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PALEOSHORES (LAKES AND SEA)

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Introduction: traces on the Rhodian shore?

In his seminal book looking at nature and culture in western thinking, Glacken (1967) stated that geography, particularly geoarchaeology, poses the question of possibilism, the idea that the environment sets certain constraints and that humans can act as geomorphic agents. In this sense, shorelines are an archetypal interface to look at rapidly changing terrestrial and aquatic environments.

More than a century ago, the American geomorphologist John Wesley Powell introduced the term “base level” to define the elevation below which a stream cannot downcut deeper into its valley. Fluvial processes cease where a river flows into a large lake or the ocean because the hydraulic gradient is reduced to zero at the origin of sedimentary deposition (Chorley et al., 1964). Since the time of Powell’s pioneering work, the ocean has been regarded as a reference base level even though sea level varies in space and time, and it is paramount in driving shoreline changes and human settlement geographies. One of the key advantages of living in coastal areas is access to marine resources, including mollusks, mammals, and birds, all of which provide potentially rich sources of energy and protein.

Geological evidence for relative sea-level changes and local crustal movements is critical to understanding the archaeological record in coastal areas. Gaps in the record increasingly point to the need for underwater exploration of submerged shorelines, and a growing body of evidence shows that archaeological sites are prevalent in submerged landscapes. Two major forcing factors explain shoreline deformations: (1) relative sea-level (RSL) changes and (2) modifications in sedimentary budgets at various spatiotemporal scales.

Geoarchaeology of paleoshorelines and Quaternary RSL changes

Past sea-level changes have been driven by eustatic and crustal factors, e.g., isostasy, tectonics, geoidal changes, and the effects of changes in the Earth’s rotation. During the past 20,000 years, these forcing agents have interacted at various spatial and temporal scales (references and synthesis in Church et al., 2010).

During the interval prior to ca. 6000 years BP, most sea-level curves are characterized by a general rise in the water level corresponding to the eustatic signature of melting continental-based ice caps. Once the last of the large ice caps had melted (around 6000 years BP), glacio-eustatism ended (e.g., Pirazzoli, 1991; Mörner, 1996; Lambeck and Bard, 2000) (Figure 1). Since this date, relative sea-level records have been dominated by crustal mobility and the irregular redistribution of water masses over the globe, primarily driven by variations in ocean and atmospheric circulation systems (marine currents, evaporation/precipitation budgets). Since the Neolithic, a plethora of archaeological indicators can be used to estimate RSL changes.

Archaeological and biological markers of RSL changes

Since 6000 years BP, ancient societies have left different types of coastal evidence indicating RSL changes, including town structures, anchorages, and ports. Submerged artifacts can provide interesting details to reconstruct ancient shoreline changes. The use of archaeological RSL markers draws upon the close interaction between

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archaeologists, geomorphologists, and biologists (Pirazzoli, 1976; Auriemma and Solinas, 2009).

Archaeological evidence for RSL variations is wide and varied (Flemming and Webb, 1986). Broadly speaking, it can be recovered within three zones.

1. The *supralittoral zone* includes residential units such as villae maritimae, private and public buildings, or town quarters (foundations, floors, roads, and pavements), thermal baths, plumbing installations (wells, aqueducts, cisterns, sewers, drains, gullies), tombs, and quarries. When inundated by rising seas, these remains can provide estimates for the amount of submersion.
2. The *midlittoral zone* includes interface structures such as quays, piers, breakwaters, or fishponds that exist at the sea level of the time. These constitute the most precise type of archaeological RSL indicators.
3. Finally, the *infralittoral zone* hosts structures such as wrecks or harbor foundations, which again provide broad estimates on the magnitude and direction of relative sea-level changes.

Under favorable conditions, measurements must be taken in relation to the mean biological sea level (MBSL), as defined by Laborel and Laborel-Deguen (1994). Marine biologists have demonstrated that, on hard substrates, the limit between the midlittoral and infralittoral zones is marked by a well-defined qualitative and quantitative change in the composition of benthic algal and animal populations (Figure 2). These subfossil zones can be preserved in the case of coastal uplift or silting of the archaeological site (Pirazzoli, 1977; Morhange et al., 2001). This limit also corresponds to distinct morphological features such as the vertex of tidal notches or the floor of erosion platforms (Pirazzoli, 1986). Seasonal or aperiodic sea-level changes have little or no influence on these biological and geomorphological belts.

Archaeological evidence brings with it varying degrees of precision when used to indicate the former RSL, and therefore care must be taken to ensure the indicator chosen has a reliable maritime association. It is also important to evaluate critically the functional elements of the indicator and the dimensions of the emerged part (if it has risen above the water) relative to present sea level (Auriemma and Solinas, 2009). Consequently, it is important to determine the chronology and the dynamics of its abandonment or destruction. This is achieved by archaeological surveys, sampling of the chronological indicators (ceramics, etc.), and excavation. Interdisciplinary work, drawing on archaeology, the geosciences, and marine biology, aims to (1) measure RSL variations based on the best preserved archaeological remains, (2) evaluate the height and functional depth of the indicator relative to mean sea level and if possible the MBSL, and (3) establish chronological and altitudinal error bars with relation to MBSL.

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Geoarchaeological case studies of eustatic sea-level changes and recent RSL variations

Quaternary marine oscillations: the prehistory of land bridges and coastal resources

It is now well established that large sea-level fluctuations accompanied the glacial-interglacial cycle. The maximum amplitude of eustatic variation in response to continental glaciation was approximately 120 m, with relatively short periods of highstand punctuating much longer periods of lowstand. The pattern of sea-level change is best attested for the last glacial-interglacial cycle, but earlier cycles were accompanied by similar fluctuations back to 2.5 Ma (Lambeck et al., 2002).

The archaeological implications of these sea-level changes have been recognized for a long time. They significantly influence the visibility of marine resources at different periods, the preservation of coastal archaeological sites, human dispersal (the creation and submergence of land bridges), changes in shoreline ecology, and alterations in the paleo-economic potential of coastlines (Masters and Flemming, 1983; Bailey and Flemming, 2008). For example, prehistoric peoples were able to exploit exposed coastal and continental resources during sea-level lowstands, and crossings by land routes were facilitated by marine regressions; the Bering Strait lays above sea level and acted as a land bridge for human migration and the movement of other biota in the late Pleistocene until 11,000 years BP (Elias et al., 1996).

As Bailey (2004) stresses, the received wisdom of world prehistory has been dominated by land-based narratives, where hunter-gathering societies gradually adopted agriculture and domestication. Little emphasis has been placed on the use of coastlines and marine resources due to three consistent biases: (1) sea-level changes have removed evidence through erosion or submergence, (2) research biases have traditionally neglected coastal hunters and gatherers, and (3) a focus on technological "primitivism" in which the tools and knowledge to exploit coastal resources were a late development in human cultural development (Bailey, 2004). Nevertheless, coastal habitats are among the most attractive for human settlement, and they have played key roles as gateways to human movement and the rise of civilizations (Flemming, 2004).

Postglacial marine transgression and the prehistory of continental shelves

Popular interest in marine archaeology, combined with the democratization of scuba equipment, has resulted in remarkable offshore discoveries (Masters and Flemming, 1983). Recent advances in bathymetric mapping and geophysics have shed fresh light on the dynamics of shoreline changes and human ecology in coastal areas.

Key problems relate to the preservation of submerged material, the sequence of burial, and taphonomy processes. What are the possibilities of coastal/marine prehistoric deposits surviving into the present, either in primary or reworked contexts? What processes are most favorable to the survival of prehistoric sites? Can the pre-transgressive landscapes be precisely reconstructed? Destruction is greatest for sites located in areas directly exposed to breaking waves. It is important, therefore, that sediments rapidly cover archaeological sites in order to ensure their long-term survival in the geologic record (Bailey and Flemming, 2008; Bailey et al., 2008).

