Land Use and Soil Erosion in Prehistoric and Historical Greece

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Soil erosion resulting from human exploitation of the land has attracted much public and scientific interest. Being regarded mainly as a modern phenomenon, however, its prehistoric and historical extent remain largely unexplored. Here we summarize three regional studies of Holocene erosion and alluviation in Greece, together with information derived from the literature, and conclude that most recorded Holocene soil erosion events are spatially and temporally related to human interference in the landscape. Wherever adequate evidence exists, a major phase of soil erosion appears to follow by 500–1000 years the introduction of farming in Greece, its age depending on when agriculture was introduced and ranging from the later Neolithic to the late Early Bronze Age. Later Bronze Age and historical soil erosion events are more scattered in time and space, but especially the thousand years after the middle of the 1st millennium B.C. *saw serious, intermittent soil erosion in many places. With the exception of the earliest Holocene erosion phase, the evidence is compatible with a model of control of the timing and intensity of landscape destabilization by local economic and political conditions. On the whole, however, periods of landscape stability have lasted much longer than the mostly brief episodes of soil erosion and stream aggradation.*

Introduction

Soil erosion has been regarded as the inevitable outcome of human land exploitation (Brown 1981) ever since such disasters as the North American "dust bowl" of the 1930s (Borchert 1971) drew public attention to the devastating effect of soil erosion on agricultural productivity and the environment. Wolman (1967) has elegantly illustrated its consequences in his study of a woodland area in Maryland which, in its original state, lost 0.2 cm of soil per 1000 years. The spread of farming in the 19th century raised this fifty-fold but when, in the early and middle 1900s, part of the land was returned to forest, the rate dropped back to 5 cm/1000 yrs.

Clearing land for farming, farming itself, deforestation for timber and by grazing, and man-made fires are the most important causes of accelerated anthropogenic soil erosion (Butzer 1982: 123–145), but there are many others (Park 1981). The resultant loss of soil in the uplands and catastrophic sedimentation in valleys and coastal plains are obvious today in many parts of the world (Butzer 1974). Judson (1968) has estimated that the total sediment load of the rivers of the world has increased nearly threefold since the arrival of human beings on earth.

In the Mediterranean, Forbes and Koster (1976) have pointed out the consequences of farming and overgrazing, Hughes (1983) and Thirgood (1981) those of timber cutting for shipbuilding, and Wertime (1983) the effect of firewood exploitation and industrial charcoal-making. It is therefore not surprising that the barren character of much of the Mediterranean landscape has been widely regarded as the result of human carelessness, thus dating the erosion to the Holocene.

To examine these issues further, the senior author in 1979 began a series of studies of prehistoric and historical soil erosion in Greece. The first of these, a part of the Argolid Exploration Project of Stanford University (FIG. 1), yielded a model that related soil erosion and alluviation primarily to human land use (Pope and van Andel 1984). Additional data were subsequently obtained in the different settings of the Argive plain (Finke 1988) and the Thessalian Larissa basin (Demitrack 1986) to test and refine this model. Below we present, after a brief synopsis of Vita-Finzi's (1969) scheme for the late Quaternary history of Mediterranean alluviation, a synthesis of the Stanford project and compare it with data on Greek soil erosion culled from the literature. We emphasize that ours is a geoarchaeological, not an archaeological, perspective and that, in contrast to the work of, for example, Osborne (1987) or Alcott (1989), we touch only in passing on matters of land use practices and rural economics.

Previous Concepts of Mediterranean Alluviation

In 1969, Vita-Finzi, using a large body of evidence from across the entire Mediterranean, presented a simple history of late Quaternary stream deposition that has provoked much debate and has had considerable influence on archaeological thinking. In his stimulating book he defined two major phases of alluviation, the Older and the Younger Fill, each silting up stream channels, valley floors, and coastal plains that had been incised during a preceding erosional phase. Because the Older Fill tends toward red tones, the Younger one to browns and greys, these units can be recognized even from afar. Renewed incision, continuing today in most valleys, terminated the Younger Fill. Vita-Finzi placed the Older Fill in the late Pleistocene (ca. 50,000–10,000 B.P.), while archaeological data suggested to him that the Younger Fill had been deposited between late Roman (ca. A.C. 400) and early modern times. Both events were attributed to climatic factors.

Vita-Finzi's model has been applied in Greek archaeology by Bintliff (1976a, 1976b, 1977). Believing that the Older Fill required much higher rainfall than occurs at present, he correlated it with a presumed pluvial phase of the early or middle part of the last glacial. Like Vita-Finzi he attributed the Younger Fill to climate changes thought to have taken place between the middle of the first millennium A.C. and late Medieval times.

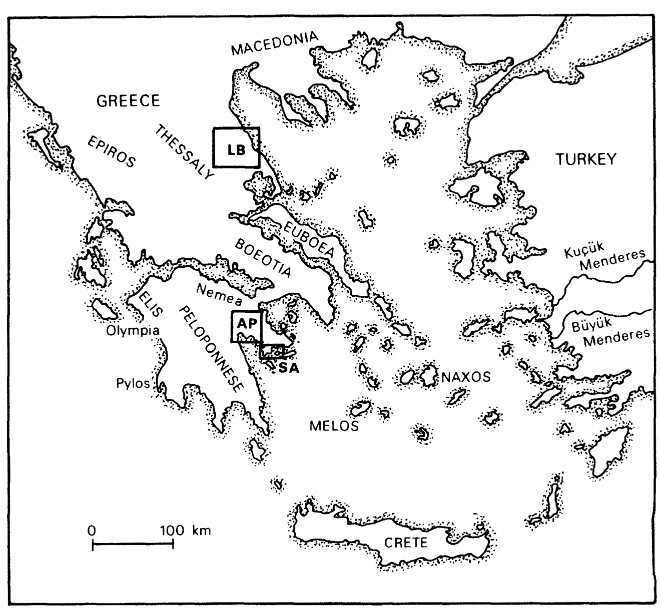
The Mediterranean is large and diverse in terms of human history, bedrock, tectonic state, climate, and vegetation. This renders such a simple model suspect from the start; criticism soon emerged (Butzer 1969), and alluviation events were described that differed regionally in age and character and indicated the existence of more than two units (Davidson 1971, 1980; Eisma 1964, 1978; Kraft, Rapp, and Aschenbrenner 1975; Kraft, Aschenbrenner, and Rapp 1977; Raphael 1968, 1973, 1978). Such diversity also suggests causes other than climatic change, which is likely to have a more uniform regional effect. Consequently, Wagstaff (1981), after a comprehensive analysis of the evidence for the complex history and local variability of late Holocene alluviation, concluded that anthropogenic rather than climatic factors might have been responsible for the Younger Fill.

It thus seems that the Vita-Finzi model as it has been applied to Greek prehistoric and historic land use is too simple or perhaps even erroneous. The three Stanford field studies summarized below were designed to examine this issue in more detail. At the same time, other archaeological surveys in Greece (e.g., Aetolia [Bommeljè 1987]; Boeotia [Bintliff and Snodgrass 1985]; Melos [Davidson and Tasker 1982], Nemea [Cherry et al. 1988]) and elsewhere in the Mediterranean (e.g., Barker et al. 1986; Brückner 1983, 1986; Delano Smith 1979, 1981; Gilman and Thornes 1985) have begun to include geological studies as well. Clearly, Vita-Finzi's ideas, although now obsolete, have raised much interest in the history of Mediterranean soil erosion and alluviation.

Three Case Histories

The three areas of study that form the core of this paper (FIG. 1) have quite distinct characteristics. The Southern Argolid (van Andel 1987) is a small peninsula until recently isolated from the rest of Greece except by sea. Its climate is semiarid Mediterranean, the individual drainages are small, and the short, steep streams flow perhaps once every 10–15 years. The coastal plains are narrow. Relative to Greece as a whole farming was introduced early here (Jacobsen 1976), but until the latest Neolithic and Early Bronze Age it remained limited to the vicinity of a single site (Jameson, Runnels, and van Andel in press; Runnels and van Andel 1987).

Figure 1. Study areas and other geographic locations in Greece referred to in the text. SA: Southern Argolid; AP: Argive plain; LB: Larissa basin, Thessaly.



