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An assessment of human versus climatic impacts on Holocene soil erosion in NE Peloponnese, Greece

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Abstract

Soil erosion is a natural geomorphological process, which can be triggered by both natural (climate, tectonics, or both) and anthropogenic (e.g., agriculture) perturbation of the ecosystem. Evidence has accrued that the Holocene climate experienced large fluctuations in amplitude and suggestions of human impact on the ecosystem provided by the Neolithic revolution dating back to the early Holocene have been made. The question of whether man or climate was the dominant factor responsible for Holocene soil erosion remains unresolved. To resolve the reasons for Holocene sediment redistribution, high-resolution chronometric data on sediments derived from colluvial and alluvial archives from southern Greece were obtained and combined with available archaeological and paleoclimatic data from the eastern Mediterranean. These data show a significant correlation between sedimentation rates and settlement history. Climatic fluctuations are only weakly correlated with sedimentation history. The results show high sedimentation rates during the Early Neolithic (7th millennium BC) in southern Greece, suggesting that Holocene soil erosion was triggered by human activity and then amplified by enhanced precipitation. This would explain the high sedimentation rates during the Early Neolithic in connection with enhanced precipitation in the eastern Mediterranean, which continued until the mid-Holocene.

Keywords: Soil erosion; Paleoclimate; Geoarchaeology; Holocene; Mediterranean, Greece

Introduction

The classical work, *The Mediterranean Valleys* by Vita-Vinzi (1969), provoked an intense debate about the causes of Holocene sediment redistribution within the Mediterranean basin (e.g., Bintliff, 1977, 2002; Wagstaff, 1981). Vita-Finzi classified alluvial sequences into two major periods of aggradation: the *Older Fill* of late Pleistocene to early Holocene age, and the *Younger Fill* of Late Roman to Medieval age. Due to their widespread and apparently synchronous appearance, which implies a regional mechanism, Vita-Finzi attributed both periods of fluvial aggradation to climatic factors.

Various scholars questioned the hypothesis of an overall synchronous aggradation of the *Younger Fill* because of its uncertain chronology (e.g., Wagstaff, 1981; Davidson et al., 1976; Davidson, 1977). Next to climatic factors, sediment redistribution was additionally attributed to anthropogenic factors. Subsequently, numerous studies from various localities within the Mediterranean supported the idea of a dominant anthropogenic cause for sediment redistribution (e.g., Pope and van Andel, 1984; Brückner, 1986; Cherry et al., 1988; van Andel et al., 1990). Since the mid 1990s, developments in paleoclimatic research suggested that the question of soil erosion with climate as an important factor controlling Holocene sediment redistribution should be revisited.

The Holocene has been characterized by significant climatic fluctuations (e.g., Battarbee et al., 2004). Consequently, the debate about rise and fall of contemporary civilizations in the eastern Mediterranean and the Near East due to abrupt climate change (e.g., Cullen et al., 2000) inspired a renewed thinking on the cause of soil erosion and sediment aggradation. Pope et al. (2003) considered both the climatic and anthropogenic impact on sediment redistribution.

Any debate on the causes of Mediterranean soil erosion and aggradation critically depends on the quality of proxies and

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their paleoenvironmental implications. In addition, reliable numerical chronometry of the archives is cardinal to all paleoecological research. During the past decade considerable advance in the reconstruction of Holocene paleoenvironments has been made using, for example, palynological studies (e.g., Jahns, 2005; Urban and Fuchs, 2005), marine archives (e.g., Ariztegui et al., 2000; Schilman et al., 2001), lake sediments (e.g., Roberts et al., 2001) or speleothems (e.g., Bar-Matthews et al., 2003).

However, the temporal resolution of these archives is typical limited. This is especially true for colluvial and alluvial sediments, which are the key archives for studies of causes of soil erosion, sediment aggradation and the interaction of humans and their ecosystem. Even though new dating techniques are available to set up reliable chronostratigraphies for sedimentary archives (e.g., Stokes, 1999; Fuchs and Wagner, 2005), their application is still not widespread (Lespez, 2003). To address this, the Phlious Geoarchaeological Project on the NE Peloponnese in Greece was set up to carry out an investigation of the interaction of humans with their ecosystem since the early Holocene (Casselmann et al., 2004). High-resolution chronologies of colluvial and alluvial sediments were established using optically stimulated luminescence (OSL) dating (Fuchs et al., 2004). In the present study, sedimentation rates derived from OSL-based chronologies from Phlious are compared with paleoclimate data from the eastern Mediterranean. This comparison shows the relevance of human activity and climate variability for soil erosion and sediment aggradation. In the following, a critical evaluation of sedimentary archives and their significance for investigating soil erosion is presented.

