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Cross-references

Inundated Freshwater Settings
Paludal Settings (Wetland Archaeology)
Shipwreck Geoarchaeology
Soil Micromorphology
Submerged Continental Shelf Prehistory

PALUDAL SETTINGS (WETLAND ARCHAEOLOGY)

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Definition

Wetlands are ecosystems created at the interface of terrestrial and aquatic environments. They arise due to inundation and accumulation of plant material dominated by anaerobic processes (Middleton, 1999, 7; Mitsch and Gosselink, 2007, 26; Burton and Tiner, 2009, 507; Keddy, 2010, 2). The Ramsar Convention of 1971 characterizes wetlands as follows: "Wetlands can be natural, permanent or temporary, with water that is static or flowing, fresh, brackish or salt. . ." (Middleton, 1999, 7; Burton and Tiner, 2009, 508; Dodds and Whiles, 2010, 86). Based on their hydrology, wetlands can be systematized into coastal wetlands within marine and estuarine systems (tidal marshes, mangrove wetlands, deltas), and inland freshwater wetlands within riverine, lacustrine, and palustrine systems (van der Valk, 2006, 7; Mitsch and Gosselink, 2007, 260; Lillie and Ellis, 2007, 3). Palustrine areas can be defined according to their dominant vegetation as follows: swamps are dominated by trees and marshes by herbaceous plants (cattail and reed beds). Both of them are often associated with river floodplains. Peatlands (bogs and fens) accumulate decaying organic matter from mosses and sedges (Dierssen, 2003, 202; Mitsch and Gosselink, 2007, 31; Dodds and Whiles, 2010, 95ff.; Keddy, 2010, 5ff.; Menotti, 2012, 11).

Archaeological sites can be found in wetland areas. After Nicholas (2012), waterlogged archaeological sites can be distinguished as "wet sites," like coastal, lacustrine, and riverine sites or as "wetland sites," located in swamps, marshes, and peatlands. Lakeside settlements are categorized within the latter, as they are placed at the amphibian interface between limnic and terrestrial environments (Menotti, 2012, 13f.).

Introduction

About 5 % of the land surface of the earth is covered by wetlands. Depending on the kind of water source and its position in the landscape, wetlands show a wide range of environments (van der Valk, 2006, 8; Menotti, 2012, 13f.). Wetland research is not covered by a single field but refers variously to limnology, hydrology, and estuarine and terrestrial ecology. This is also why wetland investigations require a multidisciplinary approach spread across several fields (Mitsch and Gosselink, 2007, 19).

Wetlands have always been important for people, as they were long utilized for resource procurement, e.g., reed, cattail, and moss cutting as building materials, as well as for food and fuel collection (Mitsch and Gosselink, 2007, 5; Nicholas, 2012, 762). Archaeological sites connected to wetlands play a very important role in archaeological research. Because of their waterlogged, anaerobic conditions, they may contain well-preserved archaeological remains in situ and offer great promise for reconstructions not only in archaeology and paleoenvironment but also in the diet and hygiene of people (Cole, 1995, 3; Kenward and Hall, 2004, 4, 2008, 585; Menotti, 2004; Larsson, 2007, 80; Menotti, 2012, 9f.).

Wetland archaeology is relevant in almost every part of the world (Menotti, 2004, 2012). In this contribution, the focus is on freshwater wetlands around lakes, where lakeside settlements developed during the Neolithic and Bronze Age in the Circum-Alpine region of Europe (Menotti, 2012). Bog and fen sites, which are common in Great Britain and Scandinavia, and hydric soils are not part of this contribution (see, e.g., Cole, 1992; Lillie, 2007; Mitsch and Gosselink, 2007, 169ff.; Menotti, 2012).

Prehistoric lakeside settlements have been known for more than 150 years (Cole, 1995, 3; Ruoff, 2004; Menotti, 2001, 2004, 2012), and since their discovery, questions concerning the depositional environment have been addressed using the archaeological sediments to obtain answers (e.g., Brochier, 1983; Jacomet, 1985; Brochier and Bocquet, 1991; Magny, 2004; Jacomet et al., 2004; Magny et al., 2012). Since 2011, 111 pile-dwelling sites from six countries around the Alps have been added to the UNESCO World Heritage List (http://whc.unesco.org/en/list/1363). Micromorphological investigations of lakeside settlements started in the early 1990s and are today often a part of the standard analyses for pile-dwelling sites (Krier, 1997; Wallace, 2000, 2003; Ismail-Meyer and Rentzel, 2004; Lewis, 2007; Karkanas et al., 2011; Ismail-Meyer et al., 2013; Ismail-Meyer, 2014).

Lakeside settlements span several depositional environments from terrestrial and paludal to littoral and limnic, and all reveal different features (Jacomet et al., 2004;

Mitsch and Gosselink, 2007, 29; Nicholas, 2012, 762). One of the most remarkable features of pile-dwelling sites is that they often contain a significant amount of organic accumulations, which in general are underlain and covered by deposits of limnic sediments. A main research issue is to explain the formation of those organic accumulations and their mostly excellent preservation in a changing environment. Geoarchaeological research provides hints to the site formation processes and environment of wetland sites between episodes of deposition and any subsequent or intermittent episodes of erosion (Menotti, 2012, 252). Recent multidisciplinary studies have produced archaeological results based on archaeobotanical, palynological, geoarchaeological, and dendrochronological analyses, leading to new insights into formation processes (Menotti, 2012, 267ff.; Heitz-Weniger, 2014; Ismail-Meyer, 2014; Bleicher, 2014; Pollmann, 2014; Jacomet et al., 2014; Wiemann and Rentzel 2015).

To understand the context of these special archaeological deposits, a look at natural wetland environments, especially peatlands, and their hydrology is essential. In this contribution, some important processes regarding anthropogenic accumulations under paludal conditions will be discussed by comparing them with natural processes in wetland environments.

Methods

There are several geoarchaeological methods for analyzing lakeside settlements. Bulk samples for sedimentological and geochemical approaches are taken on-site from representative zones. An example demonstrating such methodologies can be found in Braillard et al. (2004). The carbonate content is normally related to lake input or to ashy layers in an archaeological context. Using a binocular microscope, limnic carbonates can be separated into different types, such as "tubes," "cauliflower carbonates," and "plates," which may give hints to the height of the lake level (Brochier, 1983; Magny, 2004; Magny et al., 2006; Digerfeldt et al., 2007; Magny et al., 2012). Sand content can be linked to regressions in the littoral area, inwash from the hinterland, or it can be of anthropogenic origin (Magny, 2004; Ismail-Meyer, 2014). Evaluation and interpretation of phosphate, humus, and organic content can be difficult because phosphate may have been partially washed out, humus formation may not have occurred normally, or other factors may have complicated the analysis. The pH reflects usually the near-lake environment (generally between 6 and 8), but it may differ across the anthropogenic accumulations (e.g., due to a locally acid milieu or possibly the presence of humic acids).

Good results can be obtained using micromorphological investigation. By analyzing thin sections, it is possible to observe the structure, layer composition, and degree of preservation of each deposit (FitzPatrick, 1993; Stoops, 2003; Goldberg and Macphail, 2006). It permits the reconstruction of lake levels, site formation processes, and environments during and after the deposition of sediments, and it demonstrates whether anthropogenic layers remain in situ or were reworked. Very delicate traces such as trampling features, ashes, and dung can be detected (Ismail-Meyer and Rentzel, 2004). The autofluorescence of different types of organic matter can be used to identify them (Goldberg and Macphail, 2006, 358). The determination of well-preserved organic matter in thin section is possible but difficult because of the randomness inherent in differing section planes. Thanks to a substantial literature, close cooperation with archaeobotanists, and the existence of reference sections, it is possible to identify wood, bark, twigs, leaves, moss, grass, and some of the most common seeds (Babel, 1975, 1985; Ismail-Meyer and Rentzel, 2004; Stolt and Lindbo, 2010; Ismail-Meyer, 2016). Scanning electron microscopy (SEM) methods and punctuated (spot) microchemical data allow the examination of materials at sizes smaller than 2 μm on uncovered thin sections (Goldberg and Macphail, 2006, 362).

Selecting an appropriate sampling strategy for micromorphological investigations of lakeside settlements is crucial. A site can be fairly complex (i.e., having several occupation layers, substantial depth, and variable preservation of the archaeological deposits), and it is therefore important to adapt the sampling strategy to the existing conditions. But the strategy depends also on the size of a site and if it is underwater. The right strategy might be to sample along transects from the lake toward the beach, within the area of best preservation, or following the floor plans of the houses (if known). Usually, cores or plastic boxes of about 50 cm height and at least 10–15 cm width are used in sampling for multidisciplinary analyses. Generally, it is important to sample the anthropogenic accumulations as well as the limnic sediments above and below, in order to reconstruct the regressions and transgressions of the lake. Until the opening of the samples for analysis, it is recommended that they be stored in waterproof containers under dark and cool conditions to prevent the growth of fungi and algae.

Photographs of freshly opened and cleaned profiles are important for documenting the stratigraphic sequence. A division of the sequences into layers (preferentially with the collaboration of an archaeobotanist and palynologist) and a description with special attention to carbonate and sand content are useful. The micromorphological subsampling of the profiles (anthropogenic and limnic sediments) for further investigations, including archaeobotany and palynology, can be done with smaller plastic boxes.