Based on sea-level data and local geological and geoarchaeological records, Perissoratis and Conispoliatis (2003) have established that, during oxygen isotope stage 2 (21,500 years BP, sea level at −120 m), extensively exposed continental shelves existed in the northern and eastern Aegean Sea (Greece) and central parts of the Ionian Sea. Many islands formed larger complexes and were connected with the mainland. The peripheries of many gulfs were subaerially exposed, while freshwater lakes formed in their central parts. At 11,500 years BP (sea level at −60 m), the surface area of the exposed shelf was already greatly diminished, and the advancing sea overflowed into most of the gulfs; just a few islands retained land bridges to the mainland. Finally, from 8000 years BP and onward, the sea drowned the lowlands and gulfs, but subsequent sediment input by fluvial systems induced rapid coastal changes. Thus, many human settlements and ancient cities with maritime orientations during Hellenistic or later times are today located tens of kilometers inland.

At shorter time scales, historical relative sea-level rise has submerged numerous archaeological sites, such as the settlement of Atlit Yam (Israel). Galili et al. (1993) were able to reconstruct a precise sea-level curve based on archaeological and sedimentological evidence from submerged sites. This work has elucidated two main stages of sea-level rise: from 8900 to 7000 years BP (sea level rose from −35 to −7 m) and from 7000 to 4000 years BP (sea level rose from −7 m to its present position). The resulting rapid landscape changes, combined with the loss of vital terrestrial and underwater resources (i.e., agriculture, pasture, hunting, and fishing grounds), must have necessitated ongoing adaptations by the coastal communities. By contrast, no major RSL changes have been attested in the last 4000 years (Galili and Nir, 1993; Sivan et al., 2001).

Recent crustal movements, tectonism in Crete versus isostasy in the Pacific

Western Crete was uplifted by up to 9 m in the fourth to fifth centuries AD (Stiros, 2010). At the scale of the Eastern Mediterranean, a cluster of coastal uplifts is attested by radiocarbon and archaeological data around this time. Detailed analysis of geological, historical, and archaeological data suggests that a major earthquake in Crete was responsible for coastal uplift in 365 AD. Despite significant changes in the coastal morphology, widespread destruction, and human loss of life, the 365 AD earthquake was not responsible for any major cultural change in Cretan society (Figure 3).

In a different crustal context, many studies of the Pacific islands suggest that relative sea-level fall has driven cultural change during the 3000-year history of human settlement. This is notably the case for the Lapita culture, which was dependent on coral-reef foraging but disappeared almost simultaneously around 600 BC (Nunn, 2005, 2007a; Carson, 2008). Most colonizing Lapita settlements were established on coastal fringes, perhaps on sandspits or sand-floored reef flats. As relative sea level fell and sediment accreted, these areas emerged inducing changes in settlement character and distribution (Nunn and Heorake, 2009). It is also clear that around 1300 AD, there was a rapid fall in relative sea level of 70–80 cm that induced food shortages in coastal areas across the Pacific Islands region and led to an abandonment of coastal settlements in favor of upland fortified settlements (Nunn, 2007b; Field and Lape, 2010). Environmental change was therefore an important cause of societal transformation during the prehistory of the Pacific Islands.

Geoarchaeology of Holocene coastal changes, from marine transgression to coastal progradation

Glacio-eustatic sea-level rise after the Last Glacial Maximum brought about worldwide flooding of coastal areas, controlling the evolution of marine embayments, fluvial mouths, and rocky coasts. By contrast, its significant deceleration during mid-Holocene times resulted in shoreline progradation, which was particularly pronounced along sediment-rich clastic coasts.

These shoreline modifications forced ancient societies to adapt their settlements continuously to the evolving landscape. Such rapid changes in sedimentary environments have been investigated in detail throughout the world using many methods and disciplines, including geography, geomorphology, geology, biology, and archaeology. These studies have demonstrated that Holocene sea-level rise led to a general marine transgression, which was later countered by a strong progradational trend on alluvial-rich coasts that in turn slowed the rate of sea-level rise due to an increase in sediment yields from fluvial systems. During the last 3000 years, these sediment yields were enhanced by greater erosion rates due mainly to human-induced impacts on soil, vegetation, and fluvial systems.

All over the world, extensive coastal changes have played out on deltas, which act as depocenters storing large volumes of sediment produced by terrestrial erosion and delivered to the coast by fluvial systems. Deltas constitute excellent geo-archives for the study of settlement phases and coastal deformations. Paleogeographical studies have been important in developing new scenarios for delta and floodplain evolution. For example, Brückner (2005), Brückner et al. (2005, 2006), and many others have investigated the evolution of a number of eastern

Mediterranean deltas during the last six millennia. The spatial and temporal evolution of the deltas has been reconstructed using geoarchaeology, combining delta stratigraphy and geomorphology with archaeological sources. For example, the siltation of the seaport of Ephesus (Kraft et al., 2007) was associated with the progressive deltaic growth of the Küçük Menderes (Kaystros) river and its tributaries. Ancient Troy, too, overlooked a large marine bay that has gradually silted up with sediment from the advancing Karamenderes (Scamander) and Dümrek (Simois) river deltas, weakening the city's strategic position (Kraft et al., 2003) (Figure 4).

In Greece, Vött et al. (2007) have shown precise evidence for delta growth, based on chronostratigraphic data. The shipsheds of Oiniadai, dating to the fifth–third centuries BC, are today located 9 km inland on the Acheloos River (Acarnania) delta attesting to considerable coastal changes since the mid-Holocene. It has been demonstrated that Oiniadai's ancient shipsheds were accessible to the sea via a lagoon (Figure 5).

During the past 30 years, an acceleration in RSL rise and upstream sediment trapping by fluvial dams has led to accelerated erosion that has exposed archaeological remains, such as in Gaza (Morhange et al., 2005) and Tunisia (Trousset et al., 2004). Although coastal progradation has been the general trend during the past few millennia, many coastlines are, paradoxically, undergoing erosion linked to a human-induced decline in sediment supply that is currently destroying a great number of coastal sites.

Lacustrine geoarchaeology: a long-standing controversy

Archaeological investigations have shown that lakeshores were attractive areas for ancient societies not only in Europe, where the sub-Alpine area has famously yielded Neolithic and Bronze Age lake dwellings, but also in other parts of the world, such as the many pre-Hispanic sites around the lakes of South and Central America. Because of the abundance of limestone rocks in their catchment area, most sub-Alpine lakes are characterized by a littoral platform at least partly composed of carbonate lake marl. In the shallow water on the surface of these littoral platforms, the remains of Neolithic and Bronze Age villages were discovered in the mid-nineteenth century, first in Switzerland and then rapidly all around the Alps in France, Germany, Austria, Italy, and Slovenia. Up until the late 1970s, these discoveries were controversial and vigorously debated: how could one explain settlement remains below present water level?

The mid-nineteenth-century Swiss researcher F. Keller interpreted the hundreds of wooden posts emerging from lake sediments as piles supporting platforms for lake dwellings (Figure 6). This hypothesis assumed that lake level and climate had not varied since the Neolithic period.

In the first half of the twentieth century, investigations by the German H. Reinerth led to a reinterpretation. On the basis of careful archaeological excavations and observations of architectural structures in the lakes Federsee and Bodensee (Germany), Reinerth postulated that the prehistoric lakeshore dwellings had been built directly upon the ground, or with slightly raised floors to accommodate seasonal floods, when the lake level was lower than today due to phases of drier climate. Reinerth's proposal was also consistent with the first paleoclimatic reconstructions developed for the Holocene period by the Scandinavian palynologists A. Blytt and R. Sernander, as well as by the palynologist H. Gams, and the geologist R. Nordhagen in Central Europe.

