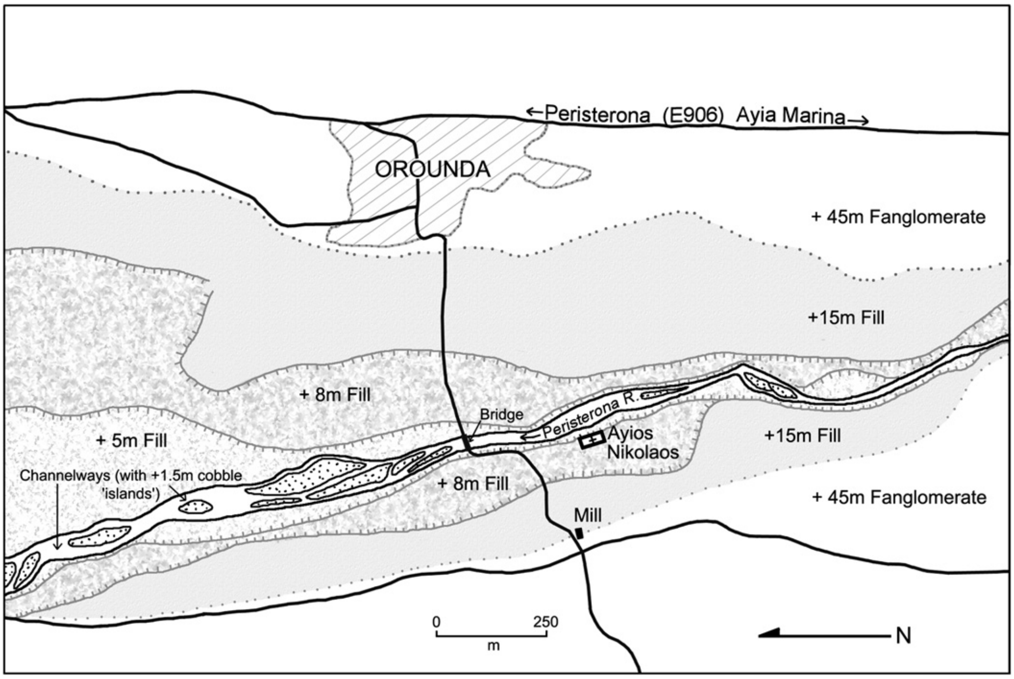

Fig. 5. Accumulation and step-wise erosion of the Peristerona Fill at Orounda (this study).

screes, derived from bedrock consisting of sheeted, diabase dykes. The unusual abundance of slope debris is greatest on the more gently sloping eastern side of the valley. This record of slope and alluvial deposits is informative, as are contrasts between the confined valley and the open plain of Nikitari, where the stream debouches amid a more complex fluvial landscape.

The channel runs on a bedrock floor (Fig. 3). A discontinuous alluvium is found at 3.5 m above the channel floor around Km 5.6 (near the abandoned settlement studied by Given et al., 2002); it consists of stony loam, with localized concentrations of rough rock derived from slopes (attributed to Unit 1 of Table 2). The surface soil is brown to light yellowish brown in color, representing a Typic Haploxerept. Thin (0.5–1.0 m), colluvial veneers on concave erosional scars cut into Younger Screes have similar soil development and may be contemporary. But rudimentary soil profiles of Xerofluvent or Xerorthent type are found on more recent 1.5/2 m fills downstream.

A more substantial alluvial body (10–12 m) is partly covered by Unit 1, in part grading into Younger Scree, with abundant slope rubble (>3 m). South of the Medieval church, at Km 4.8, this Unit 2 has a strong brown (7.5 YR) soil, with columnar structure and traces of illuviation, representing a Haploxeralf. Beyond the valley near Nikitari (Fig. 3), Unit 2 changes radically to a 6–8 m fill of lag facies with cobble-sized clasts (Unit 2B). Under a stony agricultural soil, a striking paleosol profile is preserved in places (Unit 2A). A yellowish brown (10 YR) flood silt of 30 cm has columnar structure and a weak calcic overprint.

Table 2
A first stratigraphy of Quaternary sediments and soils, north-central Troodos (Munsell colors are given dry; only hues are enumerated)

T(roodos)Unit 0	1.5/2 m channel bars and 'islands', with local flood sands. *Post-depositional soil (PDS) 0.* Brown (10 YR), stony loam, weak or massive structure; 30–100 cm A-horizons (Xerofluvents and Xerorthents of Entisol grade). Subcontemporary
TUnit 1	3/5 m alluvial fill of stony loam, possibly coeval with occasional, thin (<1 m) slope colluvia, that rest on younger scree. *PDS 1*. Grayish brown to brown or yellowish brown (10 YR), stony loam; granular structure, non-sticky when wet; 15–75 cm humic A-horizons (Xerepts of Inceptisol grade). Late Holocene, probably Medieval in main part
TUnit 2A	Flood loam mantle (to 1.2 m thick), designated as *Nikitari Loam*. *PDS 2*. Grayish brown, brown, or strong brown (7.5 YR), loam or silt loam; columnar or prismatic structure, slightly sticky when wet; 40–70 cm Bt (argillic) horizons (Haploxeralfs of Alfisol grade). End-Pleistocene or Early Holocene?
TUnit 2B	6/15 m of coarse/cobble gravel, with several erosional stages, designated as *Peristerona Fill*. Intergrades with younger scree on slopes. No *PDS* preserved. Late Pleistocene?
TUnit 3	16/40 m of coarse/cobble gravel, thinning out in the foothill zone; interdigitated with thick (>40 m?), reddish Older Scree in Asinou Valley; and equivalent to 18 m alluvial fill in Atsas drainage. *PDS 3*, poorly preserved. Reddish brown to yellowish red (5 YR), silt loam; columnar structure, sticky and plastic when wet; 30–60 cm Bt horizons (Palexeralfs of Alfisol grade). Mid-Pleistocene?
TUnit 4	~30 m *Fanglomerate Formation*, a great piedmont accumulation (Fig. 2), dissected in three stages, with renewed deposition. *PDS 4*. Reddish brown to red (2.5–5 YR), clay loam or silty clay, with friable pebbles; prismatic structure, sticky and plastic when wet; 60–80 cm Bt horizons (Rhodoxeralfs of Alfisol grade, with petrocalcic variants). Early to Mid-Pleistocene?