Features and processes in paludal environments

Lake environments are a result of many complex factors influencing the ecosystem, including limnological, geological, hydrological, geomorphological, and biological processes operating in the catchment area. These factors are mainly controlled by fluctuations of the groundwater table and/or lake level, due often to climatic influences, but in Western Europe over the last 7,500 years, humans have increasingly interacted with the environment (van der Valk, 2006, 13; Digerfeldt et al., 2007; Keddy, 2010, 270; Zolitschka et al., 2010, 90). The size of the wetland area (and the area of preserved, waterlogged, archaeological remains) depends on the local geomorphology, e.g., inclination and type of shore belt (Platt and Wright, 1991; Magny, 2004; Jacomet et al., 2004). Generally, the greater the long-term amplitude of water-level fluctuations in a lake, the larger the wetland area (Keddy, 2010, 68).

The main processes in wetland environments are accumulation, reworking, erosion, and desiccation, and they depend on the height of the lake level and/or groundwater table. In this contribution, these processes will be highlighted through the example of natural peatlands and compared to proper observations in lakeside settlements. The study results derive from eight pile-dwelling sites analyzed during the past 10 years in Switzerland: Arbon-Bleiche 3, Cham-Eslen, Zug-Riedmatt, Risch-Aabach, Stansstad-Kehrsiten, Wetzikon-Robenhausen, Hombrechtikon-Feldbach West, as well as Lake Luokesa in Lithuania (see Ismail-Meyer et al., 2013; Ismail-Meyer, 2014).

Lake platform and limnic sediments

Lakeside settlements are usually deposited atop carbonate platforms along lakeshores (Figure 1). In shallow waters, carbonate precipitates as lake marl, formed mainly by different algae (mainly stonewort – Characeae), bacteria, and diatoms. Benches are formed due to progradational deposition (Murphy and Wilkinson, 1980; Platt and Wright, 1991; Freytet and Verrecchia, 2002; Magny et al., 2006). Undisturbed, layered lake marl accumulates in the deeper sublittoral zone in about 1–10 m water depth (Murphy and Wilkinson, 1980; Platt and Wright, 1991; Magny, 2004; Haas and Magny, 2004). The lowering of the lake level results in the reworking of this lake marl due to wave action and enrichment with sand (Platt and Wright 1991; Magny, 2004; Magny et al., 2006; Digerfeldt et al., 2007). Even small-scale water-level fluctuations may cause exposure of large areas depending on the slope of the shore area. In geological sections, the tops of such regressive sequences commonly show evidence of subaerial exposure (hiatus), e.g., alteration and fragmentation of mollusk shells (Platt and Wright, 1991, 62; Cutler, 1995; Digerfeldt et al., 2007). Walking on wet lake marl is almost impossible because of the slippery surface and tendency to sink deeply into the sediment. Some lakeside settlements were placed in areas with no standing water and as far as we know on an already hardened surface (Jacomet, 1985; Ismail-Meyer, 2014). The platforms, which are poor in nutrient matter, were often almost vegetation-free, but longer regression phases permitted pioneer vegetation to grow there (Jacomet, 1985; Monnier et al., 1991; Jacomet and Brombacher, 2005).

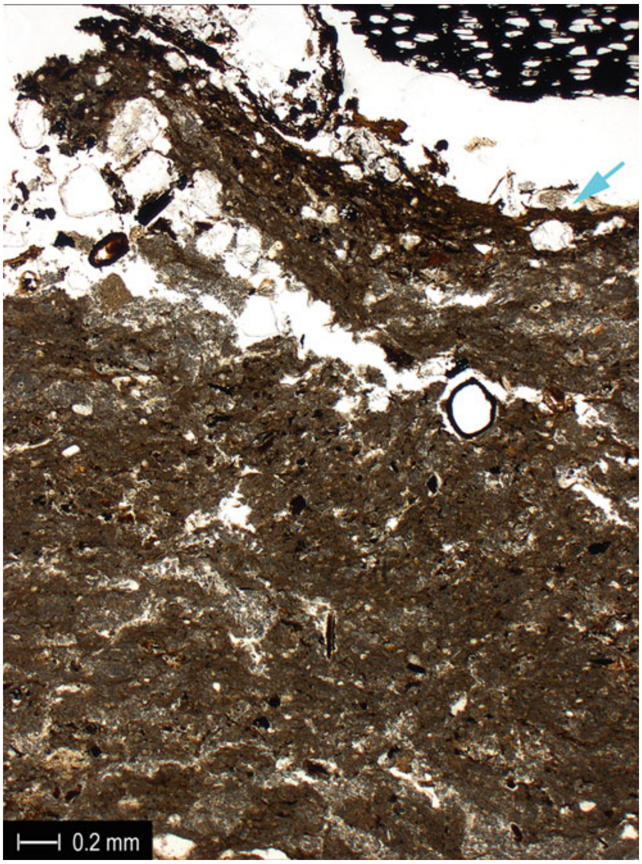
Paludal Settings (Wetland Archaeology), Figure 1 Zug-Riedmatt, Switzerland: Paludal Neolithic site (3200 cal BC) during geoarchaeological fieldwork at the archaeological excavation. In the foreground appears a dark organic layer of anthropogenic origin containing many vertical posts of different construction phases. Note the succession of gray, lumpy loam lenses interfingered with dark, organic occupation deposits (in the angle of the profile). On top, the archaeological deposits are eroded and covered by light gray, laminated limnic sediments (Photograph by D. Brönnimann, Integrative Prehistory and Archaeological Science, IPAS, University of Basel).

Micromorphological analyses of lake marl offer clues to the height of the lake level before, during, and after a settlement phase on the basis of layering, sand enrichments, and preservation of mollusk shells. The installation of a settlement in a sufficiently dry area generally led to compaction of the lake marl and enrichment of charcoal, wood, and bark chips due to house-building activities (Figures 2 and 3; Ismail-Meyer and Rentzel, 2004; Jacomet et al., 2004; Ismail-Meyer et al., 2013). These remains of scattered wood and bark chips may have helped to make these areas more easily accessible (Jacomet et al., 2004).

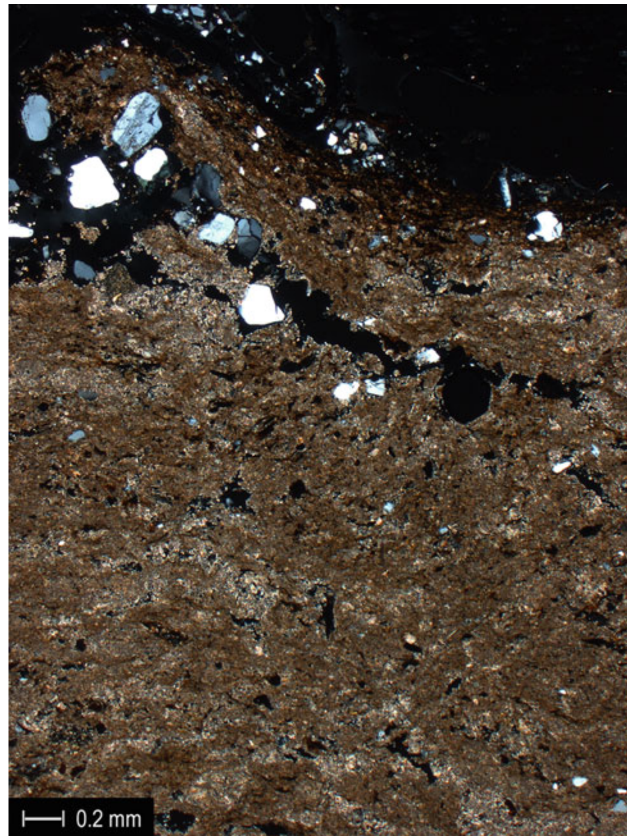
Hydrology

Hydrology in natural wetlands

Under waterlogged conditions, organic matter can accumulate over time at the surface by a sedentary process



Paludal Settings (Wetland Archaeology), Figure 2 Lake Luokesa, Lithuania, photomicrograph of a thin section in plane-polarized light (PPL): Limnic carbonate (lake marl) overlain by an archaeological deposit. The sediment of the lower part has a heterogeneous aspect due to dense gray lake marl peds enriched with some brown organic detritus. It is supposed that limnic influence led to mixing of the lake marl peds with organic matter. In the uppermost third of the picture, some transparent quartz sand grains are covered by compact organic remains, leaves (*arrow*), and a piece of charcoal at the top, the whole representing an activity surface with possible trampling features.



Paludal Settings (Wetland Archaeology), Figure 3 Same section as Figure 2, with crossed polarizers (XPL): The carbonate marl is *pale*, organic remains appear *dark brown to black*, and quartz grains *white and bluish gray*.

because anaerobic conditions reduce decay rates (French, 2003, 17; Charman, 2009, 542). The organic matter derives mainly from locally growing mosses, herbaceous material, and leaf litter (Mitsch and Gosselink, 2007, 168; Dodds and Whiles, 2010, 95ff; Menotti, 2012, 11). In natural peatlands, the water table is determined by the balance between inputs from precipitation and surface inflow and losses through evaporation and transpiration (evapotranspiration) and seepage (van der Valk, 2006, 25; Mitsch and Gosselink, 2007, 107; Digerfeldt et al., 2007; Keddy, 2010, 66).