In the mid-twentieth century, a group of German and Swiss archaeologists led by O. Paret and E. Vogt went even further and affirmed that prehistoric lake dwellings had never existed, relegating them to mere myths. Neolithic and Bronze Age villages were built on the ground when lake levels were lower than today due to drier subboreal climatic conditions.

Since the 1970s, the adoption of more rigorous archaeological techniques, in addition to exceptional findings such as the Bronze Age settlements of Fiavé-Carrera in northern Italy (Perini, 1994), has progressively demonstrated that a great diversity of lakeshore dwellings developed during the Neolithic and Bronze Age around the Alps. The French archaeologist P. Pétrequin (Pétrequin and Pétrequin, 1988) has even shown that all types may have coexisted in the same village! As the debate on sub-Alpine prehistoric lake dwellings gradually abated, paleoclimatic investigations undertaken during the last three decades have provided detailed insights into Holocene climate history. These studies have shown that the last 11,700 years have been punctuated by successive centennial-scale phases of higher and lower lake levels in West-Central Europe, in response to various forcing factors (Berglund, 1986; Magny, 2004, 2006).

Lakeshore archaeological sites and past environmental conditions

Despite these long-standing controversies regarding the general interpretation of sub-Alpine prehistoric lake dwellings, present-day investigations now operate within a more diverse and developed scientific framework. Generally, geoarchaeological studies have focused on the reconstruction of environmental conditions within these prehistoric villages built along the shores of sub-Alpine lakes. On one hand, this has entailed reconstruction of past positions of (and changes in) the water table during settlement phases in order to make more informed interpretations of architectural structures and/or to explain successive occupation and abandonment phases observed at a site. On the other hand, this has also involved the reconstruction of site paleogeography and past configurations, in addition to the general climatic and human contexts. The following section provides a brief overview of the types of proxies and strategies used in geoarchaeological studies of lakeshore sites, looking not only at reconstructions of local environmental conditions but also at the explorations into regional interactions between climate, environment, and land use.

As illustrated in Figure 7, the stratigraphic sections exposed during archaeological excavations of lakeshore sites often reveal sediment sequences displaying an alternation of layers resulting from natural lacustrine sedimentation and anthropogenic activities. Such sediment sequences reflect the successive phases of occupation and abandonment of the site by former agricultural societies. Moreover, the archaeological layers are also characterized by a more or less marked juxtaposition of anthropogenic deposits with natural sediments, which may indicate lake transgressions during the village occupation depending on both the architectural structures (houses directly on the ground or with raised floors) and the height of the water table (sensitivity to seasonal floods).

In the field, a key prerequisite for paleoenvironmental studies at lakeshore sites is the establishment of long stratigraphic sections and/or core transects within and outside the archaeological excavations, to probe the general environmental context of the site (Fouache et al., 2010). This provides evidence for phases marked by an extension of allochthonous terrestrial influxes (lowering of the water table) and those characterized by lake-dominated sediments (rising water table) (Figure 8). This also highlights layer geometry, lateral variations in lithofacies, local sediment hiatuses, stratigraphic unconformities, and sedimentation limits that can be used to reconstruct (1) the paleogeographical context of a site, as shown by investigations at Lake Clairvaux in the Jura Mountains of eastern France (Figure 9) or at the former Lake Texcoco in the basin of Mexico (Lamb et al., 2009) and (2) past variations in the lake level, as demonstrated by lake-level studies at Lake Chapala in Central America (Davis, 2003). Similarly, multiple littoral cores studied in the Upper Lerma Basin (Central Mexico) have shown how the construction of man-made islands reached a peak around 550–900 AD during a phase of shallow water and how an increase in lake level around 1100 AD may have led to the abandonment of this living strategy (Caballero et al., 2002). High-resolution seismic investigations based on GPS positioning offer an additional tool to produce reflection profiles, with a vertical resolution of 0.2 m (Chapron et al., 2005; Anselmetti et al., 2007; Chapron, 2008).

Finally, such a strategy helps to pinpoint relevant sites for sampling and analyses, based on sediment hiatuses as well as keeping in mind constraints linked to the types of proxies used for analyses.

Regarding the analyses, various proxies are available within sediment archives that can be used to reconstruct past lake levels. Beginning with the Swedish researcher T. Nilsson in the 1930s, then further developed by Digerfeldt (1986, 1988), Birks (1980), Jacomet (1985), and Hannon and Gaillard (1997), the first type of approach is based on the analysis of plant macrofossils from cores along a transect oriented perpendicular to the shore. This transect yields information useful in reconstructing changes in the spatial distribution of aquatic vegetation belts that reflect water depth (successive zones of emergent, floating-leaved, and submerged vegetation belts that fan outward from the shore). Thus, a decrease in water depth (lake-level lowering) leads to an outward extension of macrophytes, while an increase in water depth (rising lake level) leads to their inward displacement.

Another similar method of reconstruction using core transects is based on a combination of several sediment markers as follows:

1. Grain-size analyses: coarser deposits correspond to nearshore areas, characterized by shallower water and higher hydrodynamics.
2. Lithology: silty (carbonate) lake marl is deposited in lake water, whereas organic deposits such as coarse gyttja, peat, and anmoor (hydromorphic soil with high humic content) reflect nearshore areas (eulittoral zone, littoral mire). Lake-level lowering results in an outward extension of organic lithofacies possibly associated with sand (terrestrial influxes over the margins of the lake basin favored by lake-level lowstands), while a rise in lake level results in their inward retreat (Figure 8). Variations in the humification of littoral organic deposits may also provide further indications on the more or less pronounced drying of a site during a lake-level lowering.
3. Macroscopic components of lake marl: it has been shown (Magny, 2004, 2006) that in carbonate lakes, the coarser fractions (>0.2 mm) of lake marl are mainly composed of (a) carbonate concretions of biochemical origin, (b) mollusk tests, and (c) plant macroremains. The concretions can be divided into several morphotypes (Figure 10). Modern analogue studies have demonstrated that, in the >0.5 mm fraction, each morphotype shows a specific spatial distribution from the shore to the extremity of the littoral platform, with the successive domination of oncolites (nearshore areas with shallow water and a high-energy environment), cauliflower-like forms (littoral platform), platelike concretions (encrustations of leaves from the Potamogetonion and Nymphaeion belts), and finally tubelike concretions (stem encrustations from the Characeae belt on the platform slope). In addition to variations in the assemblages of carbonate concretions, the relative frequency of plant macroremains and mollusk shells provides further information on the depositional environment. The abundance of mollusk shells increases toward the shore, as do vegetal remains partly inherited from littoral vegetation and mires – particularly woody plant remains and particles of anmoor (a hydromorphic soil with up to 30 % humus content). After wet sieving, the macroscopic components of the >0.5 mm fraction are identified and counted using a binocular microscope.
4. Geometric micro-unconformities that are visible to the unaided eye resulting from erosion or nondeposition

(lake-level lowering), or micro-shrinkage cracks observed along core profiles, offer additional information about sediment deposition.

Other proxies have been used to reconstruct past variations in the water table from Holocene sediment sequences in lakes and mires (Berglund, 1986), including changes in mollusk assemblages (Clerc et al., 1989), diatoms and cladocera (Hyvärinen and Alhonen 1994; Korhola et al., 2005), chironomids (Kurek and Cwynar, 2009), and testate amoebae (Charman et al., 2007).