Below this A-horizon is a 30 cm, brown (10 YR) stony silt loam with strong prismatic structure. This Bt rests on an altered and calcified mix of cobbles and silt loam, a Bca-horizon. This is a Calcic Haploxeralf.

An AMS humate assay, corrected for ^{13}C, yielded an apparent date of 1425 ± 40 cal. CE (AA61794) for the base of the Bt. That is patently unreasonable for such a deep and complex paleosol, that grades conformably into the underlying lag gravel. Located well away from the slope to the higher terrace, this soil profile contrasts with the overlying anthropic rubble. A Medieval age would presuppose 6 m of channel entrenchment and massive stripping out of cobble fill during only a few centuries. The dated humates must relate to a much younger biochemical overprint, as is suggested by the root hairs that lace the deposit.

A much younger 3.5 m alluvium at Nikitari has a cumulic soil, with a weak AB horizon of brownish yellow (10 YR), stony loam with coarse columnar structure. Representative of the youngest fill in the drainage (Unit 1), the AMS assay of "less than 110 years" (99.5 ± 0.4 pMC) (AA61795) has multiple calibration intercepts spanning over two centuries, and also inspires little confidence.

The oldest unit recognized within the mountains is a thick body of light brown to reddish yellow (7.5 YR), mixed-grade scree that extends downslope to a 40 m alluvial fill (Unit 3). Only vestiges of surface weathering survive, but the uniform color of both alluvial and slope sediments points to extensive prior erosion and reworking of deep, reddish soils and regolith. Near Nikitari the 40 m alluvial terrace rapidly decreases in relative elevation to 16 or 18 m, and includes cobble-grade clasts. Here the reworked, surface soil vestiges suggest a Haploxeralf or Palexeralf.

In sum, the Asinou Valley exposes three alluvial bodies, each linked with a generation of slope sediments. They decline in volume with time, Unit 1 having only modest development. Intensity of weathering varies predictably, with Xerept-grade soils on Unit 1 and Haploxeralf-grade soils on Unit 2. Unit 3 is characterized throughout by eroded reddish soil components, reworked from a deep soil mantle and older slope debris. The original soil may have been similar to the Palexeralf of the Atsas Valley.

The sharp break in relative elevation of the alluvial terraces as they emerge from the valley onto the plain (Unit 2 from 10/12 m down to 6/8 m; Unit 3 from 40 m down to 16/18 m) is striking. It highlights the production of slope and alluvial sediment within the valley confines, and its divergence across a great piedmont fan draining towards the axial, Elaia River. But Unit 1 shows no such break in gradient, supporting the evidence of limited scree development, suggesting that geomorphic processes were greatly reduced or that Unit 1 is much more recent, representing a short time span.

The flood silts of Unit 2A parallel the evidence from the Karyotis River, marking a different, terminal aggradation, not linked to activation of slope deposits. These beds may have been winnowed from older alluvia by weaker floods that could not mobilize cobble-sized clasts. It is pertinent that the sinuosity of the Asinou Valley is determined by a bedrock channel, cut prior to the Quaternary sequence outlined here. Its floodplain has not meandered or changed its sinuosity significantly for many tens of millennia.

4.3. The problem of the Peristerona 'braidplain'

A hallmark of the Peristerona Valley (Fig. 4) is the body of cobble lag which, at the town of Peristerona, forms a 6–8 m alluvial terrace, similar to that of Nikitari (Unit 2B) and the Karyotis Valley. The covering mantle of flood silt (Unit 2A) displays a soil of gray brown (10 YR) clay loam, with strong prismatic structure and polygonal surface cracking. This is a Vertic Haploxeralf. There also is a 1.5 m inset of coarse/cobble grade gravel (Unit 0), which continues under the channel floor, where it is calcified and mottled a strong brown.

At Orounda (Km 1.7), a single mass of cobble lag covers the valley floor, but shows three distinct surfaces at 12–15 m, 8–9 m, and 3–5 m (Units 2B and 1) (Fig. 5). This is valley fan, remodeled at successively lower levels. The 'live' channel with its cobble islands has a relief of 1.5 m and technically forms an 'island braidplain' (Unit 0). Since such massive, clast-supported gravels are replicated in each of the valleys studied, they can be informally designated as the *Peristerona Fill* for lithostratigraphic convenience. It also forms erosional benches, mantled by flood silts and Haploxeralf soils that can be referred to as the *Nikitari Loam* (Unit 2A). The youngest, 5 m bench has a 40 cm mantle of brown loam with a Fluventic Xerept (Unit 1).

In the gorge near the Ayia Marina bridge (Km 4.7), cobble gravels underlie a 3.5 m terrace with a 75 cm cap of gray brown (10 YR) silt loam, with strong structure and a Fluventic Haploxeralf (Unit 2A). The olive trees on this surface have a similar mean girth (251 cm at 1.5 m height, on the western side; 183 cm on the eastern) as those on the Unit 2 terrace at Peristerona (242 cm). Although these olive groves cannot be dated without tree-ring measurements, most were already mapped in 1882 (Kitchener and Grant, 1885); these surfaces cannot have been ravaged by severe floods for two centuries or more.

Paleohydraulic estimates (see Rotnicki, 1983; Williams, 1983), based on empirical channel sinuosity (1.09), gradient (0.0153), wavelength (91 m), width (15 m), mean length of largest clasts (15 cm), and an estimated water depth of 95 cm, suggest a peak formative discharge of 82.5 m^3/s and a bed velocity of 3.8 m/s near Orounda (Fig. 5). If we increase the water depth to 1.5 m (Unit 0), the hydraulic radius increases from 0.806 to 1.238 and the channel cross-sectional area tenfold. In this case bed velocity would rise to 5.1 m/s and a thundering, formative discharge of almost 600 m^3/s. These gross approximations underline that the island braidplain could only be activated by exceptional peak discharges every few centuries. The 3–5 m terrace (Unit 1) would probably become mobile with a phenomenal peak discharge on the order of 1000 m^3/s.