Sedimentary archives and their characteristics

Sedimentary archives used for paleoenvironmental reconstruction are site dependent. The nature of proxies, the state of their preservation, the time resolution and the completeness of the record define the quality and use of the archive (e.g., Grosjean et al., 2003). Marine archives, for example (e.g., Cacho et al., 2002), provide continuous records with sometimes acceptable temporal resolution and well-preserved proxies. However, people live on land and it is not always easy to directly translate a marine reconstruction to events on the land. Archives on land, however are commonly discontinuous. Colluvial and especially alluvial archives are known for their discontinuous sedimentation, weathering and soil formation. This makes the paleoenvironmental interpretation non-trivial (e.g., Lewin and Macklin, 2003). Nevertheless, colluvial and alluvial sediments are essential archives for the investigation of soil erosion and sediment aggradation, and for moving toward delineation of possible anthropogenic or natural causes (e.g., Lang et al., 2003; Faust et al., 2004). Thus, despite limitation of interpretation and hiatuses, an understanding of sediment archives and processes leading to aggradation and degradation

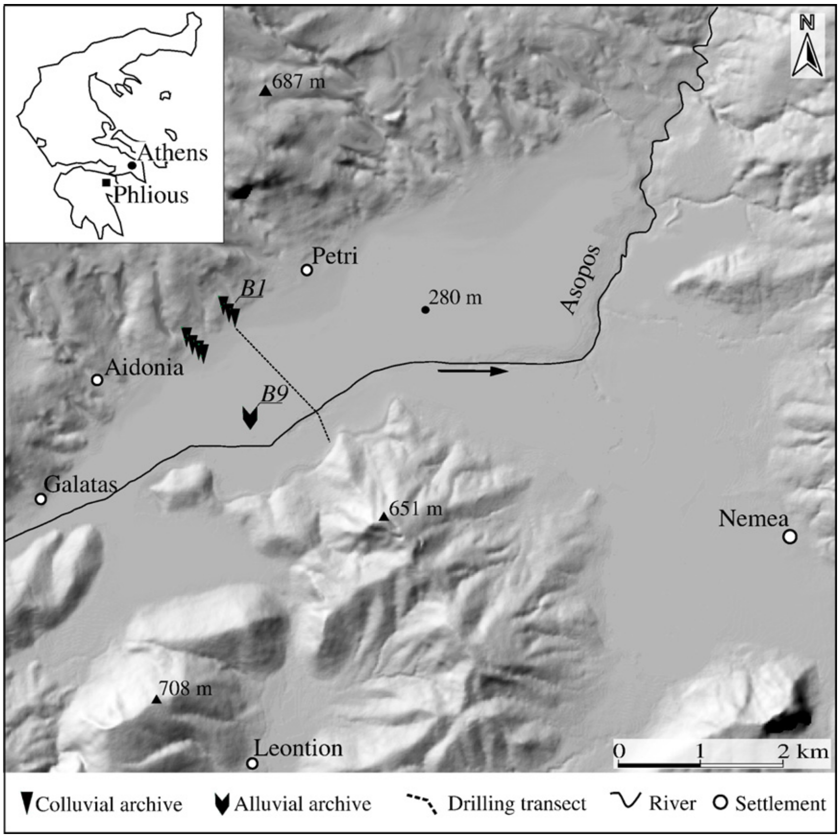

Figure 1. The Basin of Phlious on the NE Peloponnese in southern Greece (modified after Fuchs et al., 2004, Fig. 2). The studied sites and sample locations are indicated.

is needed (Houben, 2003). An understanding of the geomorphological system and its response time, threshold and coupling is necessary for the interpretation of sediment archives (Brunsden, 1979; Chorley et al., 1984).