The second region, the Argive plain, is the heartland of Greek prehistory and has maintained an important position throughout historical times as well. Extensive human exploitation began earlier here than in the Southern Argolid (Finke 1988; Theocharis 1973: 33–110) and continued on a larger scale throughout the following millennia (Dickinson 1982; Hope Simpson and Dickinson 1979; Kilian 1984; Pullen 1985). Its climate, vegetation and geological history are similar to the Southern Argolid, but its rivers are larger and its well-integrated drainage system ends in a wide coastal plain (Finke 1988). Thus, despite their proximity, the Argive plain contrasts with the Southern Argolid in geomorphology, settlement patterns, and history.

The Larissa basin in eastern Thessaly (Demitrack 1986), a large inland plain traversed by the Peneios River and remote from the influence of the sea and changing sea levels, is the third study area. Although the climate is Mediterranean with almost all precipitation in the winter months, the surrounding mountains are much wetter than in the other two regions (Philippson 1948; Furlan 1977), and the main rivers flow all year although with highly variable discharges. Most importantly for our purpose, extensive farming began much earlier in the Neolithic here than in the Peloponnese (Halstead 1984).

The Southern Argolid

This small, rugged peninsula lacks extensive lowlands or coastal plains. The northern half is traversed by steep limestone ridges with large exposures of bedrock, fringed here and there by remnants of red, semi-consolidated Pleistocene fans (FIG. 2). The intervening valleys are filled with alluvium. The softer Pliocene sediments of the southern half are deeply dissected, but the upland marls locally retain remnants of once-extensive, deep woodland soils. An integrated archaeological and geological survey was carried out in this region between 1979 and 1985; Jameson, Runnels, and van Andel (in press), Pope and van Andel (1984), Runnels and van Andel (1987), van Andel, Runnels, and Pope (1986), and van Andel and Runnels (1987) provide the documentation for the following summary.

The Late Quaternary sediment sequence in the area (FIG. 3) comprises seven depositional units separated by soil horizons. Each unit represents an episode of erosion of the headwaters and slopes that resulted in alluviation on the valley floors and small coastal plains. Each unit ends with a loam and a soil profile that indicates a long period of slope stability during which the slow process of soil formation took place. At the same time the stream channels became incised and sedimentation, except for the intermittent deposition of overbank loams in the lower courses of the streams, virtually ceased. The semiarid soils have a thin, rarely preserved upper (A) and a distinct lower (B) horizon. As the soil matures, the B horizon turns darker red in color, acquires a higher clay content and a blocky structure, and develops a lower calcareous horizon (Bca) which evolves from carbonate flecks and stringers by way of well-developed carbonate nodules to a thick, hard calcareous bank. A fully mature soil profile of this type takes many thousands of years to form.

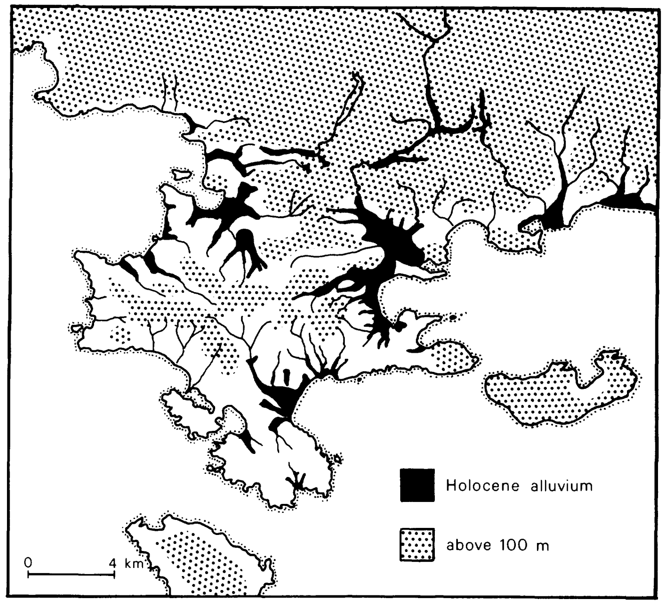


Figure 2. Relief and drainage systems of the Southern Argolid. Area above 100 m above sea level stippled; Holocene alluvium black. After van Andel, Runnels, and Pope (1986: figs. 1 and 3).

The age-related characteristics of the soils (Birkeland 1984: 203–225; Harden 1982) make it possible to correlate depositional units from one valley to another (Kraus and Bown 1986), and to construct a composite stratigraphic section (FIG. 3). In the Southern Argolid, the units of this section have been dated with the aid of prehistoric and historical sites resting on or buried under them, supplemented by the use of imbedded artifacts and ^{14}C and uranium/thorium disequilibrium dates (Pope and van Andel 1984: table 3).

In the small valleys of this region, where the sediments are laid down close to their sources, three sediment types can be recognized (FIG. 3): (1) chaotic, ill-sorted gravels in which the fine fraction supports the coarse components, a feature typical of debris flows (Innes 1983); (2) stratified, well-sorted sands and gravels laid down by streams; and (3) sandy loams formed by overbank flooding. Debris flows occur mainly in the upper reaches of a drainage and

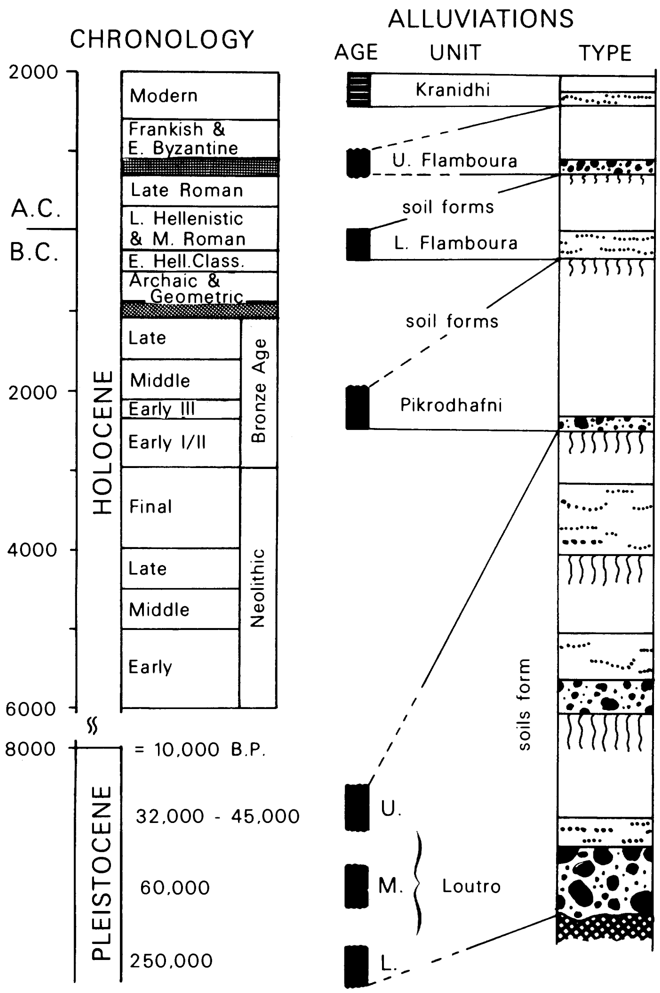


Figure 3. Chronology and stratigraphy of Late Quaternary alluvia and soils in the Southern Argolid. Archaeological timescale after Runnels and van Andel (1987: table 3); shading indicates "dark ages." Date and duration of each alluviation event shown in column labeled *Age* (broken bar: intermittent deposition; wavy terminations: uncertain age boundaries). Note change in age scale between 6000 and 8000 B.C. Black cobbles: debris flows; strings of pebbles: streamflood deposits; blank: loam. Length of wavy vertical lines proportional to soil maturity. Unit heights roughly proportional to thickness. After van Andel, Runnels, and Pope (1986: fig. 4).

are evidence of catastrophic sheet erosion of slopes when decreasing precipitation or human activity reduces the protective plant cover. Streamflood deposits form when gully cutting is enhanced by increased runoff or as a result of damage by livestock or humans. They dominate in the middle course. Overbank loams are the result of floods and are most common in the lower valleys and on the small coastal plains.