The study of archaeological layers may be more time-consuming due to a possible dilution of natural elements by anthropogenic material (organic and mineral). Micromorphology offers an additional means to study archaeological layers using microscopic examination of loose sediments impregnated with epoxy resin in thin section. Such a microscopic analysis used at Marin/Les Piécettes (Lake Neuchâtel, Switzerland) has revealed depositional characteristics similar to those of a lake-margin marsh, with soil formation processes, advanced decomposition of organic matter, and traces of bioturbation. Micromorphology can also provide a very high-resolution record of successive events with an accumulation of occupational remains, dismantling or reconstruction, trampling by inhabitants, and reworking by lake water (Guélat and Honegger, 2005).

Finally, the study of sediment archives from the deepest areas of lacustrine basins also provides useful continuous records of regional interest to complement local data deriving from a lakeshore archaeological site (Arnaud et al., 2005). Magnetic susceptibility measurements, geochemical (isotopes, XRF), and mineralogical analyses, in addition to pollen and charcoal studies, offer the opportunity to establish continuous records not only for past variations in environmental and climatic conditions but also for human impact and land use history. Thus, paleoenvironmental and archaeological data obtained from a littoral site may be seen in a more general (i.e., regional), long-term perspective. As an example, investigations undertaken by Anselmetti et al. (2007) from a deep core at Lake Salpetén (Guatemala) have revealed how peak soil erosion rates may have occurred not during but several centuries before the period of maximum population density in the ancient Maya zone (Figure 11). Cross-correlations between deep cores and littoral sediment profiles need to be based on high-resolution chronological frameworks (Vannière et al., 2008).

Conclusion: should greater attention be paid to anthropological themes?

Multidisciplinary approaches can be difficult and complicated to implement; however, geoarchaeological methods have evolved by integrating new geochemical and physical techniques that have improved the ability of researchers to date, delineate, and interpret the different aspects of coastal and lake excavation sites. The convergence of many disciplinary inquiries has led to more accurately established chronologies and greater understanding of past environment and human behavior.

The role of natural hazards and the evaluation of paleorisks are two questions that have received significant focus in recent years. Present neo-catastrophic research bias has falsely led public audiences into thinking that ancient societies lived and developed under the constant threat of upheavals caused by natural disasters. This overly simplistic outlook masks the true problems of environmental vulnerability faced by human societies since prehistoric times. Coastal areas have changed dramatically through time, and their impact has been significant to local populations, but geoarchaeological studies must assess coastal vulnerability over long intervals (Morhange and Marriner, 2011). As Leveau (2006) has stated, the history of ancient coastlines can no longer be written using ancient texts describing calamities as the sole source of information, as was the case in the nineteenth century. During the last three decades, the development and application of geoscience techniques to such problems have radically changed our perception of the history of coastal and lacustrine shorelines.

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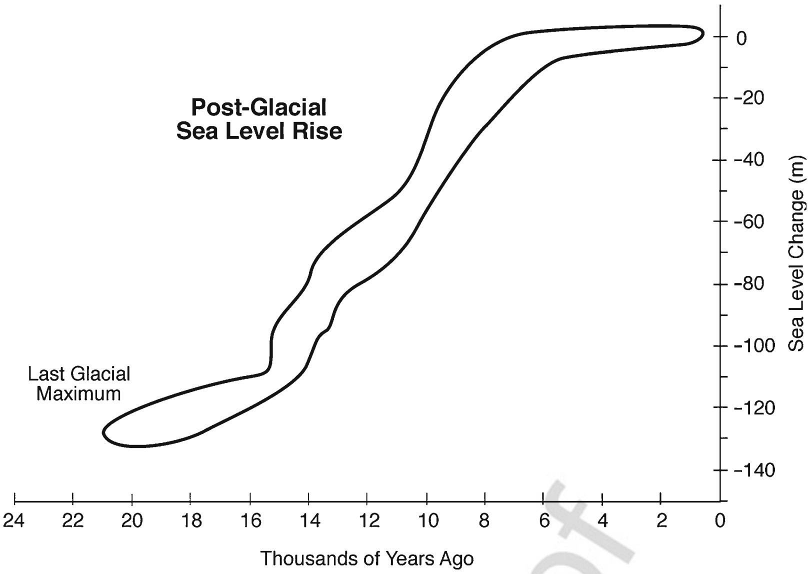
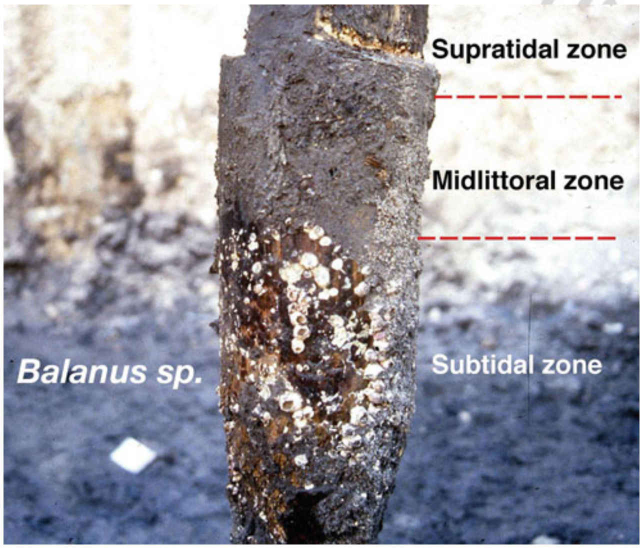
Cross-references

Inundated Freshwater Settings
Paludal Settings
Shipwreck Geoarchaeology
Soil Micromorphology
Submerged Continental Shelf Prehistory



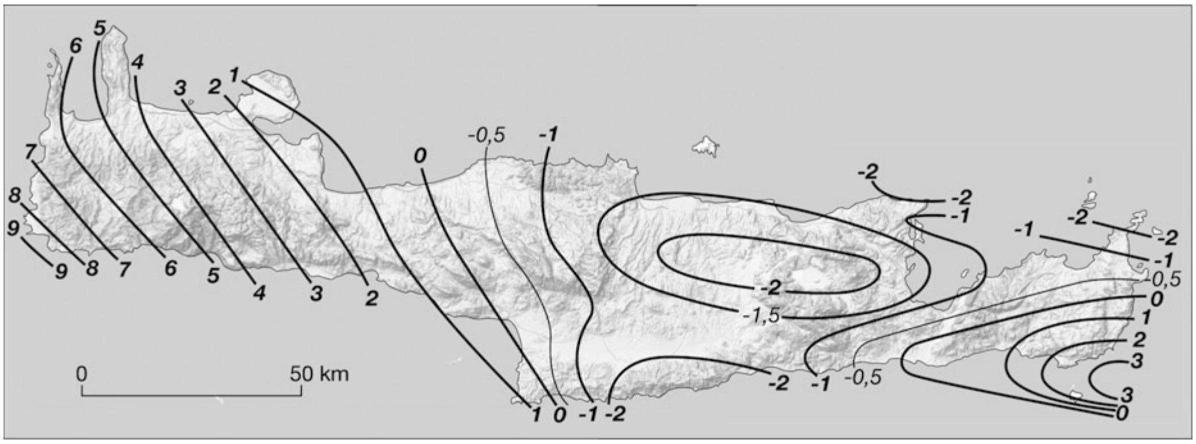
Paleoshores (Lakes and Sea), Figure 1 Sea-level changes since 18,000 years BP (Adapted from Fleming et al., 1998). The outlined area subsumes the variability in sea level spatially and temporally (tides, oceanic circulation, etc.).