Within a geomorphic system, colluvial and alluvial archives represent different hierarchical sinks that record environmental change differentially (Harvey, 2001). For example, eroded slope material has to pass the colluvial sink at the foot of slope to reach the fluvial system, where it may be stored as alluvium. Thus, a system of sediment cascades, and the magnitude and frequency of the processes involved, have to be considered. Slope-wash material derived from high-frequency, low-magnitude events is largely stored as foot-slope colluvium. Contrastingly, low-frequency, high-magnitude processes may generate larger rills and gullies that are in general directly coupled to the river channel (Harvey, 2001). Thus, depending on the processes involved, the sedimentary record may not provide complete information. The coupling between the various sediment sinks within a geomorphic system and differences in the response time of the sedimentary archives to the external perturbation are needed to assess the net impact on soil erosion (Harvey, 2002).

Colluvial archives usually respond readily (i.e. fast response time) due to their proximity to upslope erosion and downslope sedimentation areas. Fluvial systems respond slowly due to (1) longer distances between sediment source and sink, and (2) various sediment sinks in between the source and the final sedimentation regime. These factors imply a delayed sediment response. However, alluvial archives integrate the response of an extended area due to their larger catchment. Colluvial systems, on the other hand, provide a spatially limited response of an area immediately upslope of the archive.

Holocene soil erosion in southern Greece

The investigations into Holocene soil erosion were carried out in the Phlious Basin (37°59′N, 22°36′E), ca. 30 km west-southwest of the town of Corinth on the NE Peloponnese in Greece (Fig. 1). Thick colluvial sedimentation at the foot-slope was favored by unconsolidated marls, which are highly erodible under a Mediterranean climate. A detailed description of the study area is provided by Fuchs et al. (2004). More recent evidence of archeological records extending to the early Holocene (Casselmann et al., 2004) suggests that anthropogenic activities may have played a role in sediment redistribution.

Colluvial sediments from the northern foot-slope of the basin were dominantly used for these studies (Fig. 1). Here, wedge-shaped colluvial bodies with a maximum thickness of 8.8 m overlay Neogene marls (Fig. 2), interfingering downslope with the basin fills. These archives present a simple, small and well-defined sediment source—sink linkage and a limited interim storage. This close coupling of the colluvial archives with its sediment sources implies a short reaction time, and the absence of gully erosion implies their suitability for reconstructing upslope soil erosion.

To establish a high-resolution sediment chronology, sediment samples at 50-cm intervals were taken for OSL dating. Several pits were sampled. Based on OSL ages, time-averaged sedimentation rates were computed to reconstruct the general evolution of the northern foot-slope colluvium (Fuchs et al., 2004). Based on these previously published results (Fuchs et al., 2004), representative sedimentation rates for the Holocene are synthesized in Figure 3. A large-amplitude change in sedimentation rate with time can be seen. Low sedimentation rates (<0.1 mm/a) are seen during the Pre-Neolithic times. With the onset of the Neolithic, a strong increase in sedimentation is shown, with an additional increase for the Middle and Late Neolithic (ca. 0.6 mm/a). The period from the following Chalcolithic Period until the beginning of the Middle Bronze Age is characterized by a decrease in sedimentation rate to a value of ca. 0.2 mm/a, which is still higher than calculated for the Pre-Neolithic. With the onset of the Middle Bronze Age sedimentation rates again strongly increase, and for the end of the Late Bronze Age a sharp and sudden increase to very high values of at least 1.4 mm/a is documented. The following period of the Early Iron Age again shows a decrease of sedimentation, although rates are still higher than during the Chalcolithic and Early Bronze Age. The Classical Period is characterized by a distinct increase in sedimentation rate with a pronounced increase during the Roman Period, producing the highest values for the entire Holocene of ca. 1.9 mm/a. During the Medieval and the beginning Ottoman Period, sedimentation rates decreased to a Middle Bronze Age level, showing again high values from the middle Ottoman Period until the present.