Three alluvial units date to the Pleistocene, at ca. 272,000, 52,000 and 33,000 B.P. (Pope, Runnels, and Ku 1984), whereas four mark the last 5000 years of the Holocene. The voluminous Pleistocene units combine all three sediment types, but the thin Holocene ones consist either of debris flows (Pikrodhafni and Upper Flamboura) or of streamflood deposits (Lower Flamboura and Kranidhi), always topped with loam (FIG. 3).

The Holocene alluvia, although thinner and more restricted in extent than the Pleistocene alluvia, are much more closely spaced in time, but all except the youngest one have soil profiles indicative of prolonged slope stability between erosion events. By comparison, most erosion events were brief. The Lower Flamboura event is bracketed by dates that allow a duration of at most a few centuries, and inspection shows that several meters of the youngest (Kranidhi) unit have accumulated since products made of plastic were introduced in the region (Pope and van Andel 1984).

During the Final Neolithic and Early Bronze Age (mid-4th to mid-3rd millennium B.C.), the deep woodland soils of the hills and some valley bottoms of the Southern Argolid were widely settled by farmers (Runnels and van Andel 1987). Evidence for soil erosion, however, is lacking until the end of the 3rd millennium when Pikrodhafni debris flows covered the valleys of those drainages that were occupied by settlers. They are broadly bracketed to between ca. 2300 and 1600 B.C. by the enclosed late Early Helladic II sherds and superimposed Late Helladic sites. This date eliminates initial woodland clearing as the cause of the implied catastrophic sheet erosion of slopes, and van Andel, Runnels, and Pope (1986) have attributed it instead to gradual intensification of land use with shorter fallow, expansion onto steeper, less stable slopes, and the introduction of the plow (ard).

During the Late Bronze Age (Mycenaean), which brought more extensive use of the same soils after a sharp decrease in site density in the early 2nd millennium, soil erosion appears to have been kept in check. This development may be attributed to the introduction of soil conservation by means of terracing and gully checkdams, although no securely-dated terrace walls of this period are known. No soil erosion occurred during the post-Mycenaean "dark age" of the 11th–10th centuries B.C. either, probably because the natural vegetation is capable of rapid recuperation in the absence of tillage or grazing (e.g., Naveh and Dan 1973; Rackham 1982, 1983). Recolonization began in the 8th and culminated in the late 5th to early 3rd centuries B.C. in a major increase in site numbers. The site pattern resembles that of a classic market-oriented central-place distribution (Runnels and van Andel 1987), and the dry, stony fans and alluvia apparently utilized for the first time are well-suited to olive culture (and are so used today) but not for cereal and pulse farming.

Subsequently, during the last few centuries B.C., extensive, well-sorted and stratified streamflood deposits (Lower Flamboura) were laid down in the valleys, simultaneously with a sharp decrease in the number of sites, abandonment of the city of Halieis, and decay of the city of Hermion (Runnels and van Andel 1987). A similar decline has been observed elsewhere in Greece at this time (Alcock 1989), and there is historical evidence for it as well. Alcock (1989) has analyzed this evidence on a much broader base and shows that it can be interpreted either as a rural economic depression or in terms of a different exploitation system not based on single-family farms. Provided this latter mode of land use was to be of reduced intensity, it too could account for the evidence of serious soil loss.

In response to economic stress modern Greek farmers withdraw to their best soils, turning over more distant or poorer fields to pasturage (van Andel, Runnels, and Pope 1986). Without an incentive to repair damage caused by livestock, it takes but a few decades for terrace walls to tumble and gully erosion to strip the stored soil and lay it down in the valley bottoms as streamflood deposits. The evidence for an alternate cause, a climatically-induced increase in runoff, is weak.

Widespread settlement on all usable lands reappeared in Late Roman times (3rd through 6th century A.C.), apparently with good soil conservation practices, because erosion and alluviation did not occur. The landscape continued to remain stable, presumably because of rapid recolonization by the Mediterranean shrub vegetation called *maquis*, during the next period of depopulation which began in the 7th century. Then, possibly as early as the 9th century A.C., upland and headwater areas away from the sea were resettled, while extensive deposition of debris flows took place in the valleys below the new settlements (Upper Flamboura), but stability returned eventually. The final alluviation episode (Kranidhi) began in early modern times. It is localized in extent, happened at different times in different parts of the region, and continues today in several places. Its relation to local economic conditions is clear: land speculation related to a booming tourist industry is more rewarding than olive groves, and the valued crops, such as citrus and vegetables, can only be grown on the best soils. Hence terraces are allowed to decay and land is carelessly cleared with bulldozers (Pope and van Andel 1984; Sutton 1987).

Thus we see a strong case for attributing the frequent but quantitatively minor alluviations of the middle and late Holocene to human activity. Once the Greek landscape had been controlled by soil conservation measures, its equilibrium became precarious, the price of maintaining the equilibrium was high, and economic perturbations were only too likely to disturb it.

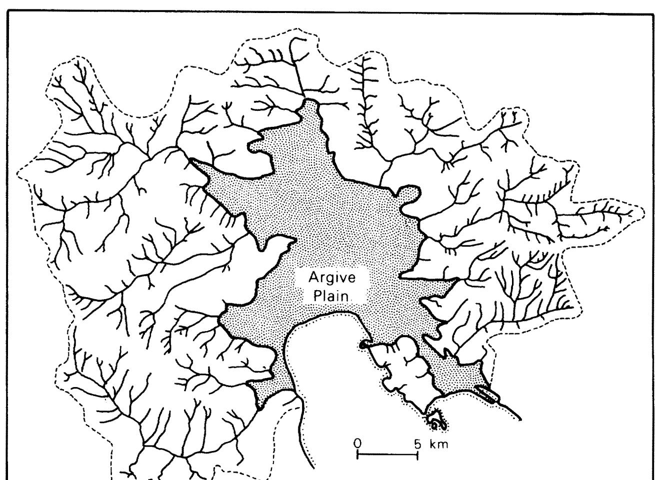
The Argive Plain

The Argive plain (Lehmann 1937) was chosen to test, in a different setting, concepts developed in the Southern Argolid. The investigation, undertaken between 1984 and 1987, was similar in approach to that of the Southern Argolid except that the existing archaeological database was used instead of an archaeological survey. Finke (1988) furnishes the documentation for the following summary. We note that, because in this lowland area river loams and fine-grained coastal sediments predominate, the distinction between debris flows and streamflood deposits, so useful in the Southern Argolid, is not applicable.

The Argive plain, 243 sq km in area, occupies a subsiding coastal basin bordered by the steep slopes of 400–700 m-high mountain ranges and open to the Gulf of Argos. Instead of the small drainages and short streams typical of the Southern Argolid, the region has an integrated drainage system of 1167 sq km (FIG. 4). Sediments eroded from this large region are transported mainly by the seasonal Inachos River which skirts the western margin of the plain and deposited mainly near the present coast, at times causing rapid seaward progradation of the shore (Kraft, Aschenbrenner, and Rapp 1977).

Many large alluvial fans of Middle to Late Pleistocene age (Koutsouveli-Nomikou 1980) fringe the central plain;

Figure 4. The Argive plain and its drainage system. Within the plain, stream courses are not shown because they tend to be ill-defined or have been canalized. After Finke (1988: fig. 9).



