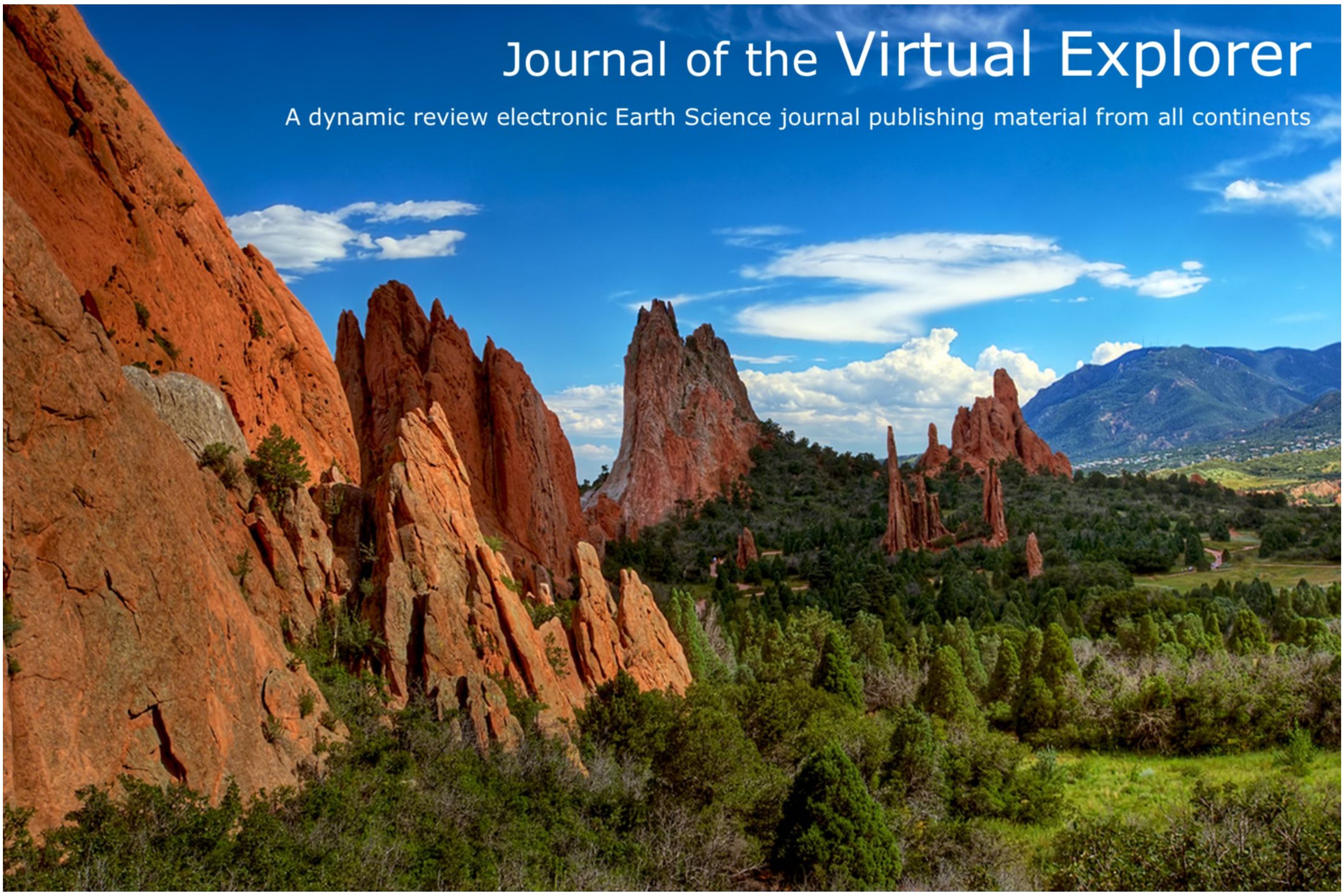

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Abstract: This paper examines the history and disciplinary trajectory of geoarchaeology in Greece. Comprising one of the most complex and tectonically active geological settings and entailing one of the richest and most important archaeological records in Europe, Greece was among the first places where the discipline of geoarchaeology was originally applied. The peninsular and maritime character of the country, the extensive coastlines and the pronounced sea-level oscillations occurring in the Quaternary explains why geoarchaeological approaches were at first employed on famous archaeological sites situated along or near the coast. Geoarchaeology in Greece never lost its 'coastal focus', but it did enter a second phase during the 1980's, when there is a shift of interest towards the study of human-environment interactions. This phase initiates a long-lasting debate over landscape instability and the anthropogenic versus climatic impact as major drivers of alluviation and soil erosion during the Holocene. The third stage in the history of the discipline is marked with a dual emphasis on both broad, landscape-scale perspectives and site-specific, micro-scale applications. Particularly during the last decade, geoarchaeological investigations in Greece have been characterized by pioneering studies of site formation processes, archaeological sediments and the micro-stratigraphic context.

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Introduction

The origins and scientific maturation of archaeology have always been closely related to developments in geology, and these parallel trajectories reach back to the times when Sir Charles Lyell, one of the founders of modern geology, published *The Geological Evidences of the Antiquity of Man* (1863) –conceivably the first book on geoarchaeology. Colin Renfrew (1976: 2) couldn't put it more categorically when he noted that "since archaeology [...] recovers almost all its basic data by excavation, every archaeological problem starts as a problem in geoarchaeology". Geoarchaeology is broadly defined as the application of principles and techniques of geosciences to archaeology (French 2003; Goldberg and McPhail 2006) and yet, ever since the term was first used in print (Butzer 1973), it meant to describe more than that (Butzer 2008). Some researchers opt to distinguish between *geoarchaeology* as archaeology conducted by methods of earth sciences, and *archaeological geology*, viewed as research that is primarily carried out for geological objectives but has implications for archaeological interpretations (see discussion in e.g. Waters 1992; Rapp and Hill 2006). For the purposes of this review we follow Goldberg and Macphail (2006) in considering the two terms as part of the same rubric, hence we see no need to differentiate them and we view geoarchaeology as a cross-disciplinary research domain that aims primarily at

(1) assessing the (chrono)stratigraphic context and integrity of archaeological sites

(2) reconstructing the landscape context of archaeological sites and the human-environment interactions, including human-induced landscape modification and land use

(3) understanding site formation processes

A full account of the definition, etymology or the disciplinary range of geoarchaeology falls outside the scope of this contribution (see e.g. Leach 1992; Waters 1992), as the way one wishes to delineate geoarchaeology and its applications depends on many different factors, including academic backgrounds and fields of interest –e.g. in North America geoarchaeology is mainly practiced by geologists, while in Europe mostly by archaeologists and geographers (Butzer 2008). All the same, we concur with Butzer (1982) and Renfrew (1976) who see a clear distinction between archaeometry and geoarchaeology and so we feel it reasonable to exclude from this review geophysical and geochemical research that deals with (1) archaeological prospection (remote sensing) (2) materials identification and provenance studies, and (3) chronometric dating methods. Geoarchaeology lies at the intersection of earth sciences with archaeology and, being *ipso facto* a multi- and inter-disciplinary endeavor, it encompasses disciplinary subfields with complementary and even overlapping agendas; consequently, deciding on which work is geoarchaeological or not is bound to be often blurred and more or less subjective. That being said, geoarchaeologists make use of techniques that derive from stratigraphy, sedimentology, pedology, geomorphology, micromorphology and geochronology.

As it is conceived and practiced today, geoarchaeology emerged hand-in-hand with the introduction of a positivist epistemology in the archaeological reasoning, which sought to make archaeology a 'hard science'. The so-called New Archaeology of the 1960s and 1970s and the employment of the Middle Range Theory as a key concept of the processualist school (see Atici 2006) brought geology into play, as exemplified by the work of L. Binford (e.g. 1964, 1977), who emphasized the significance of investigating all processes –both cultural and natural– that affect the creation and post-depositional modification of the archaeological record. This realization laid the foundations for the development of a systemic, largely functionalistic and process-oriented methodological framework, in which *context* was the keyword: archaeology cannot reconstruct past human behavior before assessing first all geomorphic and anthropogenic agents that have potentially influenced the biography of the sedimentary matrix, in which the material culture is preserved. Thus, the study of what is now known as 'site formation processes' (Schiffer 1987) was one of the earliest targets of geoarchaeological applications. *Contextual archaeology (sensu* Butzer 1982) further promoted the conceptual and methodological convergence of archaeology with earth sciences, by advocating the study of past human behavior within an ecological framework, which linked archaeological interpretations with approaches from cultural/behavioral ecology, geomorphology and environmental history.

The application of geoscience techniques to archaeological investigations is undoubtedly linked more tightly to theoretical and methodological concerns born in prehistoric archaeology, rather than in the archaeology of historical periods. Due to a number of reasons that range from national policies (or even: nationalistic politics) to scholarly trends, funding interests and institutional objectives, archaeological research in Greece has been largely dominated by a persistent focus on the Classical, Hellenistic, Roman and Byzantine periods. As a result, historical archaeology –overall gripped by the perpetual power of classical studies and idiosyncratically practiced in Greece as art history– insulated the local scientific community from the new paradigm of processual and 'science-based' archaeology and functioned as a long-lasting buffer to Binford's calls for viewing 'archaeology as anthropology', or Butzer's advocacy of 'archaeology as human ecology'. Nevertheless, credit should be given to a number of prominent Greek prehistorians, such as D. Theocharis (1919-1977) or G. Chourmouziadis (1935-), who were ready to explicitly welcome such new ideas. Notwithstanding this historical estrangement of Greek archaeology from the natural-science-perspective, the peninsula of Greece came to be one of the few places where geoarchaeology was –on global standards– first practiced. This is not astonishing if we take into account that Greece is exceptionally rich in archaeological remains, while at the same time it is characterized by a remarkably complex geology and geomorphology.