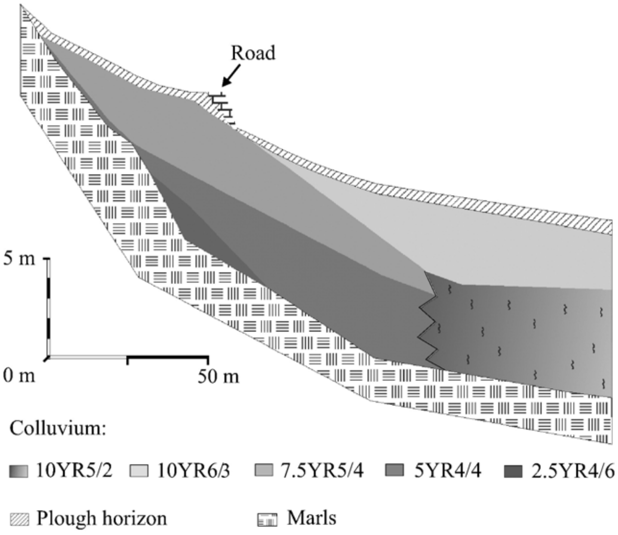

Figure 2. Representative colluvial section from the northern foot-slope (modified after Fuchs et al., 2004, Fig. 4). Wedge-shaped colluvial bodies with a maximum thickness of 8.8 m overlay Neogene marls and interfinger downslope with the adjacent infillings of the basin. The colluvium are differentiated by their Munsell colors and do not represent chronostratigraphic units. These sediments, among others, were used for OSL dating.

Holocene climate evolution of the eastern Mediterranean

Continuous climate records for the Holocene are not available for southern Greece. So far, the most widely used paleoclimate proxies for Greece are pollen records, providing information on past vegetation assemblages. There are two

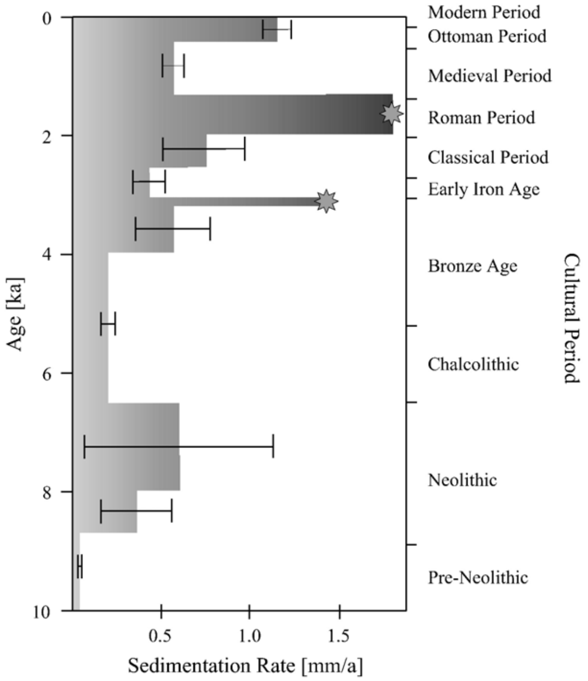

Figure 3. Holocene sedimentation rates derived from OSL-dated colluvium from various northern foot-slope sections of the Basin of Phlious (modified after Fuchs et al., 2004, Fig. 9). Bars marked with stars represent minimum sedimentation rates. Holocene chronology of the cultural periods in the study area shown on right axis.

difficulties with pollen: (1) poor preservation due to the hot and dry climate conditions resulting in patchy Holocene pollen reconstructions (Atherden and Hall, 1994; Jahns, 2005; Urban and Fuchs, 2005), and (2) non-trivial extrapolation of pollen records to causative factors for vegetational changes. Several patchy Holocene pollen profiles are available for southern Greece. They all show some evidence of *Olea* pollen occurrence and non-arboreal pollen that indicate human influence since the onset of the Bronze Age and possibly since the Early Neolithic. In the absence of clear and independent paleoclimate information, pollen cannot be used to interpret the vegetation changes in terms of climatic or anthropogenic factors.