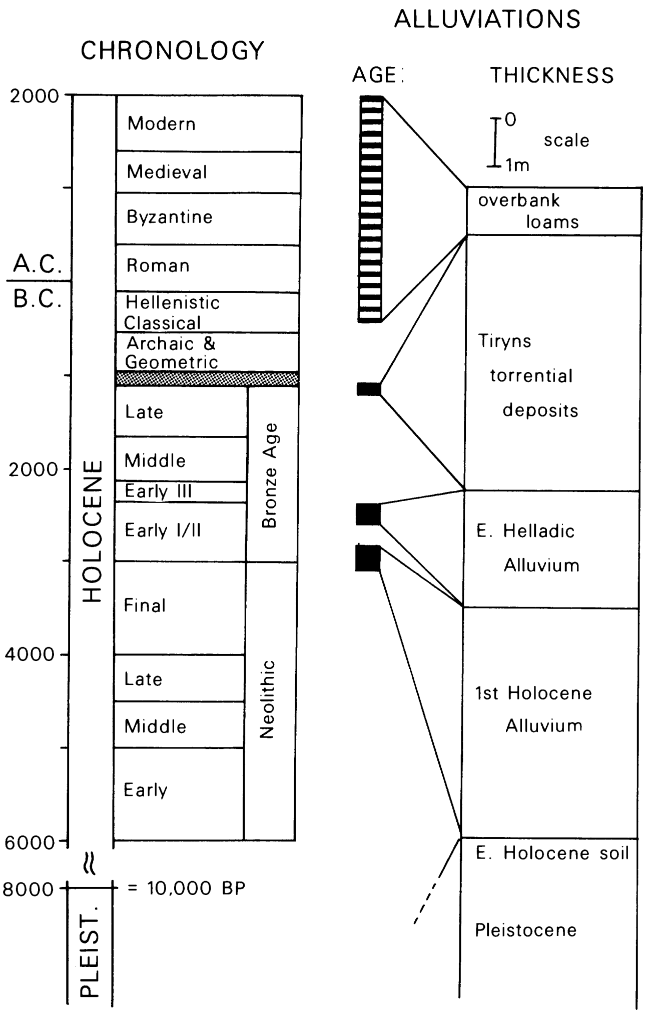


Figure 5. Stratigraphy and chronology of Late Quaternary alluviations of the Argive Plain. Archaeological time scale simplified after Runnels and van Andel (1987: table 3); shading indicates "dark age." Date and duration of alluviation events shown in column labeled *Age* (broken bar: intermittent deposition; wavy terminations: uncertain boundary age). Third column: name and thickness of the alluvial units. After Finke (1988).

their mature soils indicate a long-lasting surface stability. In the plain itself, these deep red paleosols are buried under a Holocene alluvium that reaches a maximum thickness of 8 m at the present coast.

The early and middle Holocene land surface consisted of Pleistocene strata formed during the last glacial when sea level was ca. 100 m lower than today. This surface, marked by a dark-brown organic soil with many roots and locally abundant charcoal and pottery sherds indicating Neolithic or later occupation (Finke 1988), is only preserved where it is buried under younger alluvium.

In the coastal zone, an early Holocene alluvium, consisting of coarse, poorly sorted sediments like those of the Pleistocene fans, rests on this land surface (FIG. 5), but its extent inland is not known. Since it has buried a Middle Neolithic site, it must be later than ca. 5000–4000 B.C. but probably predates 3000 B.C. After this alluviation event the landscape stabilized and a soil formed on the deposits. At the same time, the still-rising postglacial sea continued to push the coastline landward until it reached its northernmost position around 2500 B.C. Coastal outbuilding then began, a process that has continued intermittently to the present day (van Andel and Lianos 1983, 1984).

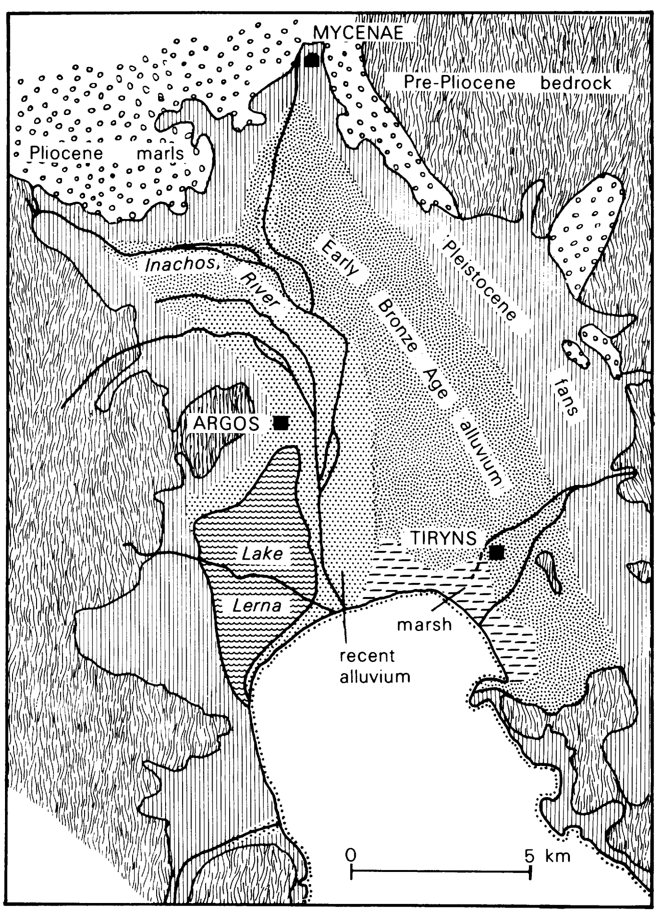
The most pervasive environmental changes in the Argive plain came late in the 3rd millennium B.C. (Early Helladic II). Floodplain deposits, the equivalent of the overbank loams of the Southern Argolid and 1–3 m thick, spread across the early Holocene plain where today they form most of its surface (FIG. 6). This Early Helladic alluvium, easily identified by its reddish brown color, good consolidation, and ubiquitous Early Helladic (Early Bronze Age) pottery, is most extensive on the inner plain and along its streams, but thickest in the coastal zone. Slope stability then returned and lasted until nearly the end of the Late Bronze Age (Late Helladic IIIB), long enough for a soil to form on the Early Helladic alluvium.

This Early Helladic alluviation phase, the largest in the area during the Holocene, resulted from a major soil erosion event that stripped the Pliocene marls and Pleistocene fans of the foothills along the eastern, northern, and NW margins of the plain of most of their brown woodland soils. Bintliff (1976a, 1977) has claimed that those marls were the only ones exploited (and exploitable!) during the Bronze Age. There is no doubt that these soils, as in the Southern Argolid and the Nemea basin (Cherry et al. 1988), were preferentially used and later seriously eroded; only remnants are found today. That erosion, however, took place well before the beginning of the Middle Bronze Age, and its alluvial deposits in the plain would by Mycenaean (Late Bronze Age) times have been much like the old woodland soils themselves in quality or better. Moreover, the swampiness of the Argive plain regarded by Bintliff (1976a, 1977) as an insuperable obstacle to its use as cropland, was in reality very limited in area (FIG. 6; Finke 1988). The ever increasing number of Late Bronze Age, Classical, Hellenistic, and Roman sites found in the plain confirms that the alluvium there was indeed inhabitable and extensively used from at least Mycenaean times on.

Since the late 3rd millennium B.C., no alluviation events have affected the Argive plain in its entirety, although major changes have taken place in the coastal zone. At the end of the Early Bronze Age (Early Helladic III), immediately after the peak of the marine transgression and approximately simultaneous with the Early Helladic alluvium, the rate of sediment supply to the coast increased and a rapid progradation of the shore began. The outbuilding of the coast, although slower during the subsequent period of stream incision, has continued intermittently ever since, its focus episodically shifting from the eastern to the western segment of the coast and back.

This should not be taken to mean, however, that there has been no erosion and sedimentation inland on the Argive plain for 4000 years. Late in the Bronze Age (Late Helladic IIIB), torrential flooding, possibly associated with anthropogenic soil erosion in the large inland valleys on the east side of the plain, buried parts of the lower town of Tiryns under several meters of alluvium (Finke 1988; Kilian 1978). The problem was solved by the construction of a large dam and a diversion channel upstream (Balcer 1974), but this merely displaced the deposition area farther to the SE.

Figure 6. Late Quaternary deposits of the Argive plain. The Early Bronze Age alluvium, derived from the Pliocene marls and Pleistocene alluvium of the surrounding hills, was deposited late in the 3rd millennium B.C. A large lake existed since the Bronze Age in the plain south of Argos but is now reduced to a small swamp. Flood deposits of the Inachos River, its tributaries, and various small ephemeral streams have been laid down intermittently over the past few thousand years. After Finke (1988: fig. 18).



Otherwise, the landscape has remained fairly stable. The remains of Classical, Hellenistic, and later settlements and isolated buildings generally lie less than 1 m below the surface, demonstrating that for the last few millennia sedimentation in the Argive plain has been less than in the Southern Argolid and much less than the thick "Younger Fill," as assumed by Bintliff (1977). The only exceptions are black, unsorted deposits of Classical age near Argos which may be the result of landslides after forest or brush fires.