How well does the Peristerona braidplain actually conform to the concept of a braided stream? A typical example (see Best and Bristow, 1993) would be dominated by a mainly sandy bedload, with rapidly shifting, interwoven ephemeral channels, while the island bars should change their shape and location after major floods. That does not match the form and dynamic of the Peristerona channel, which is entirely covered by large, lag clasts and has been stable since at least 1882. This is then an *atypical braidplain*, 'underfit' with respect to the masses of cobble gravel in indefinite storage. For much, perhaps most of Holocene time, the Peristerona and its hallmark fill has been essentially fossil.

Only part of the Peristerona Fill issued directly from the mountain valley upstream of Ayia Marina. Near Panayia (Km 7.3), the channel is deeply entrenched in bedrock, with spurs of 12–15 m coarse/cobble gravel weathered to a strong brown or yellowish red (5–7.5 YR) and grading upslope into scree aprons and talus. But for the next 5 km upstream there is little sediment in slope or channel storage, so that the source must be more indirect. Near Orounda the Peristerona Valley runs between steep bluffs of the Fanglomerate Formation (see Ducloz, 1965; Poole and Robertson, 1991). Some 30 m of these undifferentiated, clast-supported gravels are exposed at Orounda, 45 m above the channel; they include boulders that attest to the primal energy of this early Pleistocene (?) accumulation. The surface is weathered by a Rhodoxeralf soil, and the knickpoints of the streams draining it to the northwest indicate three stages of remodeling, prior to cutting of the river due north, across the grain of the Fanglomerate, but following an old fault line of the Troodos basement. After initially forming a great valley fan, directly derived from undermining of the Fanglomerate, the Peristerona Fill was superficially remodeled to form the stepped surfaces exposed at Orounda. This is a Quaternary-scale, rather than 'historical'-style record.

5. A provisional synthesis for the Troodos evidence

The lithostratigraphy of our Troodos watersheds is synthesized in Table 2, on the premise that the major soil classes are regional, as opposed to local phenomena. The picture is dominated by several Pleistocene cycles of environmental change, during which stable conditions, with soil formation, alternated with dynamic episodes of debris mobilization and deposition, emanating from the high Troodos. Such cyclic change in the Aegean sphere is documented by repeated and radical alternations of vegetation in deep pollen cores from Greece that correlate with the Pleistocene marine isotope stages (MIS) (Tzedakis et al., 2003). In this perspective, Table 2 covers a time span measured in hundreds of thousands of years, but the regional, Troodos units 0 and 1 suggest much shorter episodes. Given the practical absence of isotopic dates, correlation of the soils with those from similar contexts in other parts of Cyprus must serve as a relative stratigraphic framework.

Particularly promising is the Alfisol that marks the Nikitari Loam (TUnit 2A) and postdates the Peristerona Fill (TUnit 2B) (Table 2). Soils fixed by coastal stratigraphies can acquire chronostratigraphic import, as for example on Mallorca (Butzer, 1975) and in the Mediterranean-type environments of South Africa (Butzer, 2004), where sequences of eolianites accumulated in coastal areas during the course of glacioeustatic oscillations of global sea level. Eolianites are coastal sands, consisting of comminuted molluscan and other biogenic debris, deflated from the emerging shallow-water zone during regressive oscillations of sea level. Such sands are often interbedded with soils, so at Cypriot sites examined near Paphos, Episkopi, and Zyyi (Fig. 1). Eolianite sequences are also present in eastern Cyprus, where we have not had opportunity to study them.

North of Paphos, the so-called Royal Tombs were cut into thick sequences of eolianites during the Hellenistic era, providing deep and extensive geological profiles. Tomb 9, in particular, shows three generations of eolianite, with large-scale, low angle crossbeds; they are separated by two thin bands of reddish soil sediment, and capped by a pink (5 YR) paleosol embedded in a petrocalcic crust. The Paphos 'red beds' were eroded from Alfisols of great age.

The second example comes from ongoing excavations by Gisela Walberg at Episkopi-Bamboula (see also Section 7.1). A trench face at the NW edge of the site exposes an Archaic wall foundation, on top of pink (7.5 YR), weathered eolianite; Late Bronze tombs had earlier been emplaced within this sediment, cutting across the grain of the horizons, so that soil formation will have terminated long before ~1600 BC.

The third case is more specific. Near Zyyi, between the mouths of the Vasilikos and Maroni rivers, an unexcavated Late Roman/Byzantine settlement has been truncated by beach erosion, so that wave-worked cultural debris now rests on features that cut deeply into a reddish paleosol. That soil was developed on a sheet of buff (10 YR), fine-grained sediment, with some marine shell, that dips to well below modern sea level. The soil has a 40 cm pinkish gray (7.5 YR) Bt, above a calcic horizon, representing a Calcic Haploxeralf. Since both soil and sediment are in primary position, accumulation and pedogenesis had to take place while sea level was substantially lower, i.e., during a marine regression. That matches the gradients of south coast gravel terraces, projected to sea levels lower than today.

The loamy sediment at Zyyi fills a shallow declivity, eroded after formation of a calcified, cobble beach gravel, that elsewhere is capped by a thin, crossbedded eolianite. The beach presumably represents some substage of MIS 5, both the fill and the paleosol falling somewhere within MIS 4, 3, or 2, i.e. 65,000–10,000 years ago. Since such prominent pedogenesis is not random, stratigraphic correlation with the Calcic Haploxeralf of the Nikitari Loam is plausible, in which case TUnit 2A of Table 2 would be on the order of 10,000 years old.

6. A critical evaluation of previous studies on Cyprus

To situate the previous information in a comparative context, we review other geoarchaeological studies on Cyprus that represent different geomorphological developments and alternative stratigraphic interpretations.