The landscape of Greece has long been used as a natural laboratory, where famous scholars from various disciplines of both Earth Sciences and Humanities applied and tested their models, developed theoretical frameworks and elaborated on novel methodological approaches. The Aegean region and its surrounding areas comprise one of the most rapidly deforming parts of the Alpine-Himalayan belt (see e.g. papers in this volume), and as an active tectonic setting it has contributed profoundly to resolving fundamental issues in structural geology and plate tectonics, hydrogeology, geomorphology, and many other subfields of geology (e.g. McKenzie 1978; Le Pichon and Angelier 1979; Leeder and Jackson 1993; Jackson 1994; Bell *et al.* 2009). Tectonic activity restricted the development of broad alluvial reaches in Greece (Macklin *et al.* 1995). Coupled with a markedly seasonal climate, this configuration resulted in the development of a landscape that does not promote extensive ecological zonation. The prevalence of mosaic environments, with a striking heterogeneity and a variety of diverse ecological resources over short distances, has attracted the interest of ecologists, paleoclimatologists and biogeographers (e.g. Tzedakis *et al.* 2002; Medail and Diadema 2009). Major researchers working in the domain of prehistoric or landscape archaeology were soon to appreciate the opportunities that this highly 'broken-up' ecogeographic setting offers for the unraveling of key aspects in human-environment relationships. For example, Claudio Vita-Finzi, a geographer, and Eric Higgs, a prehistorian, advanced the method of 'site-catchment analysis' during their work in the rugged relief of Epirus, initiating a long-lasting tradition of ecological/landscape approaches in the study of hunter-gatherer economy, which draws much attention to the topographical and geomorphological attributes of the landscape by focusing on such parameters as the availability, spacing and seasonality of plant, animal and mineral resources in determining prehistoric site locations (Higgs and Vita-Finzi 1966; Higgs *et al.* 1967; King and Bailey 1985; Bailey *et al.* 1993; Bailey 1997). In these lines, it comes as no surprise that all four major North American geoarchaeologists, namely K. Butzer, W. Farrand, G.R. Rapp and J.C. Kraft, "who played important roles in building geoarchaeology into a discipline" (Rapp and Hill 2006: 20) have worked in Greece, some of them early in their career and in decades-long research projects.

The following review of geoarchaeological research in Greece is structured along a dual axis, which brings together both a chronological ordering and a thematic grouping of the relevant investigations. As we see it, geoarchaeological applications can be grouped into two main categories: one that involves *regional* or *landscape-scale* studies, and another one that entails on-site research with micro-stratigraphic, sedimentological and micromorphological analyses at the scale of the individual site. With this distinction in mind, we have reviewed the latter group of studies separately (section 5) and yet from a historical perspective, as with the case of the preceding sections. As noted above, pinpointing the beginnings of geoarchaeological approaches is a relatively subjective task, since the blending of geosciences methods with those traditionally ascribed to archaeology has been time-transgressive and, in a broad sense, it reaches back to the very foundations of the two disciplines and their subfields. Similarly, for a number of reasons if not simply due to space limitations, it is inevitable for any review of this kind to include only part of a broad spectrum of published studies. For those and for any other unwillingly-occurring omissions, we ask for the reader's understanding.

First phase: coastal geoarchaeology in the 1970s to mid-1980s

Greece has the longest coastline in the Mediterranean, consisting of 13,780 km and including 6,000 islands and islets that make up around half of the country's coastline (*ec.europa.eu/maritimeaffairs*). It is thus obvious that a great component of geomorphological and geoarchaeological processes in the Greek territory has been critically influenced by sea-level fluctuations. The continental shelf of the Aegean is wide along the northern and eastern coasts, where large rivers from the Balkans and Asia Minor have formed broad alluvial plains with thick sedimentary sequences that make up a smooth morphology of low slope gradients (Perissoratis and Conispoliatis 2003). Those coastal alluvial plains extend seaward until water depths of about 120-140 m, where a distinct shelf-break occurs. In contrast, on the coastal zone of Western Greece, the eastern coast of Peloponnesus and the fringes of ca. 200 islands, the continental shelf is mostly narrow (<10 km) and rocky; in those cases the shelf break is largely controlled by major bounding faults and it occurs at depths of 130-150 m, beyond which very steep slopes (up to 1:20) lead into deep basins (Aksu *et al.* 1995). Overall, the Aegean region has been intensely fractured by tectonic movements, resembling now "a tectonic puzzle made up of relatively small pieces" (Muscle and Martin 1990: 276), with a complex topographical structure and an irregular bathymetry (Stanley and Perissoratis 1977). The fact that major archaeological sites occur at or near the current shoreline, along with the aforementioned intricate character of the coastal configuration, drew the attention of geoscientists and encouraged their involvement in archaeologically-oriented projects. At the same time, this interest was further enhanced by the realization that archaeological evidence (e.g. submerged archaeological sites) can be used as proxies for inferring vertical tectonic movements along coastlines (e.g. Flemming 1998; Pavlopoulos *et al.* 2012). Being subject to intense tectonic activity and sea-level oscillations, the coastal landscapes of Greece were all the more suitable for assessing the three main components, namely the eustatic, isostatic and tectonic contribution, which need to be corrected for in the construction and calibration of sea-level curves (e.g. Lambeck 1995). As a consequence of all the above, *coastal geoarchaeology* was the first research domain where geological methods were used in Greece for the resolving of archaeological research questions, and, to our knowledge, these were some of the very first geoarchaeological studies to appear on a global scale.

A number of important and pioneering publications appeared in the 1970s and 1980s, dealing with coastal change, shoreline stratigraphy, sea-level fluctuations and paleotopographic reconstructions – all of which were carried out with reference to the locations of archaeological sites, their palaeoenvironmental settings and the investigation of (past) coastal settlement patterns (Raphael 1973; Kraft and Aschenbrennen 1977; Kraft *et al.* 1975, 1977, 1980, 1987; van Andel *et al.* 1980; van Andel and Shackleton 1982; Shackleton *et al.* 1984; van Andel 1989). Those studies came as a result and in parallel to a renewed interest in Mediterranean shoreline/sea-level investigations, which was spurred by global advances in deep-sea research and chronometric dating techniques (Butzer 1983). The oxygen isotope record, as recovered by *foraminifera* analyses in deep-sea sediment cores, provides a history of global continental ice volume and hence of the glacio-eustatic component of sea-level change. Progress in this field revolutionized Quaternary geochronology (e.g. Fairbanks and Matthews 1978; Shackleton 1987) but also showed that, albeit more complete and of higher resolution, the marine record was no less complex than its terrestrial counterpart. Building upon this sort of previous works on marine research (e.g. Flemming 1968, 1978; van Andel and Lianos 1984); and along with a gradually-growing appreciation of the role of paleogeography on archaeological interpretations (e.g. with regard to colonization processes and maritime/insular occupational patterns; Cherry 1981), those studies refreshed the research agenda of geoarchaeology and further promoted interdisciplinarity in research designs.

It is in this historical context that in the early 1970s J.Kraft, S. Aschenbrennen and G. Rapp began their work on the subsurface geology of some major embayments in Peloponnesus (Kraft *et al.* 1975, 1977; Kraft and Aschenbrennen 1977). Using a combination of drill core data, radiocarbon dating, geomorphological indicators and archaeological evidence, Kraft and colleagues (1977) were able to reconstruct the paleogeographic coastal settings of important archaeological sites and presented a relative sea-level curve for the Peloponnesian embayments. They created Neolithic to Bronze Age paleogeographic maps for the landscapes of the Argolid and Helos plains, and showed that ancient Tiryns was in Mycenaean times much closer to the shoreline, thereby supporting the view that Tiryns might have served as a port. This work (ibid), virtuously published in the journal Science, prefaced subsequent research on the role of alluvial infilling and/or marine regressions/transgressions in altering the paleotopography of archaeological sites (e.g. Zangger 1991; Maroukian *et al.* 2004). A few years later, the same team published a similar study on coastal change, this time presenting a paleogeomorphic reconstruction of the Navarino Bay and its surrounding area, where a number of important Bronze Age sites are located, including the late Helladic complex identified as the palace of Nestor, as well as sites of the Classical, Hellenistic and Roman times (Kraft *et al.* 1980). In another important research, Kraft and his associates (1987) reconstructed the physiography of Thermopylae, where the famous battle between the Greeks and the Persians took place in 480 BC. By use of geological and geomorphic investigations that included also extensive drilling, they estimated a 15-km shoreline progradation for the last 4500 years and showed that, due to widespread alluviation, the site of the battlefield is now buried by up to 20 m of sediment; in addition, this study raised the issue of the relative importance of the ‘pass’ at Thermopylae, in showing that the pass was closed for great portions of the last five thousand years and, when open, was frequently very narrow and marshy.