The present appearance of the Argive plain has thus been shaped by three regional soil erosion and alluviation events, which occurred in the Pleistocene, in the later Neolithic, and in Early Helladic II respectively. Except for episodic progadation of the coast and the intermittent deposition of overbank loams along the Inachos River and its tributaries (FIG. 6), landscape changes since about 2000 B.C. have been of minor extent, although some had a significant local effect.

The two regional alluviation events between 5000 and 2000 B.C. are approximately contemporaneous with the maximum invasion of the sea. Of course, the transgression itself did not increase the rates of erosion and sediment supply, its impact being limited to the coastal zone. The increasing Late Bronze Age population of the Argive plain (Dickinson 1982; Kilian 1984), on the other hand, must have required land clearance or intensified agriculture for subsistence. This could not fail to produce slopes seasonally unprotected by vegetation, soil erosion, alluviation of the plain itself, and an increased sediment supply to the coastal zone as well.

This version of the Holocene history of the Argive plain is at variance with Bintliff's reconstruction (1977) which rests on his interpretation of Vita-Finzi's Younger and Older Fill scheme. Bintliff saw the Argive plain as a swamp of little economic value until ca. 1500 years ago when the Younger Fill, his only Holocene phase of soil erosion, began to bury the wet lowlands. By his estimate, many meters of alluvium were deposited on the swampy plains during historical time. Only when this phase ended about 200 years ago did the soil exist that now supports the thriving agriculture of the region.

In reality, the main erosional event occurred much earlier, and only a single meter of sediments has been depos-

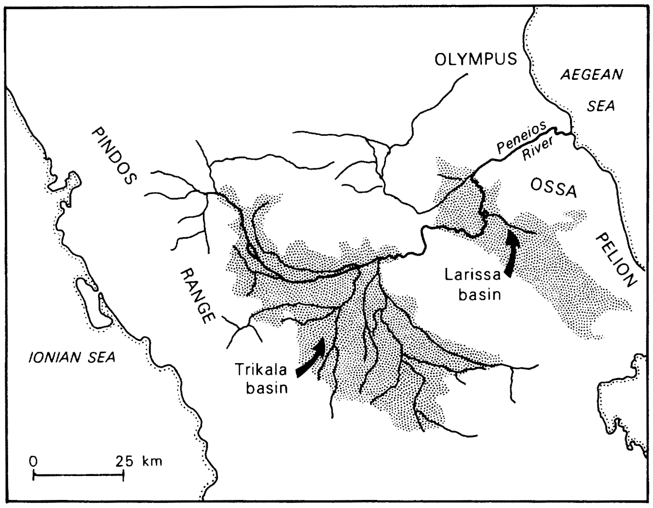


Figure 7. The Peneios drainage system in Thessaly and the Trikala and Larissa basins (shaded).

ited in the last 3000 years or more. Furthermore, except for Lake Lerna and some small, spring-fed ponds and bogs that existed locally prior to the overexploitation of groundwater since the middle of this century, the plain was never a swamp (Finke 1988). Therefore, the soils that are the source of the current prosperity of the Argive plain were available to prehistoric and early historical farmers as well and exploited by them since the Bronze Age.

The Larissa Basin in Thessaly

The Peneios River, rising far to the NW in the high Pindos range, crosses the Thessalian plain before it finds its way, joined by several tributaries, through narrow gorges across the Pelion-Ossa-Olympus coastal massif to the Aegean Sea (FIG. 7). The plain itself, one of the largest in Greece, is divided into an eastern (Larissa) and a western (Trikala) basin by a low NW-SE trending ridge of Pliocene marls (Schneider 1968). Today trees are rare in this region, but before major deforestation took place during the last few millennia, the plain and surrounding hills were covered with an open woodland characterized by *Ostrya* and *Carpinus* and dominated by oaks (Bottema 1979; van Zeist and Bottema 1982).

The Larissa basin was occupied in the Middle and early Upper Paleolithic, but appears to have been (mostly?) deserted during the later Upper Paleolithic and Mesolithic (Runnels 1988). Settled again early in the Neolithic, the population expanded slowly throughout the Neolithic and Bronze Age (Halstead 1977, 1981).

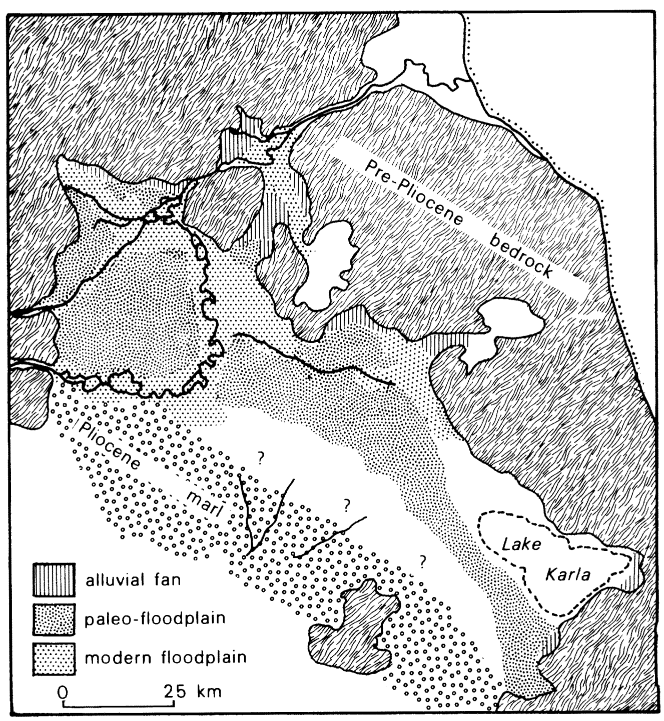
Beginning in 1983, we undertook a detailed study of this basin with methods similar to those employed in the Southern Argolid, using the archaeological background compiled by Halstead (1984). For documentation of the following summary see Demitrack (1986). We note that, as in the Argive plain, we deal here with a lowland river plain where the distinction between debris flows and streamflood deposits used in the Southern Argolid is not applicable.

Alluvial fans fringe the tectonically-active northern rim of the Larissa basin, but the basin itself is covered with river deposits (FIG. 8). As in the Southern Argolid and Argive plain, deposition has been episodic throughout the late Quaternary, each unit ending with a paleosol indicative of a long period of slope stability during which the streams incised their valleys.

Eight fan units, separated by paleosols and ending around 54,000 B.P., constitute the earliest dated Pleistocene sequence (Old Red fans: FIG. 9). After a period of tectonic activity and stream incision, fan building (New Red fans) resumed during the last glacial maximum until stream incision took over once again around 14,000 B.P. The minor Rodia fan unit formed a few millennia later. In the Holocene fan building was reactivated twice, between 5000 and 4000 B.C. and in historical times (Old and New Deleria fans).

The floodplain deposits form two groups now at different elevations: 1) an older, Late Pleistocene to Middle Holocene set called the Niederterrasse (Schneider 1968),

Figure 8. Late Quaternary floodplain and fan deposits of the Larissa Basin, Thessaly. The Agia Sophia, Mikrolithos, and Girtoni floodplains are shown together as Niederterrasse. After Demitrack (1986: fig. 6).