One of the most important characteristics of peatlands is a high groundwater table, which lies at, or near, the surface (van der Valk, 2006; Keddy, 2010, 22; Armstrong, 2010, 30). In the temperate zone, groundwater fluctuates seasonally from a high in winter to a low in summer due to changing transpiration rates (Middleton, 1999, 9; Corfield, 2007, 144; Baker et al., 2009, 141). According to Holden and Burt (2003, 91), in a natural environment, the water table does not drop more than 5 cm below the peat surface. In raised bogs, the water table is naturally raised above the normal height because of capillary conduction by the growing plants adapted to waterlogged conditions, such as sphagnum mosses (Armstrong, 2010, 31). It seems that organic accumulations can also act as a "sponge" and raise the local water table so that the fringe of capillary water rises above it (Kenward and Hall, 2000, 522). The hydraulic conductivity (capacity of soils to retain water) is generally low in peats, meaning that they have strong water retention and remain wet for lengthy durations of time (Corfield, 2007, 147; Charman, 2009, 541).

Peats reveal an internal succession: in the upper, active zone called the *acrotelm*, fresh plant material is added at the surface. Here, the organic matter is loosely packed and loses more water due to evaporation (higher hydraulic conductivity). Fungal and bacterial growth leads to rapid decomposition of organic matter. The thickness of the acrotelm layer ranges from a few mm up to 75 cm, depending on the local hydrology (Mitsch and Gosselink, 2007, 173; Lindsay, 2010, 6). Water can move quickly horizontally and vertically (Dierssen, 2003, 204; Baker et al., 2009, 133; Charman, 2009, 542f.). The deeper, less active zone, the *catotelm*, lies below the local water table, where water moves slowly through the more compacted matter. Due to the constantly waterlogged conditions, there is minimal decay by anaerobic bacteria (Dierssen, 2003, 204; Baker et al., 2009, 133f.; Charman, 2009, 542f.).

With a vegetation cover, evapotranspiration rates are higher, but a dense covering of dead vegetation prevents sunlight from reaching the soil surface and lowers the evaporation rates (Baker et al., 2009, 139).

Wetlands lying adjacent to a lake or river may be termed "surface water slope wetlands". They are fed mostly by precipitation, surface flow, and flooding from the lake or river (Mitsch and Gosselink, 2007, 136), and they form only where the topography of the lake margin is flat (Jacomet et al., 2004; Baker et al., 2009, 125).

Hydrology in lakeside settlements

Lakeside settlements were constructed at the interface between limnic and terrestrial environments (Menotti, 2012, 13f.). They may be compared to "surface water slope wetlands," fed mainly by surface flow and lake inundations. The presence of large amounts of organic accumulations, often showing neither limnic nor terrestrial signs, demonstrates the complexity of the hydrological balance in lakeside settlements (Jacomet, 1985, 385; Ismail-Meyer and Rentzel, 2004). There is evidence that the acrotelm-catotelm model observed in natural peats also fits anthropogenic accumulations in several ways. Following the hydrology in peatlands, it is assumed that organic accumulations in pile-dwelling sites have significant water retention, which is due to a "sponge" effect. Without a dense active plant covering over the organic layers (there is some evidence for locally growing plants: Jacomet et al., 2004; Jacomet and Brombacher, 2005), evapotranspiration must have been rather low. The accumulations must have been water saturated over most of the time in order to maintain conditions that allowed such excellent preservation of organic matter (Kenward and Hall, 2004; Jacomet et al., 2004).

Organic accumulation

Organic accumulation in natural wetlands

Plant parts transported into lake bodies accumulate at the sediment-water interface and in shallow water (Gastaldo and Demko, 2011, 254f.), usually in areas with minimal wave action or flowing water (Keddy, 2010, 22f.). Wetlands develop only in areas that possess water-saturated surfaces during the major part of their existence in time and where the rate of accumulation exceeds that of organic-matter decay (French, 2003, 17; Mitsch and Gosselink, 2007, 156; Charman, 2009, 542f.; Gastaldo and Demko, 2011, 256).

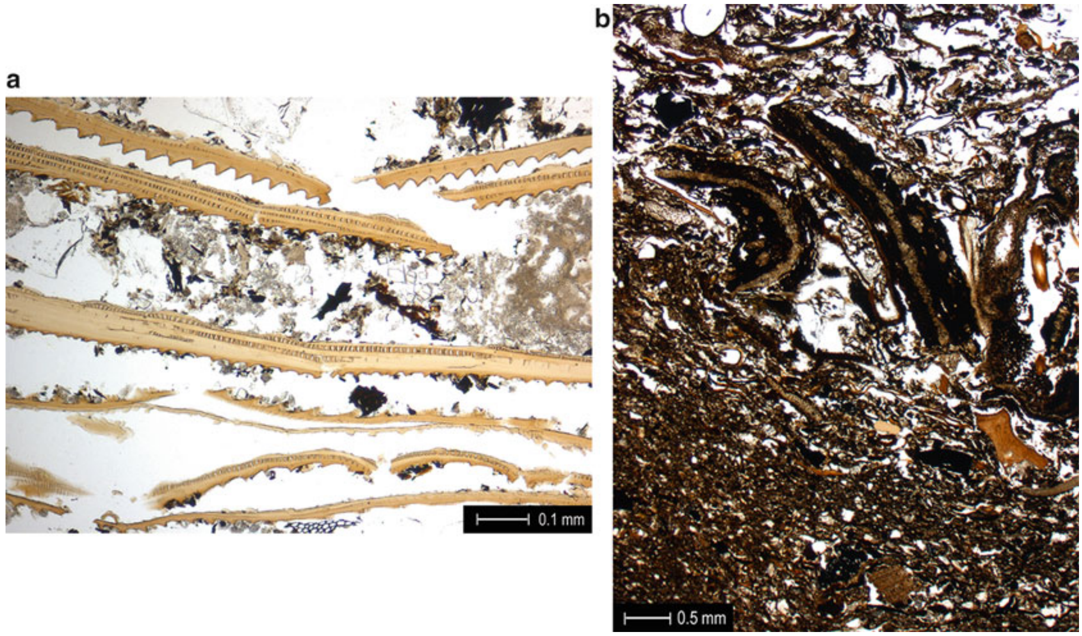
The fibrous composition of peats provides a strong structure and very high moisture content because of high capillarity. In the acrotelm, fresh plant material from mosses, sedges, and grasses is added at the surface, where most of the decay takes place (Charman, 2009, 541ff.). The residence time of the organic remains in the acrotelm may be about 100 years before they pass into the waterlogged catotelm. This implies a very slow growth rate of 0.5–2 mm per year (Lindsay, 2010, 78; Keddy, 2010, 193). Bones found in peat bogs are tanned by humic acids and often demineralized, which can be attributed to the lowering of pH or the presence of sphagnum moss, which decalcifies bone (as it does with "bog bodies"). Framboidal pyrite may form within cracks and pores in bones due to the colonization by sulfate-reducing bacteria (Turner-Walker and Mays, 2008).

Anthropogenic accumulation

In archaeological contexts, organic accumulations in wet environments resemble natural peats, but they are often of pure anthropogenic origin (Kenward and Hall, 2008, 585). Natural peat growth can also occur in settled areas, but this should be confirmed by botanical analyses (e.g., Maier, 2011).

Anthropogenic accumulations of organic matter consist mainly of wood and bark chips, leaves, twigs, mosses, agricultural remains, dung, bones, charcoal, ashes, sand, and loam (Figure 4a, b). Due to their morphology, wood, bark, foliage leaves, needles, mosses, and some seeds may be identifiable (see Schoch et al., 2004; Ismail-Meyer, 2016). The structure and shape of excrements sometimes allow the identification of the animal (Brönnimann et al., 2016a, 2016b). Bones of large animals, fish, and amphibians may also accumulate within the organic sediments; often, they still show their histological features (Huisman et al., 2009). Ashes can be distinguished due to their internal structure (Braadbaart et al., 2012). The accumulations are the result of different activities in the settled area – house building, food preparation, disposal of waste, handicrafts, animal husbandry, gathering, hunting, and fishing (Ismail-Meyer and Rentzel, 2004; Jacomet et al., 2004).