An alternative and promising way for reconstructing paleoclimate is the use of speleothems, including stable isotopes and trace elements as paleoclimate proxies. High-resolution ^{230}Th–U TIMS dating as well as precise analyses of the stable isotopes have improved dramatically in the last few years, nowadays enabling high-resolution paleoclimate reconstruction (e.g., Fleitmann et al., 2004). For the eastern Mediterranean, cave speleothems are available from the Soreq and Peqiin Cave of central and northern Israel, which enable high-resolution paleoclimate reconstruction (Bar-Matthews et al., 2003). Through a comparison of δ^{18}O and δ^{13}C isotopic records from two terrestrial cave speleothems with marine δ^{18}O values from planktonic foraminifera, high-resolution paleoclimate conditions were reconstructed. The amount of rainfall was estimated by Bar-Matthews et al. (2003) for the past 8 ka (Fig. 4). Accordingly, δ^{18}O values indicate a transition from cool and dry conditions during the Younger Dryas (ca. 11.6 ka–12.7 ka) to warm and moist conditions at the onset of the Holocene (11.6 ka). More humid conditions during the early Holocene were followed by a trend towards drier conditions from 7 ka to the present. This general picture is punctuated by numerous abrupt fluctuations of δ^{18}O and hence paleorainfall estimates. Exceptional cool and dry events around ca. 8.1 ka and ca. 5.1 ka, and a humid episode from ca. 4 to 4.5 ka, are seen. Speleothem-based climate reconstruction is confirmed by early Holocene formation of sapropel S1 (ca. 9–7 ka) in the eastern Mediterranean (Ariztegui et al., 2000; Kallel et al., 2000). This sapropel layer S1 suggests enhanced rainfall during its formation. Furthermore, the general trend towards aridity after ca. 7 ka in northern Africa (e.g., deMenocal et al., 2000) supports the spatial validity of paleorainfall estimates for the eastern Mediterranean.

As a first approximation, paleorainfall reconstruction by Bar-Matthews et al. (2003) from Soreq and Peqiin Cave can be used as a surrogate for paleorainfall for southern Greece. This is reasonable as the spatial validity of paleorainfall estimates by Bar-Matthews et al. (2003) are supported by the above-mentioned sapropel layers and the north African aridity period. Furthermore, cyclone trajectories responsible for rainfall in Israel are dominantly coming from the west, thus crossing the Peloponnese of southern Greece (Weischet and Endlicher, 2000).

Results and discussion

To discuss the reasons for Holocene soil erosion and sediment aggradation in the Phlious Basin, the cultural history of the study area has to be considered. Archaeological investigations suggest that the human activity in the region dates back to the Early Neolithic of the 7th millennium BC (Cherry et al., 1988; Casselmann et al., 2004). At the same time, sedimentation rates strongly increased (Fig. 3) and the sediments showed a sudden appearance of ceramics. Sediments older than 8.7±0.6 ka are archaeologically sterile (Fuchs et al., 2004). From the Chalcolithic Period to the present, archaeological evidence of human activity exists. The evidence is sparse for the Chalcolithic and Early Iron Age, probably due to

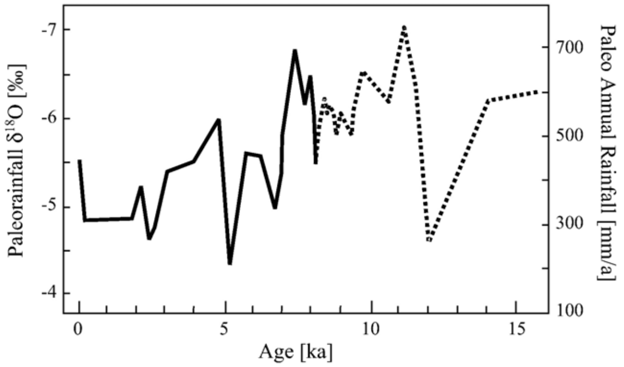

Figure 4. Calculated paleorainfall δ^{18}O values and estimated annual paleorainfall amount for the eastern Mediterranean (from Bar-Matthews et al., 2003). Solid line: δ^{18}O values and annual paleorainfall model based on δ^{18}O values. Dashed line: δ^{18}O values. For more details see Bar-Matthews et al. (2003).

discontinuous settlement activity. Archaeological evidence of extensive settlement during the Early and Late Bronze Age, the Classical Period, and the Roman Period abounds.

Knowledge of the settlement history and cultural activity is dominantly based on the methodologies used for archaeological surface surveys. Archaeological remnants covered by thick sediment bodies are commonly not identified, implying that unless extensive exploration is conducted, findings from older cultural periods are likely to be limited. An example is a Neolithic site in the centre of the basin that was covered beneath 4 m of alluvium and was detected only accidentally (Fuchs and Wagner, 2005).