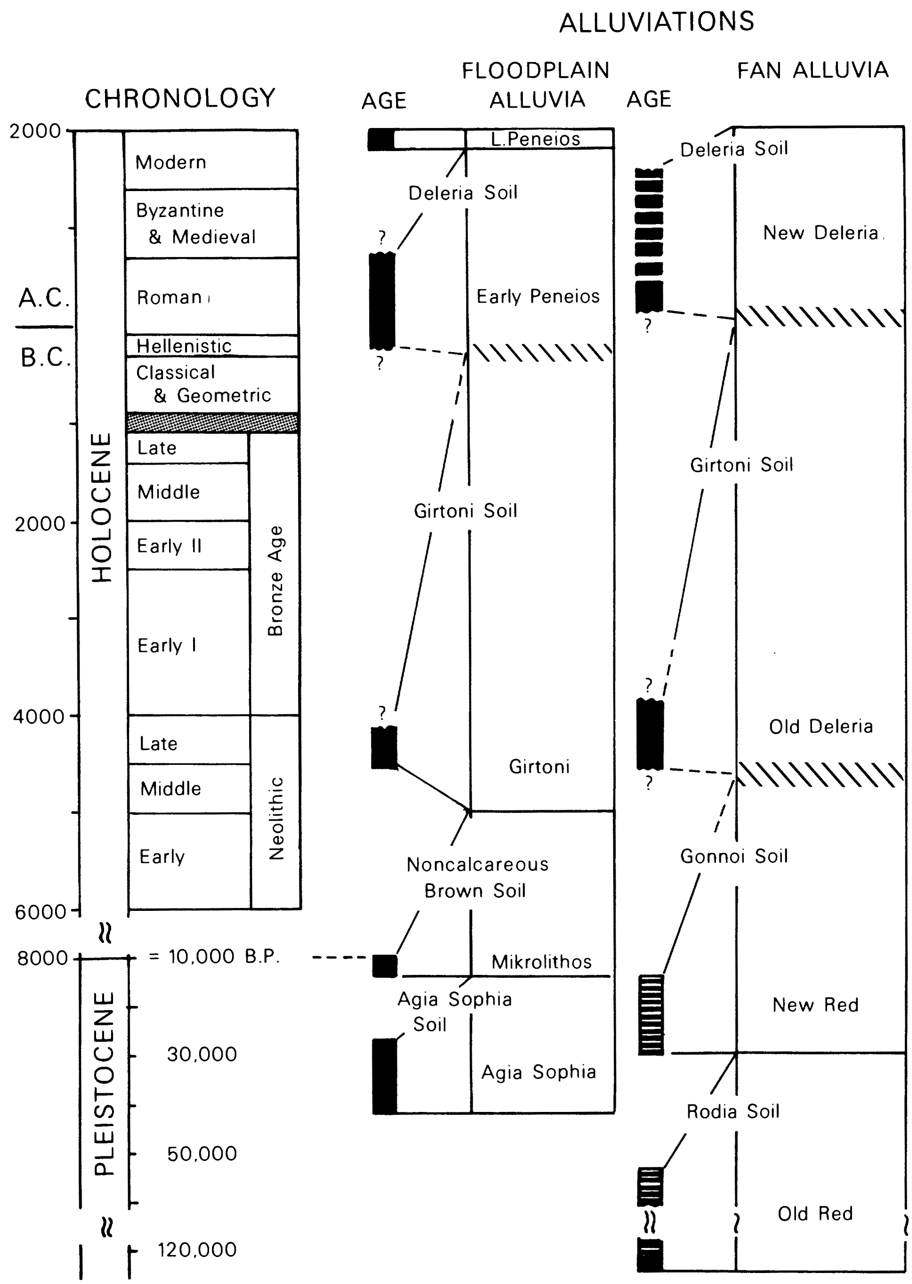


Figure 9. Stratigraphy and chronology of Late Quaternary floodplain and fan alluvia and their soils in the Larissa basin, Thessaly. Archaeological chronology after Halstead (1984: section 4.2). Date and duration of alluviation events shown in column labeled *Age* (broken bars: multiple units; wavy terminations: uncertain boundary age). Note change in age scale betwen 6000 and 8000 B.C. After Demitrack (1986).

now well above the river; and 2) a lower, historical pair (FIGS. 8, 9) that forms the present floodplain. The earliest and most extensive unit of the Niederterrasse (the Agia Sophia alluvium) dates to the middle of the last glacial (ca. 40,000–27,000 B.P.), and is topped by a mature paleosol (Agia Sophia soil). Deposition resumed between 14,000 and 10,000 B.P. with the Mikrolithos alluvium on which the Noncalcareous Brown soil formed during an early Holocene period of landscape stability. The construction of the higher floodplain was completed in the middle Holocene with the deposition of the Girtoni alluvium, topped by the Girtoni soil.

The present floodplain, built in two stages that could be archaeologically dated, lies 5–15 m below the Niederterrasse. The first episode (Early Peneios alluvium) seems to have Roman structures on it, and has an immature (Deleria) soil, but without further work its precise age cannot be established. The Late Peneios alluvium is from the last few centuries and too young to have a well-developed soil.

Numerous Neolithic and Bronze Age settlement mounds rest on the old floodplain surfaces of the Larissa basin, of which a subset was correlated with the various alluvial units (Demitrack 1986: 33–39, table 5). At least some of the earliest Neolithic settlements were built ca. 6000 B.C. on the late Pleistocene Agia Sophia soil, which had by then been eroded down to its calcareous lower B horizon. There is, on the other hand, no evidence that the Mikrolithos surface, formed between 12,000 and 8000 B.C. (Demitrack 1986: table 3), was occupied or exploited until the Middle Neolithic (5000–4500 B.C.).

In the Bronze Age many sites were established on top of the Girtoni alluvium, thus dating its deposition to ca. 4500–4000 B.C., about 1000 years after the high Thessalian floodplain began to be farmed (the Thessalian Bronze Age [Halstead 1984] begins 4000 B.C., being partly synchronous with the Final Neolithic of FIGS. 3 and 5). At least one Late Neolithic site also occurs on the Girtoni surface. Its edges are covered by more than a meter of Girtoni alluvium, with a soil profile suggesting that it was subject to intermittent slow sedimentation during spring floods.

The depositional history of fan and floodplain sediments in the Larissa basin is a function of distant events in the high Pindos and at the Peneios River mouth, as well as of intrabasin climatic, tectonic, and anthropogenic factors. The coincident beginning of the dry (Bottema 1979; van Zeist and Bottema 1982) glacial maximum and cessation of Agia Sophia aggradation in the floodplain, and the renewal of floodplain deposition (Mikrolithos alluvium) during the shift from dry late glacial to more humid post-glacial conditions (van Zeist and Bottema 1982) imply climatic control. Fan building, on the other hand, did occur also during the dry late glacial, responding to intermittent tectonic activity rather than to climate alone.

Here the human factor is of greatest interest. The Girtoni alluviation, coming about 1000 years after the Larissa basin was first settled, points to a causal relationship between land use and the resumption of soil erosion and floodplain aggradation in the middle Holocene. During those 1000 years the number of sites, and presumably the population, increased steadily (Halstead 1977, 1984) without serious loss of soil. Therefore, as in the Argive plain and Southern Argolid, the initial land clearance cannot be held responsible for the erosion.

Eventually, however, soil erosion did take place. Halstead (1981, 1987, 1989) has argued that, given the low population density of Neolithic Thessaly and the good fertility of its virgin soil, the continuous use of a small area of cultivation adjacent to each settlement would have sufficed to provide the cereals and pulses needed for the slowly growing population. He visualized tiny, self-sufficient villages, isolated in woodland clearings, that exploited rain-fed, animal-fertilized fields (Halstead 1987, 1989). At the same time, an increasing proportion (and number?) of goats and cattle relative to sheep were being grazed in the woodlands between the settlements, producing progressive woodland degradation (Halstead 1981). He did not, on the other hand, see evidence that the slopes of the Larissa basin were exploited to any great degree.

The pollen record for Thessaly, admittedly difficult to interpret in terms of human interference (Bottema 1982), fails to provide solid evidence for extensive forest clearing during the Thessalian Neolithic (Bottema 1979); the trend towards a more open and drier woodland seen after ca. 8000 B.P. can be explained adequately by climatic change, but could indicate progressive degradation by grazing as well.

Halstead's concept of little villages fails to account for the record of Neolithic erosion. First, the overlap of Girtoni alluvium onto the feet of several mounds indicates that some sites were located in, and their inhabitants presumably exploited, lands that flooded when the river was highest in the spring, with the great advantage that the renewable fertility of such fields lessened dependence on rain as well as on animal fertilization. Second, the considerable soil erosion producing the deposits of the Girtoni alluvium appears to have stripped the Agia Sophia and Mikrolithos (Noncalcareous Brown) surfaces of the Niederterrasse, as truncated soil profiles under the earliest Neolithic settlements on the Agia Sophia surface attest (Demitrack 1986). Because the Niederterrasse has a low relief, the erosion producing the Girtoni deposits must have been extensive and not likely to come mainly from degraded woodland, no matter how degraded this may have been. Detailed study of soil types and patterns around settlement mounds, in the manner of the archaeological map of the Netherlands (van Es, Sarfatij, and Woltering 1988: 101–108), would help to address these issues.