Au2

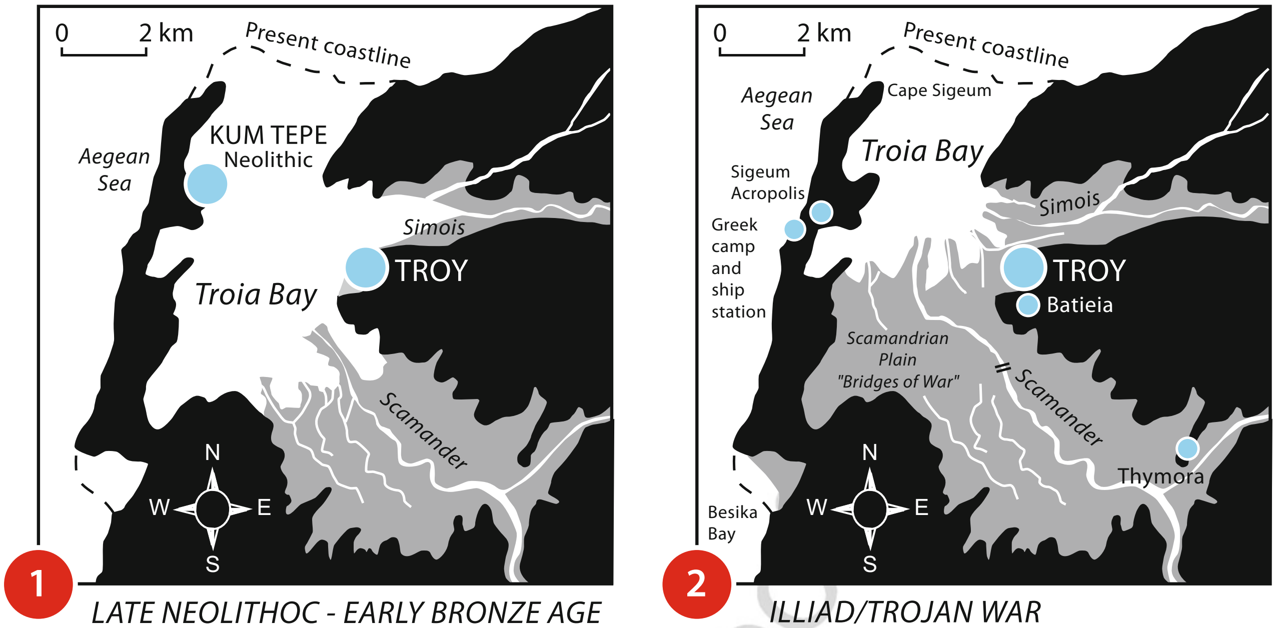


Paleoshores (Lakes and Sea), Figure 2 Biological zoning on a wooden stake from the 1993 excavation of two sixth-century BC archaic Greek ships at the Place Jules-Verne site in Marseille (Morhange et al., 2001). Barnacles (*Balanus* sp.) mark the submerged infralittoral range on the piling, while the midlittoral and supralittoral sections are clearly discernible higher up.

Au3

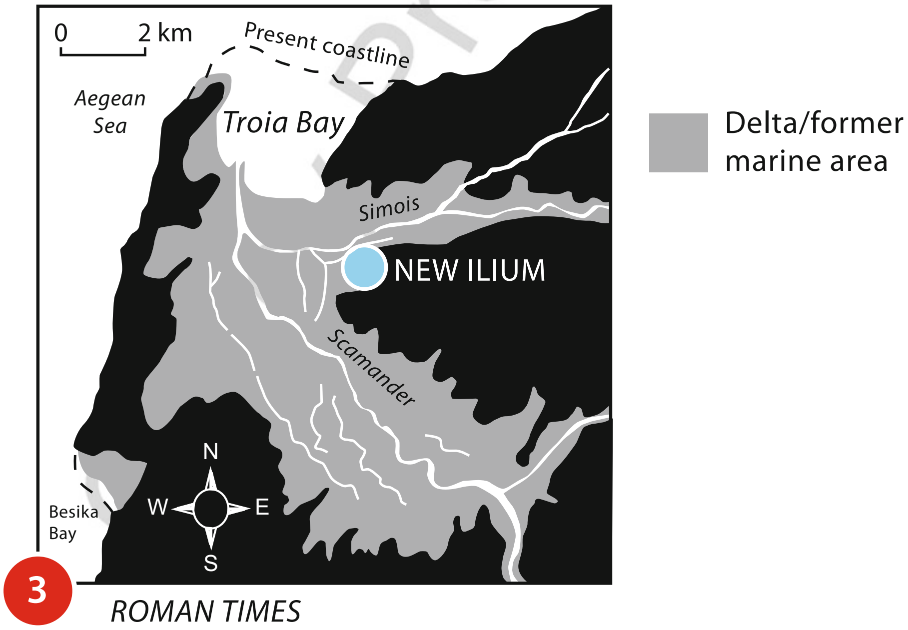


Paleoshores (Lakes and Sea), Figure 3 Holocene land-level changes in Crete (After Kelletat (1991), and Stiros (2010)). Western Crete has been generally rising and eastern Crete sinking; numerical indicators are in meters.



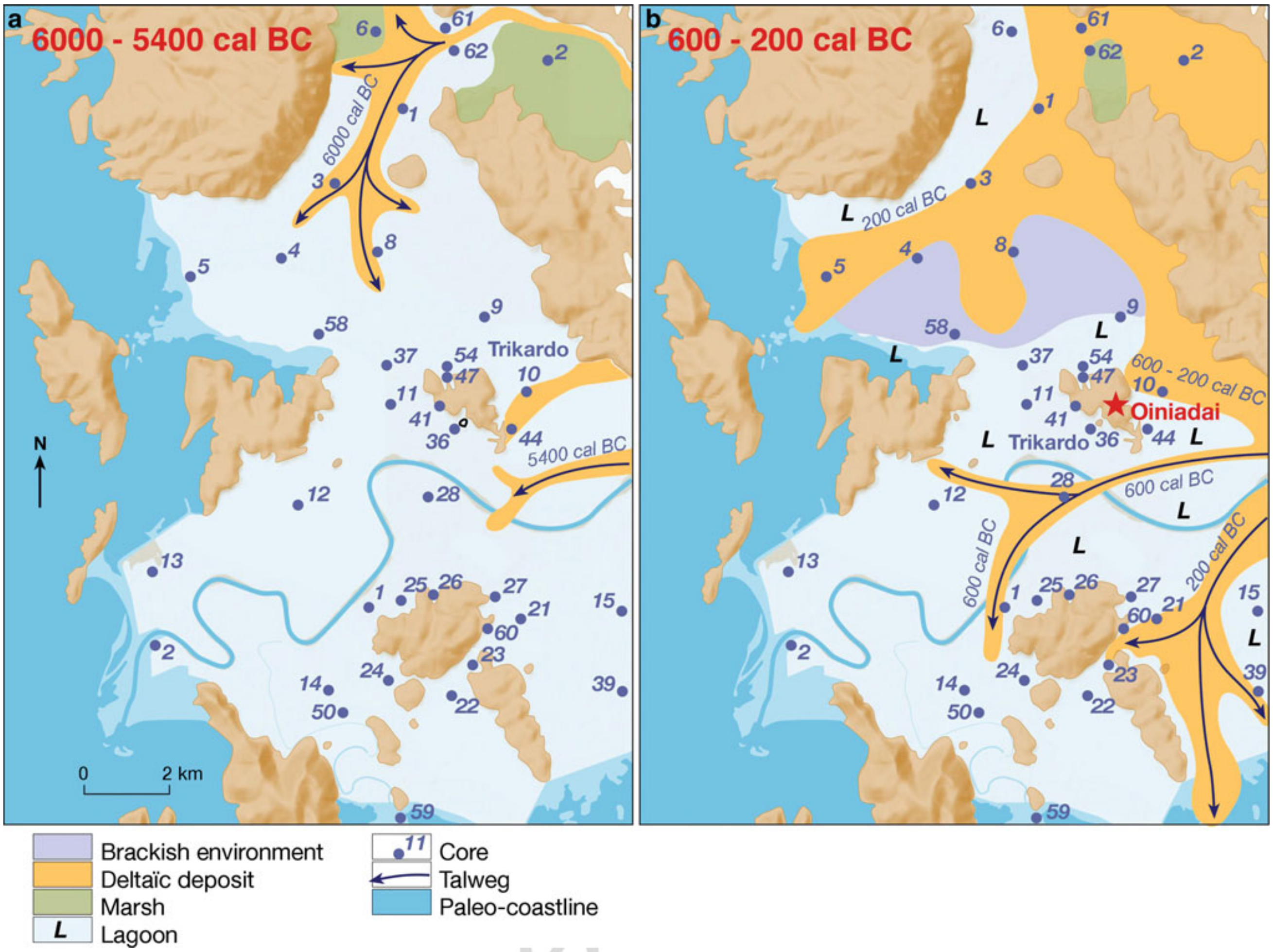
LATE NEOLITHOC - EARLY BRONZE AGE
5000-5500 years ago