6.1. Western Cyprus

Deckers (2006) and Deckers et al. (2005) have investigated several major floodplains that emanate from the western and southwestern Troodos, namely those of the Dhiarizos, Ezousas, and Stavros-tis-Psokas rivers. A range of informative sediment profiles is described, but except for two OSL dates, chronological precision is limited to the use of *terminus postquem* archaeological dating. A total of 69 embedded sherds were screened by TL (thermoluminescence), but dose rates were estimated only, implying substantial ranges of error (15–50%). The resulting assays generate much ‘noise’, with only one or two of the youngest sherds in a profile offering gross estimates of a minimum age. They do however show that most of Deckers’ sedimentary units fall within the last millennium, i.e. Medieval to Ottoman. As a group and taken at face value, these dates also suggest sizable local populations during the 11th and 13th centuries.

Replotted as a composite, to allow direct comparison of paleosols (undated by AMS) and facies changes, the key profiles of Deckers suggest at least two alluvial phases, separated by a fairly consistent humic horizon. This soil is dated 1010 ± 70 CE, and a lower one approximated at 850 ± 400 CE by OSL. The overlying unit is a detrital fill, forming a surface typically 40–100 m wide, at 2–2.5 m above channel floor. Minimum TL assays suggest an age of perhaps 1250–1600 CE, but a single ‘date’ of 1821 CE is insufficient to demonstrate a late Ottoman correlate of the ‘Little Ice Age’. The dominant facies is a coarse to cobble gravel, with examples of colluvial soil or poorly structured, pinkish gray to brown overbank silts, up to a meter thick. This identifies the lowest valley fill with high-energy stream activity during the Lusignan to Venetian period and possibly later. The characteristics of this unit compare well with the development of TUnit 1 (Table 2), the immature soils precluding correlation with TUnit 2A/2B.

Slope stability, soil formation, and low-energy flooding were more typical during a few centuries around perhaps 1000 CE. There also are older fills *under* the Late Medieval deposits that suggest earlier, high-energy floods, perhaps of Late Roman age. Mid-Holocene deposits may be uncommon or absent in western Cyprus (Deckers, 2006).

6.2. Mitsero Basin

A small catchment around Mitsero in the northeastern Troodos foothills has been studied by C. Whitehill (in Given and Knapp, 2003, pp. 146–154). Embanked 6 m above the floor of the Kryon Neron is an extensive spread of coarse to cobble gravel, up to 3 m thick, and attributed to a braided channel. A near-surface Abk horizon has a ^{14}C date of 8390 ± 235 bp, indicating a Late Pleistocene fill (*Hat1*). A sedimentary gap of ~8 ka follows, and all subsequent deposits are no more than 3 m above channel, and dated within 300 years of the present (Given and Knapp, 2003, Table A2.2). Two alluvial subunits (*Hat2–3*) represent this recent evolution of the channel, but the available dates make little sense.

This picture is complicated by a second report in the same volume, but that uses a different terminology in the same location (V. Kassianidou in Given and Knapp, 2003, pp. 82–83 and map, Pl. XI): Whitehill’s central site is SCY 213 while Kassianidou’s is SCY 021, located only 200 m away. The latter report recognizes: (a) a thin sheet of slope rubble encroaching onto the 6 m gravel unit from adjacent talus drapes; (b) an alluvium of intermediate age (*Hmal*); and (c) a younger Holocene fill (*Hyal*) that may flood during extreme flood events. But *Hyal* is the same feature as Hat2–3 on the geomorphic map. Archaeological recovery on this surface includes some Medieval sherds (only found downslope of concentrations on higher-lying surfaces) but abundant Ottoman pottery (independent of upslope concentrations) (Given and Knapp, 2003, Pl. XIV).

In other words, accretion of the late Holocene alluvium (*Hyal = Hat2–3*) was completed by Ottoman times, and the ^{14}C dates appear to be a little too young. This feature is equivalent to Deckers’ Medieval fill (also multiphased), as well as to our TUnit 1 (Table 2). TUnit 2B is the same as *Hat1* at Mitsero, but there is no equivalent to TUnit 2A.

Shallow embankments within the channel are attributed to old check dams, with a residual relief of less than a meter. These support olive trees said to be 200–350 years old at Klirou (Fig. 1) (Given and Knapp, 2003, pp. 153–154). Since extreme floods that destroy olive groves will also blow out check dams (and vice versa), this corroborates our case from the Peristerona River that the flood regime of the Troodos streams has been relatively subdued for several centuries. In effect, there appears to be considerable comparability of alluvial histories across the Troodos.

6.3. Dhali-Potamia

Mid-Holocene alluvium is developed at Dhali-Potamia, beyond the confines of the Troodos, at the junction of the Gialias and Alykos rivers, based on partly published work by Devillers (2003, n.d.) and Devillers et al. (2002). He recognizes a set of three Holocene alluvial fills with a cumulative thickness of 8 m. Described mainly as stratified sands, they are attributed to ‘accelerated erosion’. The age of the earliest phase is largely inferential, perhaps Aceramic Neolithic. The youngest is roughly dated 800–1800 CE, but the most interesting is intermediate.

The link is provided by a ‘hydromorphic paleosol’ that extends from the valley bottom onto the footslope, where it covers Late Bronze structures within colluvium; this soil is cut by drains, filled with Archaic materials, that have a calibrated AMS date of 850 ± 70 BCE. Rapid alluviation on the adjacent floodplain is suggested for ~1900–1100 BCE, and the soil itself may date ~1050–750 BCE, followed by another short burst of aggradation ~850–500 BCE (as inferred from Devillers’ illustrations). At face value, the mid-Holocene fill would reflect Middle to Late Bronze and Archaic sedimentation, interrupted by pedogenesis during the Iron Age (Geometric). Attributed to anthropogenic erosion, alluviation ceased with depopulation at the end of the Late Bronze, but then briefly resumed. The meter-thick paleosol recalls the Nikitari Loam, which however is a sometimes vertic, cumulic soil. Closer comparison must await appearance of the documentation.

This French team also reports on a deep coring (SBA 1) taken near Famagusta, in a former embayment of the Pediaios River (Devillers et al., 2002). Above a shingle beach or alluvial gravel, some 11.5 m of suspended sediment accumulated in a fluvio-marine environment during as little as 500 years, probably during the 6th millennium BCE. A further 6 m of silty clay were deposited under similar marine conditions, during a few centuries prior to a date of 1850 ± 165 cal. BCE.