Correlation between sedimentation rates and cultural activity (Fig. 3) suggests an increase of sedimentation with the onset of the Neolithic and with the Late Bronze Age, and the Classical and Roman Periods. High sedimentation rates at the end of the Bronze Age could have been caused by the collapse of the Mycenaean Empire (Kilian, 1980), due, for example, to abandonment of agricultural terraces. Reduced sedimentation rates coincide well with the periods of reduced settlement activity during the periods of the Chalcolithic and Early Iron Age. Although the Early Bronze Age was archaeologically a period of prominent settlement activity, no enhanced sedimentation rates could be identified. Consequently, with the exception of the Early Bronze Age, the overall picture of fluctuating sedimentation corresponds well with the cultural evolution of the study area.

The evolution of settlement activity and sedimentation rates are compared with the evolution of paleorainfall (Fig. 5). For the onset of the Neolithic and its increase in sedimentation, estimated paleorainfall shows an increasing trend to higher values. The fluctuating climate conditions within this period, especially the decline of rainfall around 8.1 ka, are not represented in the colluvial archive. This may be attributed to the lower resolution of the sedimentary chronology in comparison to the speleothems. The transition from more humid to drier conditions around 7.2 ka and the distinct decrease in rainfall around 6.9 ka and 5.1 ka do not correlate with sedimentation. A change in sedimentation is seen much later in the transition from the Neolithic to the Chalcolithic Period around 6.4 ka, when sedimentation decreases and remains constant until ca. 4 ka. During this period of constant sedimentation (Chalcolithic Period to the Middle Bronze Age), climate conditions fluctuate with distinct high and low rainfall around 5.1 ka and 4.8 ka. The period from 4 ka to 2.5 ka is characterized by a trend towards drier conditions. The fluctuating sedimentation rates with a peak around the end of the Bronze Age (ca. 3 ka) and the subsequent decline during the Early Iron Age do not correspond with the record of paleorainfall. The same applies to the period from 2.5 ka to the present. A

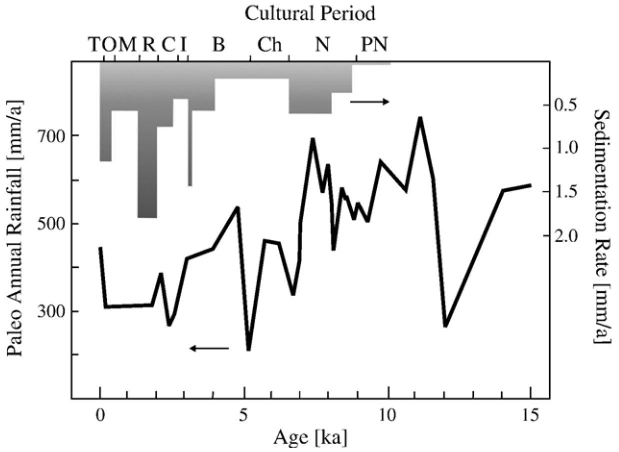

Figure 5. Holocene sedimentation rates (grey bars) and paleorainfall (line) based on $\delta^{18}O$ values for the eastern Mediterranean. Generally humid conditions for the early Holocene change to more dry conditions since the middle Holocene. For discussion see text. (Abbreviations of cultural periods: T=Modern, O=Ottoman, M=Medieval, R=Roman, C=Classical, I=Early Iron, B=Bronze, Ch=Chalcolithic, N=Neolithic, P=Pre-Neolithic).

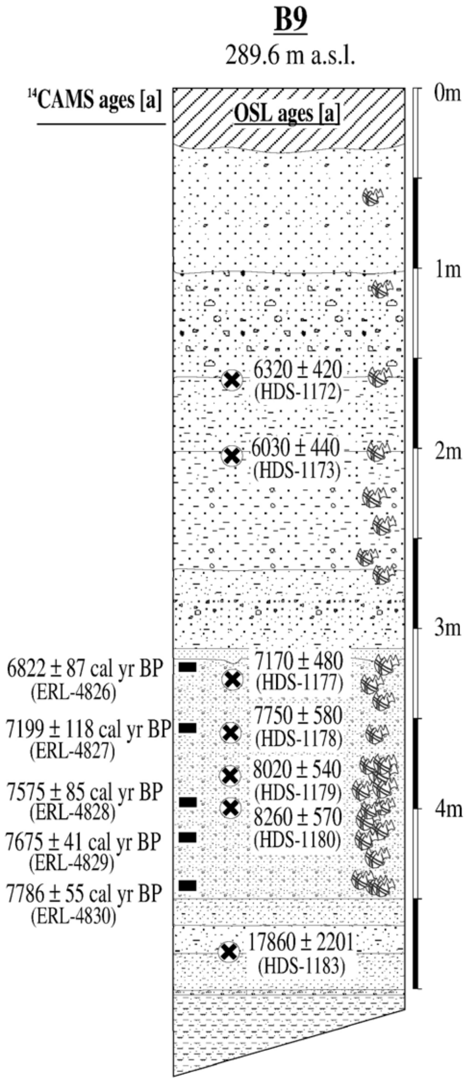

Figure 6. Chronostratigraphy of an alluvial archive in the centre of the Basin near the river Asopos (Modified after Fuchs and Wagner, 2005, Fig. 2). Next to OSL ages, calibrated ^{14}C AMS ages are given with their 1σ errors. OSL and ^{14}C AMS sampling locations are indicated by black crosses and black rectangles, respectively. OSL and ^{14}C laboratory numbers are given in brackets. Greyish sherd symbols within the profile represent archaeological ceramic remains. First sherd appearance coincidences with increased sedimentation during the Neolithic, documented by ^{14}C and OSL ages.

short increase to moist conditions ca. 2.1 ka is followed by constant climate conditions until ca. 0.3 ka. The last 300 yr until the present show an increase in moisture. Sedimentation rates from 2.5 ka to the present do not follow the rainfall trend, except for the last 300 yr, when increased sedimentation coincides with an increase in moisture.

The plot of rainfall reconstruction and sedimentation rate through time (Fig. 5) indicates that increased sedimentation is not strictly related to periods of enhanced precipitation and vice versa. In contrast, the cultural history of the studied area corresponds well with the sedimentation for most of the Holocene. In the case of the Early Bronze Age, pronounced human activity is not represented in the colluvial archive, and sedimentation dynamics stay constant at a moderately low level.

Thus, to understand soil erosion, a multi-parameter system needs to be considered such that different parameters can either synergistically enhance or dampen erosion (Bintliff, 2002). For example, the high sedimentation (soil erosion) at the beginning of the Neolithic could be due to a combination of factors, such as the clearance of natural vegetation and enhanced precipitation. An alluvial archive in the centre of the basin (Figs. 1, 6) supports this multicausal approach (Fuchs and Wagner, 2005). Here, a Neolithic site covered with 4 m of sediments provides evidence of widespread cultural activity during this early stage of agriculture. Archaeological evidence of an abrupt abandonment of the settlement and a rapid sedimentation are seen at the alluvial archive (Figs. 1, 6) and possibly reflect a combination of enhanced precipitation with degradation of vegetation due to animal husbandry. This inference is supported by several colluvial archives from the northern foot-slope, showing a sudden increase in colluviation and a parallel appearance of ceramics with the onset of the Neolithic in the 7th millennium BC (Fig. 7). Evidence of enhanced sedimentation ca. 8.5 ka in both alluvial and colluvial archives and appearance of artifacts suggest the regional nature of human impact.

A general prerequisite for soil erosion in the studied region is the degradation of vegetation. If widespread Holocene soil erosion has natural causes such as climate change, vegetation degradation has to occur. The limiting factor for Holocene vegetation growth in the study area is the availability of water, thus precipitation. Taking into account recent (ca. 600–800 mm/a after Morfis and Zojer, 1986) and calculated (Fig. 4, ca. 200–700 mm/a after Bar-Matthews et al., 2003) paleorainfall amounts, it is unlikely that rainfall reduced to a level that reduced the vegetation cover sufficiently to facilitate erosion. However, for a detailed reconstruction of seasonal vegetational variations and of climate parameters, the required time-resolved data are not available. Nevertheless, climate-driven soil erosion and sediment aggradation should have had a widespread impact on the environment, leading to synchronous periods of sediment redistribution. So far, this is not shown by comparing the available data on soil erosion and sediment aggradation from Greece, even though these data lack robust chronologies (cf. Brückner, 1986; van Andel et al., 1990).

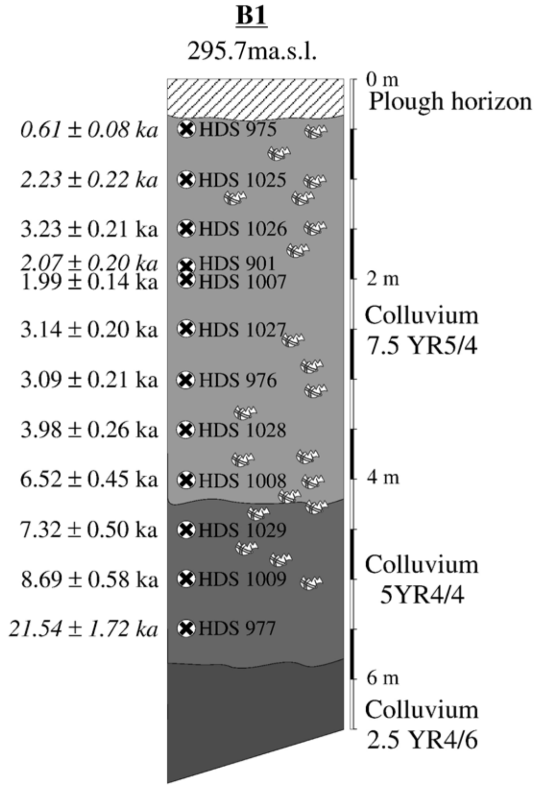

Figure 7. Chronostratigraphy of a colluvial archive at the northern foot-slope of the Basin (modified after Fuchs et al., 2004, Fig. 8). OSL ages are given with their 1σ errors and laboratory numbers. Sample locations are indicated by black crosses. Ages given in italics are interpreted as maximum ages due to insufficient bleaching. Greyish sherd symbols within the profile represent archaeological ceramic remains. First sherd appearance coincidences with increased sedimentation during the onset of the Neolithic (7th millennium BC). Thus, the colluvial archive shows a similar evolution as the alluvial archive (Fig. 6), representing a regional occurrence.

On the basis of the forgoing, it is likely that without anthropogenic influence, soil erosion during the Holocene should have been lower. We suggest that it is only the human impact on the landscape that results in accentuated soil erosion. Climate only modifies soil erosion and sediment aggradation. In this context, future research on past soil erosion should focus on both: high-resolution chronologies for sedimentary data and paleoclimate. Additionally, socioeconomic data of the past should be considered. Only numerical high-quality chronologies provide a base for reliable correlations between different information sources. Furthermore, different types of sedimentary archives react differently to the impact of soil erosion, both in time and in the type of reaction. Therefore, valuable information could be provided by investigating the reaction time of an erosion impact to the colluvial, alluvial, down to the deltaic archive within the same catchment.

Conclusions

Colluvial sediments from NE Peloponnese in southern Greece were used to establish chronologies and sedimentation rates for reconstructing soil erosion during the Holocene. The key inferences are:

(1) Sedimentation rates show significant variability during the Holocene.

(2) Periods of enhanced sedimentation took place in (a) the Neolithic Period, (b) the Middle to Late Bronze Age, (c) the Roman Period, and (d) the last 500 yr.
(3) Sedimentation rates correlate weakly with paleorainfall data.
(4) Sedimentation rates correlate well with cultural activities.

Thus, there is evidence to suggest that Holocene soil erosion and colluviation are dominantly human-driven, and climate variability is of secondary importance. However, for the early to mid-Holocene, high precipitation matches high sedimentation rates, which coincides with the onset of agricultural activity during the Neolithic Period. Thus, a combination of factors can amplify human-triggered soil erosion, resulting in strong colluviation. This seems to be true for the studied area, where the first vegetational degradation during the Neolithic Period in combination with enhanced precipitation for the early to mid-Holocene is responsible for a sudden increase in soil erosion and sedimentation. Nevertheless, human disturbance of the soil-protecting vegetation seems to be the essential prerequisite for Holocene soil erosion in southern Greece.

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