In generally the same period, i.e. from the late 1960s-beginning of 1970s and up to the late 1980s, archaeological investigations in the Argolid (Peloponnesus) undertaken by the universities of Indiana, Pennsylvania and Stanford, brought together a remarkable number of important archaeologists and geoscientists, now renowned as leading experts in geoarchaeological applications (to name but a few: T. Jacobsen, M. Jameson, C. Renfrew, C. Runnels, N. Shackleton, J. Shackleton, W. Farrand, T. van Andel and J. Hansen). Central to this ‘joining of forces’ was the excavation of Franchthi Cave, a site of world-wide significance that preserves an almost continuous habitation for more than 20,000 years, from the Upper Palaeolithic through the Mesolithic and up to the end of the Neolithic period (Jacobsen 1981; Douka *et al.* 2011 and references therein). Shackleton and van Andel (1980, 1986) and van Andel and co-workers (1980) examined the shell assemblages from Franchthi and the evolution of the coastal environment near the cave after the post-glacial rise of the sea level, and demonstrated how the gradual change of the topography might have influenced the subsistence strategies and occupational choices of the cave’s inhabitants. A couple of years later, van Andel and Shackleton (1982) were the first to publish a reconstruction of the late Palaeolithic and Mesolithic paleogeography of Greece and the Aegean, elaborating on the archaeological implications with regard to coastal plain recourses and migration routes. Notably, they were also the first to provide a quantitative and qualitative account of the estimated *loss of coastal* zone due to the rising sea level in a given area of Greece (in their example, the southeast Argolid). Such accounts and their accompanied maps provide a means of envisaging how much of the (potential) archaeological record lies submerged since the post-glacial marine inundation: for instance, the coastal land exposed in Greece during the Last Glacial Maximum (sea level lowered at -100 to -120 m) would correspond to more than a third of Greece’s current continental extent (Table 1). In archaeological terms, these spatially extended, most likely well-watered and biologically productive coastal plains (cf. Tourloukis 2010) may have supported food acquisition and resource procurement strategies that are not reflected in the sites preserved inland and on the present shorelines (van Andel and Shackleton 1982). In addition, the landmasses that would emerge during sea level low-stands could have served as landbridges and migration pathways for animal and human population movements (cf. Cherry 1981; Shackleton *et al.* 1984; van Andel 1989; Tourloukis and Karkanas 2012; see also below). Therefore, the decline or total loss of these resources needs to be seriously considered when explaining site- or regional-specific archaeological patterns.

Table 1. Estimates of the extent of exposed coastal areas in Greece at different depths of lowered sea-level during the last glacial period.

Depth of Continental Shelf	Area (km^2)	% in relation to mainland Greece
0 – 50 m	20159	15.3
50 – 100 m	21240	16.1
100 – 120 m	7496	5.7
0 – 100 m	41399	31.4
0 – 120 m	48895	37.1

The last column on the right shows the percentage of exposed areas when compared with the total extent of mainland Greece, (131,957 km^2). Data provided by V. Kapsimalis (personal communication 2009). This account has considered only the eustatic contribution and has not been corrected for the tectonic and glacio-isostatic effects; nevertheless, these values give a fairly close approximation of the true extents of exposed surfaces, as the glacio-isostatic effect would give a correction in the order of only a few meters and because the subsidence that has occurred up to the present has not been taken into account (cf. Perissoratis and Conispoliatis 2003, 149-150; Lambeck 1995, 1996). Note that the amount of exposed areas remains noteworthy (an equivalent of ca. 10% of the extent of the mainland) even when considering the value of -40 m, which would be the level that best defines the coastal palaeogeography of ca. 110 to 30 ka (van Andel 1989, 739); and this amount of exposed areas would again be raised appreciably if we consider the levels of -60 to -70 m as better representatives for the most severe stadials of that time-span.

Overall, those studies served as the point of departure –as well as a point of reference– for a long-lasting research tradition on the effects of coastal dynamics upon past human behavior and the role of paleogeography in the preservation and detectability of archaeological sites. If not directly integrated, they were at least highly influential to the first intensive archaeological surveys in Greece, which had a regional focus and explicitly sought to understand settlement patterns in conjunction to landscape evolution; this was, for instance, the case with the Minnesota Messenia Expedition (McDonald and Rapp 1972), the Argolid Exploration / Southern Argolid survey project(s) (e.g. Jameson *et al.* 1994) or the Pylos Regional Archaeological Project (e.g. Zangger *et al.* 1997). The aforementioned works by J. Kraft and colleagues, or T. van Andel and his associates, did not simply provide palaeogeographic contexts for the archaeologists to use in their explanatory narratives; they were also pivotal for the designing and execution of survey projects that subsequently discovered new sites, as well as for excavations –such as that of Franchthi– that established state-of-the-art standards in multidisciplinary research. Moreover, they can be deemed as pioneering not only for their conceptual contributions, i.e. as regards the way in which an archaeological inquiry can be approached, but also for the methodological advances that they promoted. For example, van Andel and Lianos (1983, 1984) were able to pinpoint the sea-level position of the last glacial maximum on the self of the southern Argolid by using high-resolution seismic profiler records; this investigation offered the first 'direct' evidence for the identification and reconstruction of submerged paleosurfaces in the Aegean, foreshadowing the importance of seismic reflection profiling as a powerful tool in marine geology.

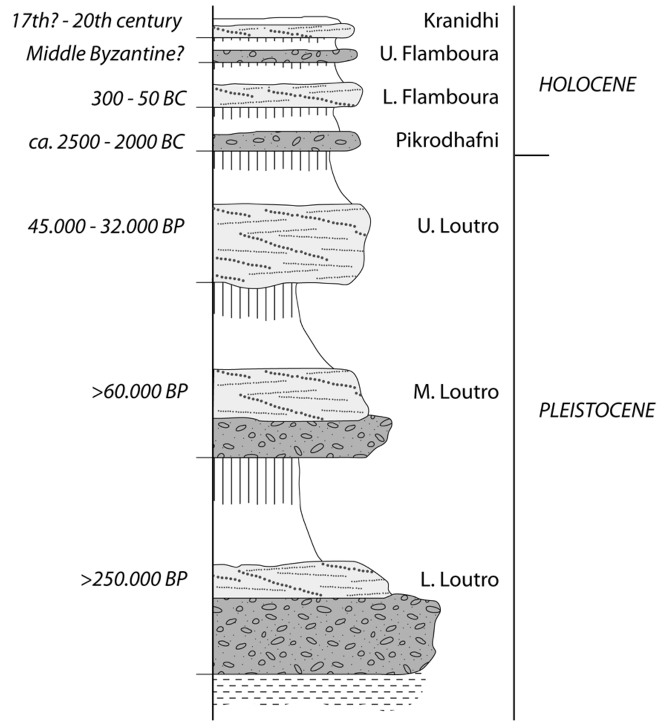
Second phase: the mid-1980s to late 1990s debate over the climatic vs. anthropogenic impact on landscape changes

One of the main concerns of geoarchaeology is to understand landscape histories and the ways in which they have affected and co-evolved with human societies. Deciphering the role of climate is particularly important in such an investigation, for climatic parameters influence both human behavior and the preservation and visibility of this behavior in the archaeological record. Although generally weaker in amplitude than those of the last glacial cycle, suborbital climate fluctuations characterize also the Holocene and may occur rapidly (i.e. in a few hundred years or shorter), perhaps legitimizing the view of the present interglacial as "a period of climatic instability" (Jalut *et al.* 2009, 13). Holocene climate variability indicates that quasi-periodic changes could be abrupt and profound even in the absence of the voluminous and unstable ice masses of the Pleistocene (Mayewski *et al.* 2004). The general trend towards a warmer and wetter climate in the early Holocene of Greece was interrupted by short-term climatic deteriorations, when vegetation communities were subjected to repeated, centennial-scale setbacks, mirrored by decreases in arboreal pollen and occasional increases in steppic taxa, which probably reflect reduced moisture availability (Kotthoff *et al.* 2008). One such abrupt deterioration at around 8.2 ka (Geraga *et al.* 2010) is thought to be correlative with the well-known 8.2 ka cold event of the Northern Hemisphere (Alley and Ágústsdóttir 2005). The colder and drier conditions of this short interval are also recorded in the isotopic record of the Soreq Cave (Bar-Matthews *et al.* 1999) and it is possible that they correspond to a major erosional event in Theopetra Cave (Thessaly, Greece) as well as to a stratigraphic gap in Franchthi Cave, altogether suggesting a broader impact on the caves of the area (Karkanas 2001). According to a recent geoarchaeological study of major Neolithic sites in Greece, Cyprus, Anatolia and Bulgaria, the introduction of farming to South-East Europe may have been triggered by the markedly cold and arid conditions that prevailed around 8200 cal yr BP (Weninger *et al.* 2006; but see also Drake 2012). Aridification was gradually intensified during the mid- and late Holocene, culminating at around and after ca. 5.6 ka (Jalut *et al.* 2009) and short-term arboreal pollen minima (e.g. at ca. 5.6, 4.7, 4.1 and 2.2 ka) are thought to represent drought events in the Aegean region (Kotthoff *et al.* 2008). However, a slightly different picture is recorded in the southeastern Aegean Sea with a pronounced wet phase recognized between 5.4 and 4.3 Ka, before the onset of the late Holocene aridification (Triantaphyllou *et al.* 2009). Yet, for this younger part of the Holocene and due to the advent of the Neolithic period, it is difficult to distinguish climate-induced terrestrial responses from those that should be attributed to the human impact. Greece is nevertheless well suited to such an investigation, because it has a long history of human land use and a sub-humid to semi-arid climate that renders its landscape sensitive to climatic change and human interference alike (van Andel and Zangger 1990).

Indeed, the effects of anthropogenic landscape modifications on soil erosion and landscape development have been the focus of a number of geoarchaeological, geomorphological and ecosystem management studies in the Mediterranean in general and particularly in Greece (e.g. Allen 2001; Grove and Rackham 2001; Kosmas *et al.* 2002; Butzer 2005; Thornes 2009). Since the publication of Vita-Finzi's classic work 'The Mediterranean Valleys' (1969), in which he argued for climate forcing behind major late Pleistocene and Holocene alluviation events, a long-lasting geoarchaeological debate has been generated (for thorough reviews see Bintliff 1992, 2002, 2005). There were two main controversial issues in Vita-Finzi's work: first, the fact that he simplified late Quaternary alluviation into two main episodes widely separated in time (the so-called 'Older' and 'Younger Fill', dating to last glacial-early Holocene and late Roman to Medieval times, respectively); second, his suggestion that both of these major events of landscape change were basically climate-driven. Triggered by and/or in reaction to this controversy, a number of important geoarchaeological studies appeared, some of them advocating Vita-Finzi's model (e.g. Bintliff 1975, 1976, 1977; Rackham 1982), but most of them presenting contrary viewpoints and essentially stressing the importance of anthropogenic impact in the evolution of the physical environment (Davidson 1971, 1980, 1988; Davidson *et al.* 1976; Raphael 1978; Wagstaff 1981; Pope and van Andel 1984; Demitrack 1986; van Andel *et al.* 1986; Brückner 1986; van Andel and Runnels 1987; van Andel and Zangger 1990; van Andel *et al.* 1990a; Zangger 1992, 1993, 1994; Jameson *et al.* 1994; James *et al.* 1994; Cavanagh *et al.* 2002). This debate and the associated studies signaled the beginning of a second phase of geoarchaeological investigations in Greece, and, as it is discussed below, left their own signature in both the history and the future prospects of the discipline.