Only then was sea level equilibrium attained, while organic or sandy muds with conspicuous redox phenomena built up more slowly during and after the Late Bronze. These coastal data do not match closely those of upstream Dhali-Potamia.

6.4. The Vasilikos Valley

In the lowermost Vasilikos Valley, draining the eastern Troodos, pits dug below the channel floor revealed two units of flood silts (Gomez, 1987). The younger consists of 40 cm of ‘khaki’ (? buff, 10 YR) silt, with a basal calcic horizon, and charcoal dated to 1425 ± 100 cal. CE. The older flood silt has 200 cm of laminated silts with waterworn Middle Bronze sherds; below that are 75 cm of crossbedded, gravelly silt, and at the base another 300 cm of laminated, gravelly silt, embedding hearths and bone. A charcoal date of 5300 ± 130 cal. BCE falls within the dating range of the Aceramic Neolithic at the adjacent site of Tenta. Both units rest on igneous cobble gravels, recalling the Peristerona Fill. In another pit, the top 25 cm of the underlying cobble unit is ‘reddened’ (Gomez, 1987).

The Vasilikos evidence suggests an alternative, Early Holocene age for the Nikitari Loam, but still compatible with a continuing yet oscillating rise of sea level at that time. The soil profiles at Zyyi and Nikitari seem less ambiguous than a flood loam under the Vasilikos channel, so that we prefer to await OSL studies on Zyyi and Nikitari; but their placement in Table 2 remains ambivalent as ‘End-Pleistocene or Early Holocene.’ The older Vasilikos flood silt could be interpreted as a symptom of Neolithic disturbance in the area, but there are no Neolithic or Chalcolithic sites anywhere in the Karyotis, Asinou, or Peristerona watersheds.

6.5. Overview

Despite its uncertainties, Table 2 allows some interim impressions:

(a) Examination of four north Troodos catchments reveals a prominent, cyclical rhythm of erosion or deposition, alternating with stability and soil development. Climatically induced environmental changes have been the overriding force in shaping the Troodos channelways, until Late Holocene times.

(b) There is a reasonable correspondence between our watersheds and those reported from western Cyprus and the Mitsero Basin, but comparison with Dhali-Potamia and the Vasilikos Valley is more complicated. Significant is that TUnit 1 of Table 2 represents Lusignan-Venetian times, but basal deposits in some valleys may be as early as Late Roman; the degree to which this fill may have continued to accumulate during part of the Ottoman period is uncertain.

(c) Without adequate study, some features could mistakenly be attributed to ecological degradation, e.g., the braidplains. But cobble-lags in the Troodos foothills are part of an inherited Pleistocene legacy. Braiding stopped many millennia ago, and the braidplains are fossil.

(d) There may be a temptation to infer changing channel sinuosities or hypothetical meanders from the location of artifactual concentrations found during archaeological survey. But in the north-central Troodos most channels are incised into bedrock and do not shift. They are inherited and fossil. The same applies to cobble lags in channels, such as the Peristerona Fill, which are similarly intractable to shifting under Late Holocene climatic conditions.

Are watersheds too coarse a net to record and preserve a history of land use change? Alternatively, have human impacts on landscape ecology been too subtle or localized, or the evidence overridden by climatic forcing? This can best be examined at the micro-scale, by site or off-site geoarchaeological investigation. Three examples are given here.

7. On-site geoarchaeology

Around the site-complex of Kalavasos-Kopetra, colluvium replete with Late Roman/Byzantine sherds is widespread and between 1 and 2 m thick (Gomez, 2003; Rautman, 2003). But without a spatial context, what does that mean in default of a finer-grained geoarchaeology?

7.1. Episkopi-Bamboula

Bamboula is a low hill, shaped like a settlement mound, but formed of limestone. Although the city of Kourion was abandoned in favor of Episkopi (Fig. 1) during the 7th century CE, Bamboula itself may have been used as a refuge precinct. At the NW edge of the hill, Walberg’s excavations reveal weathered, reddish yellow (7.5 YR) eolian sands of a paleosol. Eastward these sands are banked against an older, light reddish brown (5 YR) clay loam soil with angular blocky structure, that thickens to over a meter in the SE excavation, with calcite laminae dipping parallel to the topography of the underlying limestone contact. The A-horizon is a dark gray brown (2.5 YR) loam of 20 cm. This Calcic Rhodoxeralf (or classic terra rossa soil) reflects a long period of Pleistocene weathering; it was followed by spring seepage charged with calcium carbonate, during a period with accentuated rainfall seasonality.

The sedimentary sequence of interest here rests on the base of the Archaic wall (Fig. 6). It begins with 20–60 cm of buff (10 YR, here and below) loamy colluvium (local Unit 1), that incorporates pockets of derived soil as well as abundant rock from collapse of the wall. Forming the lining of a declivity, this bed is followed by a buff stony colluvium of 20–25 cm (Unit 2A), with scattered and partly upended rocks, resembling a slope channel filling. It grades up into Unit 2B, a homogenous, buff loam (30 cm), with eolian sand and without structure. Again with a smooth transition, Unit 2C follows with a pale brown stony colluvium (15–25 cm), incorporating organic soil material and weathered limestone. Unit 3 is a buff to pale brown loam (40–60 cm), irregularly stratified, with basal lenticles of reworked humified soil, and pockets of fine to coarse stone. Unit 4 is a grayish brown (10 YR) A-horizon (0–20 cm), partly eroded, perhaps fairly recently.

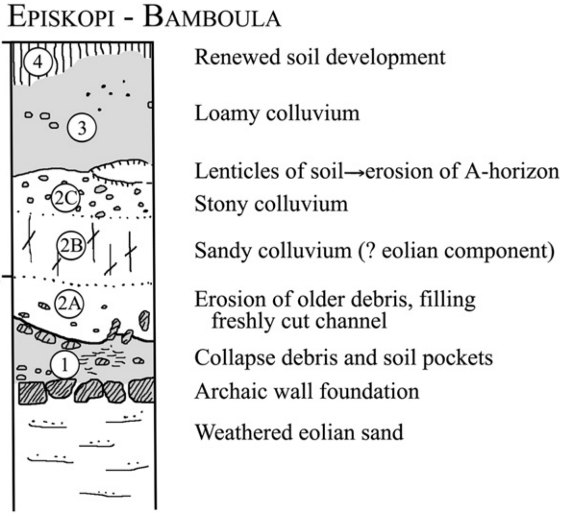

Fig. 6. Composite stratigraphic profile and interpretation for Episkopi-Bamboula (western sector) (this study).