The well-preserved cultural layers show horizontally oriented remains of different sizes in a small-scale patchwork. This arrangement is the result of complex interaction between erosive and accumulative processes and various human and animal activities (Jacomet et al., 2004). The organic remains are usually very well preserved under waterlogged conditions. The presence of chlorophyll in some cases indicates a very fast sealing and burial, perhaps in less than 3 days or even within hours (Meyers and Ishiwatari, 1993, 886; Jacomet et al., 2004; Kenward and Hall, 2004, 8). Generally, such preservation is possible only because of a rapid accumulation rate (e.g., several centimeters every year) that occurred in the central



Paludal Settings (Wetland Archaeology), Figure 4 (**a**) Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): Several well-oriented fish remains (gills and scales) in different stages of preservation (well preserved at the *top*) and showing layers of micropores (possibly due to chemical dissolution) in the rest of the picture. (**b**) Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): Highly organic anthropogenic deposit and in the lower part, a laminated layer composed of highly fragmented organic matter (detritus). The upper, more porous part contains bigger organic remains with many dark brown bark fragments. An example of an outdoor area within a water-saturated, paludal depositional environment.

part of a village or in protected, swampy areas beneath raised houses (Jacomet et al., 2004; Ismail-Meyer and Rentzel, 2004; Ismail-Meyer et al., 2013). Such features demonstrate that, compared to the annual growth rate of a natural peat, lakeside settlements demonstrate a very different kind of accumulation process. Signs of decay in such waterlogged accumulations occur and can usually be attributed to anaerobic bacteria. This includes degradation of wood (Huisman and Klaassen, 2009). Bones may show a dark staining of the surface due to humic acids, precipitation of framboidal pyrite due to sulfate-reducing bacteria, tunneling caused by cyanobacteria, and loss of collagen, the major organic component of bones (Bocherens et al., 1997; Turner-Walker and Mays, 2008, Huisman et al., 2009).

Flooding events

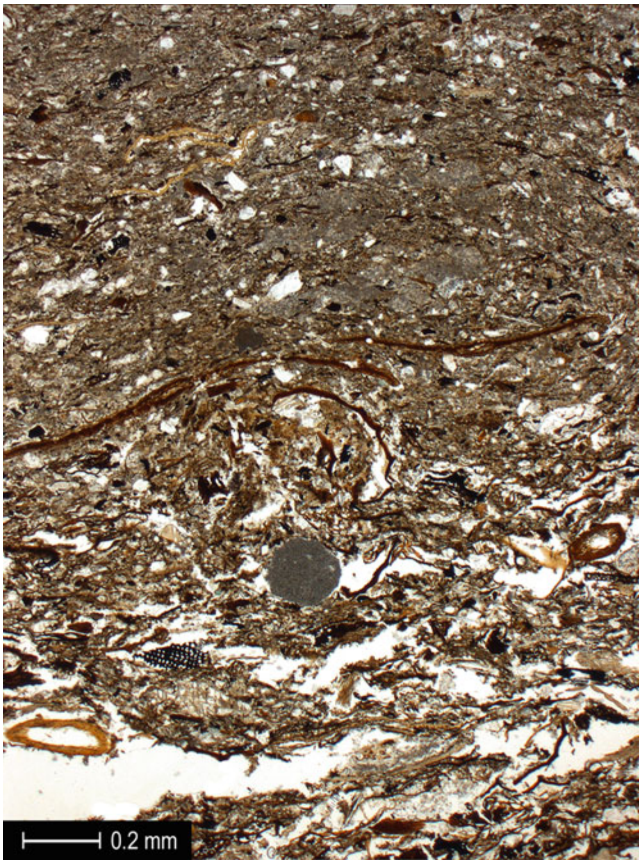
Lake-flooding events in natural peatlands

Flooding in wetland areas represents a natural event, and it occurs either seasonally or interannually. In the temperate zone, floods are produced each spring by the rapid melting of the precipitation accumulation of an entire winter, especially in mountainous areas (Middleton, 1999, 9; Mitsch and Gosselink, 2007, 132; Baker et al., 2009, 127; Keddy, 2010, 44). Therefore, large lakes depending on an alpine water regime may show yearly fluctuations in the water table of a few meters, while in small lakes and ponds, such fluctuations are rather weak (Keddy, 2010, 77). Long-term fluctuations in rainfall due to climate change may cause dramatic changes in the shoreline (Keddy, 2010, 44, 59).

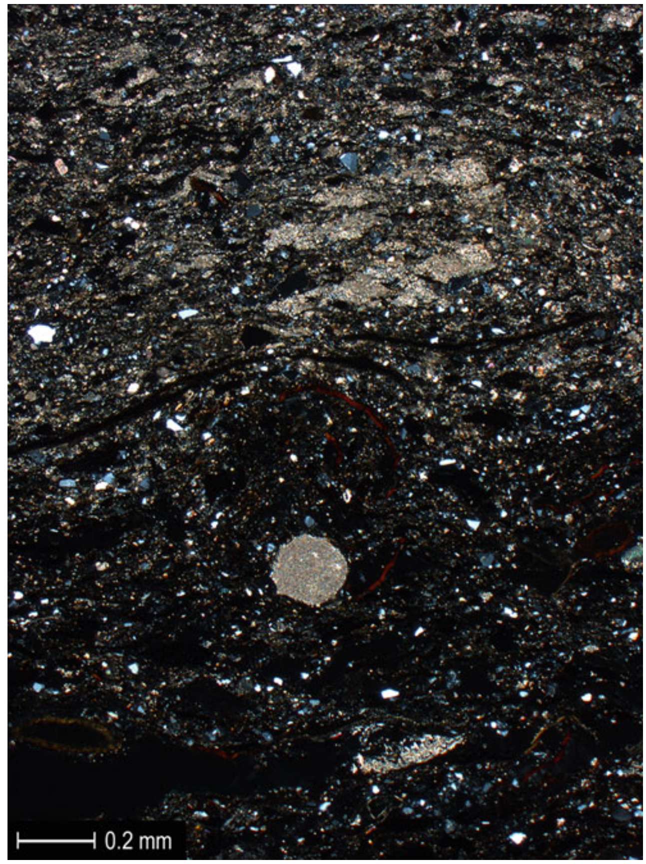
The major effects of flooding are erosion and deposition (Turnbaugh, 1978, 595). During flooding, wetland areas may be exposed to wave action, which imposes complex effects on littoral areas. The amount of wave energy impacting a shoreline increases with distance to the opposite shore and with the number of directions from which waves can arrive (Keddy, 2010, 121). With high levels of exposure to waves, fine particles and biomass tend to be removed, and sorted, coarser substrates such as sand and gravel are left behind (Magny, 2004; Digerfeldt et al., 2007; Keddy, 2010, 121). Resuspension of sedimented organic matter can be considerable, but it is usually more frequent in large rather than in small lakes (Meyers and Ishiwatari, 1993, 868).

Lake flooding in lakeside settlements

Flooding events may be frequent in lakeside settlements of the Circum-Alpine region, and they are also mainly linked to the spring flood. Climatic changes in late prehistoric times led to more permanent inundation of shore areas and may have caused the abandonment of a number of lakeside settlements (Menotti, 2001, 2004). High lake levels led to flooding, erosion, and/or redeposition of remains (Figures 5 and 6).



Paludal Settings (Wetland Archaeology), Figure 5 Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): In the lower half of the picture appears an organic cultural layer, truncated and overlain by limnic sediments with gray lake marl peds mixed with some eroded organic remains. Example of a flooding event after an occupation phase in a paludal environment.



Paludal Settings (Wetland Archaeology), Figure 6 Same section as Figure 5, with crossed polarizers (XPL): In the upper half of the picture, the limnic carbonates appear gray, and the layered organic remains are black.

Micromorphological analyses show that organic layers may be eroded by water movements coming from the lake. Erosion boundaries are difficult to detect, even in a thin section. Often, parts from the flooded organic accumulations are suspended and redeposited together with limnic sediments. Such layers consist of homogenous limnic carbonates containing mollusk shells, algal remains, and frequently large amounts of highly fragmented organic detritus (see below). It is also possible to observe organic layers with very rare algal remains, diatoms, sponge needles, and mollusk shells which seem to be in situ, but they must have been in suspension for a short period without any visible effect of wave action (Jacomet et al., 2004). It is obvious that palisades, house constructions, and on-site vegetation, such as reeds, have influenced the water movement through a lakeside settlement by breaking down wave energy.

Deposition of reworked lake marl, which shows no signs of laminations, may be the result of a single storm event. During longer phases of transgressions, laminated lake marl precipitates in situ (Digerfeldt et al., 2007).

Flooding due to runoff in natural peatlands

Erosion by water also occurs during spring through runoff from the upper slopes caused by rains and snowmelt, especially when the vegetation cover has been disturbed by forest clearance and agriculture (Turnbaugh, 1978, 606; French, 2003, 17, 22; Goldberg and Macphail, 2006; Keddy, 2010, 193; Zolitschka et al., 2010, 82). Infiltration into unsaturated peat (acrotelm) is fast. When a peat is already completely water saturated, surface flow occurs and may affect a large area of a floodplain (Baker et al., 2009, 126). Therefore, surface runoff can be strong, occurring even on gently sloping areas (Turnbaugh, 1978, 597). About 80 % of surface water flows through the acrotelm, and 98 % of the runoff occurs in the topmost 3 cm (Holden and Burt, 2003, 91; Baker et al., 2009, 122). Runoff follows immediately after rainfall or spring thaw. Even small amounts of precipitation produce long-lasting surface flow, and just 1 day of heavy rain will cause a sharp rise in the water table (Holden and Burt, 2003, 91f.; Mitsch and Gosselink, 2007, 126; Lindsay, 2010, 129). The waterlogged catotelm, where water moves very slowly, is usually not affected by flood events (van der Valk, 2006, 25, 150; Charman, 2009, 543f.; Lindsay, 2010, 128).