Discussion: Land Use and Soil Erosion in Ancient Greece

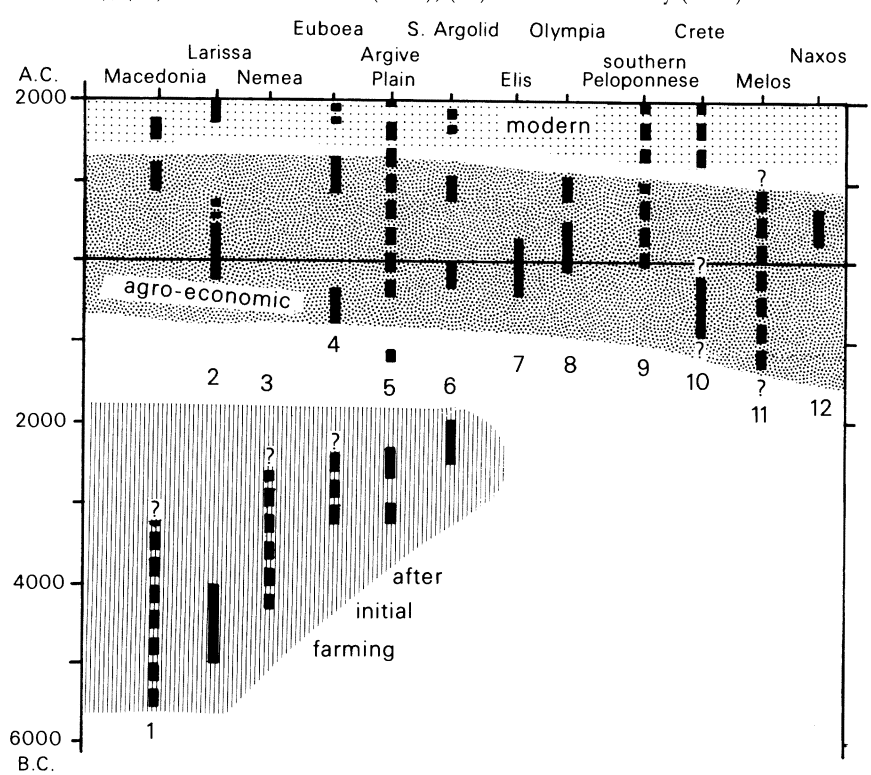
Our three studies cast little light on Pleistocene slope erosion and stream aggradation, because detailed stratigraphic sections and a chronology of sufficient reliability and resolution are not available. The Thessalian sequence shows how complex the dependence of late Quaternary alluviation had been on changes in neotectonic activity, climate, sea level, runoff, slope stability, and vegetation: a conclusion not unexpected for this time of major tectonism and climatic change. Neither the Argive nor the Thessalian sequence correlates with global glacial-interglacial or stadial-interstadial climatic changes, suggesting that a NW European sense of the geomorphological effect of the Pleistocene upon the landscape needs to be adjusted when we deal with the eastern Mediterranean.

This is regrettable, because there is the suggestion that these were the times that, in essence, shaped the present Greek landscape and that it was stripped by nature much more than by man, as Hutchinson (1969) has suggested for Epiros and Rohdenburg and Sabelberg (1973) for the western Mediterranean.

The Holocene alluviation history (FIG. 10) presents an altogether different case. The last two decades have seen a considerable deepening of our understanding of the depositional and postdepositional processes in continental settings, and the resolving power of our chronological and environmental methods has much increased. The stratigraphic use of paleosols has added a new dimension to correlation and chronology, and integration with archaeological surveys also has proved to be a powerful approach.

The Holocene histories of soil erosion and valley deposition of the Southern Argolid, the Argive plain, and the Larissa basin agree only in part, even if we allow for large uncertainties in dating (FIG. 10). Somewhat surprisingly, in view of the major climatic change involved, which includes the postglacial warming and greatly increased precipitation (van Zeist and Bottema 1982), the landscapes of all three regions seem to have remained stable from the late Pleistocene through the early Holocene. Major slope destabilization and alluviation did not come until much later, about 1000 years after the first spread of settlement and farming. In the Argive plain and Thessaly, these early alluviations were also the most extensive and

Figure 10. Chronology of Holocene alluviation events in Greece and the Aegean. Broken bars are dated uncertainly or represent intermittent deposition. Dates taken from the original publications: (1) L. Faugères in Delibrias (1978); (2) Demitrack (1986); (3) Cherry et al. (1988); (4) Genre (1988) and Rust (1978); (5) Finke (1988); (6) Pope and van Andel (1984); (7) Raphael (1968, 1973, 1978); (8) Dufaure (1967) and Büdel (1965); (9) Hempel (1982, 1984); (10) Hempel (1982, 1984); (11) Davidson and Tasker (1982); (12) Renault-Miskowsky (1983).



voluminous ones; their regional extent and influence on the landscape exceed that of all later episodes. In the Southern Argolid the early phase, although quite marked, is smaller than, and mostly buried under, the deposits of the later Hellenistic-Early Roman erosional event.

Subsequently, the histories of the individual areas diverge. The torrential floods of the Late Bronze Age that affected the important but small area of the Argive plain near Tiryns are absent in the Southern Argolid. There, however, very extensive alluviations took place in the late first millennium B.C., and again in early medieval times. Other erosion/alluviation events, smaller and more dispersed in space and time, have intermittently troubled various Argolid valleys since the 17th century. These early medieval and more recent alluviation episodes of the Southern Argolid probably correspond to those of the low Peneios floodplain in Thessaly, although the dating of the latter is uncertain. The Argive plain, on the other hand, has remained essentially stable since the Bronze Age.

Some alluvia are dated closely, for example by the common occurrence of datable pottery fragments in Argive plain sediments or by the accurate positioning of sites of known age on or under alluvial units in the Southern Argolid, to show short durations and rapid sedimentation. Near Tiryns, 4.8 m of Late Bronze Age (Late Helladic IIIB2) sediments were deposited in as little as 50 years, and the Late Hellenistic- Early Roman event in the Southern Argolid (Lower Flamboura) did not last more than two or three centuries. The age of many alluvia is not as well constrained, but many of them also have been quite brief. In contrast, the degree of maturity of the late Pleistocene and all but the latest Holocene soils shows that the episodes of stability and soil formation have lasted thousands to tens of thousands of years. Overall, stability appears to have been the prevailing state of the Greek landscape during the last 100,000 years or more (see Thornes and Gilman [1983] for a similar conclusion concerning the Iberian peninsula), destabilization being a rare and often brief event.

The same spatial and temporal diversity of the Holocene alluviation history can be inferred for other parts of Greece from the literature (FIG. 10). Unfortunately, few data are available for the Neolithic and Early Bronze Age, surely in part because the earliest Holocene alluvia resemble the "Older Fill" in color, and are easily but wrongly assigned to the Pleistocene. A loam deposit postdating 5500 B.C. and widespread in Macedonia (L. Faugéres in Delibrias 1978) may be a case of soil erosion associated with Neolithic land use, although early settlement was less dense there than in Thessaly (Jarman, Bailey, and Jarman 1982: 146–154), and major deforestation came much later (Wijmstra 1969). On Euboea, Genre (1988) has noted alluviation well before 2000 B.C., and in the Nemea basin brown woodland soils like those preferred in the Southern Argolid were extensively occupied in the Middle Neolithic (Cherry et al. 1988). The soils have been washed away, but the time of erosion has not yet been determined. The same woodland soils appear to have been preferred elsewhere, too (e.g., Delano Smith 1972).

There are few reports of alluviation in the later Bronze Age (2nd millennium B.C.). Other than our own data for Tiryns and the suggestion by Davidson and Tasker (1982) that soil erosion began on Melos in the late 2nd millennium B.C., no reasonably documented cases are known to us. Apparently, soil erosion and alluviation were not troublesome in Mycenaean times, except locally; given the considerable density of settlement, effective soil management, such as the use of terracing, seems the only plausible explanation.

Turning to historical times, one finds a good deal more, although the data are sometimes poorly constrained in time or geologically weak. It is also difficult to decide whether the relative wealth of information derives from a greater interest in the period or is evidence for a real increase in soil erosion and sedimentation. The alluviation of later Hellenistic and Early Roman times in the Southern Argolid seems to have been quite widespread. Besides its occurrence in Thessaly, it has been noted in Elis between ca. 350 B.C. and A.C. 300 (Raphael 1968, 1978). Dufaure (1976) has placed an extensive alluviation of the Alpheios valley above Olympia in the 2nd–6th centuries A.C., but the dating of this earliest of his two alluviation phases is not robust. Anecdotal references to the burial under alluvium of Classical, Hellenistic, and Roman structures abound (Vita-Finzi 1969), but once again the dating tends to be less than exact.