Geoarchaeological research shifted the 'Vita-Finzi paradigm' towards human agency, manifested in two main ways: settlement expansion accompanied with forest clearance and the resultant soil erosion, and changes in land use and agricultural practices, such as the abandonment of terrace preservation (e.g. van Andel *et al.* 1986; 1990a). Van Andel and colleagues (1990a) evaluated a number of geoarchaeological evidence from three major projects (in the Southern Argolid, the Argive Plain and the Larissa Basin); they concluded that all three case-studies point to landscape instability due to –and after– the spread of farming populations and the onset of woodland clearances, which resulted in extensive slope erosion and valley aggradation. Zangger (1992) stressed the diachronic nature of these human-induced landscape changes, showing also that such disturbances differ from region to region according to physiographic characteristics and settlement history. All the same, most of these studies entail some recurrent themes with respect to causal factors and consequential effects. For example, triggering parameters and processes inferred include mainly a combination of the following: the expansion of farming settlements; forest clearance; intensive cultivation, cropping and/or over-exploitation of fertile soils; pastoralism and related vegetation disturbance by animal husbandry (grazing, etc); inadequate soil conservation and ineffective or total abandonment of terrace maintenance and gully check-dams; economic and demographic circumstances and policies; settlement expansion into upland, marginal areas (Pope and van Andel 1984; van Andel *et al.* 1986; van Andel and Zangger 1990; van Andel *et al.* 1990a; Zangger 1992; Whitelaw 2000; Halstead 2000). Erosion and destabilization or, alternatively, stability, is inferred from geomorphological, sedimentological and pedological indications from the depositional archives, generally encompassing evidence and conclusions such as the following: soils indicate periods of stability (e.g. Pope and van Andel 1984); erosional events are envisaged as catastrophic sheet erosion on slopes (e.g. van Andel *et al.* 1986); gully erosion stripped off soils, which were then deposited in valley bottoms as stream-flood deposits, whilst debris flows have also been feeding many of the Holocene alluvia (Figure 1; van Andel *et al.* 1990a); shifts to instability, signaled either by mass movements (e.g. debris flows) or channel aggradation, can be abrupt (Pope and van Andel 1984). In most – if not all– explanatory schemes the degradation of vegetation by cultural or natural processes (or both) is a general prerequisite (e.g. van Andel *et al.* 1990a; James *et al.* 1994; Lespez 2003).

Figure 1. Quaternary alluvial sequence from southern Argolid (Peloponnesus).



Cobbles with a chaotic structure indicate debris flows, whilst stratified gravels are streamflood deposits; blank zones are overbank loams and vertical lines denote soil profiles. Although the dates give only approximate ages, they do highlight an apparent discontinuity in alluviation events. Modified after van Andel et al. 1986: Fig. 4.

Anthropogenic slope alteration, agricultural practices, land abandonment or change of land use, all may result in contrasting effects for the ability of soils to resist erosion: in some cases, such parameters lead to the deterioration of soils, whilst in other contexts they tend to improve soil stability (e.g. see papers in Conacher and Sala 1998 and in Geeson *et al.* 2002; Grove and Rackham 2001). Likewise, there is ongoing discussion about the role of terraces in erosion control and whether abandonment of terraced cultivation does indeed result in increased erosion or not (Allen 2009). Terracing affects artefact mobility and hence the integrity of archaeological sites, whereas terrace construction methods may either impede or improve archaeological preservation and visibility. In a recent investigation on the implications of polycyclic (prehistoric and historic) terracing in Kythera Island, Krahtopoulou and Frederick (2008) report that after terrace abandonment, the main types of erosion are sheet wash and gully erosion, the latter affecting mainly unconsolidated formations on steep topographies, occasionally causing almost complete denudation of the slope, which in turn produces significant sediment flux to the local fluvial system. Another recurrent feature in studies of the relation between land use and erosion is the apprehension of the importance of slope gradient. For example, neglect or abandonment of terraces on steep slopes is often thought to have been followed by erosion and downslope sediment redistribution, which may result in different artefact densities between steep and gentle slopes (e.g. James *et al.* 1994; French and Whitelaw 1999). As expected, slope inclination becomes more significant mainly on the upper and middle reaches of the hillslope-channel system (evidenced as e.g. debris flows and streamflood deposits in alluvial/colluvial units), whilst it may be less effective in the lower valleys and coastal plains where flooding predominates during erosional episodes (evidenced as e.g. overbank loams in floodplain deposits; van Andel *et al.* 1990a).

Overall, the aforementioned studies demonstrated the contribution of "man's role in the shaping of the eastern Mediterranean landscape" (Bottema *et al.* 1990) and showed that soil erosion, valley alluviation and landscape (in)stability may have been preferentially connected with human settlement histories. More importantly, this corpus of research has brought to light a number of conceptual and methodological weaknesses in geoarchaeological approaches and it is this very same critique generated, which should be deemed fruitful. For instance, inasmuch as climatic forcing was invoked based on an assumed contemporaneity of landscape change, so was anthropogenic causation called upon to interpret a postulated temporal correlation between landscape change and cultural phenomena; however, correlation or coincidence does not straightforwardly prove causation (Halstead 2000; Brown 2008). Because of the different thresholds that operate in geomorphic systems (e.g. Schumm 1979), there can be considerable time lags between natural- or human-induced causes and their effects on the landscape. Furthermore, local and regional diversity in geological substrates, topography, vegetation patterns, climatic regimes and settlement histories complicate the degree in which geomorphic change can be synchronous across different regions and/or relatively contemporaneous to archaeological patterns. Even if this sort of spatial-temporal variation was in fact acknowledged (e.g. Pope and van Andel 1984; van Andel *et al.* 1990), there still has been a trend to fit dates from different depositional sequences into a common model of correlation with settlement patterns (Bintliff 1992; Whitelaw 2000). Being currently much better but significantly worse in the 1990s, the available chronological resolution is usually too coarse to firmly support a causal linking, be that natural or cultural (Endfield 1997; Krahtopoulou 2000). It is in these lines that the 'climatic vs. anthropogenic impact' debate effectively forced researchers to recognize that, as Whitelaw puts it (2000, 145, 150),

> *"we are likely to be dealing with much more subtle interactions between climate, soils, vegetation, and human exploitation strategies, which played through in different ways, even in adjacent valley systems […] We are likely to develop a better understanding of the different processes involved by paying more attention to local differences, and by considering in their own right the implications of different variables, such as overall population levels, the relative sizes of individual sites, the relative distribution of population among sites of different sizes, and the location of different types of sites within the landscape"*
>
> —Whitelaw, T.

Bintliff (2002) stresses two main issues as of critical importance in this discussion: the role of extreme events, and the complexity that arises due to the interactions between different geomorphic and cultural variables. He suggests that instead of focusing on climate or anthropogenic causation as monocausal or deterministic alternatives, there is much stronger evidence for viewing geomorphic and environmental parameters as setting up a 'pre-adaptation scenario' of a sensitive landscape, where cultural and natural trajectories intersect to create 'windows of opportunity', during which extreme erosion events are likely to occur. This viewpoint is best understood when considering Mediterranean landscape evolution as a "punctuated equilibrium rather than a uniformitarian process of prolonged change" (Bintliff 2002: 418). From this perspective we can evaluate the evidence for prolonged times of stability interrupted by erosional events, the latter being rare and brief but extreme enough to have caused large-scale disruptions, which are now occasionally and discontinuously preserved in depositional sequences in the form of e.g. alluvia and colluvia (Pope and van Andel 1984; van Andel *et al.* 1990a; Bintliff 2002).

Third phase: regional-scale geoarchaeology from 2000 to the present

By the advent of the 21st century geoarchaeology had acquired a strong hold on archaeological field applications in Greece, a development that came along with an ever-increasing apprehension of its scientific importance by the Greek academic community. Especially in prehistoric archaeology and starting already during the 1980s and 1990s, there has been a growing shift in the research paradigm towards regional surveys and land-use studies, which focus on the examination of regional settlement patterns (Runnels 2003). While intensive regional surveys were being carried out in parallel and complementary to local excavations (e.g. Bailey 1997), novel site detection techniques and the interpretation of regional distribution patterns called for a closer cooperation between archaeologists and their colleagues from the earth sciences.

Accordingly, geoarchaeological research continues in this phase to be oriented mainly towards palaeoenvironmental and palaeogeographic reconstructions and the understanding of past socio-cultural developments within a broader framework of geomorphological, ecological and paleoclimatic processes. While some studies serve to provide a diachronic or inter-regional account of palaeoenvironmental changes with regard to important archaeological sites (e.g. Lespez *et al.* 2004; Triantaphyllou *et al.* 2010; Vouvalidis *et al.* 2010), other works apply and test novel computer-based techniques that are integrated into multi-method approaches for the reconstruction of macro-topographic changes (e.g. Alexakis *et al.* 2011). In addition, several investigations aim at testing specific claims put forth by historians and archaeologists or assumptions raised by ancient literary sources, such as those of Herodotus, Homer or Strabo. This is, for example, the case with the search for the location of Homer's ancient Ithaca (Underhill 2009); the examination of the position and nature of the port of Oeniades (Fouache *et al.* 2005) and the harbor of ancient Corinth (Morharge *et al.* 2012), or the insular character of Piraeus in late prehistoric times (Goiran *et al.* 2011); and the investigation of the shoreline displacements and the evolution of the landscape in today's plain of Thessaloniki, around the ancient city of Pella or in the vicinity of other specific archaeological monuments (Ghilardi *et al.* 2008, 2010).