This micro-sequence (Fig. 6) records several phases of erosion upslope, beginning with reworking of local rubble and loose soil, continuing with a strong component of sand, and concluding with erosional products from both A and C horizons of an upslope soil. When erosion stopped, modest soil formation resumed for at least several centuries, perhaps after Limassol was destroyed by the Ottomans in 1538, and this coastal sector abandoned. With only scattered surface sherds, there is no firm dating for the Roman period. But local soil erosion began only after collapse of the Archaic wall (during the earthquake of 365 AD?).

7.2. Tamassos

Tamassos, near modern Politiko (Fig. 1), once was a famous copper-producing town (Buchholz and Untiedt, 1996), and evidence for Late Bronze Age copper extraction and processing has been documented in the badlands further upstream (Given and Knapp, 2003; also Koucky and Steinberg, 1989). Of immediate interest was a former sanctuary of Apollo, the finds of which range in age from the 7th century BC into early Imperial Roman times (Buchholz and Untiedt, 1996, pp. 46–47; Figs. 61c,d, 62, 63, 65). At some unknown point after ∼100 CE one or more great floods tore through this sanctuary and reworked much of the limestone statuary and sculptures within the bed of the Pediaios River, from which an exquisite bronze was uncovered in 1836. The extant museum pieces were excavated from the gravel floor in 1889 by Ohnefalsch-Richter (1894).

The modern channel is 15–20 m wide, and runs between bars of coarse and cobble gravel, directly on top of bedrock. According to the rough survey map of Ohnefalsch-Richter (reproduced in Buchholz and Untiedt, 1996, Fig. 61b), the sanctuary was once situated on what today is a cobble floodplain with a covering, cumulic soil, 2 m higher than the channel floor and forming a terrace 200 m wide. But this alluvial surface (our TUnit 1) is younger than the sanctuary, which must have been located on an older, bedload valley bottom. Most of the larger archaeological objects were concentrated in linear fashion but, given the mass of the colossal limestone statue and a stone chariot set, the core of the sanctuary would have been close by.

Despite the vulnerable original setting, the site appears to have been stable for perhaps 700 years before it was ravaged by flood. Much of the old floodplain was then destroyed and a new channel created, running directly through the former sanctuary and some 70 m west of the original course. This avulsion points to a peak discharge exceeding the hydraulic threshold for cobble mobilization. In 1889 the original, eastern branch had atrophied, but remained visible, so that there has been little channel remodeling since the late or post-Roman flood disasters.

This is remarkable, because if it is a complete picture, it implies that the environment around Tamassos had remained stable during a millennium of ongoing copper production and tree-felling upstream of the early metallurgical center.

7.3. Athienou-Malloura

With the cooperation of Michael Toumazou, significant detail was gleaned from the geoarchaeology of Athienou-Malloura (Figs. 1 and 7). The site complex consists of tombs, an Archaic to Early Roman sanctuary, a Roman to Byzantine settlement, and evidence for Venetian and later use (Toumazou et al., 1998). It is situated amid tabular hills on a wide, rolling plain formed by Miocene limestone, marls, and chalks.

The foundations of a first, Archaic to Classical sanctuary (∼600–400 BCE?) rest on bedrock some 2.5 m below the modern land surface (Fig. 7). They are directly overlain by

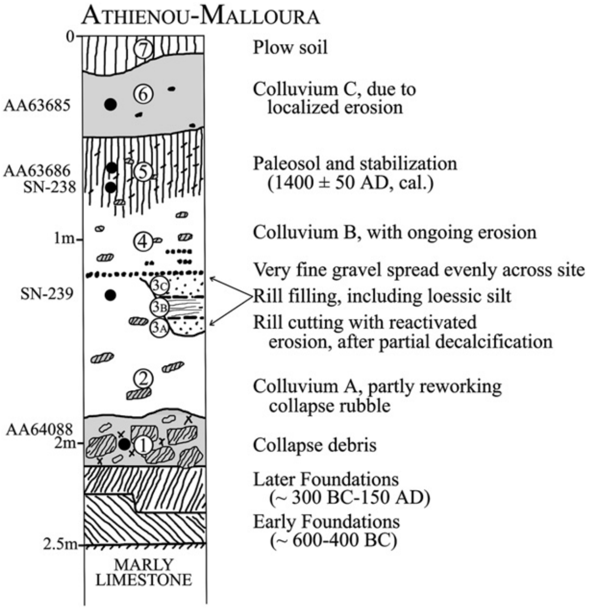

Fig. 7. Composite stratigraphic profile and interpretation for Athienou-Malloura (this study). AA numbers indicate University of Arizona AMS samples, SN numbers refer to samples with insufficient organic matter for dating.

the base of another, Hellenistic to Early Roman sanctuary (∼300 BCE to 150 CE), but with a different orientation. Neither here nor in the rock-cut, Archaic to Early Roman tombs (5th century BCE to 2nd century CE) of Mağara Tepesi is there evidence of colluvial activity at the time.

After the second sanctuary fell into disuse, a white (all Athienou hues 10 YR) colluvium (A) of 70 cm accumulated fairly rapidly over the collapse rubble (Unit 1) even as the sanctuary continued to disintegrate. This local Unit 2 fills small irregularities and incorporates large stones, suggesting sheetflooding or rill flow on a slope without groundcover. A barely finite AMS date of 99.8 ± 0.4 pMC (AA64088) would appear to be contaminated with post-nuclear humic acids.