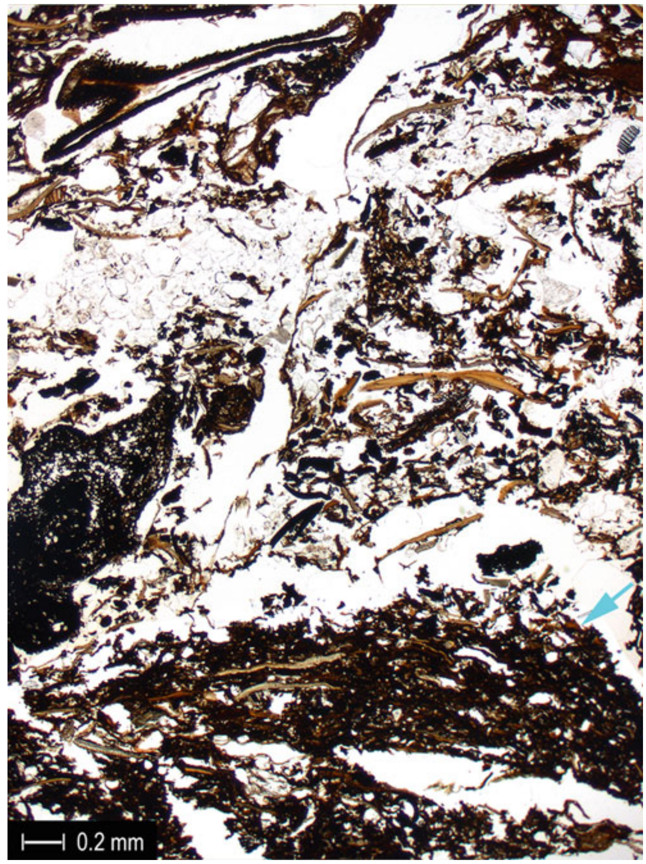
Wetlands that are characterized by inflows from a wider catchment receive allochthonous sediment inflows. The rate of sediment brought in depends on the magnitude and frequency of precipitation (Baker et al., 2009, 153). The main sediment charge arrives during the short, intensive period of water discharge in spring (Mitsch and Gosselink, 2007, 133). But it is also known that forest clearing and human land use lead to destabilization of slopes. The consequences are soil erosion, increased runoff, and higher levels of minerogenic sediment transfer from the catchment area into the lakes (Dierssen, 2003, 199; French, 2003, 24; Digerfeldt et al., 2007; Baker et al., 2009, 153; Zolitschka et al., 2010, 82; Menotti, 2012, 256). Except under very low flow velocities, silts and sands are quite easily detached from the soil mass and redeposited (French, 2003, 24).

Vegetation, such as reeds and bushes, slows down surface flow, so that in summer the flow resistance is high, and in winter the resistance declines. Seasonal cycles of plant growth have an impact on the timing of sediment mobilization (Baker et al., 2009, 136). A plant cover, roots, and leaf litter at the surface may also protect wetlands from erosion (Turnbaugh, 1978, 597; Baker et al., 2009, 158). Burial by successive layers of sediment leads to compaction and consolidation, so that only a little of the sediment is resuspended (Baker et al., 2009, 158).

Flooding due to runoff in lakeside settlements

Micromorphological analyses show that flooding from the hinterland also results in erosion and inwash by surface flow of well-sorted and graded sands from the catchment area (Figures 7 and 8). Due to surface water outflow into the lake, highly fragmented organic matter (detritus; see below) may be lost from the settlement site (Mitsch and Gosselink, 2007, 158f.). Unsorted layers rich in sand can also be anthropogenic in origin due to (1) loss of organic matter, (2) alteration of cultural layers, or (3) disaggregation of construction material such as loam walls.

Sequences of alternating organic layers and sandy inwash are interpreted as seasonal deposits (see below). Microstratigraphic observations have documented that flooding and/or reworking of organic layers does not involve the entire anthropogenic sequence – as such a result would yield homogeneous sediments without laminations – but only the uppermost part of the sequence is affected (Jacomet et al., 2004). This situation may be explained by the acrotelm-catotelm model, indicating that surface flow occurs mainly in the uppermost part, while the denser, waterlogged catotelm is not affected. Obviously, it is impossible to know how much of the sediment was previously removed by erosion, but it was probably not more than a few cm per flooding event. Generally, the lakeward parts of sites were more affected by lake flooding, while the areas toward the landward side were influenced instead by surface runoff (Jacomet, 1985; Jacomet et al., 2004; Ismail-Meyer and Rentzel, 2004; Ismail-Meyer et al., 2013). House constructions, palisades and on-site vegetation may have slowed water movement through the site.



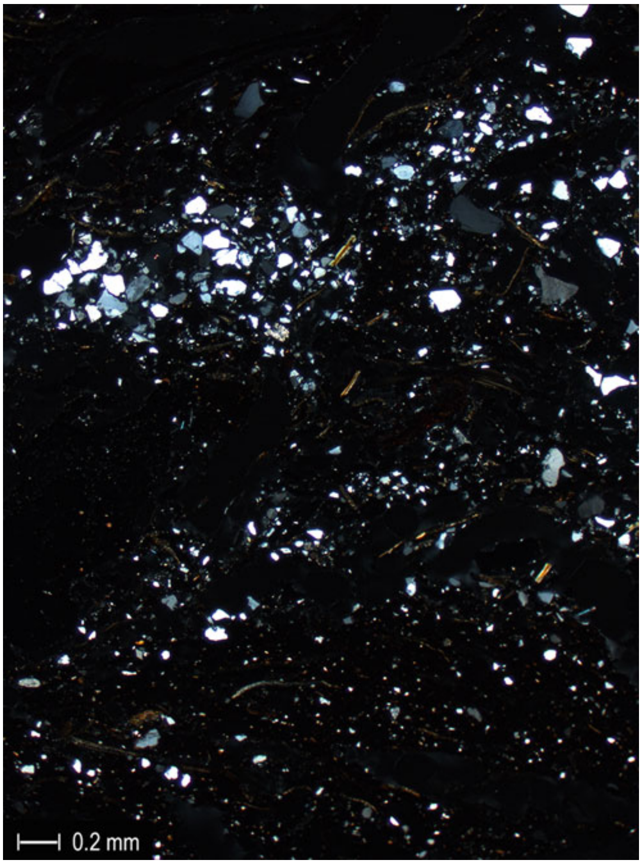
Paludal Settings (Wetland Archaeology), Figure 7 Lake Luokesa, photomicrograph of a thin section in plane-polarized light (PPL): Dense organic crust (*arrow*) of decomposed organic matter, probably due to desiccation. A sandy layer, possibly an inwash from the hinterland, covered the organic layer.

Lowering of the water table

The preservation of organic remains in wetlands is connected to the height of the lake level or the groundwater table. This section will explain how and why organic matter decays in wetlands and waterlogged archaeological sites.

Lowering of the water table in natural wetlands

During the summer, the water table in wetlands may drop due to higher evaporation rates, causing desiccation and decomposition of organic matter (Keddy, 2010, 66;



Paludal Settings (Wetland Archaeology), Figure 8 Same section as Figure 7, with crossed polarizers (XPL): The quartz grains from the sandy inwash are visible in *white and bluish colors* in the upper half of the picture.

Gastaldo and Demko, 2011, 255). Decay of plant remains occurs in approximately three stages. First, plant cell contents and food stores of seeds disappear through fermentation; second, plant cell walls and insect remains decay; and third, most remaining organic matter disintegrates, and only the most resistant plant residues survive and can be recovered, such as cuticles, lignin-containing cells from wood and bark, and phytoliths (plant silica) (Kenward and Hall, 2000, 520, 2004, 5; Gastaldo and Demko, 2011, 255). The so-called detritus or particulate organic matter – also a result of organic decay in wetlands – measures between 0.45 µm and 1 mm in size. In wetlands, oxygenation, desiccation, and bacterial and fungal activity (without arthropods and other typical soil animals) lead to detritus formation. Dried-out peats are reduced to a loose detritus powder as a result of the combined effect of sun and wind – without further physical abrasion (Mitsch and Gosselink, 2007, 157; Lindsay, 2010, 85; Gastaldo and Demko, 2011, 255). Detritus appears after the dry period due to peat erosion, and it accumulates at the surface during a short period of stability. Due to precipitation, it enters into streams mainly between September and the end of November (Blazejewski et al., 2005, 1323f.; Lindsay, 2010, 110; Marxsen and Wagner, 2011, 77; Gastaldo and Demko, 2011, 255).