As expected, the new studies elaborate on, reexamine and sometimes challenge research carried out in the previous decades. Thus, in the frames of the Nikopolis Survey Project (Wiseman and Zachos 2003), Runnels and van Andel (2003; van Andel and Runnels 2005) revisited some major open-air Palaeolithic sites associated with the poljes of north-west Greece (the so-called 'red-bed' sites of Epirus) and discovered new Palaeolithic and Mesolithic sites. Their work furnished a regional chronostratigraphic scheme for the Palaeolithic sites of Epirus based on combined paleosol and TL/IRSL-dated stratigraphy (see also Zhou *et al.* 2000), presenting at the same time a model for the tecto-sedimentary evolution of the karst landscape, reconstructions of Quaternary paleoshorelines, grain-size and mineral composition of archaeological sedimentary contexts, as well as a discussion about the way in which Palaeolithic stone-tools may have been incorporated into the *terra rossa* matrix. This research built critically upon earlier geoarchaeological studies of the depositional environments of Palaeolithic artefacts (e.g. Bailey *et al.* 1992) and especially *terra rossa* and *paleosols* as archaeological contexts (van Andel 1998; Pope *et al.* 1984); but also continued on and juxtaposed its results to a thread of research on the tectonic and geographic background of the Quaternary landscapes of Epirus and the ways in which tectonic movements or topographic configuration may have influenced Palaeolithic land-use strategies and/or archaeological preservation (King and Bailey 1985; Sturdy and Webley 1988; Bailey *et al.* 1993; King *et al.* 1997; Sturdy *et al.* 1997).

Geoarchaeological research in Greece never lost its 'costal focus' and, after the first pioneering works that appeared in the 1970s and 1980s, coastal geoarchaeology carried on in the nineties (e.g. Niemi 1990; Zangger 1991; Mourtzas and Marinos 1994). In fact, as it becomes evident by the sheer number and quality of publications that have appeared in the last dozen of years, geoarchaeological applications have uninterruptedly, widely and successfully been used to solve archaeological problems or to reconstruct the environmental settings of coastal archaeological sites (e.g. Jing and Rapp 2003; Kraft *et al.* 2005; Vott *et al.* 2006; Pavlopoulos *et al.* 2006; Bruins *et al.* 2008; Vott *et al.* 2008; Shaw *et al.* 2008; Kapsimalis *et al.* 2009; Pavlopoulos *et al.* 2010; Athanassas *et al.* 2012; Mourtzas 2012; Pavlopoulos *et al.* 2012; Ferentinos *et al.* 2012; Ghilardi *et al.* 2013). Most of these works were largely based on and/or benefited from geological and geomorphological research on coastal paleogeography and sea-level fluctuations (e.g. van Andel *et al.* 1990b; Lambeck 1996; Perissoratis and Conispoliatis 2003; Pirazzoli 2005; Evelpidou *et al.* 2012), as well as sedimentological and stratigraphic studies of the continental shelf or of marine basins, gulfs and river deltas (e.g. Collins *et al.* 1981; Cramp *et al.* 1988; Perissoratis and Mitropoulos 1989; Mascle and Martin 1990; Roussakis *et al.* 2004; Kapsimalis *et al.* 2005; Lykousis *et al.* 1995, 2005; van Andel and Perissoratis 2006; Papanikolaou *et al.* 2007; Poulos 2009; Lykousis 2009).

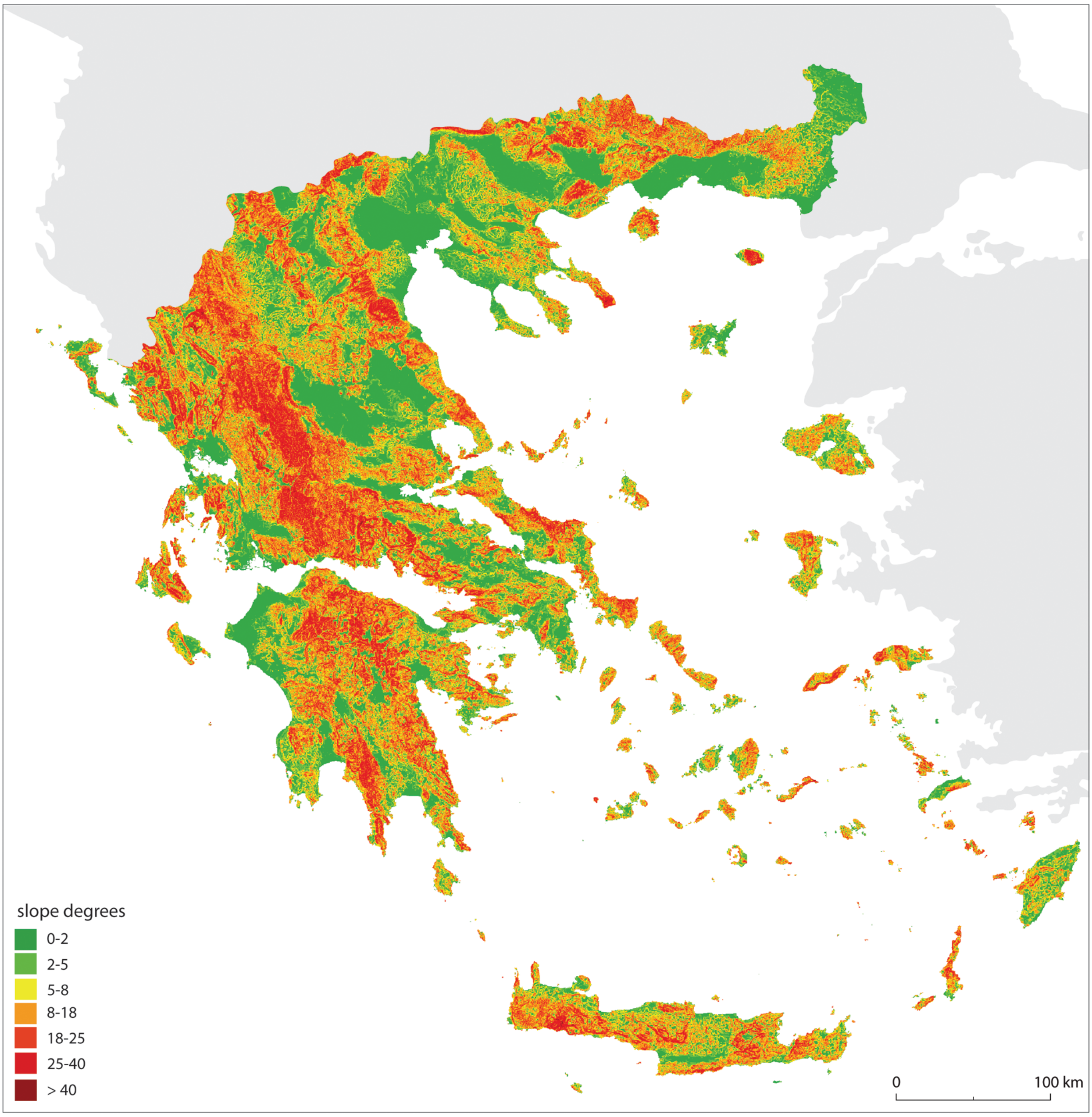
In a similar manner, research on human-environment interactions and on the relative contributions of climate- or human-induced processes as factors of landscape change remains a common target for geoarchaeologists working in Greece (e.g. Pope *et al.* 2003; Bintliff 2005; Bintliff *et al.* 2006; Fuchs 2007; Berger and Guillaine 2009). Although research on Holocene erosion in Greece continues to provide evidence for some degree of correlation between erosional episodes and cultural rather than natural processes (e.g. Fuchs 2007), there is at the same time a Mediterranean-wide growing awareness of the driving role that climate, tectonics and geology acquire in preconditioning human-induced erosion (Allen 2001; Casana 2008; Thornes 2009). Importantly, what seems to progressively gain attention in explaining past landscape changes, is the significance of short-lived, natural extreme events that can be related to recurrent but non-linear climatic episodes, bringing torrential rains and/or dramatic reductions in vegetation cover (e.g. Thornes cited in Bintliff 2002); or to tectonism (Gaki-Papanastasiou and Maroukian 1995; Maroukian *et al.* 2004; and also Zangger 1994, for a flash flood at Bronze Age Tiryns possibly associated with an earthquake). On the other hand, even though anthropogenic causation is still favored in many interpretations of alluvial aggradation (e.g. Lezpez 2003) and no less in pollen-based investigations (e.g. Jahns 2005; Kouli *et al.* 2009), a better understanding of Holocene climatic variability and the synchronicity of some fluctuations in the Mediterranean (Jalut *et al.* 2009), re-entered climate as a key-player and forced researchers to accept a mutual feedback between climatic triggering and anthropogenic disturbance (cf. Bintliff 2002). In a different but relevant line of research, Drake (2012) discusses how climatic stress –in the form of unusually arid conditions affecting agricultural productivity– might have contributed to the demise of Late Bronze Age societies, eventually leading to population decline and the collapse of the Greek Minoan and Mycenaean centers and palatial civilizations; in this work, the 'climatic explanation' for the dramatic changes seen in settlement patterns between the Late Helladic and the 'Greek Dark Ages' is tested against a number of climate proxies, including isotopes from speleothem records, pollen data, sea-surface temperatures, solar irradiance data and paleotemperature proxies derived from ice-cores.

As a whole, research carried out in Greece during the last two decades and centered on what could be considered as *regional* or *landscape-scale geoarchaeology* has profoundly contributed to a reconsideration of the role of the landscape in our understanding of past human behavior. The landscape was for long implicitly conceived more or less as a static, 'inexorable' background that needs to be solely reconstructed in order to become the setting for the archaeological narrative. Even in a slow-paced fashion, this view is being in recent times progressively abandoned in favor of more holistic and integrated approaches of landscape evolution in the archaeological reasoning. Evidently, such a development is rooted to concomitant advances in the theoretical and methodological armory of geoarchaeology, but it also echoes a deeper apprehension of the inherent complexities that become apparent when assessing natural and cultural environments and processes in conjunction. It is now, for instance, well-established that, due to their threshold-dominated nature (Schumm 1979; Vanderkerckhove *et al.* 2000; Bloom 2002), geomorphic systems are characteristically non-linear, exhibiting complex behaviors, controlled by dynamic instability and deterministic chaos (Thornes 1985; Phillips 1993); under such conditions, small and short-lived disturbances or changes to the initial conditions may result in disproportionately large and long-lived effects (Phillips 2006).

It is in this kind of geoscience rubric that a recent fieldwork-based, geoarchaeological approach of the Lower Palaeolithic record of Greece set out to explain the status of this record and outline the prospects of its future enrichment from a geomorphological perspective, by conducting a landscape-scale analysis and assessing preservation potential in juxtaposition to archaeological visibility (Tourloukis 2010). The central archaeological question here was straightforward and yet tricky: considering the paleontological, paleoanthropological, biogeographical and paleoecological status of Greece in the Quaternary, it has for long been expected that the Greek peninsula should produce valuable evidence for the earliest occupation of Europe; however, its early Pleistocene archaeological record stands out as a conspicuous ‘gap’ amidst the rich records of the circum-Mediterranean region. The fact that a large portion of this scanty evidence lacks a stratigraphic context and/or is associated with secondary (reworked) contexts emerges as a wider pattern that cannot be attributed to inappropriate research designs, the intensity of investigations or a lack of specialists in the field. Then, should this general ‘absence of evidence’ be ultimately regarded as ‘evidence of absence’ of hominins? The remains of hominin activities are likely to have been preserved, accessible/visible and stratified until the present only in areas where the relevant geological record is equally complete enough and has remained largely undisturbed. Disturbance versus preservation, erosion versus deposition, and deposition/preservation versus archaeological visibility/accessibility, are all conditioned mainly by geomorphic factors. These factors and their potentially biasing effects upon the archaeological record are tightly interrelated, but were examined as separate as possible, into four major groupings: climate, tectonism, sea-level changes and surface (slope) processes. A basic premise in this examination was the consideration of artefacts as another form of clastic material, because their hydromechanic, taphonomic and trasportational behavior does not differ from that of geological clasts (cf. Rick 1976; Schick 1987; Fanning and Holdaway 2001). Triggered either by climatic (e.g. deluges), tectonic (e.g. earthquakes) or anthropogenic processes (e.g. land use), it is principally the episodic but catastrophic events that induce most of landscape instability and result in the fragmenting and/or reworking of artefact-bearing deposits.

Employing the ‘nine-unit land-surface model’ of Dalrymple and colleagues (1968) in the form of a heuristic tool (cf. French 2003, 30-32), Tourloukis (2010) produced a slope map of Greece and used slope angle as a surrogate for mean local relief and as a morphological measure, in order to assess the potential for archaeological preservation and recovery as a function of surface steepness (Figure 2). On this basis, a quantitative and qualitative assessment was achieved, thereby evaluating how much of the Lower Palaeolithic record may have been lost compared to the geological record at our disposal, how much of it is likely to have escaped the biasing geomorphic agents, and what kind of geoarchaeological contexts we are facing today and we should expect to deal with in the future (Table 2). The conclusion that geological opportunities in Greece are limited and unpropitious for preserving early Palaeolithic material in stratified/primary contexts was explained in terms of landscape dynamics and their spatio-temporal specifics. Particularly, it was argued that Quaternary landscape evolution in Greece was primarily controlled by four main driving mechanisms: (1) a *tectonic activity* with rates of vertical and horizontal deformation that are among the highest in the entire Eurasia; (2) a markedly *seasonal climate* in which the seasonality of precipitation is the most important parameter, being accentuated mostly during glacials, and, in turn, affecting runoff and river flow fluctuations; (3) *sea-level oscillations* exposing and submerging large areas, at the same time controlling inland patterns of fluvial incision and aggradation; and, last but not least, as the land-surface manifestations of all of the above, (4) *slope processes* on a predominantly high-relief terrain with spatially restricted drainage basins, erodible lithologies, skeletal soils and an effectively strong slope-channel coupling. Rather than temporally continuous, landscape disturbance occurred in an episodic fashion and in the form of extreme erosional events of low duration but high amplitude and high frequency of recurrence, in time-windows that were pre-conditioned by the combined forces of some (or all) of the four above-mentioned factors. Changes to the thresholds at which a disturbance-event became effective could be due to climatic transitions (mostly cold-to-warm ones) at millennial, centennial or decadal scales, and/or associated sea-level changes (e.g. affecting base-levels of rivers); if not climate, tectonic movements would have been equally efficient as triggering factors. Following this line of reasoning, a landscape dominated mainly by *transient landforms* (cf. Brunsden and Thornes 1979; Phillips 1995) indicates that the fragmented and scanty status of the early Pleistocene archaeological record is to be interpreted as the outcome of the biasing and destructive effects of Quaternary geomorphic processes: in this sense, the ‘absence of evidence’ should not be understood as an indication of a former absence of hominins.

Figure 2. Slope map of Greece.



The map was produced in ArchGIS 9.2 and it is based on 1:250,000 topographic maps with a 20-m contour interval; adopted from Tourloukis 2010. The areas covered by the first slope class (0º-2º, shown in dark green) mainly represent the sedimentary basins and lowland coastal plains of Greece, which are also the places where the vast majority of Pleistocene sediments have accumulated. As a working hypothesis, Tourloukis (2010) argued that future investigations in search of Lower Palaeolithic sites should focus on areas of the first two slope classes, and particularly on basins that have been inverted in the Late Pleistocene and Holocene.

Table 2. Summary of main geoarchaeological conclusions deduced from a hypothetical classification of the landscape according to the nine-unit land-surface model.

Unit	Slope Angle (degrees)	Geomorphic Process	Potential for Preservation	Archaeological Context	Archaeological Visibility
1, 2	0 – 1 2 – 4	soil formation	high	primary	low, medium? high?
7	0 – 4	alluvial sedimentation	medium	?primary? secondary	low, medium
4	45 to >65	slope failure (landslides)	none	none	---
3, 5, 8, 9	26 – 45, possibly even higher	sheet erosion, soil creep, mass movements, channel corrosion, streambed transport	low	secondary, tertiary	high
6	modal angles	redeposition of colluvial material by mass movement, surface wash	medium	secondary	low, medium
Assessments on archaeological context and visibility are to some degree of speculative nature and are noted here only as 'most probable possibilities'. Artefact visibility, for example, can be high on lagged surfaces, low on depositional surfaces (because of burial) and somewhere in between (medium) on erosional surfaces. Reproduced from Tourloukis 2010.					

In essence, this study elaborated on the concept of landscape taphonomy, namely the assessment of the processes by which elements of the landscape become selectively removed due to the action of natural or cultural agents, resulting in a biased record of past landscapes – hence also a biased archaeological archive. Ultimately, this work demonstrated that evaluations of site distributions and occupation (dis)continuities or densities are likely to be flawed unless the observable patterns have been evaluated against the effects of geomorphic biases. Moreover, it showed how a geoarchaeological application at the landscape-scale may have considerable implications for upcoming archaeological investigations in Greece, not only because of its net results, but also *as a methodological approach* that sets novel points of departure for the designing of fieldwork practices: in this case, the aforementioned work sketched out new perspectives and narrowed down the focus on *where* to look for Palaeolithic material, as well as *how* to look for it. In the same vein, the study and interpretation of landscape dynamics can alter our understanding of the potentiality of a region for yielding new evidence: for instance, results presented elsewhere (Tourloukis and Karkanas 2012), emphasized the potentially central role of the Aegean region in hominin dispersals, since half of the Aegean Sea would have been subaerially exposed during most of the early Pleistocene. This conclusion (cf. Tourloukis 2010) opens up new prospects for future fieldwork in an area that was hitherto essentially neglected and it has already inspired new research on insular archaeology (e.g. Ferentinos *et al.* 2012).

While it is acknowledged by Mediterranean archaeologists (e.g. Barton *et al.* 2002; see papers in Athanassopoulos and Wandsnider 2004), the role of landscape taphonomy has been only limitedly explored in geoarchaeological research practiced in Greece, even though GIS-based investigations in this direction have been notably successful when focusing on micro-regions and/or individual survey areas (e.g. Bevan and Conolly 2002-2004; Gouma *et al.* 2011). However, geomorphic agents have significantly influenced the quantity and quality of the archaeological material that we find and collect from the modern land-surfaces or geological outcrops of Greece. Using an ecologically- and geomorphologically-informed perspective, ‘landscape geoarchaeology’ allows for a holistic, multidisciplinary and integrative approach to both the human-environment interactions and the way in which the archaeological evidence comes to be embedded into the geoarchaeological envelope.

Site-specific applications

Although regional geoarchaeological investigations are of primary importance in archaeology, a fundamental premise of the geoarchaeological endeavor, as originally formulated by Renfrew (1976), is to understand how a site is formed –in other words, to understand the *context* of the archaeological finds. Archaeologists who conduct excavations are well aware that the only means to reveal the context of the artefacts and features that they excavate is by studying the sediments and stratigraphy of the site (Goldberg and Macphail 2006). The geoarchaeology at the site-scale is concerned with the deposits of the site and with what people have left behind. It is thus focused on the formation processes that built the site and actually deals with archaeological sediments per se. The infinitive repertoire of anthropogenic settlement activities demands a special range of expertise. Fine-scale geogenic sedimentary processes such as rain-, sheet-wash or ponding, and human-induced post-depositional alterations and disturbances such as trampling, dumping, digging and backfilling usually fall outside the ‘background knowledge’ of geoarchaeologists working in large-scale projects. Therefore, it is not a surprise that this side of geoarchaeology is comparatively underexplored, even though its importance is being ever more appreciated in recent times.