Rapid coastal progradation, such as occurred after 3000 B.C. near Pylos in the Bay of Navarino (Kraft, Rapp, and Aschenbrenner 1980), may indicate a period of enhanced soil erosion inland. On the Aegean coast of Turkey (FIG. 1), Eisma (1964, 1978) found a major phase of fill dating 500–100 B.C. in the Küçük Menderes valley near Ephesus, and Aksu, Piper, and Konuk (1987) placed the main delta advance there between 900 B.C. and A.C. 100. In the next valley to the south, the main depositional activity of the Büyük Menderes came slightly later, ca. 100–300 A.C. (Eisma 1978) or, more broadly, between 500 B.C. and A.C. 500 (Aksu, Pipe, and Konuk 1987). Caution is advisable, however, when deducing soil erosion from coastal accretion, because long-shore drift bringing sediment from elsewhere, and small changes in the rise and fall of sea level can be easily mistaken for changes in sediment supply and hence in inland erosion rates (Curray 1964).

Even leaving this class of data aside, there seems to be sufficient reason to suggest that the last few centuries B.C. and the first few of our era were a time of widespread but by no means ubiquitous destabilization of the Greek landscape (FIG. 10). This does not mean, however, that the preceding Archaic and Classical periods enjoyed complete freedom from soil erosion problems. Genre (1988) and Rust (1978) document two brief but troublesome events of alluviation in central Euboea between 720 and 680 B.C., and another at the end of the 5th and beginning of the 4th century B.C. They hold deforestation in the upper parts of the drainage basin responsible for both. As at Tiryns in the Argive plain, the remedy was found in sophisticated engineering works. Localized soil erosion also took place between 700 and 200 B.C. in the southern Peloponnese and on Crete (Hempel 1982, 1984). On Melos a historical phase of erosion and alluviation may have begun in the first quarter of the 1st millennium B.C., reaching its peak around A.C. 500 (Davidson and Tasker 1982).

Alluvial deposits of medieval to modern times are common. Büdel (1965) and later Dufaure (1976) have described major alluviation at Olympia between the 7th and 14th centuries A.C. Renault-Miskovsky (1983) says that alluvial loams were emplaced on Naxos between the 3rd and 7th centuries A.C. Major stream aggradation in the 9th–12th centuries A.C., comparable to and roughly synchronous with the Upper Flamboura of the Southern Argolid, has been described by Genre (1988) for central and northern Euboea. L. Faugéres (in Delibrias 1978) mentions alluviation in Macedonia from the 9th century A.C. onward. Many other cases, ranging from the 9th century (Middle Byzantine) through the Turkish period, have been compiled by Wagstaff (1981) in his analysis of Vita-Finzi's "Younger Fill." From this he concluded (as we do) that, over the last 1500 years, stream aggradation was episodic and localized in the eastern Mediterranean, with intensities and dates that varied from place to place. This implicates human interference with slope equilibrium as the principal cause, rather than climatic changes such as the Little Ice Age (15th through mid-19th century A.C.).

This view contrasts with that of Vita-Finzi (1969) and Bintliff (1976a, 1977), who attributed both the Older and the Younger Fill to climatic changes. Hassan (1985), in his review of stream aggradation in semiarid and arid regions, also stressed climatic factors. Genre (1988) and Brückner (1986), on the other hand, concluded after a thorough consideration of other potential causes that neither climate nor changes in the relative levels of land and sea could have induced the observed alluviation events. Instead, they too opted for the human factor.

This is not to say that climatic and sea level changes of tectonic or eustatic origin are not potentially important factors in Holocene geomorphology (Hassan 1985; Nir 1983; Thornes 1987), and they should not be casually dismissed. For the time being, however, we regard these natural factors as of minor importance in the Holocene alluviation history of Greece. First, changes of sea level and/or stream base level have been small (a few meters) during the period considered here, except for a few areas where neotectonic uplift and subsidence are well documented, as in the Gulf of Corinth. Climatic changes, on the other hand, are usually invoked merely by reference to the Holocene climatic history of NW Europe, an inappropriate analogue, and hard local evidence for their existence has not yet been presented. In our view, the burden of proof rests for the time being on those who propose climatic, tectonic, or sea level changes as causes of landscape destabilization in the Aegean.

The complex nature of the processes that have produced the alternating stability and destabilization of the Greek landscape is somewhat bewildering and encourages oversimplification. It is, for example, widely believed that valley aggradation and coastal accretion tend to be unrelated and are seldom concurrent. This is rarely true. The response of a stream system to a change in conditions is complex and a single cause, e.g., increased slope erosion, can set off a chain of down-valley consequences that evokes different responses in different parts of the system (Schumm 1977, 1981; Schumm, Harvey, and Watson 1984; Patton and Schumm 1983). The aggradation accompanying slope destabilization in the upper reaches of a drainage often, although not always, begins at the shore and proceeds up-valley with time, accompanied by changes in sediment type (Patton and Schumm 1983; Pope and van Andel 1984; Schumm 1981). Nondeposition, erosion, and the formation of various different sediment types may thus simultaneously take place in the same drainage.

Conclusions

Alternations between stability and destabilization analogous to those cited above have occurred elsewhere in the Mediterranean as well and appear to support our conclusions as, for example, the work of Delano Smith (1979, 1981) shows. Also in southern Italy, the earliest valley fill, assigned by Brückner (1983) to the late Pleistocene or early Holocene, is weakly dated and might well be Neolithic in age. A subsequent stable period lasted for much of the last two millennia B.C.; it was followed by extensive deposition between the 5th and the 3rd century B.C., attributed to land clearing and land use during the Greek colonization (Brückner 1983, 1986). A more poorly-dated early medieval erosion phase caused by resettlement and by cultivation of hill lands ended in the 11th–12th, or alternatively the 14th–15th century. Finally, large-scale 19th to early 20th century alluviation was caused by the extensive deforestation (Brückner 1986) that accompanied the opening-up of wooded hinterlands by roads and railways.

Overall, this and other Mediterranean depositional histories compiled by Brückner (1986: fig. 7) demonstrate the same local and temporal variability that is found in Greece and the Aegean.

Thus the evidence that can be brought to bear on the problem of natural versus human-induced landscape destabilization in the Aegean, although still limited, appears to us to point first and foremost to the dominant role of human activity. The chronology remains less certain than one might wish, and this is also true for our understanding of how the processes of soil erosion and alluviation relate to land use practices and rural economics (see Alcott 1989). A few inferences regarding the role of cultivation techniques come from the small drainages of the Southern Argolid (van Andel, Runnels, and Pope 1986), but much more research is needed.

We suspect that the soil preferences of the early Greek farmers were not strong and played only a secondary role in land use patterns. The brown woodland soils that had formed in late and postglacial times on Pliocene marls and shales and late Quaternary alluvial loams seem to have been preferred for cereals and pulses, as they still are to some extent. The coarser deposits of alluvial fans and slopes were not widely exploited until the introduction of large-scale olive culture, probably not before the Late Bronze Age (Runnels and Hansen 1986). Beyond this broad generalization, and while we recognize that the properties of a soil measured today cannot tell us very much about their quality when they were farmed in the distant past, we see little that points to a large influence of soil quality on past land use. On the whole, water more than soil appears to have determined land use and settlement patterns in Greece from the early Neolithic to the 19th century, as far as the current data show.

Many problems remain, such as our lack of knowledge of the time of introduction of terrace agriculture or the important question of how "catastrophic" (Brückner 1986) the consequences of anthropogenic soil erosion in the Holocene have really been. A reasonably secure estimate for the Southern Argolid (Jameson, Runnels, and van Andel in press) suggests that on average less than 40 cm were stripped from that area. This is insignificant in geomorphic terms and confirms the view expressed by Rohdenburg and Sabelberg (1973) and Thornes and Gilman (1983: 75) that the present Mediterranean landscape was shaped mainly during the Pleistocene. These solitary examples, of course, need to be augmented before we can put a finger on the dominant cause of the barren state of so many Greek slopes.

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