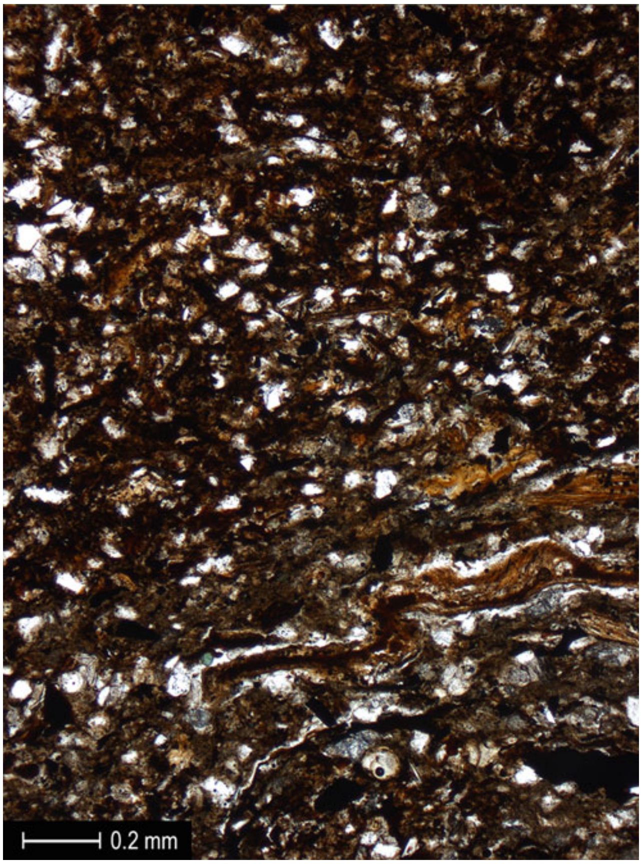
Fluctuations in the groundwater table also introduce oxygenated waters leading to biochemical processes that play a part in reducing plant parts (Gastaldo and Demko, 2011, 255). For instance, the redox potential, or Eh (the tendency of oxidation or reduction), is probably one of the most significant variables influencing the rate of organic degradation (Retallack, 1984). Oxidation occurs mainly in aerobic conditions and leads to decomposition and humification (Kenward and Hall, 2004, 6f.). When oxygen-rich water is introduced into peats, it normally takes only a few hours or days until the oxygen in the flooded layers is depleted by bacterial and fungal activity (Mitsch and Gosselink, 2007, 173). Under reducing conditions, anaerobic bacteria are the primary active microorganisms that are responsible for organic decay (Lillie and Smith, 2009, 17, 21). Rotting of wood has been observed due to fungi (white and red rot; Schweingruber, 1982; Huisman and Klaassen, 2009). Faunal activity in wetlands also leads to a reduction in peat volume and the development of humus, such as mull or moder (Babel, 1975; Malterer et al., 1992). Peats possess about 80 % pore space, which is filled with water in saturated areas (Mitsch and Gosselink, 2007, 166). Lowering of the water table in a natural peat leads to rapid subsidence of the surface because the porosity collapses. The increasing weight of the drier sediments above affects the peat column beneath. Every centimeter of drawdown in the water table results in an increased load of 10 kg m^{-2} (Lindsay, 2010, 123). Drying out and alteration of bogs, the so-called peat ripening, can also lead to compact sediment showing cracking and prismatic or granular microstructure (Malterer et al., 1992; Stolt and Lindbo, 2010, 385; Lindsay, 2010, 135). Dissolution of organic matter in acidic waters, probably combined with desiccation, may cause a transformation into amorphous, dark brown, jellylike concentrations, called dopplerite (Stolt and Lindbo, 2010, 385). As a consequence of syn- and postsedimentary dissolution phenomena, gelatinous dopplerite may be formed, but needs a phase of drying out to become insoluble (Wetzel 2001, 631). Another result of low water table in peats is the formation of amorphous organic matter (AOM) (Comont et al., 2006).

Bones from desiccated peat bogs show signs of demineralization, shrinkage, and cracking due to drying and may contain gypsum crystals (see below; Turner-Walker and Mays, 2008).

In wetlands, a slow process called terrestrialization may take place whereby wetlands become shallower and shallower with time; eventually, the wetland turns into dry land (van der Valk, 2006, 98).

Lowering of the water table in lakeside settlements

For archaeological remains, the main phase of decay generally occurs before, during, and for a short period, after



Paludal Settings (Wetland Archaeology), Figure 9 Stansstad-Kehrsiten, Switzerland, photomicrograph of a thin section in plane-polarized light (PPL): Compact organic detritus with fine-grained sand – the result of an alteration (desiccation) of the organic matter and runoff from the hinterland.

deposition. Soon after burial, ground conditions typically become more or less stable (Kenward and Hall, 2000, 522). Later episodes of decay due to dewatering (drainage or lake level corrections) lead to uniformly and poorly preserved remains within the near surface deposits (see below).

Micromorphological signs of dropping groundwater level, desiccation, and decay include a very dark brown color of the organic matter, a higher rate of compaction, fragmentation to the size of detritus, and the formation of dopplerite, organic crust, and AOM (Figure 7, see below). Mesofaunal droppings in decomposing wood and bark, fungal spores, and hyphae occur, but usually there are no signs of arthropod or other soil animal activity (Pawluk, 1987; Stolt and Lindbo, 2010).

Lowering of the water table in lakeside settlements allows the entry of air and rainwater rich in oxygen. Repeated wetting and drying cycles produce fragmentation of the organic remains and the development of detritus (Figure 9). Desiccation also leads to the collapse of porosity and, consequently, surface subsidence (Lindsay, 2010, 123). The formation of organic crusts, i.e., compact, layered, organic aggregates, may be connected to such processes, as seen in peat environments (Comont et al., 2006). Fungal and bacterial activity may also reduce plant parts to detritus (Gastaldo and Demko, 2011, 255). Wood may be heavily attacked by fungi, such as white and red rot (Schweingruber, 1982; Huisman and Klaassen, 2009). After hiatuses, e.g., due to abandonment of a site, organic layers showing strong signs of decay and mesofaunal droppings, of e.g. springtails (Collembola) and/or pot worms (Enchytraeidae) may be observed (Ismail-Meyer, 2014). Due to weathering, sediment can become more minerogeneous. The presence of dopplerite and amorphous organic matter (AOM) seems to indicate drier parts of lakeside settlements or may be formed during acidic phases, but it may also have been precipitated as a result of modern drainage in wetland areas (see also below). Animal bones may show diverse signs of degradation, such as loss of birefringence due to loss of collagen (Gilbert, 1989, 59), tunneling as a result of aerobic bacteria and fungi (microfocal destruction or bioerosion), cracking, and signs of dissolution due to chemical weathering. Gypsum crystals may also occur in cracks and pores as a result of the reaction of dissolved calcium with sulfate released by pyrite decay (Bocherens et al., 1997; Jans et al., 2004; Turner-Walker and Mays, 2008; Huisman et al., 2009).

Heterogeneous conservation of the organic remains indicates synsedimentary alteration (and inherited elements) if conditions have been stable through time. If signs of decay appear confined to single layers of lakeside settlements, followed by well-preserved ones, a possible interpretation is that these altered levels reveal seasonal drying, with decay having occurred pre- or immediately post-burial (see below; Kenward and Hall, 2000, 521; Ismail-Meyer, 2014).

Postdepositional processes in natural wetlands and lakeside settlements

After burial, only very slow decay and almost no post-burial alteration (diagenesis) occur, as long as the ground conditions persist (Kenward and Hall, 2000, 522, 2004, 6f.). Under permanent waterlogged conditions, organic remains from pile-dwelling sites may show, more or less, the same preservation upon excavation as existed shortly after their burial. But the recent growth of reed belts around lakes could have major effects on the arrangement of the remains, leading to mixing of several layers (Ismail-Meyer and Rentzel, 2004; Jacomet et al., 2004).

Human activities such as agriculture, forestry, stream canalization, dam and dike construction, mining, groundwater extraction, and the creation of water pollution have major impacts on wetlands (Middleton, 1999, 56ff.; Mitsch and Gosselink, 2007, 289), which are disappearing very fast (Menotti, 2012, 226). Modern drainage leads to peat loss due to consolidation, compression, oxidation, and pedogenesis (Lindsay, 2010, 124; Gastaldo and Demko, 2011, 261), and as an example, the drainage of a freshwater lake in England led to the loss of 4 m of peat volume (Lindsay, 2010, 123ff.). Archaeological wetland sites experience the same effects as natural wetlands due to drainage, and such changes can be seen in the landward part of Arbon-Bleiche 3 (Jacomet et al., 2004).

When the natural wetland environment vanishes, our cultural heritage is lost, too. Maintaining the natural environment by stabilizing the water table, controlling water quality, and taking anti-erosion measures can protect many wetlands and archaeological wetland sites from post-burial decomposition (Cole, 1995, 31ff.; Mitsch and Gosselink, 2007, 305; Menotti, 2012, 19, 226). Thanks to the Ramsar Convention, an international contract originally begun in Ramsar (Iran) in the early 1970s, the protection of wetland habitats around the world has been promoted (Mitsch and Gosselink, 2007, 519; Ramsar Convention). The interest group "Preserving Archaeological Remains In Situ" (PARIS) regularly organizes international conferences about in situ preservation. Discussion of in situ protection for wetland sites can be found in Cole (1995), Vernimmen (2002), Lillie (2007), Lillie and Smith (2009), and Kenward and Hall (2008).

Excellent preservation in lakeside settlements

Organic matter in wetlands often shows excellent preservation because of waterlogged, anoxic conditions (Figure 4a, b; Kenward and Hall, 2000, 521), and the best preservation of organic remains occurs in areas that lie between the limnic and terrestrial environments. On very flat and protected lakeshores, plant remains may accumulate, constantly soaking up humidity from the groundwater as happens in natural peatlands (Jacomet et al., 2004; Gastaldo and Demko, 2011, 254f.).