A more stable period followed, before surging rill flow excavated a shallow channel which was then filled with three subunits of buff sediment (40 cm): of these, Unit 3A is a loamy sand with concentrated magnetic minerals and a reduced chalky matrix that had been partly decalcified in the interim; Unit 3B is a laminated, loess-like silt, possibly derived from eolian dust; and Unit 3C is a chalky, loamy sand with evidence of soil structure and lower energy flow. At that point in time, a thin (1–5 cm) horizon of very fine limestone pebbles (3–8 mm diameter) spread evenly across much of the site, with a half-degree dip (Unit 4A). Accumulation of the buff colluvium (B) (Unit 4B, 45 cm) followed a chalky sandy loam with dispersed stones and lenticles of very fine gravel. This microstratigraphy of rapidly changing facies suggests anomalous climatic patterns, with erosion facilitated by a degraded ground cover that allowed an even and uninterrupted dispersal of the pebble horizon (Late Roman/Byzantine).

These units grade up into a chalky loam (Unit 5), that was weathered to a paleosol with coarse columnar structure, and has an AMS humate date of 1400 ± 50 cal. CE (AA63686, Fig. 7). This is a Calcixerollic Xerochrept (or xerorendzina), that formed while the groundcover recuperated, probably after the nearby hamlet was destroyed and abandoned during the mid-7th century. Soil formation continued even after the local area was resettled during Late Medieval and Venetian times; local climate apparently was wetter and more equitable, with sufficient water to operate a local gristmill, given the breached dam on a small dry creek and two large millstones.

A dramatic turn of events, perhaps in late Ottoman times, saw cutting of a 50-cm deep channel that was filled with a structureless plug of white, chalky loamy sand ("Colluvium C") (Unit 6); it suggests a rapid mudflow, a damaged ground cover, and recurrent extreme precipitation events. The AMS date is hypermodern (103.9 ± 0.5 pMC) (AA63685) and is rejected. Probably relevant is that houses of a nearby hamlet were standing empty in 1882 (see Kitchener and Grant, 1885), and the site surface today is mantled by a white to light gray, anthropic soil, that dries to the consistency of adobe.

The Athienou sequence (Fig. 7) argues for Archaic to Early Roman landscape stability, followed by an interval of rapid soil erosion (Colluvium A). The long, gentle slope had stabilized before Late Roman/Byzantine times, when a more protracted and complex period of soil erosion (Colluvium B) appears to have begun. We attribute this erosion to a combination of extreme weather anomalies and intensive land use, with degradation of the biotic mantle (compare Butzer, 2005, Table 1). Once the area was abandoned, there was partial environmental reconstitution, with sustained soil formation. Stability continued despite a resumption of settlement and active land use in Venetian times (Toumazou et al., 1998), probably favored by a greater and better distributed rainfall. Finally, a brief episode of soil erosion during Late (?) Ottoman times also suggests the co-agency of extreme rainfall events.

Tightly controlled by archaeology, the microstratigraphy of Athienou shows pedogenesis and stability during Lusignan-Venetian times, rather than extreme flooding, as in western Cyprus. In the Vasilikos Valley flood silts apparently were accumulating under low-energy conditions during the 15th century CE (a date picked up by AMS assays at three different sites). The partial contradiction between Athienou and western Cyprus may reflect inadequate dating or poor stratigraphic resolution in high-energy fluvial environments, where coarse sediments are repeatedly reworked. But it may also reflect different settlement histories in the Troodos than near Athienou, namely the population growth in the mountains that is implicit from the painted churches built from the 11th to 16th centuries (inventory by Stylianou and Stylianou, 2001), coinciding with the strong mobilization of stream sediments in Deckers' study area. In our view this demands archaeological follow-up in the mountain valleys, to test a promising case of human impact on the environment, in the context of possible climatic perturbations.

7.4. Outlook for site geoarchaeology

In their own right, the three site-specific studies are highly informative. Athienou inspires the most confidence, given a large and deep excavation, exposing a complex record, with additional access to a number of dated satellite sites. There also are analogous features at the older, University of Chicago excavations of Dhali (Fig. 1). The Athienou record highlights land use and environmental change, culminating in Late Roman/Byzantine times, followed by perhaps a millennium of slope stabilization and soil formation. High populations did not necessarily lead to degradation but climatic anomalies had a triggering effect. Tamassos, on the other hand, presents a catastrophic turn of events at some point after the Early Roman era, in spite of more than a millennium of previous large-scale mining and smelting upstream. Finally, at Bamboula there was a succession of small environmental interventions during Late Roman and perhaps later times, possibly within a short time span. Here cultivation was a less likely factor than periodic use of the site as a refuge for crowds of people, repeatedly seeking to escape foreign marauders.

Such priceless insights show how a well-tailored site geoarchaeology can help unravel a local landscape history—something that rarely emerges from standard site reports. The limitations are that we need a dozen more such investigations from the same time range, including the Medieval period, to crosscheck the validity of negative evidence and to evaluate the variability that will emerge from a larger suite of didactic examples.

These might address or draw attention to a number of questions. Is the inference of soil stability or low hydrological variability, from Archaic to Early Roman times, a function of insufficient or unrepresentative data? What transpired during the Late Ottoman period, when the available geo-records are inadequately dated and perhaps not compatible? What other lines of cross-disciplinary evidence could provide a multidimensional perspective? Can dendrochronology, extended into Medieval times by dating of monastery timbers, clarify forest history before 1571, or help identify a more hands-on Ottoman administration on Cyprus during the mid-1700s?

Key sites such as Khirokitia and Tenta were excavated several decades ago, with insufficiently focused geoarchaeological research components. Many Neolithic and Bronze Age sites are on ridges or hilltops, where external sediments are less likely to accumulate. But situations like those of Dhali or Dhali-Potamia are conducive for landscape evaluation. Even within a site, there is much to be learned from study of the changing residues of mudbrick; from laminae due to rain-puddling; from weathering horizons that reflect settlement breaks; or the presence of possible eolian components (see Butzer, 1982, chapters 6, 7). Exploratory trenches can also be dug downslope of hilltop sites, to search for interfingering of artifactual materials with colluvial or fluvial deposits.

Such perspectives unfortunately still are uncommon in later prehistoric archaeology, and call for comprehensive research planning and systematic integration at each stage of a project. To be effective, a geoarchaeologist needs to have a say on where trenches are to be dug, whether in-site or off-site, and how deep they should be. That will of course require considerable adaptation on the part of excavation directors. Even at smaller projects with modest funding it is possible to secure professional input if the archaeologist is better informed and makes a serious effort to consult knowledgeable people. Much the same applies to the potential role of bioarchaeologists (see Table 1).