ILLIAD/TROJAN WAR
Around 3520 years ago



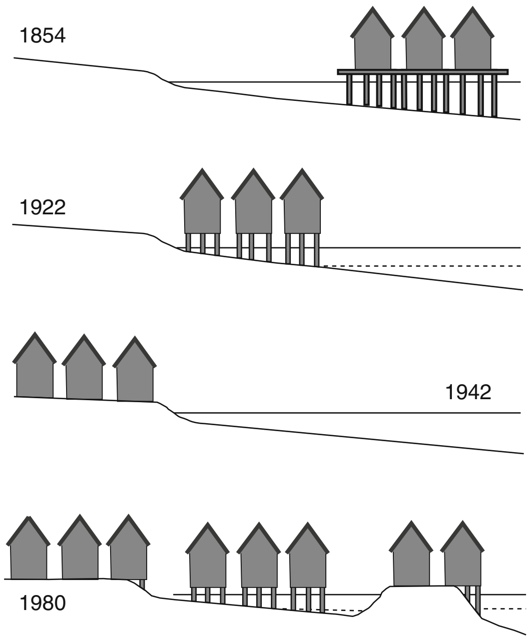
ROMAN TIMES
Around 2000 years ago

Paleoshores (Lakes and Sea), Figure 4 Paleogeography of the coastal area around Troy (Adapted from Kraft et al. (2003)) made famous by Homer's epic Greek poem the *Iliad*. At the time the *Iliad* is set, more than 3000 years ago, Troy overlooked a vast marine embayment that has since been infilled by sediments from the Scamander and Simois rivers. The archaeological remains at Troy today lie more than 6 km from the present coastline and bear testimony to the rapid changes in geography that can take place on deltaic systems with high sediment supply.

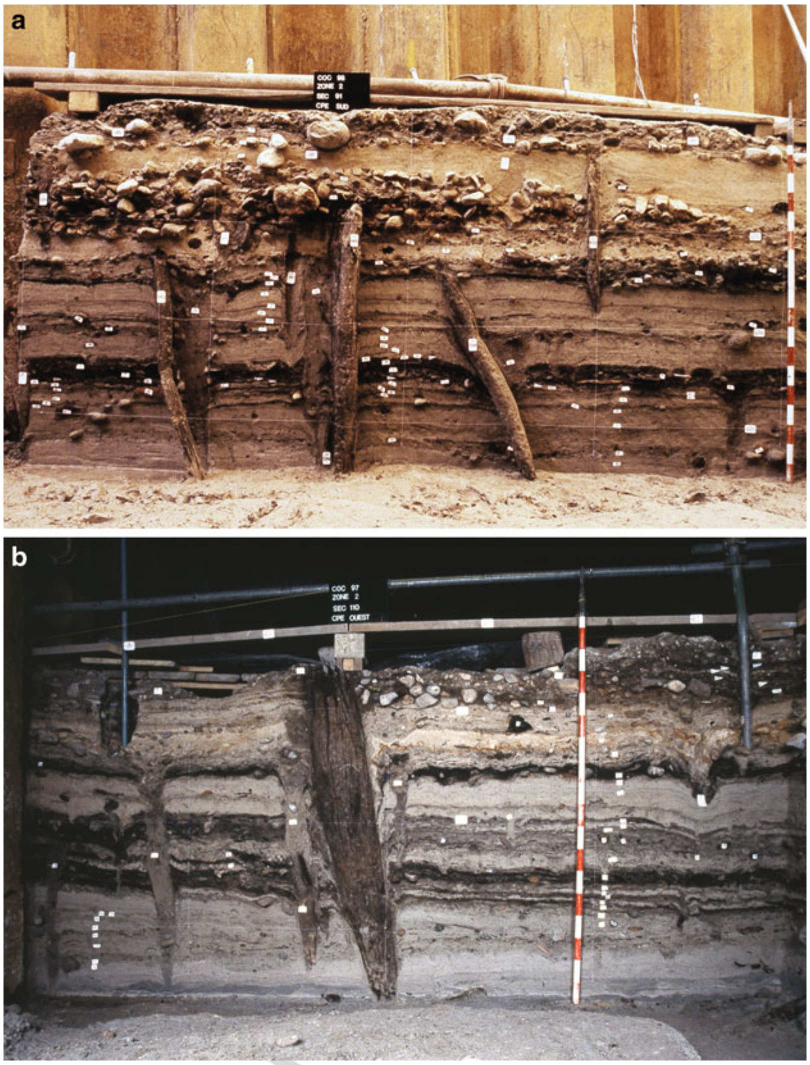


Au5

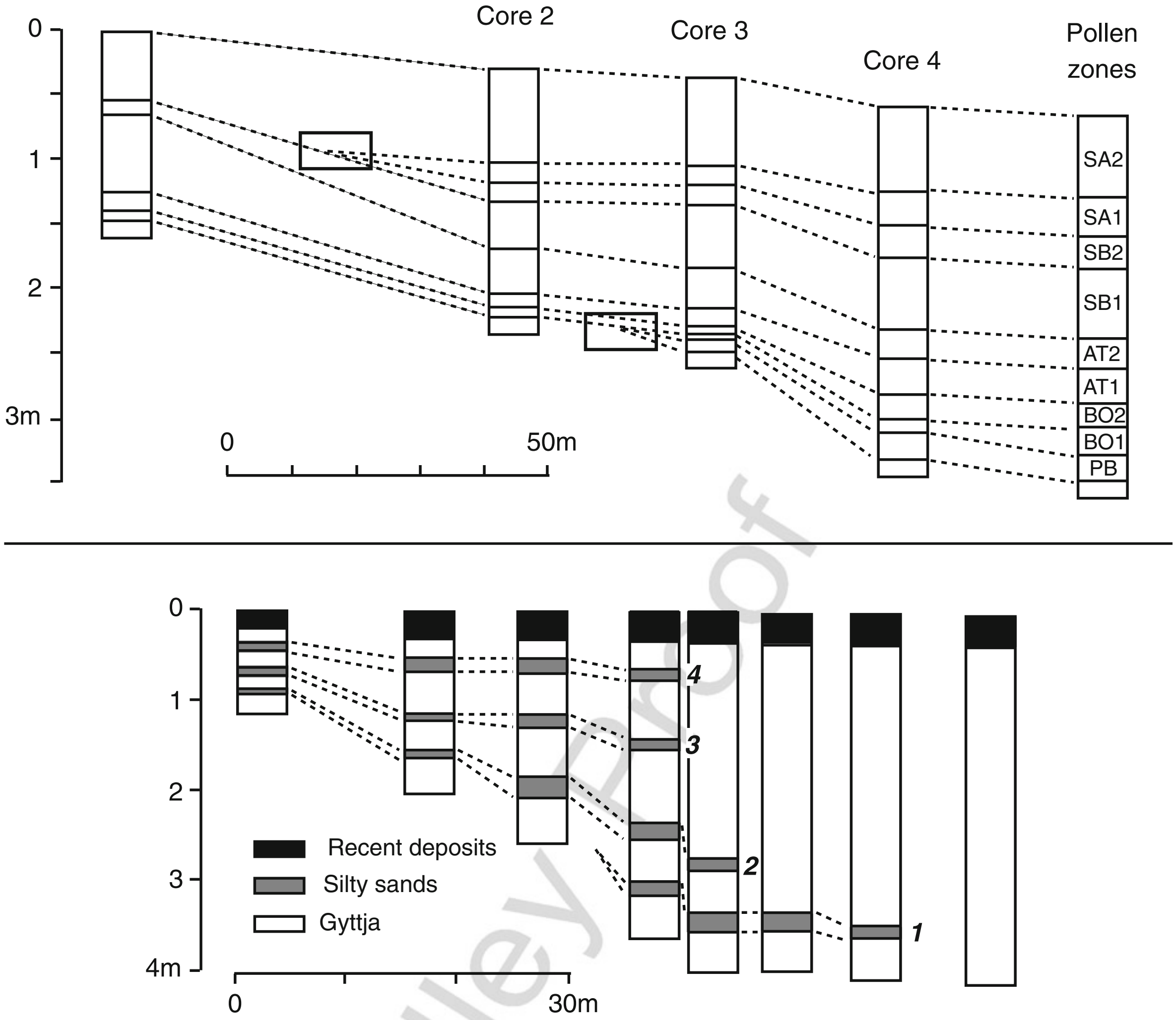
Paleoshores (Lakes and Sea), Figure 5 Progradation of the Acheloos River delta since 6000 years BP and location of the ancient seaport of Oiniadai (northwestern Greece), from Vött et al. (2007). The numbers denote core locations used in the paleogeographical reconstruction.