Nevertheless, studies in ‘microarchaeology’ (sensu Weiner 2010) have been conducted at a number of Greek sites already from the very beginnings of geoarchaeological applications. One of the first works was that of Davidson (1973), who applied grain-size and phosphate analyses in the Neolithic tell of Sitagroi, northeastern Greece. Particle size was used to locate the source of the tell material, which was found to be the local alluvium that was used for the construction of houses. Moreover, phosphate analysis was employed to define occupational intensities and abandonment phases. With his work on the processes of tell-formation and erosion in the plain of Drama in northern Greece (Davidson 1976), the same researcher contributed to the first edited volume of geoarchaeology (Davidson and Shackley 1976). Davidson and his co-workers recently continued their research on Greek tells, showing how a multi-element analysis of onsite deposits can identify the geochemical distinctiveness of several archaeological contexts (pit, house, plaster floor, alley, road and yard) (Davidson *et al.* 2010).

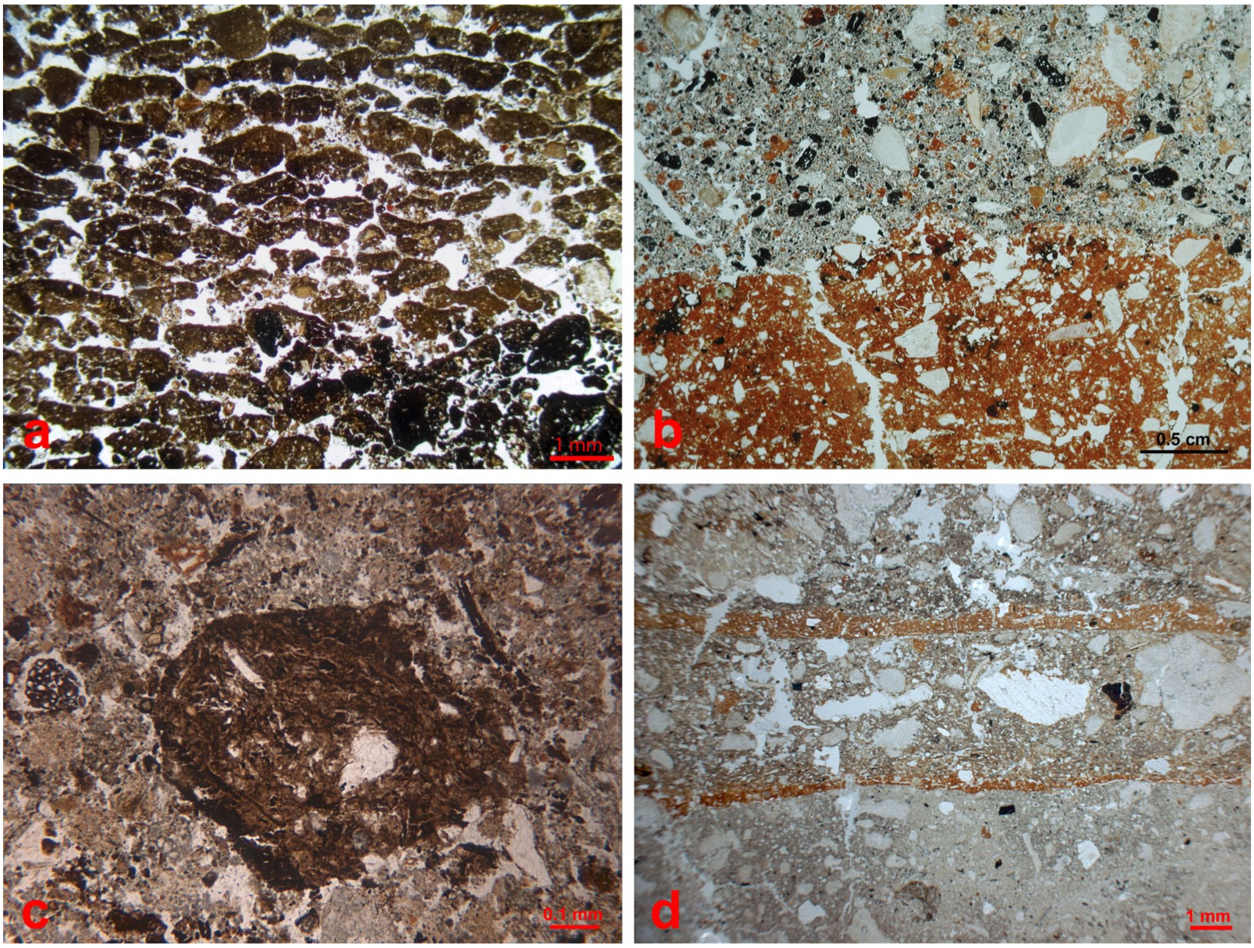
Most of the early on-site geoarchaeological investigations in Greece, however, were conducted in the course of projects targeting Palaeolithic caves, such as those of Kastritsa, Asprochaliko and Kalamakia (Higss and Vita-Finzi 1966; Bailey *et al.* 1983; De Lumley and Darlas 1994). Later on, in line with the golden period of the regional geoarchaeological studies associated with the Franchthi project, William Farrand studied the stratigraphy and the sediments of Franchthi Cave. His complete work was published in an individual volume (Farrand 2000), but results from the same study were also published separately and often in comparison with other cave studies (Farrand 1987, 1988, 2001 and 2003). One of the main contributions of Farrand’s work in the study of Franchthi Cave was the recognition and interpretation of hiatuses in the cave sequence on the basis of stratigraphic criteria and a set of sedimentary laboratory examinations. The laboratory analysis included particle size, pebble morphology, roundness and porosity, $CaCO_3$ content, organic matter and pH measurements. Another important finding was the identification of a volcanic tephra layer at the base of the sequence attributed to the well-known Campanian Ignimbrite eruption at ca. 40 ka (Vitialiano *et al.* 1981), which was recently re-analyzed by Lowe *et al.* (2012). The same tephra was identified at another nearby Palaeolithic cave, Klissoura Cave I; combined with research at other sites from the eastern Mediterranean, tephrostratigraphy enabled the synchronization of archaeological and paleoclimatic records and thus provided important insights into the Middle to Upper Palaeolithic transition and the co-occurrence of Neanderthals with anatomically modern humans in Europe (Lowe *et al.* 2012).

The same array of sedimentary laboratory methods was also used in another major on-site geoarchaeological project in the Upper Palaeolithic rockshelter site of Klithi, Epirus (Bailey and Woodward 1997; Woodward 1997a). Likewise in the case of the Franchthi Cave, in this study it was shown clearly that the size and form of the coarse limestone particles found in Mediterranean caves and rockshelters are conditioned more by tectonic preparation of the host rock than by the influence of exogenic detachment mechanisms such as cryoclastism (Woodward and Goldberg 2001; Bailey and Woodward 1997; Woodward 1997a; Farrand 2000). In addition, it was shown that an understanding of fine sediment sources and related off-site processes is important for the reconstruction of site formation (Bailey and Woodward 1997). In the same line, Woodward *et al.* (2001) proposed a new approach in the quantitative estimation of the contribution of potential source materials in rockshelter sediment records. This approach employs a composite sediment fingerprinting method, which includes trace element analysis and magnetic susceptibility measurements complemented by micromorphological examination of the sediments.

At the same time, the above-mentioned studies revealed also the limitations of the traditional approaches in sedimentological analysis. Bailey and Woodward (1997) admitted that the sediment record in Klithi revealed a striking variability and complexity in the formation of the deposits, which resulted in a loss of resolution. Given this site-specific complexity that cannot be adequately scrutinized with field observations and conventional sedimentological analysis, the best alternative is to apply a microtextual approach based on microstratigrapy and microfacies analysis. Using these microscopic techniques it is possible to detect specific past human activities, identify the use of space and understand the depositional context of all archaeological remains. In particular, such an approach involves the application of micromorphology, namely the study on intact sediments and soils at a microscopic scale (Courty *et al.* 1989), as well as microchemical or physicochemical analyses of the same micromorphological samples by use of instrumental techniques (Mentzer and Quade 2013). The first attempts to apply micromorphological analysis in Greek archaeological sites are those carried out by Jamie Woodward (1997b) in Megalakkos rockshelter, Epirus and by Paul Goldberg in the sanctuaries of Demeter and Koros in Korinth (Bookidis *et al.* 1999). Both studies, however, were focused on specific archaeological features and were not meant to assess the entire array of formation processes of the sites. The study of soil erosion, agricultural terracing and site formation processes in the Early Bronze Age site of Markiani (Amorgos Island, Aegean Sea) is among the first systematic applications of micromorphology in Greece, albeit in a more regional context (French and Whitelaw 1999). That being said, it was not until the geoarchaeological investigations carried out in Theopetra Cave that micromorphology actually started to be conclusively applied in the study of site formation processes in Greece (Karkanas 1999, 2001).

The micromorphological study of the cave sediments at Theopetra revealed a very intriguing paleoenvironmental data-set. Repeated freeze/thaw activity during cold periods of the Late Glacial produced platy and spherical microstructures, which are the result of seasonal freezing temperatures well below 0°C (Figure 3a). Impressive and thick anthropogenic remains in the form of superimposed ash layers were found only in-between the cryogenically altered sediments. On the basis of the new series of thermoluminescence dates produced on burnt chert artefacts, it appears that the site was occupied only during warm climatic periods of the Upper Pleistocene (Valladas *et al.* 2007). In addition to the aforementioned assessments, the case of the Theopetra Cave exemplifies how powerful micromorphology can be, also as a tool in resolving problems related to *post-depositional* alterations. Elemental analysis performed on the micromorphological thin sections facilitated the identification of certain chemical alteration patterns and allowed for the reconstruction of the chemical palaeoenvironment prevailing at the site. In turn, these findings were used to determine whether the primary fossil and anthropogenic remains (bone, teeth, ash, phytoliths, organic matter, etc.) had been affected by chemical alteration and, by extent, to indicate their past presence or absence (Karkanas *et al.* 1999, 2000).