8. Concluding discussion

The primary goal of this paper has been heuristic. It does not presume to sketch an environmental history for Cyprus. Nor does it attempt to review the status of Mediterranean geoarchaeology or claim to implement a novel technology. It does however call for something more than routine alluvial histories, and for the presence of an engaged geoscientist at ongoing excavations. It further appeals for more sophisticated conceptual frameworks, that include genuinely interdisciplinary strategies, and more effective geoarchaeological implementation at several scales. That applies to the directors of archaeological projects as much as it does to the associated geoscientists.

This general plea is central to the research agenda articulated here, namely that just ‘doing’ some geo-science work probably will not answer the important questions. An effective geoarchaeology is predicated on research at several scales and with somewhat different procedures. Watersheds and sites represent complementary categories and arenas of study. In isolation, neither the one nor the other may prove adequate to fully appreciate the systemic interweaving of variables in space and time. Environments are complex, and identifying, let alone interpreting, change depends on how well we can separate the impact of background climatic change, the sporadic or sustained intervention of people and land use, and the many potential feedbacks intrinsic to the environment in response to natural or human inputs. There are no simple answers or diagnostic tests. Environmental history requires multiple readings, attention to interlinear clues, discourse, and deconstruction of accepted truths.

A few questions will make the point. Thus it is our impression that slope stability during the last 2700 years was at least as sensitive to climatic anomalies as it was to land use practices. Whether true or not that identifies a number of issues:

(a) Was the soil erosion documented at these Cypriot sites sufficiently common, massive, sustained, and synchronous to leave an imprint on the alluvial record? Our case studies identified localized phenomena that did not necessarily impact watershed hydrology. Does that imply that transformations during the last two millennia did not impact watersheds as a whole? In the Troodos valleys there is only one, but very complex feature (TUnit 1, Table 2) that appears to fit in this time frame. The Troodos was marginal to settlement until the discovery of copper ore in the pillow lavas of the Troodos piedmont, but became important during Medieval times.

(b) Was there just one cluster of catastrophic floods like that of Tamassos during perhaps a millennium? That seems unlikely, but the lack of information to answer the question properly clarifies the need for a much more comprehensive data base.

(c) Were the cyclic pulses of climate a driving force or merely a trigger in transforming landscapes already under heavy land use? Evidence from the Greek Peloponnese suggests that after the Bronze Age, climate was mainly a trigger pushing a stressed ecosystem across a threshold to disequilibrium (see Butzer, 2005 and unpublished). More work is called for to examine this proposition for Cyprus.

(d) Was land use stress on Cyprus insufficient to effect significant biotic change without climatic reinforcement? Without much more bioarchaeological information that is a moot point, but a fundamental one.

It is tantalizing that the geoarchaeological and Quaternary insights of this study suggest severe constraints to the amplitude and spatial extension of anthropogenic impacts on Cyprus. We therefore propose a testable hypothesis, that the environment of Cyprus has suffered more by *attrition* than by devastation, and that long intervals of partial ecological recovery followed upon periods of intensive land use pressure. How that would have played out with insular and foreign demands on the timber resources of the Troodos remains unclear. In our mountain watersheds there is no case for cumulative ecological degradation during the mid or Late Holocene. At times, some sectors of the forest may have been felled for shipbuilding, but the rugged terrain and a lack of navigable rivers probably sheltered the most valuable stands—the cedars and black pines—from wholesale destruction. Access, distance, elevation, and topography will always have worked in favor of forest survival on Cyprus. Despite the litany of lamentations about the *condition* of the forests since 1860, no specialist has ever suggested that the old-growth Troodos forests are 'secondary.'

The tentative evidence for partial biotic recovery and pedogenic renewal supports the notion that the Mediterranean biota of Cyprus were sufficiently resilient, so that environmental transformation was cyclical, rather than linear and progressive. Landscapes can deteriorate, especially after agricultural abandonment, but they may also be reconstituted (see also Butzer, 2005).

Oral accounts of the productive 20th century cultivated landscape of Athienou stand in dramatic contrast to the picture of desolation given by Turner for this countryside in 1815: "long grass, brushwood, heath and thistles" (in Cobham, 1908, p. 436). But how significant was the difference? Except for steeper hillsides, cultivated fields have replaced Mediterranean shrub-brush. There were very few people in the villages in 1815, and land use was mainly pastoral. There is no evidence for a recent change in the soil resource, and spring activity remains minor. What Turner failed to see in 1815 were people tending manicured, cultivated fields. He could not relate to a semiarid pastoral landscape. How is a 'degraded' Mediterranean landscape 'supposed' to look? How profound are cycles of demographic growth and decline for destruction or resilience of the enduring land, and what does that imply for sustainability?

Acknowledgements

The Cyprus Department of Forests and its staff facilitated this research in numerous ways. We thank the Director of Forests, Aristos Ioannou, for allowing us access to his staff, and Alexandros Christodoulou, the Chief Conservator of Forests, for the time he devoted to our exploration of the Troodos and Paphos Forests and the insights he provided. We especially appreciate the interest and inputs of Michael Toumazou (Davidson College) and Gisela Walberg (University of Cincinnati) in showing us Athienou and Episkopi, and giving us permission to study their ongoing excavations. A special thanks for Michael's generous hospitality, so redolent of Mediterranean culture. We are also grateful to Karl Appuhn, Alastair Dawson, Eric Dursteler, Michael Given, Carol Bliss Griggs, Bernard Knapp, Peter Kuniholm, Jay Noller, Sturt Manning, Alan Simmons, and Kevin Walsh for discussion or information. Paul Hudson, Timothy Beach, and two other referees provided critical feedback. John Oswald contributed significantly to the field phases of the study, and was responsible for digital drafting of the figures. Robert Dull facilitated the magnetic susceptibility readings. This project was made possible in part by the endowment of the R.C. Dickson Centennial Professorship of Liberal Arts, the University of Texas at Austin.

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