Paleoshores (Lakes and Sea), Figure 6 Successive interpretations of Neolithic and Bronze Age lakeshore villages in the sub-Alpine zone (Modified from Schlichtherle and Wahlster (1986)).

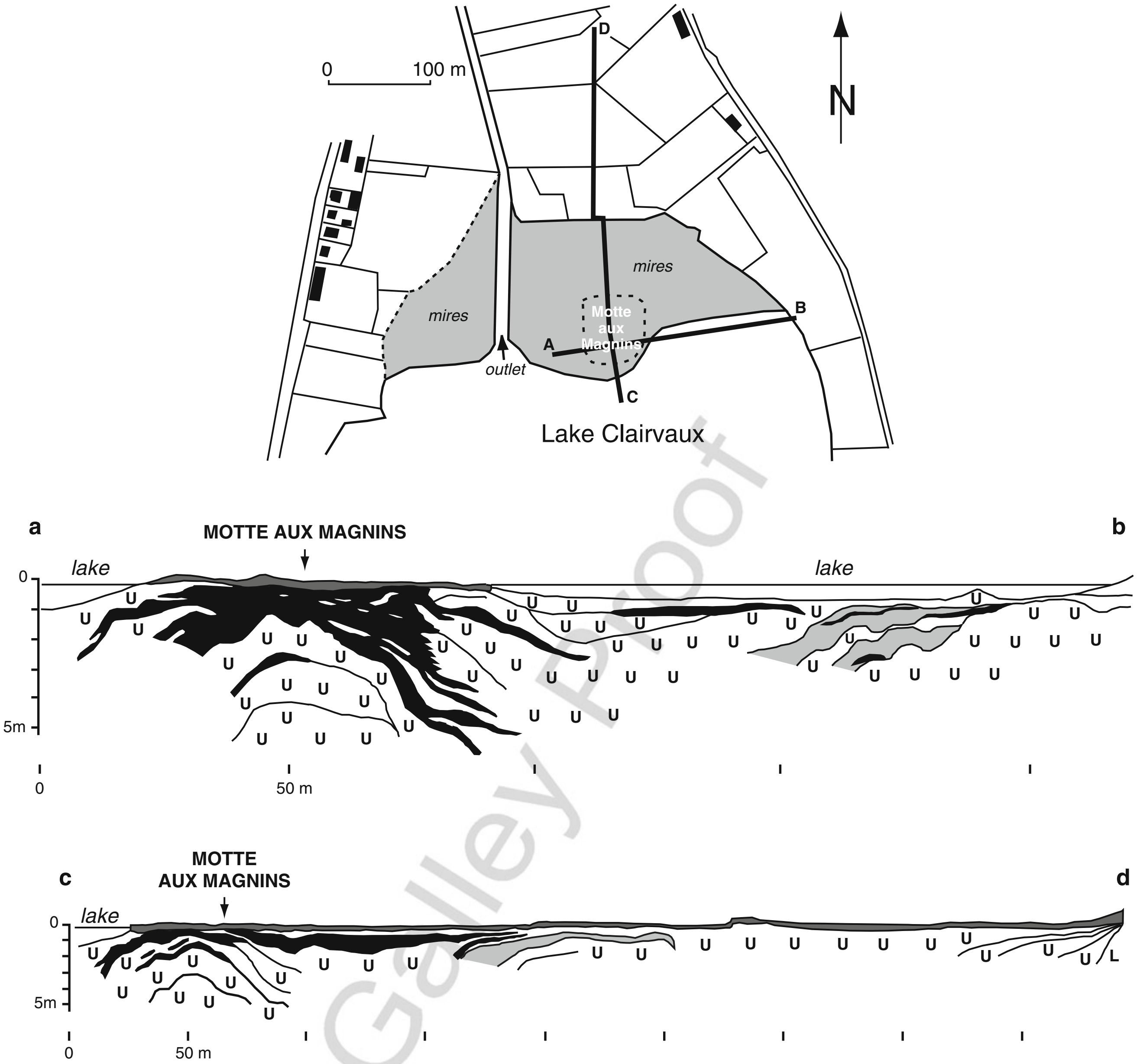


Paleoshores (Lakes and Sea), Figure 7 (**a**) and (**b**) show two stratigraphic sections at an archaeological lakeshore site from Concise, Lake Neuchâtel in Switzerland (photograph by P. Muller, Section de l'Archéologie Cantonale Vaudoise, in Magny (2008)). Note the alternation of (1) dark organic archaeological layers sedimented during the occupation phases and (2) light (carbonate) lake-marl layers deposited during the intermediate abandonment phases. Also note remains of vertical wood posts used by prehistoric people for the construction of houses. Au6