Figure 3. Photomicrographs in plane polarized light of selective micromorphological samples from Greek archaeological sites.



a) Lenticular microstructure due to repeated freeze-thaw activity. Middle Palaeolithic, Theopetra Cave, Thessaly. b) Hearth construction made of red clay-rich sediment overlain by loose reworked burnt remains. The burnt remains consist of a chaotic mixture of grey calcitic wood ash, black charcoal and clay fragments detached from below. Upper Palaeolithic, Klissoura Cave I, Argolis. c) Half-burnt ovicaprine dung fragment inside burnt remains. Grey wood ash crystals are visible. Neolithic, Kouveleiki Cave A, Lakonia. d) Superimposed constructed floors made of different mixtures of lime and occupational debris. Fine black particles are microcharcoal. The red clay-rich layers represent finishing coats of the floors. Neolithic, Makri, Thrace.

Further micromorphological investigations in the Palaeolithic sites of Klissoura Cave I and Lakonis Cave provided detailed insights on site formation processes, specific burning activities and the use of space (Figure 3b), such as *in situ* burning and dumping areas, thereby enhancing our understanding of human behavior in the Palaeolithic (Panagopoulou *et al.* 2002-2004; Karkanas 2001; Karkanas 2010). In the Aurignacian layers of Kleisoura Cave I dated to 32-34 ka BP, several basin-like clay lined structures were examined with micromorphological, thermoanalytical and spectrophotometric techniques. Among other things, it was found that the clay structures were heated to temperatures between 400 to 600°C and, therefore, it was suggested that they were used as hearth structures for cooking purposes (Karkanas *et al.* 2004). Consequently, the analysis of combustion features demonstrated advanced human skills related to pyrotechnology and provided new information on the social life of humans in the beginning of the Upper Palaeolithic period.

One of the best examples of 'site geoarchaeology' is the study of stabling activities in caves of southern Europe. Micromorphological studies in Kouveleiki Caves A and B, Laconia, revealed specific human practices during the Neolithic, such as dung burning for clearing purposes and construction of mud floors (Figure 3c). The

Kouveleiki case presents coherent evidence of a small-scale, self-contained and mixed farming household in a marginal area (Karkanas 2006). In another Neolithic cave in Poros, Cephalonia Island, lime plaster floors were identified, offering important insights into domestic activities during the Neolithic period (Karkanas and Stratouli 2008).

In Dispilio, a lakeside settlement by the Orestias Lake (Kastoria, northern Greece), microfacies analysis of the sediments, supported by a suite of environmental indices, has provided detailed palaeoenvironmental data and elucidated the main processes involved in the formation of the site throughout its history of occupation from the Middle Neolithic to Chalcolithic Period (Karkanas *et al.* 2011). The microfacies approach indicated a complex occupational pattern as the result of the interaction of fluctuating lake levels and the variable input of anthropogenic sediments at the site.

More recent micromorphological studies of occupational sequences in sites with architectural remains like Mycenae (Peloponnese) and Palamari (Skyros Island) reveal valuable information on the structure and history of the sites (Karkanas 2013a and b). In the Neolithic tell-site of Makri in northern Greece, different types of floors were identified (Figure 3d), implying specific maintenance practices and activities related to social behavior and organization (Karkanas and Efstratiou, 2009), whereas in the Bronze Age site of Mitrou, changes in floor maintenance practices are associated with cultural and social developments (Van de Moortel and Karkanas 2013). Micromorphology has even provided details about the process of backfilling and re-opening of the corridors of Mycenaean chamber tombs and the location, number, and slope of these re-openings. Constructed floors were also identified in the corridors and chambers of the tombs, allowing for the reconstruction of complex histories of mortuary practices and their social meanings (Karkanas *et al.*, 2012). All of these recent studies bring a new dimension in the archaeology of urban sites and the investigation of sites with architectural remains, demonstrating that sediments, be that geogenic or anthropogenic, are of fundamental importance for the unraveling of past human behavior and the development of testable archaeological hypotheses.

A different on-site geoarchaeological approach in the examination of site formation processes is provided by the study of micro-artefacts in combination with particle-size analysis and novel computation methods (Kontogiorgos and Leontitsis 2005; Kontogiorgos *et al.* 2007; Kontogiorgos 2008, 2010). Micro-artefacts (i.e. cultural remains smaller than 2 mm in dimension such as micro-shell, micro-bone, micro-fragments of charcoal, etc.) constitute a significant part of a site's cultural component and carry the potential of providing significant information on the use of space. The application of this methodology in the Neolithic sites of Paliambela and Korinos in central Macedonia enabled researchers to show the differences in the spatial organization of activities carried out at the sites (Kontogiorgos 2008, 2010).

Today, several important sites like Lykaion in Arcadia, Avgi in western Macedonia, Paliambela in central Macedonia, Koutroulou Magoula and Imvrou Pigadi in Thessaly and Sissi in Crete are the focus of ongoing micromorphological investigations with very promising results, conducted by a new generation of geoarchaeologists (Mentzer 2009; Roussos 2010; Karpentier 2011; Koromila 2012; Kyrillidou 2012).

Conclusions

It can be argued that, even on a global scale, geoarchaeology made some of its first disciplinary steps on the mosaic-like and physiographically complex landscapes of Greece, providing valuable knowledge to the archaeology of an equally intricate cultural landscape. The long archaeological record of the country, manifested by impressive –and yet often enigmatic– archaeological sites, along with a pronounced littoral diversity, rendered the Greek seaboard an appropriate laboratory for the development of close working ties between archaeologists and earth scientists. Consequently, archaeological sites situated at or near the coast became the working fields where geoarchaeological techniques were first applied and tested. Notwithstanding an arguably exploratory character, the geoarchaeological studies carried out during this initial phase left a prominent imprint for the years to come: they were pioneering in the methodology that they advanced, offered original –and often unanticipated– data, and bolstered up a hitherto staggering effort of the Greek archaeology to respond to the epistemological calls of the processualist school of thought. A second phase in the history of regional geoarchaeological research in Greece is marked by what proved to be a long-lasting debate over the relative contribution of climatic *versus* anthropogenic impact on soil erosion, valley aggradation and landscape modification. Along with an improvement in dating methods and laboratory techniques, it has by now become all the more obvious that neither natural nor human-induced processes have left utterly unequivocal signals in the terrestrial records. While some first-order linkages can indeed be established, correlations between environmental and archaeological records are not always straightforward, and cannot be strengthened by merely associating different local sequences (natural or cultural) with a single process during one chronological horizon. As the discussion continues to the present, two main outcomes can be emphasized from the research carried out thus far in this domain: first, the importance of the complexities that arise due to the interrelations and feedbacks between different geomorphic and cultural agents –complexities that usually preclude monocausal or over-deterministic interpretations; second, the significant role (at least in Mediterranean settings) of extreme natural events that were brief and episodic but potentially of high magnitude and/or high frequency of recurrence, and which ‘pre-conditioned’ time-windows for terrestrial responses to environmental and/or cultural triggering factors.

Deciphering the temporal and spatial patterning in landscape change and its relation with human settlements remains a major concern for geoarchaeology in Greece by the advent of the twenty-first century. Geomorphological, paleoclimatic and ecological assessments provide the basis for palaeoenvironmental and palaeogeographic reconstructions, which are in turn used as frameworks for the examination of past socio-cultural developments. Whereas some studies offer diachronic accounts of the changes in the environmental context of an archaeological site, other investigations evaluate specific historical or archaeological hypotheses, or apply and test novel techniques and multi-method approaches. At the same time, the geoarchaeology of coastal settings continues to be commonly and effectively practiced, while research on human-environment interactions keeps fueling the discussion over the relative role of cultural and natural agents in the shaping of landscapes. In fact, recent macro-regional geoarchaeological approaches have shown how an earth-sciences perspective can shed light to archaeological questions with a spatio-temporal scale as broad as that related to the potential role of Greece in the earliest hominin dispersals and the first occupation of Eurasia (cf. Tourloukis and Karkanas 2012).

Even if geoarchaeology in Greece largely started off as a ‘coastline matter’, Davidson’s contribution to the first edited volume on geoarchaeology (Davidson and Shackley 1976) dealt with tell-formation processes; this should remind us that, like elsewhere in the globe, geoarchaeology in Greece was essentially born out of studies examining site formation processes. Undeniably, it is in this realm that the practice of geoarchaeology has gained momentum in Greece during the last decade: with an ever-growing body of microstratigraphic and micromorphological research, on-site geoarchaeological studies have provided high-resolution insights on a variety of crucial archaeological issues, elucidating processes related to site formation, post-depositional alterations, domestic activities, mortuary practices or the use of space (e.g. Karkanas 2002).

From the time-scale of the Quaternary glaciations and a landscape-wide areal extent, to the time-scale of a Mycenaean burial and the particle-size analysis of the microfacies in an occupation floor, geoarchaeology has proved to be a powerful tool that operates at a wide range of spatial and temporal scales. Yet, it is not so much the scale but the nature of the questions asked that will ultimately dictate the appropriate methodological toolkit to be used (cf. Brown 2008). Geoarchaeology has rightfully become an indispensable part of this toolkit for the analysis of contextual data and the interpretation of archaeological patterns. As this review has aspired to show, recent and on-going geoarchaeological applications in Greece are part of a long and successful legacy, which has early on laid the foundations and in fact raised the standards for even more fruitful geoarchaeological studies to appear in the future.

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