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Why are they still there? A model of accumulation and decay of organic prehistoric cultural deposits

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ABSTRACT

The circumalpine lake side settlements are a unique source of detailed information on the past. Nevertheless, little has been published by now on why the organic matter (fumier lacustre) in these settlements has been preserved and how exactly this happened. It is, therefore, necessary to closely explore the decomposition of organic matter under different conditions. We present data from the literature and a decomposition model simulating the outcome of different archaeological hypotheses and comparing the result with the actual archaeological record. We conclude that different scenarios of deposition should result in clearly discernible and measurable features in the archaeological record, whose presence or absence allows deducing the mode of deposition. The best conditions of organic preservation are to be expected under such conditions where a large organic input happens in shallow still water. Seasonal flooding and a later rise in lake level can also result in good preservation but imply a greater loss through mechanical erosion and in many cases clear preservation gradients within the deposits. The theoretical outcomes presented here find clear analogs in the archaeological record.

1. Introduction

1.1. Context and aims

Due to organic preservation prehistoric wetland settlements provide detailed data on the past environment and the cultural of their population. For archaeological interpretation it is important to know how complete the actual record is and how the milieu of deposition can be characterized. This is particularly obvious, where social and economic reconstructions are heavily based on organically preserved material (e.g. Doppler et al., 2010; Schibler, 1997; Schibler and Jacomet, 2010) but where there is still an unresolved debate over the setting of the houses on the shore (see for a summary Dieckmann et al., 2006, 207–219). Little has been written on how the organic matter has been preserved. In archaeological literature it is commonly thought that the term *waterlogged* sufficiently explains the presence of organically preserved finds. If this was true then all organic matter that was ever naturally deposited in lakes should be preserved as well.

For English sites Caple (1994) has drawn attention to the lack of knowledge and research in the chemical conditions of waterlogged archaeological deposits that give rise to preservation of organic material. His main concern was to maintain or re-establish such conditions in order to preserve archaeological remains in situ. Since then quite a number of studies have been conducted focusing on soil chemistry and the relation between organic preservation and water tables (e.g. Kenward and Hall, 2000; van de Noort et al., 2001; Holden et al., 2006; Martens et al., 2012; Hollesen and Matthiesen 2015). The aim of virtually all these studies, however, is to elucidate how such conditions can be maintained and how deposits can be preserved for the future. In the past, the question, why and how such conditions evolved in the first place was mostly only of marginal concern and was only dealt with to the extend it seemed necessary. Caple (1994) sketched the general process and although it became clear that apart from the water table other (chemical) factors were important for organic preservation (van de Noort et al., 2001; Holden et al., 2006), the influence of the water table remained the major focus.

In the circumalpine lake shore sites water tables are of much less importance, since most sites are situated well under the lake's water table. In lake Zurich for example the highest organically preserved archaeological deposits lie at around 405 m above sea

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level and thus 1 m below current lake level. Concerning the protection of these sites mechanical erosion has proven to be far more detrimental and thus research was more focused on sediment movement and wave action (Hofmann et al., 2013; Weber, 2013; Weber et al., 2013). Virtually no research was done on the chemical characterization of archaeological lake deposits. Again there are no studies on why conditions for organic preservation have developed at all. Since the beginnings of lake side settlement research some scholars thought that only a lowering of the lake level made it possible to settle on the shore with organic accumulation analogous to fens (Speck, 1990) and this idea has remained popular (e.g. Corboud, 2001). Magny (2004, 72) used archaeological layers as a proxy for a declining lake level by treating them just like peat that formed during phases of low lake levels. It should, however, be noted that on lake shores the organically preserved cultural layers have never been shown to be linked to fen peats outside the settlement. It appears, therefore, questionable whether the conditions under which the organic layers formed, were the same as for peat. This is what sets the lake side settlements apart from the bog settlements.

To understand the formation of the organic cultural deposits we need to consider the processes of organic preservation that have been studied in soil- and peat-sciences. While the studies cited above focus on the maintenance of preserving conditions, the scope of this paper is rather to elucidate how and why these conditions developed in the first place and what this means for the interpretation of prehistoric sites.