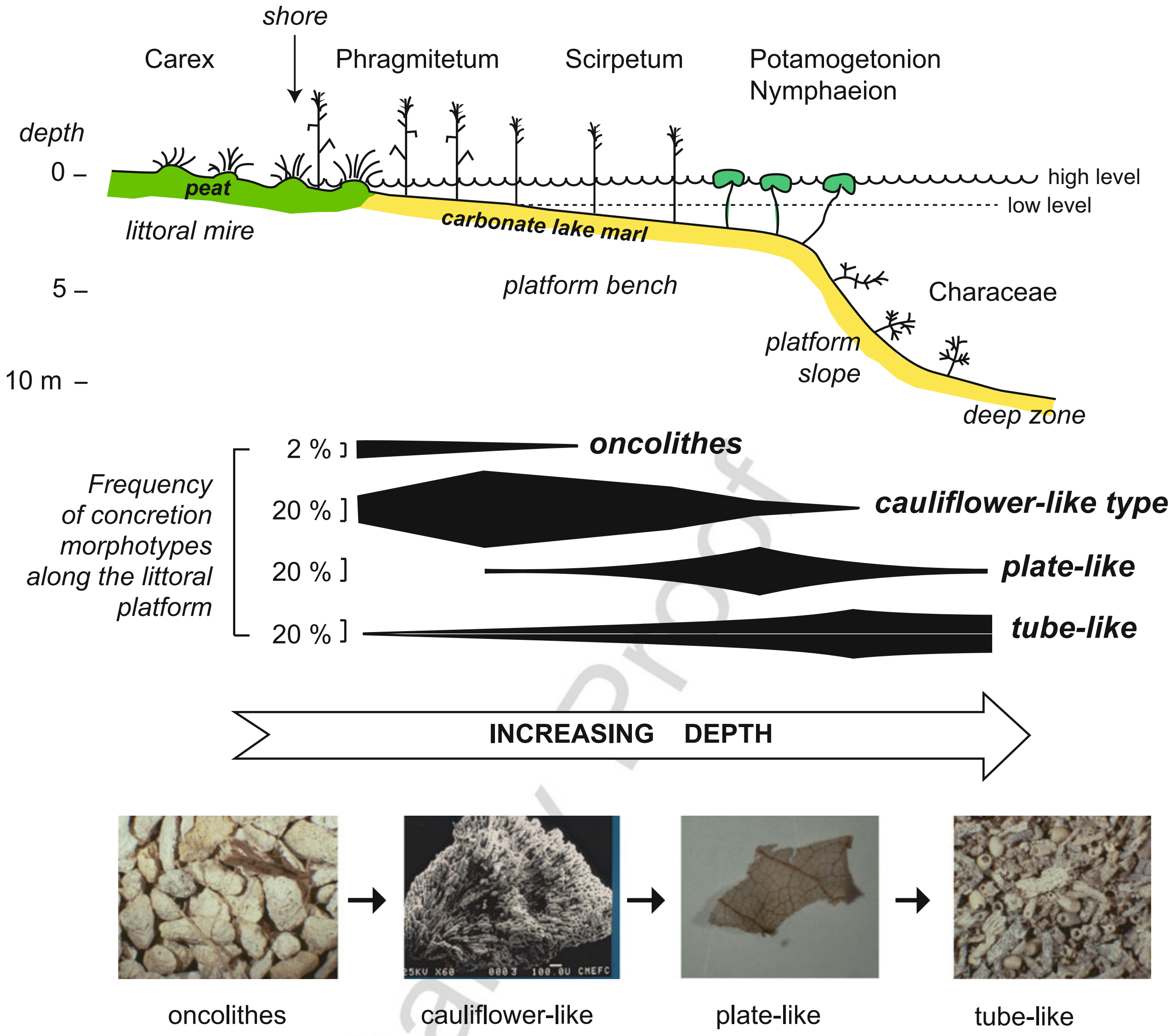


Paleoshores (Lakes and Sea), Figure 8 Upper panel: core transect established in Lake Trummen, southern Sweden (Modified from Digerfeldt (1986)). The section shows two distinct periods of lower sediment limit (*rectangles*) and associated sediment hiatuses (*thick lines* in cores 1 and 2) indicating lower lake level at phases PB–BO1 (Preboreal to Boreal 1) and SB1–2 (Subboreals 1–2). At both times, low water level prevented lacustrine sedimentation above the shoreline. *Lower panel*: core transect of Lake Växjösjon, southern Sweden (Modified from Digerfeldt (1986)). Sandy-silty layers mark phases of lower lake level favoring an extension of (allochthonous) terrestrial minerogenic material within the lake basin. Gyttja, marking the lake margins, is a mud produced from the aerobic decay of peat.

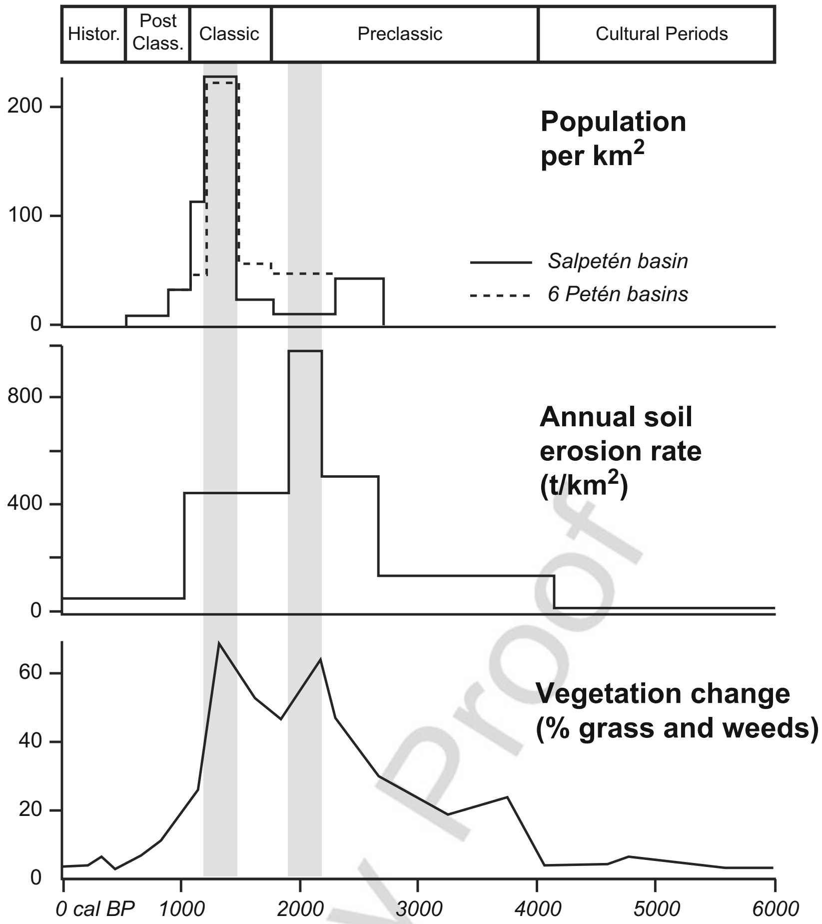
Au7



Paleoshores (Lakes and Sea), Figure 9 Reconstruction of the paleogeographical changes at the northern extremity of Lake Clairvaux, Jura Mountains in eastern France, using core transects. Note that the site of Motte aux Magnins (indistinct within the present-day northern littoral mires) was an island during the mid-Neolithic (Magny, 1991). The *arrow* shows the intersection between the stratigraphic sections *AB* and *CD*. *Black*, archaeological layers; *dark gray*, peat; *light gray*, gyttja; U, carbonate lake marl; L, silts.



Paleoshores (Lakes and Sea), Figure 10 Section showing the distribution of carbonate concretion morphotypes along the littoral platform of Lake Clairvaux (Jura Mountains) in relation to morphology and vegetation zones. The relative frequency of each morphotype is indicated as a percentage of the sample components (Modified, after Magny (2006)).



Paleoshores (Lakes and Sea), Figure 11 Annual soil erosion rates compared with the population densities in the Salpetén region in Guatemala.

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AU1	Please confirm if author affiliations are okay.	
AU2	Does this explain why the curve is so fat? Yes.	
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AU6	The reference pagination indicated paper by Magny; but should it refer to the entire book (Winiger, 2008)? Yes, it indicates the paper by Magny	
AU7	Thick lines not distinct; all lines appear same thickness. Core 1 has no label, but one can surmise it is the first on left.	
AU8	Please provide publisher name and publisher location for Bailey et al. (2008).	
AU9	Nic Flemming has a figure of a diver emerging from a submerged well at Atlit-Yam in his entry on Submerged Continental Shelf in this encyclopedia: same feature? If so would you want to refer readers to it? I am not sure if this is the same feature, but yes it would be a nice idea to refer readers to this.	