Under waterlogged, anoxic conditions, often only the first stage of organic decay occurs, i.e., loss of cell content and food stores of seeds before, during, or shortly after deposition (Kenward and Hall, 2000, 520–522, 2004, 5). Rapid sealing of the remains under a high sedimentation rate during the growing season – possibly enhanced by compaction caused by human and animal trampling – leads to excellent preservation. In many lakeside settlements, green leaf tissue is still preserved, cattle and sheep/goat dung has kept its original shape (and smell), and dung-dwelling insects are practically absent (Kenward and Hall, 2004, 8; Jacomet et al., 2004; Ismail-Meyer et al., 2013). The bones often show very good preservation, and even highly fragile fish gills and scales can be recognized (Figure 4a). Soon after burial, ground conditions become more or less stable because of the quickly depleted oxygen resulting from fungal and bacterial activities (French, 2003, 17; van der Valk, 2006, 19; Kenward and Hall, 2008, 585; Lillie and Smith, 2009, 11; Keddy, 2010, 22; Menotti, 2012, 228f.). This is probably the reason why there are almost no signs of fungi in waterlogged areas (van der Valk, 2006, 40). Waterlogged organic material may account for 75–90 % of all the material recorded (Lillie and Smith, 2009, 9). If such conditions that are conducive to long-term preservation are not stable over time, remains usually decay quickly and completely (Kenward and Hall, 2000, 522).

Trampling effects on waterlogged organic accumulations

In settled, terrestrial areas, occupation activities generally produce compacted surfaces. In wetland sites, the most clearly visible effect of trampling can be seen in the minerogenic lake marl sediments at the base of the anthropogenic accumulations and loam floors in houses (see, e.g., Rentzel et al., 2016). Highly organic accumulations seem not to preserve clear signs of trampling over a long period of time because they expand to their original shape like a sponge (Jacomet et al., 2004; Ismail-Meyer and Rentzel, 2004). Dense organic crusts are not the result of trampling, but refer to phases of decay (Figures 7 and 8; see above; Ismail-Meyer, 2014).

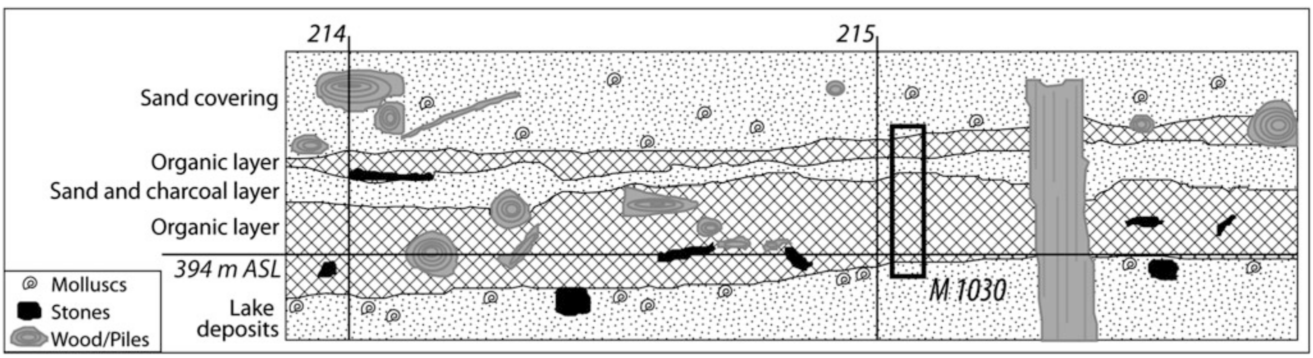
Seasonal processes

Many processes observed in lakeside settlements are linked to seasonal events. Micromorphological observations often show organic laminations (from a few millimeters up to several centimeters in thickness), which may confirm a decomposition and compaction of organic matter at the surface. Sometimes, they are covered by a tiny layer of well-sorted and graded sand, which shows a sharp lower boundary. In near-shoreline areas, the sandy layers can be replaced by lake marl layers containing substantial amounts of detritus and amorphous organic matter (Figure 9). These sequences may be the result of seasonally induced changes, as observed in Lake Luokesa, Arbon-Bleiche 3, and Stansstad-Kehrsiten. Multidisciplinary investigations have demonstrated that they can be interpreted as follows. During phases with high water tables, large amounts of fresh material accumulate in the settlements as a result of human (and animal) activities. A quick sealing by covering deposits under waterlogged conditions leads to extremely good preservation. During the hot season, the groundwater level can drop a few cm causing desiccation, as well as fungal, mite, and bacterial involvement. In spring, flooding and substantial surface flow can lead to erosion of the topmost layer (a maximum of a few cm) as well as deposition of sand from the catchment area. Sand inwash seems to occur especially during settlement phases which are associated with forest clearing and agricultural activities. Near the lake, flooding may occur at the same time, depositing lake marl with eroded detritus from the site (Ismail-Meyer, 2014).

Fire events

Fire events occur regularly in wetlands when the peat surface is sufficiently dry during seasonal or interannual dry

Paludal Settings (Wetland Archaeology), Figure 10 Arbon-Bleiche 3, Switzerland: Field view of the south profile through House 1. The laminated, gray lake and beach deposits are overlain by the dark brown cultural layer. Note also the effects of modern trampling of the water-saturated lake marl in the right foreground, leading to ductile deformation phenomena (By Amt für Archäologie Thurgau, www.archaeologie.tg.ch, D. Steiner).



Paludal Settings (Wetland Archaeology), Figure 11 Arbon-Bleiche 3: West profile through House 1 showing the sequence with two main organic cultural layers divided by a charcoal-rich sandy layer. The rectangle M1030 corresponds to the micromorphological block sample (see Figure 12) (Drawing by Amt für Archäologie Thurgau, www.archaeologie.tg.ch and K. Ismail-Meyer, modified from Ismail-Meyer et al., 2013).

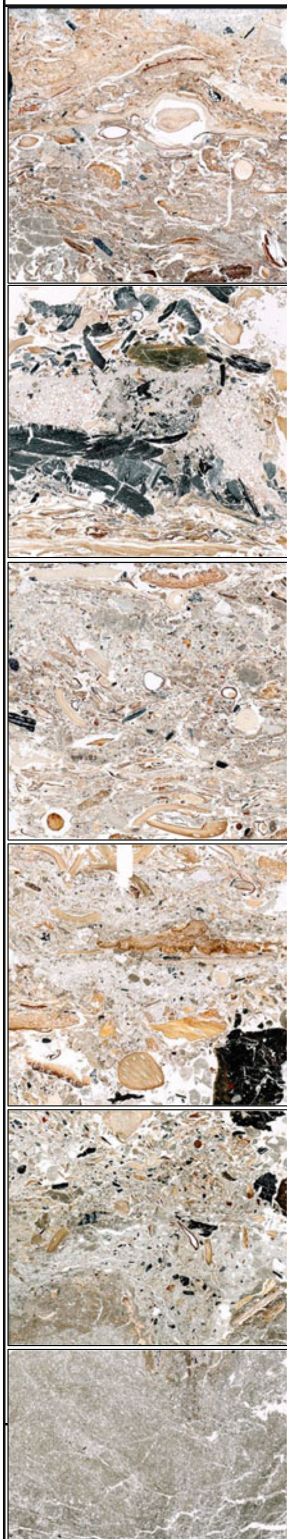
periods. The major sources of combustion are human activities and lightning (Middleton, 1999, 42ff.; van der Valk, 2006, 98; Lindsay, 2010, 215). Fire affects only the surface vegetation of a peat (Charman, 2009, 545) and produces much ash, which is easily removed by wind or washed away by rain. Fire is one of the most important causes for extensive peat erosion (Lindsay, 2010, 144, 248).

Lakeside settlements show signs of fire events that led to the destruction of single houses or even entire villages. The use of fire must have been dangerous, especially during the dry season. Thin sections reveal organic layers that bear indications of heat in the form of burnt plant material, ashes, and organic slags (melted phytoliths). Entire layers of charcoal occur, too, but these are rare, which must be due to the fact that charcoal is easily dislocated, fragmented by trampling, and removed by flooding events (Macphail et al., 2010, 47). For instance, a village destroyed by a fire will most likely be subsequently flooded, at which time substantial parts of the burned layers will be removed by wave action (Jacomet et al., 2004; Ismail-Meyer and Rentzel, 2004).

Case study: House 1 from Arbon-Bleiche 3

A micromorphological case study from Arbon-Bleiche 3 is presented here to illustrate the main processes in the

House 1: Scanned thin sections



Phase	Seasonal process	Microscopy	Dating
	Lake flooding	Erosive sandy layer with limnic aspect. Final flooding.	3370 cal BC
Stable	Winter?	Compact organic layer with altered and well preserved sheep/goat coprolites, mistletoe, and needles of white fir. Pollen indicating winter season.	
House in use	Dry Summer (low water table)	Compact organic layer with sandy clay matrix and detritus, fish scales, ashes, and altered sheep/goat coprolites.	
House in use	Dry Summer (low water table)	Compact organic layer with large amounts of matrix and detritus, altered sheep/goat coprolites, some seeds.	
House in use	Dry Summer (low water table)	Fine sand with clay and detritus, well preserved and altered bark remains.	
Renovation	Accumulation with high water table	Loose organic layer with charcoal, white fir needles, clay aggregates, twigs, no detritus.	
Renovation	Accumulation with high water table	Compact layer with charcoal, loam aggregates	3375 cal BC
	Hinterland spring flooding	Erosive sandy layer with well sorted sand and large amounts of poppy seeds. Disturbed.	
fire	?	Layer of large charcoal fragments with some fine sand.	
Raised house with goat/sheep staying sometimes beneath	Dry Summer (low water table)	Loose organic layer with wood, bark, white fir needles, moss, some detritus.	
Raised house with goat/sheep staying sometimes beneath	Accumulation with high water table	Organic layer with bark, white fir needles, wood, no detritus.	
Raised house with goat/sheep staying sometimes beneath	Hinterland spring flooding	Well sorted sandy layer.	
Raised house with goat/sheep staying sometimes beneath	Winter?	Compact layer with sand, gravel, twigs, some charcoal, and altered coprolites. Pollen indicating winter season.	
Raised house with goat/sheep staying sometimes beneath	Autumn?	Loose organic layer with many hazelnut shells, moss, twigs, leaves and loam aggregates, some sheep/goat coprolites. No detritus.	
Raised house with goat/sheep staying sometimes beneath	Accumulation with high water table	Compact layer with fine sand and clay matrix, some ashes and bark.	
Raised house with goat/sheep staying sometimes beneath	Hinterland spring flooding	Sandy layer.	
Raised house with goat/sheep staying sometimes beneath	Autumn?	Loose sand with bark, mollusk shells, organic remains, loam aggregates, twigs, mistletoe, fish bones, 1 ceramic fragment on the right side.	
Raised house with goat/sheep staying sometimes beneath	Lake flooding	Dense sandy layer with organic remains, charcoal, ashes, melted phytoliths, seeds (poppy and flax), mollusk shells, many bones, some with heat signs, loam, leaves, mosses, white fir needles, and one sheep/goat coprolite.	
Raised house with goat/sheep staying sometimes beneath	Lake flooding	Loose sandy layer with limnic elements, bark, charcoal, some seeds and bones, all reworked.	
Raised house with goat/sheep staying sometimes beneath	Dry Summer (low water table)	Compact lake marl (disturbed) with detritus, bark, weathered mollusk shells, bones, seeds, and leaves.	3384 cal BC
	Lake flooding	Sandy lake marl without layering, disturbed probably by a post. Many mollusk shells, some with signs of weathering. Precipitated in the littoral area, reworked by wave action, lake level flucuations occurred.	

Seasonal processes
- Lake flooding
- Hinterland spring flooding
- Accumulation with high water table
- Dry Summer (low water table)
- Autumn?
- Winter?

Paludal Settings (Wetland Archaeology), Figure 12 Arbon-Bleiche 3, House 1, sample M1030 (see location of sample in Figure 11): A compilation of scanned thin sections with a brief micromorphological description and a suggested interpretation of the archaeological layers, including possible seasonal processes (based also on botanical and palynological evidence).

formation of lakeside settlements. Arbon-Bleiche 3 is one of the most suitable examples for this purpose, as it is an extensively explored pile-dwelling site in the Circum-Alpine region that has received much interdisciplinary study (published by Jacomet et al., 2004; Menotti, 2012). This Neolithic site lies in northeastern Switzerland on the southern shore of Lake Constance, south of the town of Arbon. Today, the site lies inland compared to its original setting, which was located directly on the shore of a protected bay. The settlement was built in 3384 BC and was inhabited until 3370 BC (all dates coming from dendrochronology). This period falls in the middle of a cold phase (Piora 2) that experienced generally high lake levels. The site was constructed during a brief favorable climatic phase, when lake levels dropped for a short span of time (Haas and Magny, 2004).

The economy of Arbon-Bleiche 3 was based on the cultivation of plants, animal husbandry, and on gathering, hunting, and fishing. Animals were kept within the settlement during the winter months. The village was settled only once and for a relatively short time (15 years). Because the ground plans of the dwellings were clearly visible during the excavation, it was possible to take micromorphological samples from different functional areas of the site (e.g., within houses and alleys).

The basic stratigraphy of Arbon-Bleiche 3 consisted of sandy lake marl at the base, followed by a thin sandy beach layer that formed due to a regression of the lake before the settlement was installed (Figures 10 and 11). During the occupation, a 5–40-cm-thick archaeological stratum with several organic and sandy bands was deposited. The floors of the buildings were raised above ground level (Leuzinger, 2000). During the interval of settlement, depositional conditions must have been continually humid but without permanent standing water covering the area. The layers represent a complex puzzle of deposition and erosion. The entire anthropogenic deposit was covered by 2 m of sandy deposits almost “immediately,” thereby promoting excellent preservation of the site until the moment of excavation.

Detailed geoarchaeological interpretation of the organic accumulations has enabled a reconstruction of the chronological biography of house number 1 (Figure 12). House 1 was the first to be constructed, dated to 3384 BC, and it was located in the middle of the settlement (and excavated area; Leuzinger, 2000). After its installation, a 10 cm sequence of organic layers was deposited, interrupted several times by sandy inwash from the hinterland. A local burned layer was then partially eroded by a further sandy inwash. The accumulation of a 7-cm-thick organic layer followed; it contained large amounts of sheep/goat coprolites and mistletoe.

This sequence can be interpreted as follows. The installation of House 1 led to compaction of the dry carbonate platform surface beneath it. During the time of settlement, organic layers accumulated but were repeatedly eroded and covered by thin sand layers, probably during spring floods and increased runoff. After 9 years of occupation, House 1 burned down and was subsequently flooded for a short period. A renovation in 3375 BC is demonstrated by dendrochronological investigations. Later, the roof collapsed and the house was abandoned. Botanical and palynological analyses confirm that the accumulation of the ovicaprid coprolites is an indication that the ruin was used as a stable for sheep and/or goats during the winter. In the spring of 3370 BC, the entire village burned down completely, and shortly after, the area was flooded by the lake (Haas and Magny, 2004; Ismail-Meyer and Rentzel, 2004, 76f.).

Summary

Geoarchaeological methods, including especially micromorphology, have become essential tools for the study of archaeological settlements in wetlands. In this contribution, special emphasis has been placed on micromorphological analyses of several prehistoric lakeside settlements in the Circum-Alpine region.

By comparing with actual processes ongoing in natural wetlands, the site formation processes of ancient lakeside settlements can be studied, and they are here summarized as accumulation of organic matter and its erosion, reworking, and decay, which is closely related to the height of the groundwater table and/or lake level.

Micromorphology, possibly combined with standard sedimentological investigations, shows great potential in reconstructing environments and site formation processes in wetland sites. Collaboration among different disciplines is fundamental, especially with archaeobotany, palynology, and dendrochronology, to obtain optimum results. In this way, it is possible to use the mosaic of different accumulations within a lakeside site to detect many human activities as well as natural processes, from flooding and erosion to dry periods associated with seasonal changes (Jacomet et al., 2004; Keddy, 2010, 131; Menotti, 2012, 19f.; Ismail-Meyer et al., 2013). The results of research obtained so far in this field have been remarkable, but there is much potential for significant applications of geoarchaeological methods to wetland archaeology in the future.

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Cross-references

Inundated Freshwater Settings
Organic Residues
Paleoenvironmental Reconstruction
Paleoshores (Lakes and Sea)
Sedimentology
Site Formation Processes
Site Preservation
Soil Micromorphology
Trampling

PASTORAL SITES

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Definition

Pastoral sites are those devoted to or based on livestock raising. This definition should be applied with care, because stock rearing may have played a variable role in the economies of past populations, and consequently, traces of pastoral activities may be more or less evident in sites where other subsistence practices were more apparent. In the majority of cases, the term applies to cultural contexts in which a production economy was at least partly engaged in pastoral pursuits for subsistence. Through time, pastoral sites were integrated into economic systems of increasing complexity, and they also included settlements with different pastoral functions, many of which exploited, managed, and modified the surrounding and intervening territories.

Introduction

Due to the diffusion of stock rearing practices from its earliest appearances, pastoral sites are widespread and can be found in extremely diverse environments from the lowest latitudes to the edge of the polar ice caps and from lowlands to high mountains. As a result, a very wide range of "natural" geological processes can be involved in the formation processes of these sites. These processes will be not treated here, as more information about them can be found in specific manuals.

On the other hand, the anthropogenic and human-influenced animal components tend to be less variable and depend more on the animal species involved than on specific practices connected with pastoral economy or – more simply – with stock rearing. Nevertheless, it must be noted that the species of animals raised are partly a consequence of the environmental characteristics of the area where the sites are located. This entry will focus on the components that are distinctive of pastoral sites.

Eventually, it can be argued that pastoral sites may represent just a minimal part of much larger agropastoral systems of landscape use, because animals (and shepherds) spend more time on pastures than in the limited