1.2. Decomposition of organic matter

Organic matter usually consists of biopolymers, notably cellulose, proteins, chitin, lipids, and lignin. These compounds are degraded to their monomers i.e. carbohydrates, fatty acids, amino sugars, and amino acids. However, these substances and their precursors are not equally degraded. Most sugars and amino acids can be quickly broken down, while complex carbohydrates such as cellulose are more recalcitrant. The slowest material to decay in most organic litter is lignin. In the literature on organic decay a distinction is therefore made between so-called solubles, non-lignified carbohydrates, lignified carbohydrates and lignin (Berg and McClaugherty, 2008). Under aerobic conditions organic material is generally decomposed by the cooperation of several agents. Animals feeding on litter- and organic detritus use energy-rich compounds such as sugars, starch and proteins and achieve a mechanical breakdown of the refractory material, aiding the further decomposition by bacteria and fungi. Microorganisms use oxygen to break down organic matter into increasingly smaller and less complex chemical substances. Carbohydrates are broken down into water and CO_2. The decomposition of lipids, proteins and amino acids also releases nitrogen. During the process enrichment of more refractory material such as lignin is achieved. Lignin then can be decomposed under oxic conditions by specialized fungi and bacteria (Killops and Killops, 1993; Berg and McClaugherty, 2008), while it is practically not decomposable if oxygen is absent (Madigan et al., 1997, 516). Normally not all organic carbon is reduced but a lower limit is reached with the organic material partially entering a stable state. This organic fraction (humus) can persevere for millennia and consists mainly of humic acids, humic substances, and fulvic acids. Humus can accumulate and form considerable layers in the topsoil (Berg and McClaugherty, 2008, 228).

For different substrates there are factors that favor or hinder decay. While higher levels of nitrogen, phosphorous and sulphur cause higher rates of decay in solubles, nitrogen will slow down the degradation of lignin (Berg and McClaugherty, 2008; Jacob et al., 2010; Enríquez et al., 1993). In some situations nitrogen was also added separately, e.g. as faeces, with the same effect (Carpenter and Adams, 1979). Abundant availability of water is favorable for decomposition as long as no anoxia develops. Finally, higher temperatures favor higher rates of decay, but interdependencies are complex (Berg and McClaugherty, 2008). For twigs of different species very different rates of decay have been reported, with sometimes even lower rates for small diameters than for larger ones (Erickson et al., 1985). Probably smaller twigs dried quicker which prevented further decay. In a scenario in which water was not as limiting twigs of beech had completely decayed after four years (Müller-Using, 2005). A recent study has also shown that today's climate change will probably speed up decomposition of woody debris in temperate forests (Berbeco et al., 2012).

Anaerobic conditions can arise especially in water, since the diffusion rate of oxygen is much slower in water than in air. For an anoxic environment to develop a period of time is necessary where oxygen demand outstrips oxygen supply. This happens when the sum of both the production of oxygen by plants, algae and phytoplankton on the one hand and the uptake at the interface between water and air on the other is less than the sum of oxygen needed by all organisms for respiration and decomposition. Furthermore, rising water temperatures and increased salinity lead to decreased oxygen solubility and the size and surface area of the water body and the water–gas exchange through water flow are also important. Since respiration and decomposition are the most prominent factors, the probability of anoxic conditions rises and falls according to the amount of decomposing activity. Organic preservation through eutrophication is a well-known phenomenon (Killops and Killops, 1993, 224 f.) and it has been noted very early on that sewage sludge can build banks and reduce the amount of oxygen even in flowing water (Baity, 1938). Anoxia also quickly develops within sediments because oxygen enters the pore water only through water flow or diffusion. Both processes are slow, so that oxygen is quickly depleted in the sediment's uppermost millimeters due to microbial decay (Killops and Killops, 1993). The depth to which the milieu in sediment is still oxygen-rich is determined by the characteristics of the sediment, which influence the rate of water flow. The most prominent factor is the size of the interstitial spaces, which is controlled by grain size (Caple, 1994, 67). This is probably the reason why on archaeological excavations it has frequently been noted that wood under clay-rich loam was better preserved than the same wood embedded in organic detritus or sand. Pore size is equally relevant to lateral water flow. Therefore, once that organic material is buried anoxia depends on the relation of infiltration speed and oxygen uptake speeds. If infiltration is low, oxygen will not reach the interior of a sediment (Banwart, 1996).

Under anaerobic conditions detritivores and fungi as well as all obligate aerobic bacteria cannot decompose organic matter. During decomposition of organic detritus first a group of bacteria uses hydrolysis to break down macromolecules into simpler components. These smaller molecules form the substrate of other bacteria. These can be obligate or facultative anaerobes and have to use other electron-acceptors than oxygen such as nitrate or sulphate. Consequently they become dependent on the availability of these electron-acceptors (Killops and Killops, 1993; Caple, 1994). Furthermore anaerobic decay will lead to a build-up of reducing species to a degree where they suppress microbial activity (Caple, 1994). The breakdown of organic matter using oxygen is much more energy-efficient and therefore much quicker than anaerobic decay.

Decomposition of organic matter can be modeled numerically (Berg and McClaugherty, 2008) and numerous studies for very different ecological settings exist. Frequently a simple exponential model is applied: