Schichtbildungsprozesse in prähistorischen Seeufersiedlungen Europas aus mikromorphologischer Sicht

Site formation processes in European Prehistoric pile dwelling sites from the micromorphological view

Inauguraldissertation zur Erlangung der Würde eines Doktors der Philosophie vorgelegt der Philosophisch-Naturwissenschaftlichen Fakultät der Universität Basel von

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Prof. Dr. Jörg Schibler, Dekan

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Danksagung

Wetlands and aquatic environments were and are exceptional worlds,
both for life in the past and for the archaeological research of today.

Eda Gross, 2014 (www.wetwideweb.ch; zuletzt abgerufen am 19. August 2015)

Im August 2002 begab ich mich auf eine Reise in die Welt der Mikromorphologie von Seeufersiedlungen; eine reichhaltige Welt aus gut erhaltenen organischen Resten und Seeablagerungen. Obwohl die Fülle an organischen Resten unüberschaubar war, schien die Deutung der Ablagerungen recht einfach; Seeablagerungen bilden sich im See, Sande konzentrieren sich am Strand und organische Schichten akkumulieren sich in der Uferzone. Bei näherer Betrachtung stellten sich allerdings rasch Fragen, mit denen wir uns auch heute noch beschäftigen: Wie konnten sich die organischen Reste so gut erhalten? Haben sie sich im stehenden Wasser abgelagert? Weshalb sind sie nicht abgeschwemmt worden, wie sonst fast jeder Spülsaum an Seen? Oder war da keine Wasserbedeckung? Wo war wann Wasser und was lag wann frei? Je länger ich mich mit dieser amphibischen Welt beschäftigte, umso komplexer und paradoxer erschienen mir deren Vorgänge. So entstand die Idee, sich wiederholende Charakteristiken in mehreren Seeufersiedlungen zu analysieren und die Schichtbildungsprozesse übergreifend zu rekonstruieren.

Für die Chance, im geoarchäologischen Labor arbeiten zu dürfen, möchte ich mich herzlich bei Philippe Rentzel bedanken; für die tollen Projekte, die Unterstützung und die stets angenehme Zusammenarbeit. Ich danke Urs Leuzinger dafür, mir Arbon-Bleiche 3, die erste meiner Seeufersiedlungen, anvertraut zu haben und für die Begleitung meiner Arbeit als Korreferent. Ohne die Projekte von archäologischer Seite gäbe es diese Arbeit nicht; ich danke Gishan Schären, Kurt Altorfer, Ursula Hügi, Christine Michel-Tobler und Francesco Menotti. Für die unzähligen Diskussionen zwischen Archäologie, Geoarchäologie und Botanik möchte ich mich bei Eda Gross, Renata Huber, Britta Pollmann und Elena Pranckėnaitė bedanken.

Die Vielfalt an Resten, die sich in den Ablagerungen von Seeufersiedlungen erhalten, ist enorm, vor allem was organische Reste anbelangt. Dank der Unterstützung und intensiven Zusammenarbeit mit der archäobotanischen Abteilung des Institutes für Integrative Prähistorische und Naturwissenschaftliche Archäologie (IPNA) an der Universität Basel, konnte ich in den letzten 13 Jahren viele Erkenntnisse gewinnen und eine Referenzsammlung aufbauen. Herzlichen Dank für die Unterstützung an Stefanie Jacomet, Petra Zibulski, Marlu Kühn, Bigna Steiner, Örni Akeret und Christoph Brombacher. Matthew Canti, der mir seine unglaubliche organische Referenzsammlung zur Verfügung gestellt hat, gilt mein besonderer Dank.

Man erkennt nur, was man kennt; für Diskussionen am Dünnschliff, Literaturtipps und weiterführende Informationen danke ich Christine Pümpin, David Brönnimann, Richard Macphail, Hans Huisman, Carolina Mallol, Karen Milek, Renate Ebersbach, Niels Bleicher, Luc Vrydaghs und Yannick Devos.

Ich danke allen Editoren und teils anonymen Reviewern, die sich mit meinen Texten auseinandergesetzt haben; Paul Goldberg, Małgorzata Latałowa, Allan Gilbert, Stefanie Jacomet, Panagiotis Karkanas, Dagmar Fritzsch, Cristiano Nicosia, Georges Stoops, Roger Langohr, David Lindbo und Flavio Anselmetti. Danke auch an Madeleine Hummler für die rasche und kompetente Übersetzung des Summary und der Conclusion.

Dokumentieren von Proben, Eingiessen, Dünnschliffe herstellen, eine zeitraubende und intensive Arbeit, herzlichen Dank an Thomas Beckmann für seine unübertroffenen Dünnschliffe, Roman Schmidig, Mathias Lutz, Sarah Lo Russo und Philipp Wiemann für Fotodokumentation, Eingiessen und Aufsägen der zahlreichen Proben.

Danke für Eure Unterstützung und Geduld, Toufiq, Lina und Vivek.

Ich bin sehr glücklich, dass diese Arbeit eine Fortsetzung im gross angelegten Auswertungsprojekt Zug-Riedmatt (Kanton Zug) findet, wo ich Teil eines transdisziplinären Teams in einem NF-Projekt bin (Formation and taphonomy of archaeological wetland deposits: two transdisciplinary case studies and their impact on lake shore archaeology, Projekt-Nr CR3012_149679/1). Es wird intensiv geforscht, diskutiert, lamentiert, entwickelt, umgestellt und dazu viel Kaffee getrunken; ich bin dankbar für die abwechslungsreiche Zusammenarbeit, Bigna Steiner, Annekäthi Heitz-Weniger und Eda Gross. Die Seeufersiedlungen bergen noch viele Geheimnisse, die auf uns warten.

Kristin Ismail-Meyer

Zug-Riedmatt: Sondierung auf der Wiese Riedmatt. Es wurden zwei Schnitte durch die rund 7 m tiefen fluvialen und limnischen Ablagerungen ausgeführt. Es kamen zwar Pfähle, aber keine Kulturschicht zum Vorschein (Aufnahme K. Ismail-Meyer, April 2007).

Zug-Riedmatt: Sondage in the meadow Riedmatt. Two trenches were excavated through the about 7 m deep fluvial and limnic sediments. Poles have been found, but no cultural layer (photograph by K. Ismail-Meyer, April 2007).

1 Einführung

Seeufersiedlungen im Alpenraum sind ein viel beachtetes Phänomen, nicht erst seit der Aufnahme von 111 Fundstellen Europas in das Register des UNESCO Weltkulturerbes im Jahr 2011 (http://whc.unesco.org/en/list/1363). Archäologische Auswertungen von Funden und Befunden, botanische Makrorestanalysen, Palynologie, Tierknochen und die Dendrochronologie geben uns zahlreiche Informationen, wann und wie die damaligen Bewohner der Siedlungen gewirtschaftet, gelebt und was sie konsumiert haben. Die Mikromorphologie versucht, Brücken zwischen diesen wichtigen Erkenntnissen und den eigentlichen Prozessen, die zur Akkumulierung, Degradierung und Erosion von Siedlungsresten geführt haben zu schlagen. Da Seeufersiedlungen im Strandbereich von Seen entstanden, kann man sie einem amphibischen Milieu zuordnen; sie konnten wassergesättigt sein, zeitweise trockenfallen, aber auch von Wasser überflutet werden. Aus diesem Grund muss auch Wissen aus weiteren Forschungsbereichen, wie beispielsweise Limnologie, Hydrologie, Moor- und Torfkunde einbezogen werden, um diese komplexen Vorgänge annähernd nachvollziehen zu können. Aber auch die Erhaltung der Reste, also ihre Taphonomie, ist von zentraler Bedeutung. Aktualistische Studien und Beobachtungen in diesem einzigartigen Milieu, Experimente und Recherchen zum Umgang mit dem See in noch heute existierenden Seeufersiedlungen, wie beispielsweise Dörfer am Lake Inle (Myanmar) oder die Stadt Ganvié am Nokoué-See (Benin), aber auch an unseren Seen sind von grosser Wichtigkeit; hier lassen sich noch heute natürliche Vorgänge und viele Traditionen im Umgang mit dem Wasser beobachten, welche Rückschlüsse auf die Vergangenheit ermöglichen können.

Jede Seeufersiedlung hat ihren eigenen Charakter und ihre Stärken, was Funde und Befunde, Erhaltung und Prozesse, die hier stattgefunden haben, betrifft. Im Verlauf der hier vorliegenden Untersuchungen hat sich jedoch immer mehr gezeigt, dass die grundsätzlichen natürlichen Prozesse – Akkumulation, Aufarbeitung, Erosion, Trockenfallen, Überflutung – als ein verbindender Faktor zwischen Seeufersiedlungen angesehen werden können, weitgehend unbeeinflusst von der Epoche sowie der geographischen Lage und Grösse des besiedelten Sees. Es scheint vielmehr, dass die jeweilige Positionierung der Fundstelle in Relation zum See und seinen Wasserhoch- und Tiefständen sowie das Relief des Hinterlandes eine grössere Rolle spielten. Auch ob eine Siedlung abgehoben oder ebenerdig konstruiert war, beeinflusste die Schichtbildungsprozesse.

Die Fragestellungen für die hier vorliegende Arbeit haben sich im Verlauf der mehrjährigen Analysen und Recherchen laufend verändert. Von zentraler Bedeutung war und ist jedoch immer die möglichst genaue Rekonstruktion der agierenden Schichtbildungsprozesse von jeder Seeufersiedlung;

- Wie war das natürliche Ablagerungsmilieu in den Uferzonen der Seen vor den Besiedlungen?
- Lassen sich Hinweise auf Regressionen des Sees erkennen?
- Wie zeigt sich der Übergang von der Seekreide zur anthropogen akkumulierten Kulturschicht? War die Strandplatte bei Siedlungsbeginn wasserbedeckt, feucht oder trocken?
- Lässt sich natürliches Torfwachstum erkennen?
- Sind Begehungsspuren der Bewohner ablesbar?
- Lässt die Zusammensetzung und Taphonomie der Reste Aussagen zum Wassergehalt der Ablagerungen zu? Gibt es Hinweise auf stehendes Wasser oder Trockenphasen während des Bestehens der Siedlung?
- War der See während der Besiedlungszeit aktiv? Lassen sich Umlagerungen, Erosionen oder Einschwemmungen von Seesedimenten erkennen?
- Gab es Einflüsse auf die Siedlung aus dem Hinterland oder von nahe vorbeifliessenden Bächen oder Flüssen?
- Lassen sich mikromorphologische Hinweise auf die Konstruktionsweise der Häuser erkennen, insbesondere Baulehmbefunde oder Hinweise auf abgehobene oder ebenerdige Konstruktionsweise?
- Was für Aktivitäten der Bewohner oder Ereignisse lassen sich mikromorphologisch nachweisen (z.B. Bauaktivitäten, Hinweise auf Nahrungszubereitung, Handwerk, Feuerungsvorgänge, Brandereignisse)?
- Sind Hinweise auf Haustierhaltung auszumachen (in der Regel in Form von Exkrementen/Koprolithen)?
- Weshalb wurde die Siedlung aufgelassen?
- Kann man Aussagen zur Dauer des Unterbruches zwischen der Auflassung und der finalen Überdeckung mit Seeablagerungen machen?
- Lassen sich postsedimentäre Einflüsse auf die Ablagerungen erkennen, beispielsweise Seespiegelkorrekturen oder Störungen durch rezente Wurzeln und Rhizome von Schilf?

Die hier vorliegende Arbeit versucht, diese Fragen, die wichtige Zusatzinformationen zur archäologischen Auswertung liefern können zu beantworten. Von grosser Wichtigkeit war und ist zudem aus mikromorphologischer Sicht, Beobachtungen und Erkenntnisse aus anderen Disziplinen in die Rekonstruktion der Prozesse mit einzubinden, um ein möglichst stimmiges Szenario zu entwerfen. Dies können Beobachtungen der AusgräberInnen und der ArchäologInnen sein, sie kennen die Grabung am besten. Aber auch interdisziplinäre Resultate, u.a. aus der Archäobotanik, Zoologie und Palynologie, werden, wenn immer möglich, in den Interpretationen berücksichtigt. Die Auseinandersetzung mit der Taphonomie der Reste ist und bleibt ein zentraler Punkt. Die Art der Erhaltung von organischen Resten, Knochen und Molluskenschalen birgt Informationen zum Wasserstand während deren Sedimentation und zu möglichen postsedimentären Prozessen.

Der Aufbau der Arbeit ist nicht chronologisch nach Erscheinungsdatum der einzelnen Beiträge gegliedert, sondern thematisch. Die erste Publikation zu Arbon-Bleiche 3 (TG) stellt den eigentlichen Start dieser Arbeit dar und ist die Basis für alle weiteren hier vorliegenden Studien (Kapitel 2). Die zweite Publikation beschäftigt sich mit allgemeinen Prozessen im amphibischen Milieu, wo ein Schwerpunkt das schwer nachvollziehbare Verhalten von organischen Ablagerungen ist, das anhand von Recherchen aus der Torfkunde ergründet wird (Kapitel 3). Publikation 3 liefert die wichtigsten Informationen zu generellen Schichtbildungsprozessen in mehreren Schweizer Seeufersiedlungen (Kapitel 4). Die letzte Publikation, eine Fallstudie von Lake Luokesa (Litauen) zeigt, wie die erarbeiteten Informationen in die Auswertung einfliessen und weiterführende Interpretationen zulassen können (Kapitel 5).

Die Auswahl der Fundstellen geschah nicht nach geographischen oder thematischen Kriterien, sondern gründet einzig auf der Auftragslage, Verfügbarkeit von Probenmaterial und Finanzierbarkeit von Projekten am Institut für Integrative Prähistorische und Naturwissenschaftliche Archäologie (IPNA) der Universität Basel (Schweiz). Die Seeufersiedlungen, die für diese Arbeit von Wichtigkeit waren, sollen hier summarisch vorgestellt werden, wobei die Einführung zu Arbon-Bleiche 3 im Kapitel 2 zu finden ist.

Cham-Eslen (siehe Kapitel 4)

Die Fundstelle Cham-Eslen (ZG) wurde 1996 anlässlich einer Tauchprospektion im Zugersee in 70 m Distanz zum heutigen Ufer entdeckt, auf einer kleinen Erhebung, die von rund einem halben Meter Wasser bedeckt ist. Während der ersten Tauchkampagnen (1997 und 1998/99) wurde u.a. die viel beachtete Doppelaxt mit verziertem Schaft gefunden (Gross-Klee and Hochuli, 2002). Im Winter 2004/05 fand aufgrund des grossen Erosionsrisikos eine letzte Tauchkampagne statt, bei der die gesamte Fläche der Untiefe von 102 m^2 ausgegraben wurde. Wegen fianziellem und terminlichem Druck wurde die Fundschicht in gewissen Bereichen quadratmeterweise in Säcke abgefüllt und durch Siege geschlämmt statt ausgegraben. Eine intensive mikromorphologische Beprobung sollte die reduzierte zeichnerische Profilaufnahme ergänzen (Huber, 2005; Huber und Ismail-Meyer, 2007).

Die 532 Pfähle, hauptsächlich die Eichen, liessen einen einzelnen, nord-süd-orientierten Hausgrundriss ermitteln. Mit Hilfe des Fundspektrums (Egolzwil/Cortaillod), C14-Datierungen und Dendrochronologie lässt sich ein wahrscheinliches Baudatum um 3985 v.Chr. festlegen (B-Datum). Das Haus scheint bis 3974 v.Chr. genutzt worden zu sein, wie regelmässig neu gesetzte Pfähle für Reparaturen zeigen (Huber und Bleicher, 2009). Ob das Haus ebenerdig oder abgehoben konstruiert war, lässt sich noch nicht abschliessend beantworten. Beachtenswert an dieser Fundstelle ist u.a. die grosse Menge an Netzsenkern, Fischknochen, ein spezielles Spektrum an Kulturpflanzenresten (u.a. Getreidekörner, aber kaum Spelzen), zwei Konzentrationen an teils stark verbrannten Lehmbrocken sowie zwei oder drei Einbäumen, die beide am landseitigen Rand der Fundstelle gefunden worden sind, in unmittelbarer Nähe zur Doppelaxt (Huber und Ismail-Meyer, 2012).

Das Projekt wird vom Amt für Denkmalpflege und Archäologie des Kantons Zug finanziert.

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Gross-Klee, E. und Hochuli, S., 2002. Die jungsteinzeitliche Doppelaxt von Cham-Eslen. Gesamtbericht über einen einzigartigen Fund aus dem Zugersee. Tugium 18, 69-101.

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Huber, R. und Ismail-Meyer, K., 2007. Taucharchäologie und Mikromorphologie. Neue Möglichkeiten für die Grabungstechnik in Cham ZG-Eslen. Jahrbuch der Archäologie Schweiz 90,127-134.

Huber, R. und Ismail-Meyer, K., 2012. Cham-Eslen (Kanton Zug, Schweiz): ein jungneolithisches Haus mit (fast) allem Drum und Dran? Taphonomische Aspekte einer Seeufersiedlung. In: Link T. und Schimmelpfenning, D. (eds) Taphonomische Forschungen (nicht nur) zum Neolithikum, vol 3. Fokus Jungsteinzeit, Kerpen-Loogh, 83-106.

Stansstad-Kehrsiten (siehe Kapitel 4)

Die bisher einzige bekannte Seeufersiedlung am Vierwaldstättersee Stansstad-Kehrsiten (NW) wurde 2003 zufällig von Hobbytauchern entdeckt. Während zweier Tauchkampagnen (2003 und 2004) konnte die Siedlungsausdehnung untersucht sowie 11 Profile angelegt werden (Hügi, 2006). Aufgrund der vielversprechenden Ergebnisse wurden im Jahr 2008 drei Profilschnitte von einem Meter Breite augegraben, dokumentiert und für naturwissenschaftliche Untersuchungen beprobt. Die Fundstelle liegt auf einer karbonatischen Uferplatte am Fuss des Berges Bürgenstock, der hier steil um 700 m zu einer schmalen Uferzone hin abfällt. Die Siedlung selbst liegt heute unter 7 bis 10 m Wasserbedeckung. In 60 m Entfernung zum Ufer bricht die Uferplatte ab, was auf Rutschungen, wohl durch mehrere Erdbeben ausgelöst, zurückgeht, bei denen auch ein Teil der ehemaligen Siedlung abrutschte (Michel et al., 2012).

Es konnten zwei durch eine Seekreide voneinander getrennte Kulturschichten beobachten werden. Die untere lässt sich dem Cortaillod, die obere der Pfyner Kultur zuweisen. Die Cortaillod-zeitliche Siedlungsschicht datiert aufgrund dendrochronologischer Auswertung auf ca. 4000 v. Chr. Die 10 bis 20 cm mächtige Schicht lieferte nur wenig Funde, was auf die Grösse des augegrabenen Areals (3 m^2) und wohl auch auf die deutlich erkennbaren Erosionsspuren zurückgeht. Das obere Pfyner Kulturschichtpaket konnte dendrochronologisch auf 3800 und 3485 v. Chr., wobei zwei Siedlungsphasen angenommen werden. Das bis zu 125 cm dicke Pfyner Schichtpaket enthielt u.a. zahlreiche Schnüre aus Lindenbast, Gewebe und Geflechte. Herausragend ist der Fund eines Hutes aus Lindenbastfäden (Michel et al., 2012). Ein Teil der Funde, wie auch der Hut mit einer Rekonstruktion, wurde bei der Ausstellung ‚Versunkene Welt. Die Pfahlbauer von Kehrsiten‘ in Stansstad und Zürich präsentiert (2009/2010), wo u.a. auch mikromorphologische Resultate vorgestellt wurden.

Das Projekt wurde durch den Schweizerischen Nationalfonds (Projekt-Nr 100012-116173) und den Kanton Nidwalden finanziert.

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Michel, C., Bleicher, N., Hüster Plogmann, H., Ismail-Meyer, K. und Rehazek, A., 2012. Pfahlbauten am Vierwaldstättersee – der steinzeitliche Siedlungsplatz in Kehrsiten. Archäologie Schweiz 35 (2), 56-71.

Michel-Tobler, C., Brombacher, C. und Rehazek, A., 2010. Stansstad-Kehrsiten – Neolithische Seeufersiedlungen hart am Alpenrand. In: Vernetzungen: Aspekte siedlungsarchäologischer Forschung: Festschrift für Helmut Schlichtherle zum 60. Geburtstag. Freiburg i.Br., 287-296.

Lake Luokesa (siehe Kapitel 5)

Die bisher einzige Seeufersiedlung Litauens wurde im Jahr 2000 bei Tauchsondierungen entdeckt. Der See Luokesa liegt nahe der Stadt Molėtai im östlichen Distrikt Litauens und ist Teil einer ausgedehnten Seenplatte. Bei der Fundstelle Luokesa 1 handelt es sich um einen Siedlungsplatz, der auf einer Seekreideplattform angelegt wurde. Auf der gegenüberliegenden Seeseite wurde zudem eine Holzplattform mit befestigtem Weg zum Festland ohne eigentliche Siedlungsbefunde (Luokesa 2) entdeckt (Menotti et al., 2005). In zwei Tauchkampagnen (2008 und 2009) konnten bis heute insgesamt 8 m^2 Fläche im Zentrum der Fundstelle ausgegraben werden. Dendrochronologische Analysen weisen auf eine maximal 20 Jahre andauernde Besiedlungszeit zwischen 580 und 620 v.Chr., was in die litauische Spätbronzezeit / frühe Eisenzeit fällt (Bleicher, 2014). Für naturwissenschaftliche Analysen beprobt wurde die Fundstelle Luokesa 1, was mittels eingeschlagener Kunststoffrohre im Bereich der Ausgrabung sowie entlang zweier Transekte durchgeführt werden konnte. Es wurde viel Wert auf eine interdisziplinäre Beprobung der Profilkolonnen und der Korrelation der Resultate gelegt. Die offene Zusammenarbeit zwischen Archäobotanik, Palynologie und Mikromorphologie war von zentraler Bedeutung (Pollmann, 2014; Heitz-Weniger, 2014; siehe auch Kapitel 5).

Das Projekt ‚Understanding wetland occupation in later Prehistoric Europe‘ unter der Leitung von F. Menotti und S. Jacomet wurde vom Schweizerischen Nationalfonds finanziert (Projekt-Nr. K13K1-117893).

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Pranckėnaitė, E., 2014. Living in wetlands in the southeastern Baltic region during the Late Bronze to early Iron Age: the archaeological context of the Luokesa lake settlements. Vegetation History and Archaeobotany 23, 341-354.

Zug-Riedmatt: Ausgrabung (Aufnahme K. Ismail-Meyer, Oktober 2008).

Zug-Riedmatt: Excavation (photograph by K. Ismail-Meyer, October 2008).

2 Die jungsteinzeitliche Seeufersiedlung Arbon-Bleiche 3: Mikromorphologische Untersuchung der Schichtabfolge

Kristin Ismail-Meyer und Philippe Rentzel

In: Jacomet, S., Leuzinger, U. und Schibler, J. (eds.) Die jungsteinzeitliche Seeufersiedlung Arbon-Bleiche 3: Umwelt und Wirtschaft. Archäologie im Thurgau 12 (2004). Frauenfeld, 66-80. Mit Abbildungen aus Jacomet et al., 2004.

Einführung in die Fundstelle

Die Fundstelle Arbon-Bleiche 3 befindet sich südlich der Stadt Arbon (TG) in einer heute verlandeten Bucht des Bodensees in rund 800 m Distanz zum aktuellen Seeufer (Abb. 1 und 2). Die Siedlung lag während ihres Bestehens direkt am Seeufer. Entdeckt wurde die Fundstelle bereits 1944 und wurde 1993 bis 1995 vom Amt für Archäologie des Kantons Thurgau auf rund 1100 m^2 ausgegraben. Der untersuchte Ausschnitt liess die Rekonstruktion einer einphasigen Siedlung zu, die dendrochronologisch zwischen 3384 und 3370 v.Chr. datiert. Die 27 festgestellten Hausgrundrisse konnten bereits während der Ausgrabung erkannt werden (Leuzinger 2000; Abb. 3). Es war demnach bei allen mikromorphologisch untersuchten Profilkolonnen, entnommen in eingeschlagenen Kunststoffröhren (Abb. 4), bekannt, ob sie aus einer Gasse oder im Bereich eines Hausgrundrisses entnommen worden sind. Aufgrund der Pfahlstellungen und Bauhölzer wird die Siedlung mit abgehobenen Hausböden rekonstruiert. Kulturell lässt sich die Fundstelle in der Übergangszeit zwischen Pfyner und Horgener Kultur ansiedeln. Vor Siedlungsbeginn fand eine massive Regression statt; die Häuser wurden auf der wasserfrei gewordenen Strandplatte errichtet (Leuzinger 2000).

Die interdisziplinär durchgeführte Studie der Siedlung Arbon-Bleiche 3 bot Möglichkeiten der Interpretationen, die bis heute als wegweisend für die Forschung im Bereich der Seeufersiedlungen angesehen werden darf.

Das Projekt wurde durch den Schweizerischen Nationalfonds finanziert (Projekt-Nr. 1253-635339.00).

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Magny, M., and Haas, J.-N., 2004. A major widespread climatic change around 5300 cal. yr BP at the time of the Alpine Iceman. Journal of Quaternary Science 19 (5), 423-430.

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Abb. 1: Lage der Seeufersiedlung Arbon-Bleiche 3, Blatt 1075 Rorschach, 1:25‘000 (aus: Jacomet und Leuzinger 2004, Abb. 2).

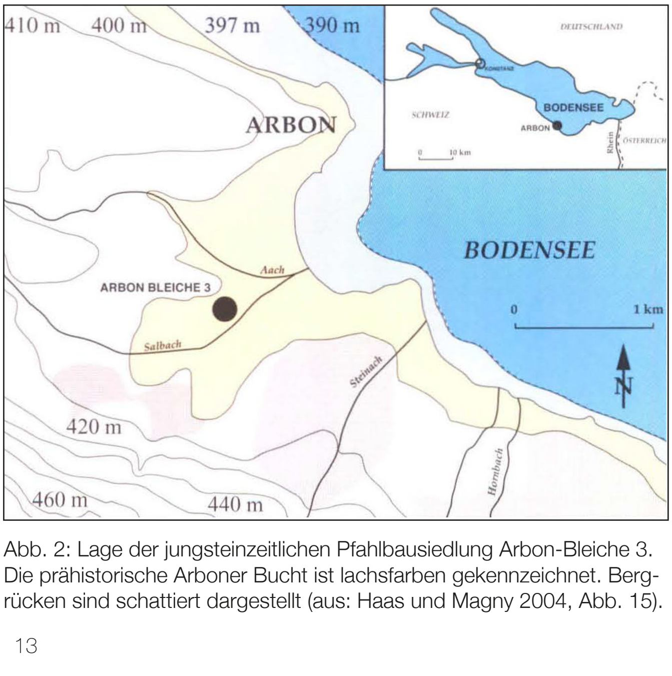

Abb. 2: Lage der jungsteinzeitlichen Pfahlbausiedlung Arbon-Bleiche 3. Die prähistorische Arboner Bucht ist lachsfarben gekennzeichnet. Bergrücken sind schattiert dargestellt (aus: Haas und Magny 2004, Abb. 15).

Einleitung und Fragestellung

Die Mikromorphologie als optische Untersuchungsmethode beschäftigt sich mit der Zusammensetzung, dem Aufbau und der Entstehung sowohl natürlicher, als auch vom Menschen beeinflusster Ablagerungen. Welche Rolle die natürlichen und die anthropogen ausgelösten Prozesse bei der Bildung einer archäologischen Schicht spielten, ist während einer Ausgrabung jedoch meist nur schwer abzuschätzen. Da diese Fragen aber letztlich die Bildungsgeschichte einer gesamten Fundstelle betreffen, sind sie von erheblicher Bedeutung, nicht nur für die Archäologie, sondern auch für weitere an der Auswertung beteiligte naturwissenschaftliche Disziplinen. Aus diesem Grund werden aus repräsentativen Schichten oder wichtigen Einzelbefunden mikromorphologische Bodenproben entnommen und diese anschliessend im Labor mittels Mikroskop untersucht. Analysen der Schichtzusammensetzung und der Feinstrukturen erlauben dabei Aussagen zur Bildungsgeschichte der Ablagerungen (Courty et al. 1989).

Für die Fundstelle Arbon-Bleiche 3 stand die Analyse der anthropogenen Ablagerungen im Vordergrund, um die von archäologischer Seite erarbeiteten Überlegungen zur Schichtgenese zu verifizieren (Leuzinger 2000, 48). Es galt somit, Hinweise auf Ablagerungsprozesse, Umlagerungen und Einflüsse des nahe gelegenen Sees zu finden, ferner auch Art und Erhaltung des organischen Materials zu charakterisieren. Dank der guten Konservierung war es zudem möglich, in Zusammenarbeit mit der Archäobotanik eine Referenzsammlung an Makroresten unter dem Mikroskop aufzubauen. Weitere Forschungsthemen betrafen das Ablagerungsmilieu und die menschlichen Einflüsse auf die makroskopisch gesehen sterilen Sedimente direkt unterhalb der Siedlungsschichten.

Methodik

Im Rahmen geoarchäologischer Untersuchungen wird eine Schichtabfolge im Idealfall auf der Ausgrabung selbst dokumentiert. Im vorliegenden Fall konnte man die Profilkolonnen, die man während der Grabung in Plastikrohren von 15 cm Durchmesser geborgen hatte, erst nach Abschluss der Feldarbeiten begutachten (Abb. 4). Zur Untersuchung gelangten 7 Kerne und eine Einzelprobe, deren Lage aus Abb. 3 hervorgeht (für die Koordinaten und Höhen der Proben siehe Tabelle 1 am Ende dieses Beitrages):

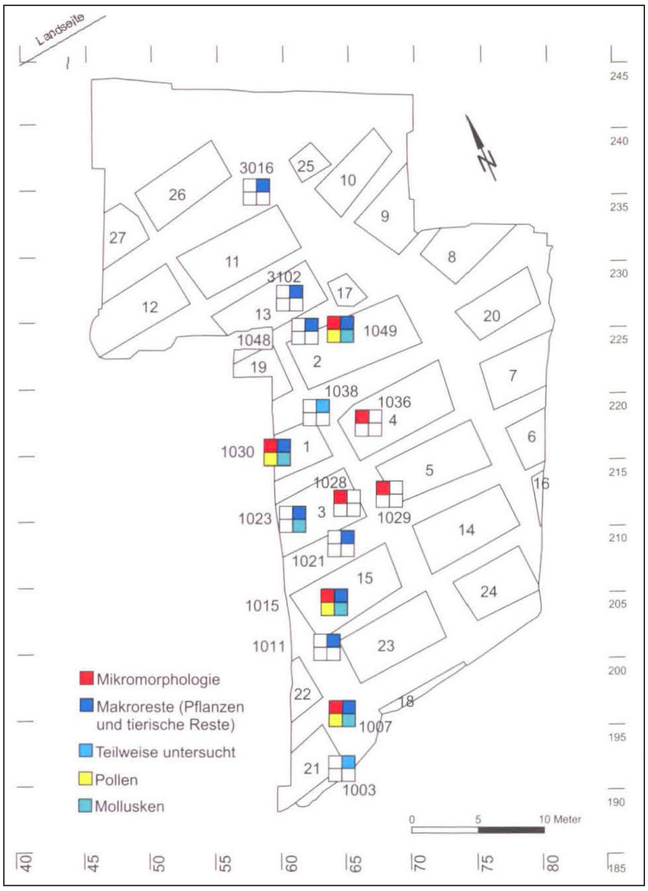

Abb. 3: Lage der auf Makroreste, Pollen , Mollusken und Mikromorphologie untersuchten Profilkolonnen in der Grabungsfläche. Lage der sedimentologisch und palynologisch analysierten Profile von M. Magny und J. Haas siehe Abb. 7 (3183 liegt in der Nähe von Kolonne 1049 im östlichen Teil von Haus 2 und 50-320 ganz im Nord-Westen, etwa im Bereich von Haus 27) (aus: Jacomet und Leuzinger 2004, Abb. 14).

Abb. 4: Profilsäulen vor dem Abbau.

a) Nr. 1030 (in Haus 1),

b) Nr. 1015 (in Haus 15). Zur Lage siehe Abb. 3. Fotos IPNA, Universität Basel, K. Ismail-Meyer (aus: Brombacher und Hadorn 2004, Abb. 26).

Probe	Lage
· 1007	Gasse nahe dem Bodenseeufer zwischen Haus 21 und 23
· 1015	unterhalb von Haus 15
· 1028	unterhalb von Haus 3
· 1029	Gasse zwischen Haus 3 und 5
· 1030	unterhalb von Haus 1
· 1036	unterhalb von Haus 4
· 1049	unterhalb von Haus 2
· 5055	unterhalb von Haus 3

Der gesamte Bereich der Kulturschicht, inklusive der unten und oben angrenzenden Sedimente, wurde im Labor als Blockproben aus den Profilen herauspräpariert. Die getrockneten Proben haben wir anschliessend in Kunstharz eingegossen und nach kompletter Aushärtung mit einer Diamantsäge in mehrere, rund 1 cm dicke Tranchen aufgetrennt. Diese sog. Anschliffe (Abb. 5) lassen die originale Schichtung gut erkennen und stellen einen wertvollen Beleg der Stratigrafie dar. Für die mikroskopischen Untersuchungen wurden anschliessend quadratische Plättchen (47 x 47 mm) herausgesägt, die dann zu insgesamt 29 Dünnschliffen, d.h. hauchdünnen, auf Glas geklebten Gesteinsschnitten verarbeitet wurden (Beckmann 1997). Die Probeliste sowie die Rohdaten der mikromorphologischen Analysen finden sich am Ende des Beitrages (Tabellen 1 und 2).

Abb. 5: Anschliff der Probe 1028, Haus 3; am unteren Bildrand das dünne Sandband 400, überlagert von der 8 cm dicken organischen Kulturschicht. In der oberen Bildhälfte Überreste der Brandschicht 303 (Holzkohle und Keramikfragmente), enthalten in der limnischen Sandschicht 290. Höhe des Ausschnittes 16 cm. Foto Archäologische Bodenforschung Basel-Stadt.

Geologische Situation

Die Siedlung Arbon-Bleiche 3 liegt heute etwa 800 m vom aktuellen Seeufer entfernt (Abb. 1 und 2), südlich einer Geländerippe, die aus einer würmzeitlichen Moräne besteht (Saxer 1964). Im Norden bildet dieser Moränenzug eine kleine Landzunge, während im Süden die Niederung von Molassehügeln abgeschlossen wird. Am Fuss dieser Hügel haben sich seeseitig breite Schwemmfächer gebildet. Die Bucht von Arbon wird im Osten durch den Schwemmfächer des Flüsschens Steinach begrenzt, was im Neolithikum eine lagunenähnliche Situation zur Folge hatte.

Geologische Beobachtungen innerhalb der Fundstelle zeigen, dass in seenahen Bereichen durch die saisonalen Überschwemmungen Teile der archäologischen Ablagerungen erodiert sind. Etwa 30 m landwärts der Siedlung sind in Bodenprofilen Bachbettsedimente dokumentiert (Abb. 6). Die mikromorphologischen Proben belegen, dass dieser Bach bei Hochwasser über die Ufer treten konnte und dabei die Siedlung kurzzeitig überflutete. Die Siedlungsstelle befand sich also in einer Position, wo sich sowohl Einflüsse vom Land, als auch vom See her manifestieren.

Unter den archäologischen Ablagerungen liegt ein dünnes Sandband limnischen Ursprungs. Landwärts hingegen kann das Sandpaket sehr mächtig werden, wobei vermutlich eine Mischung aus Seesand und von Flüssen eingebrachtem Sand aus dem Hinterland vorliegt: Eine entsprechende Sandablagerung, die Molluskenschalen enthält, wurde rund 10 m nördlich der Siedlung in einem Sondierschnitt gefasst (mündliche Mitteilung U. Leuzinger, 2003; Leuzinger 2000, 10).

Stratigrafie

Der Schichtaufbau gliedert sich von unten nach oben in 3 Abschnitte; Seekreide, Kulturschichten und Decksande (Abb. 5 bis 7). Die basalen Schichten bestehen aus einer hellgrauen Seekreide (Schicht 500, Sedimenteinheit 8 von Magny, Abb. 7), die von einem litoralen Sand (Schicht 400) überlagert wird (die in den mikromorphologisch untersuchten Profilen erfassten Teile der Schicht 400 entsprechen höchstwahrscheinlich nicht der Sedimenteinheit 7 von M. Magny, Abb. 7, die im landseitigen Bereich der Grabungsfläche gefasst und dort auch als Schicht 400 bezeichnet wurde. Bei dieser handelt es sich um eine limnische Ablagerung, die in den meisten Teilen des Siedlungsareals erodiert ist. Weiteres dazu in Haas und Magny 2004; Jacomet 2004).

Darüber folgt die dunkelbraune bis schwarze, stark organische Kulturschicht (310/320; Sedimenteinheit 6 von Magny, Abb. 7). Letztere besteht mehrheitlich aus pflanzlichen Resten, Knochen, Holzkohle, Keramik und Steinen. Lokal finden sich sandige Einschaltungen (u.a. 312) oder Lehmschichten (311, 315, 318). Nach 15 Jahren brannte die Siedlung ab, und die holzkohlereiche Brandschicht 303 wurde innerhalb von kurzer Zeit von Sand (Schicht 290; Sedimenteinheit 5 von Magny, Abb. 7) bedeckt.

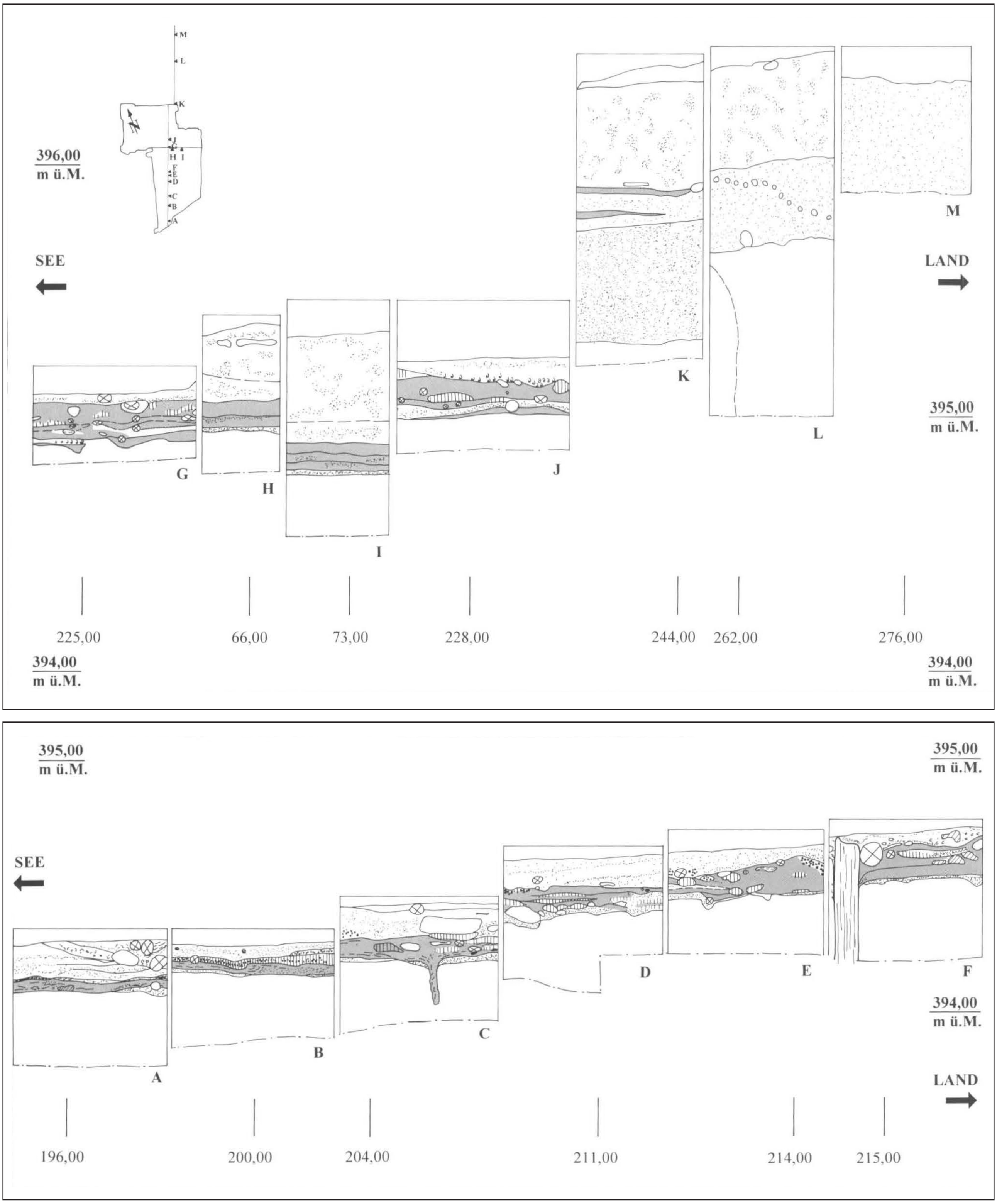

Abb. 6: Ausschnitte aus dem See-Land-Profil auf m 65 (Leuzinger 2000, Abb. 26a-f), ergänzt mit Ausschnitten aus dem Ost-West-Hauptprofil auf m 225 und dem Profil im Bereich von Haus 13 (Leuzinger 2000. Abb. 89). Das Inlet zeigt die Lage des Profiles. Dargestellt ist die Stratigraphie an ungefahr jenen Stellen, wo Profilsäulen untersucht wurden. Zeichnungen AATG, S. Divljak und M. Lier. Zur Lage der Profile: Leuzinger 2000, Abb. 12. Lage der Profilsäulen: Abb. 3 (aus: Brobacher und Hadorn 2004, Abb. 23).

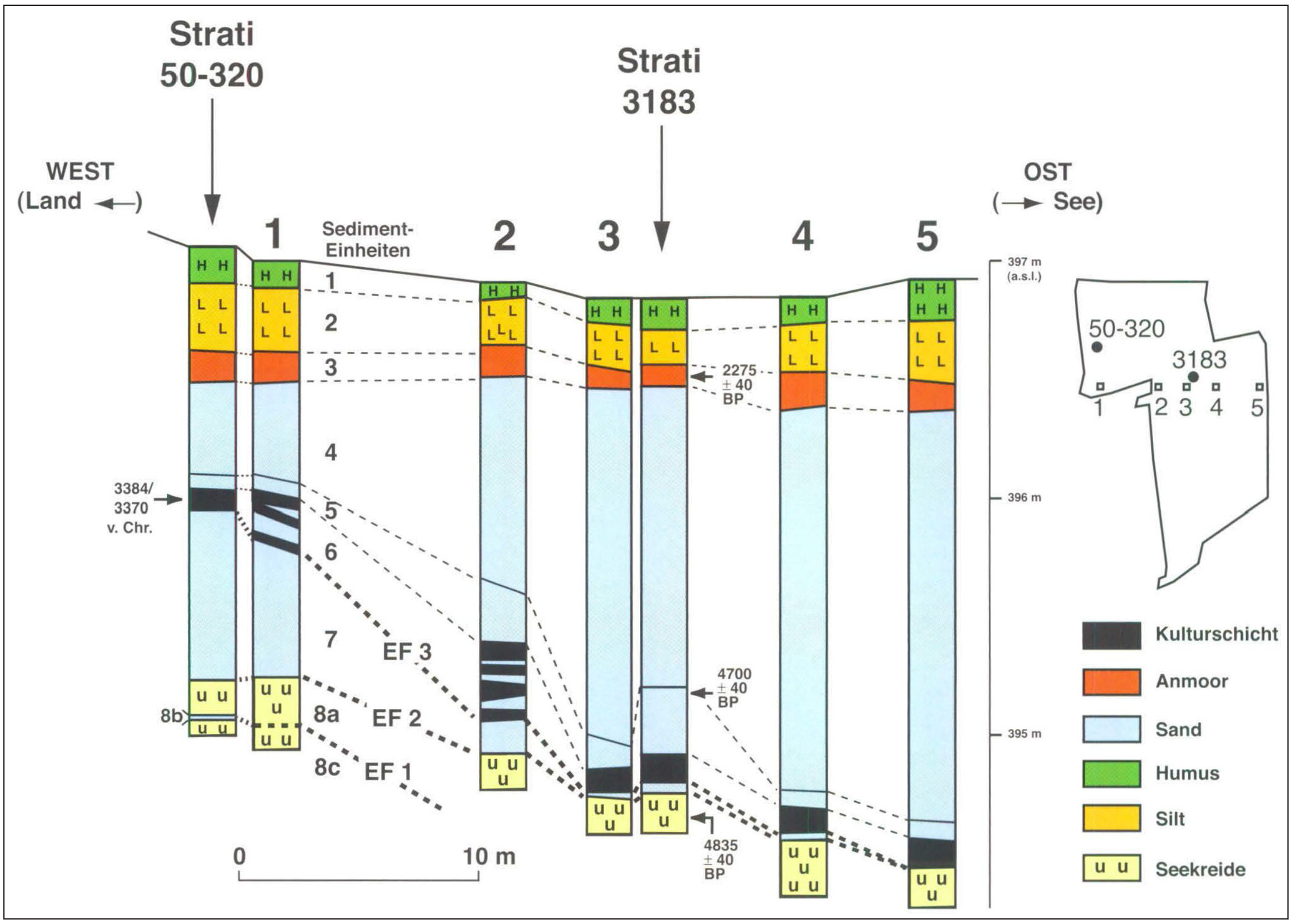

Abb. 7: Transsekt durch die Sedimentstratigraphie von Arbon-Bleiche 3 (nach Leuzinger 2000, Abb. 15, 23, jedoch ergänzt mit den hier beschriebenen Stratigraphien 50- 320 und 3183). Das Inlet zeigt die Lage des Transsekts und die genaue Lage der Stratigraphien 50-320 (Bereich von Haus 27) und 3183 (Nähe von Kolonne 1049, Haus 2) in der Grabungsfläche. Sowohl in Richtung Süd-Osten als auch Süden bewegt man sich seewärts (aus: Haas und Magny 2004, Abb. 17).

Der Schichtaufbau (von oben nach unten) sieht wie folgt aus:

Schicht	Beschreibung
· 290	Decksandschicht, durch Überschwemmung entstanden
· 303	Brandschicht
· 310/320	Siedlungsschicht, die durch dünne sandige Niveaus (312) und Lehmschichten (311, 315, 318) aufgetrennt sein kann
· 400	Sandschicht aus dem Uferbereich des Bodensees
· 500	basale Seekreide

Zusammensetzung der Sedimente

Anhand der mikroskopischen Analysen lassen sich die bestimmbaren Reste in zwei grosse Gruppen einteilen:

- Elemente, die aus dem natürlichen Milieu des Seeuferbereiches stammen. In diese Gruppe gehören Sand, Schnecken- und Muschelschalen, Algenreste und Kalkschlamm.
- Reste, die dank der menschlichen Besiedlung vorhanden sind, wie pflanzliches Material, Holzkohle, Keramikfragmente, Artefakte, Fisch- und Haustierknochen, Fäkalien sowie Steine und Baulehm.

Elemente der geologischen Schichten (Limnische Elemente)

Sandkörner (Abb. 8a)

Der Sand besteht hauptsächlich aus Quarz, wenig Glimmer und Kalzit. Sand ist in jeder Schicht vorhanden. Er wurde durch Flüsse aus dem Hinterland (tertiäre Molassesandsteine mit Moränenbedeckung) in Richtung Bodensee transportiert und lagerte sich im See ab. In den Kulturschichten ist der Sand sehr feinkörnig, während er in geologischen Schichten meist in gröberer Form vorliegt.

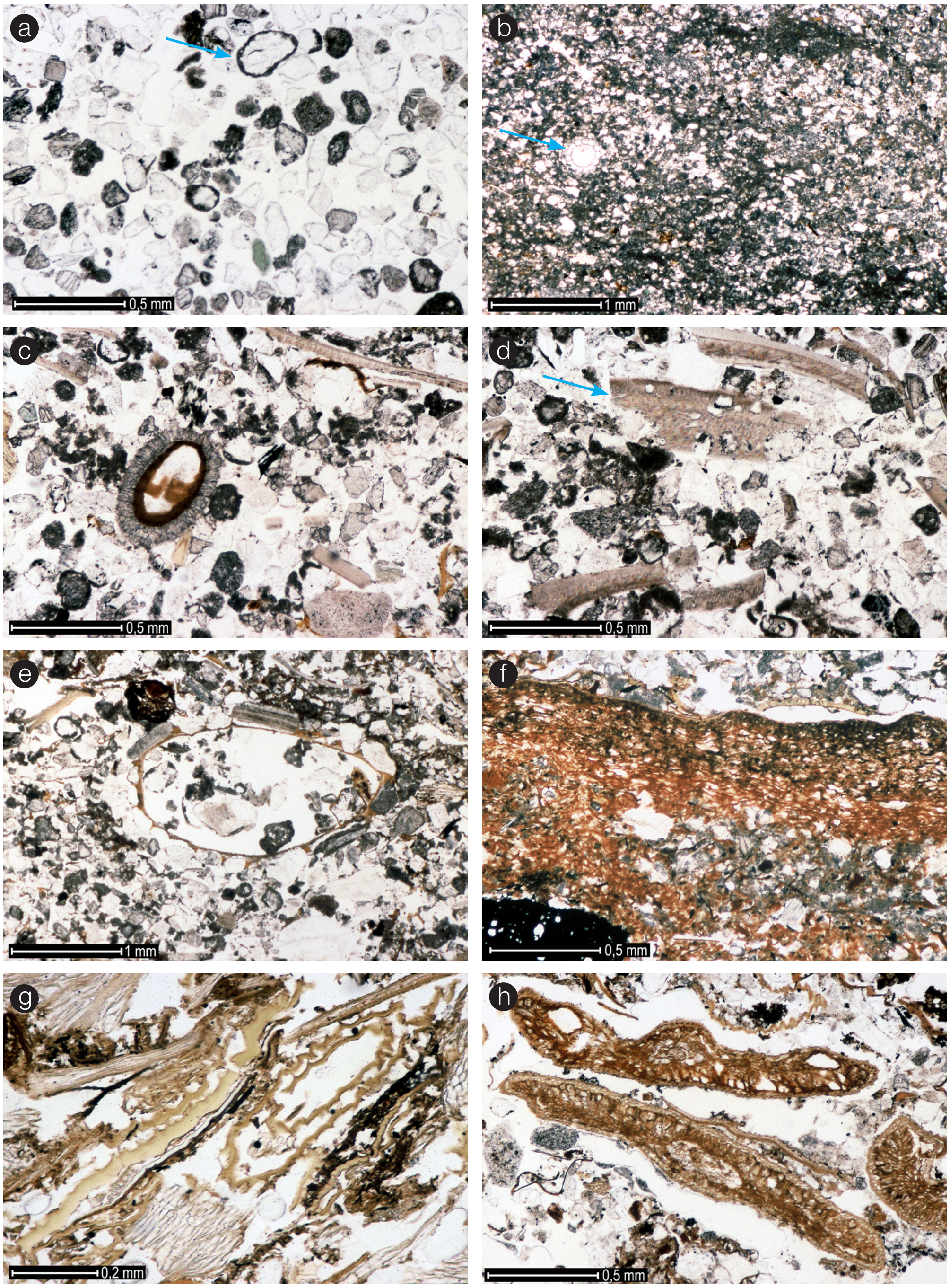

Abb. 8: Mikroskopische Aufnahmen typischer Strukturen 1 (mit parallelen Polarisationsfiltern aufgenommen):

a) Limnischer Sand mit Quarzkörnern (farblos), Karbonatkörnern (grau) und *coated grains* (Sandkörner mit Umhüllung, siehe Pfeil). Ausschnitt aus der limnischen Sandschicht 290.

b) Mikrit (grau) durchsetzt mit viel Quarzsand (farblos), am linken Bildrand ein Querschnitt durch einen Stengel einer Armleuchteralge (Characee, siehe Pfeil). Ausschnitt aus der Seekreideschicht 500.

c) Organischer Fruchtkörper (*Oogonie*) einer Armleuchteralge (Characee) und Molluskenschalen (beige) in einem limnischen Sand (Schicht 290).

d) Eingeregelte Fragmente von gut erhaltenen Molluskenschalen. Das Exemplar in der Bildmitte weist Lösungsspuren durch Algenfrass auf (siehe Pfeil, Schicht 290).

e) Köcherfliegenlarve (*Trichoptera*); quer geschnittener organischer Köcher mit anhaftenden Sandkörnern (Schicht 400).

f) Fragment einer Baumrinde, im unteren Teil in Auflösung begriffen und mit Seekreide durchsetzt (Schicht 320B).

g) Spiralförmige Mistelrinden mit der typischen Kettenstruktur (Organische Schicht 310).

h) Tannennadeln im Querschnitt (Organische Schicht 310).

Mikrit (Abb. 8b)

Ein weiteres wichtiges Element der geologischen Schichten ist Kalkschlamm, der als Mikrit bezeichnet wird. Es handelt sich dabei um feinste Kalkkristalle, die eine hellgraue Masse bilden. Diese Kristalle entstehen durch den Stoffwechsel von Wasserpflanzen, indem durch Photosynthese Kalk ausgefällt wird. Dieser umkrustet die Wasserpflanzen oder lagert sich direkt am Seegrund als Seekreide ab (Magny 1992, 30–31). Mikrit tritt in Arbon immer mit Sandkörnern vermischt auf.

Karbonatkörner (Abb. 8a)

Mikrit kann auch in Form von rundlichen Körnern in Sandfraktion vorliegen, die hier als Karbonatkörner angesprochen werden. Vermutlich sind diese Körner die Überreste von Wasserpflanzen, die mit Kalkschlamm umkrustet waren, wie Nixenkraut (*Najas*), Laichkraut (*Potamogeton*) und Armleuchteralgen (Characeen). Wellenschlag hat die Krusten fragmentiert, so dass gerundete Körner zurückblieben (Schöttle 1968, 271).

Coated grains (Abb. 8a)

Quarzkörner, die einen dünnen Saum aus Mikrit aufweisen, bezeichnet man als *coated grains*. Diese Umhüllungen entstehen durch feinste Algen, die einen Film um Sandkörner bilden und infolge Photosynthese Kalkkristalle anlagern. Diese Art der Überprägung geschieht vor allem im ufernahen Bereich (Schöttle 1968, 278).

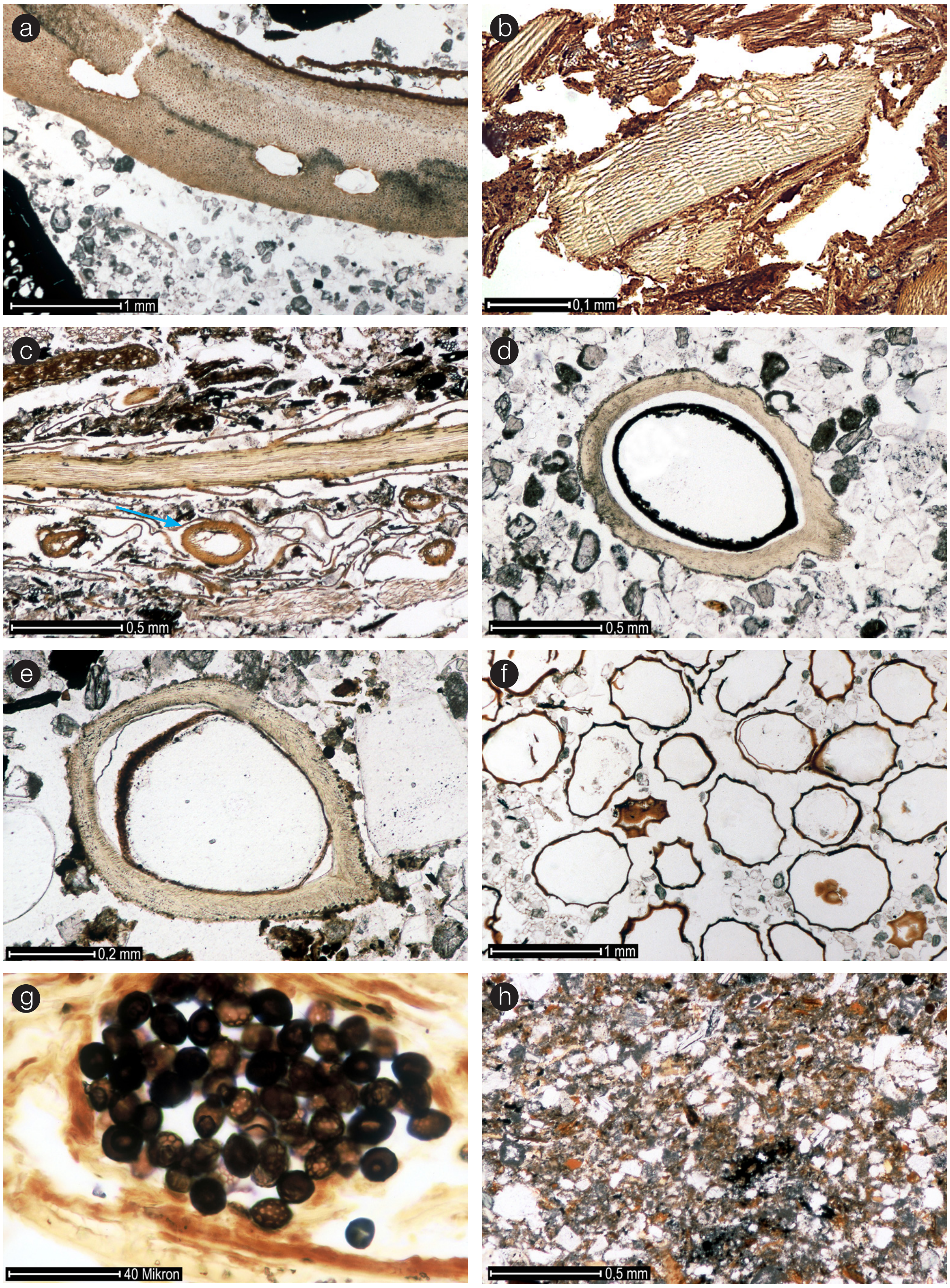

Abb. 9: Mikroskopische Aufnahmen typischer Strukturen 2 (mit parallelen Polarisationsfiltern aufgenommen):

a) Haselnussschale mit 3 Harzkanälen (Schicht 290).

b) Moosblättchen in Aufsicht, eingebettet in organische Reste (Probe 5055-1).

c) Moosstengel und –blättchen im Längsschnitt (Mitte) und Querschnitt (siehe Pfeil).

d) Himbeer-/Brombeersamen im Längsschnitt (Schicht 290).

e) Erdbeersamen im Längsschnitt (Sandschicht einer Bachüberschwemmung).

f) Mohnsamen (Sandschicht einer Bachüberschwemmung).

g) Pilzsporen (Probe 5055).

h) Organischer Detritus (braun) in einer mikritischen Sandschicht (Quarzsand farblos, Mikrit grau). Ausschnitt aus einem Installationshorizont 320B.

Algen- und Faunenreste

Von Armleuchteralgen (Characeen) sind gut erkennbare Reste erhalten. Man findet entweder die weiblichen Fruchtkörper (*Oogonien*, Abb. 8c) oder Reste der Stengel mit ihrem charakteristischen Querschnitt (Abb. 8b). Sie sind durch Kalkausfällungen imprägniert und dadurch gut erhalten. Armleuchteralgen wuchsen in der ufernahen Zone des Bodensees auf sandigem Untergrund bis in Wassertiefen von 6 m (Muckle 1942, 16; Brombacher und Hadorn 2004). Ferner finden sich gelegentlich auch Reste von Wasserschnecken und Muscheln (Abb. 8d), Muschelkrebsen (*Ostracoden*) sowie die Hüllen von Köcherfliegenlarven (*Trichoptera*, Abb. 8e). Gemeinsam ist diesen Tieren, dass sie nahe am Seeufer in seichtem Wasser leben.

Anthropogene Elemente

Pflanzliches Material

Den grössten Anteil der archäologischen Ablagerungen machen Pflanzen aus (dazu auch Brombacher und Hadorn, 2004; Hosch und Jacomet 2004; Zibulski 2004; Kühn und Hadorn, 2004). Nebst vielen, nicht näher zuweisbaren Holz- und Rindenresten (Abb. 8f) findet sich Material, das sich aufgrund seiner typischen Form oder inneren Struktur auch in den mikroskopischen Präparaten bestimmen lässt. Dazu gehören Misteln (Abb. 8g), Tannennadeln (Abb. 8h), Haselnussschalen (Abb. 9a), Moose (Abb. 9b und 9c) sowie Samen bzw. Früchte von Himbeeren oder Brombeeren (Abb. 9d), Erdbeeren (Abb. 9e) und Mohn (Abb. 9f). In manchen Proben sind ausserdem Pilzsporen in grossen Mengen vorhanden (Abb. 9g; hierzu auch Innes 2004).

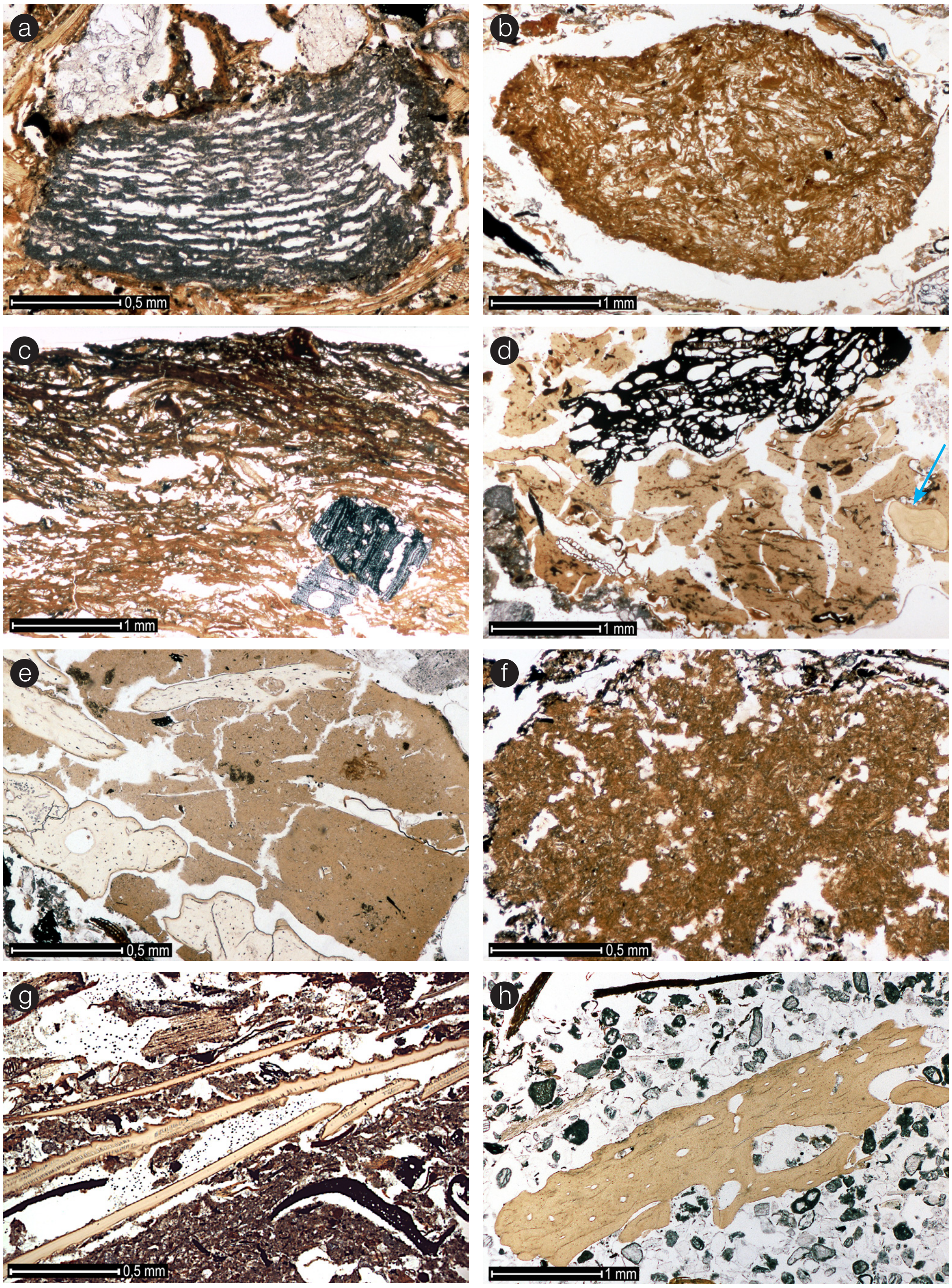

Abb. 10: Mikroskopische Aufnahmen typischer Strukturen 3 (mit parallelen Polarisationsfiltern aufgenommen):

a) Karbonatische Holzasche mit deutlichen pseudomorphen Zellstrukturen (Probe 5055).

b) Kompakter Schaf-/Ziegenkoprolith mit stark fragmentiertem organischem Material (Organische Schicht 310).

c) Querschnitt eines Rinderkoproliths mit verdichteter oberer Randzone und eingeschlossener Holzkohle (Probe 4198).

d) Menschlicher Koprolith mit Getreidebreirest (schwarz), Fischknochen (beige, Pfeil) und möglichen Getreideperikarpen (hellbraune längliche Objekte; Schicht 320B).

e) Hundekoprolith mit Knochenfragmenten (beige) und Mikroholzkohlen (Organische Schicht 310).

f) Omnivorenkoprolith (Schwein?) mit stark aufgelösten organischen Resten (Mündliche Aussage von R. Macphail; Organische Schicht 310).

g) Fischkiemen und -schuppen mit typischer gezähnter Struktur (Organische Schicht 310).

h) Fragment eines Säugerknochens, durch Wasserbewegungen verrundet (Schicht 290).

Häufig liegen in der Kulturschicht allerdings auch organische Reste vor, die so stark fragmentiert sind (Grösse der Partikel zwischen 10 und 100 Mikron), dass man von organischem Detritus spricht (Abb. 9h). Abgesehen von feinsten Holzkohleresten sind die meisten Bestandteile hier nicht näher bestimmbar. Mikroskopische Untersuchungen haben ergeben, dass der organische Detritus teilweise aus einzelnen Zellen von Baumrinde besteht (mündliche Mitteilung P. Zibulski), die vermutlich durch Begehung in feinste Partikel zerfallen ist. Welcher Holzart diese Zellen angehören, ist nicht erkennbar. Beobachtungen während der Ausgrabung ergaben jedoch, dass die Rinde von Esche jeweils schlechter erhalten war, als diejenige von Weisstanne (Leuzinger 2000, 116). Ob die Rindenreste durch eine spezielle Verarbeitung anfielen, infolge der Vorbereitung von Pfählen für den Hausbau entstanden oder ein spezielles Verwitterungsprodukt darstellen, ist nicht klar.

Ein weiteres wichtiges Element der Kulturschicht ist Holzkohle (Abb. 11h). Die Bruchstücke können von weniger als einem Millimeter bis mehrere Zentimeter Grösse messen. In Sandschichten enthaltene Holzkohle ist stärker fragmentiert und weist zudem verrundete Kanten auf, was auf Transport durch Wasser zurückzuführen ist. Mikroholzkohle (Grösse 10-100 Mikron) entsteht unter anderem durch Kompaktion infolge Begehung. Eine einzelne Probe enthielt zudem Holzasche (Abb. 10a), was auf eine ausserordentlich gute Konservierung zurückgeführt werden kann.

In einigen Proben sind zusätzlich Wurzeln vorhanden, die sich in der Regel horizontal durch die organischen Schichten ziehen. Sie stammen aus der Zeit nach der Besiedlung und gehen vermutlich auf einen Schilfgürtel zurück.

Koprolithen

Bei Koprolithen handelt es sich um Fäkalienreste, die sich durch ihre Zusammensetzung und inneren Aufbau bestimmen lassen. Da schon an anderer Stelle ausführlich darüber berichtet wird (beispielsweise Akeret et al. 1999; Akeret und Rentzel 2001; Kühn und Hadorn 2004; Haas 2004; Marti 2004; Le Bailly 2004), beschränken wir uns hier auf einen Beschrieb der wichtigsten Koprolithenbefunde aus den mikromorphologischen Bodenproben. Nachgewiesen sind Koprolithen von Schaf/Ziege, Rind, Hund und dem Menschen.

Mit Abstand am häufigsten sind die Exkremente von Ovicapriden (Schaf/Ziege, Abb. 10b). Bei guter Erhaltung weisen sie eine ovale Form auf und sind bis knapp 1 cm lang. Die Randzone erscheint verdichtet und enthält mehr phosphathaltige Matrix. Im Innern ist das pflanzliche Material relativ locker in eine konvolute Struktur gepackt (Porosität bis über 35%), und der mineralische Anteil ist allgemein sehr gering. Sie sind in fast allen organischen Ablagerungen in kleinen Mengen vorhanden und konnten teilweise bereits im Verlauf der Ausgrabungen erkannt und separat beprobt werden (Leuzinger 2000, 37; Akeret et al. 1999). In den Dünnschliffen kommen sie besonders häufig in den Proben 1030 und 5055 vor (siehe auch Kap. ‚Spezielle Abfolgen in den Proben‘).

Rinderdung (Abb. 10c) ist im Gegensatz zu Schaf-/Ziegenkoprolithen horizontal geschichtet, wobei die bestimmbaren organischen Reste wie Tannennadeln, Astreste von Weisstanne, Misteln, Brombeerblätter usw. vergleichsweise schwächer fragmentiert sind (Akeret und Rentzel 2001). Mit Ausnahme von seltenen Kuhfladenresten sind die Rinderkoprolithen von Arbon-Bleiche 3 stark zersetzt und als kleine Fetzen entsprechend schwierig zu erkennen. Gut erhaltene Schichtbefunde lassen aber vermuten, dass Rinderdung stellenweise einen beträchtlichen Anteil am Aufbau der organischen Siedlungsablagerungen ausmacht (siehe auch Kap. ‚Spezielle Abfolgen in den Proben‘).

Menschliche Fäkalienreste, die sich durch eine relativ dichte, phosphathaltige und gelbliche Grundmasse auszeichnen (Courty et al. 1989, 114; Brombacher et al. 1999, 98), waren in den Proben sehr selten und zumeist als wenige Millimeter grosse Fragmente vorhanden (auf der Grabung wurden aber mehrere, noch vollständige menschliche Koprolithen geborgen (siehe Deschler-Erb und Marti-Grädel 2004; Le Bailly 2004). Ein besonders schönes Exemplar wies ganze Fischknochen und potentielle Breireste auf (Abb. 10d). In der Regel fehlten aber mineralische Anteile oder grössere Knochensplitter. Letztere sind dagegen typisch für die Exkremente von Karnivoren (z.B. Hund), deren Unterscheidung von den menschlichen Fäkalien vor allem anhand der helleren und phosphatreicheren Matrix möglich ist (Abb. 10e; Courty et al. 1989, 114). Mehrere solcher Koprolithenfragmente (unter 2 mm), die vereinzelte Holzkohlen und Reste von Gräsern (Phytolithen) enthielten, fanden sich an der Basis der organischen Fundschicht. Typische Karnivoren-Koprolithen aus Arbon-Bleiche 3 bestehen zu rund 30 % aus unverbrannten, verrundeten Knochenbruchstücken, in deren Hohlräumen sich die Phosphatmatrix besonders gut erhalten konnte. Aufgrund dieser Tatsache, aber auch wegen ihrer allgemein starken Fragmentierung, ist ihre Erhaltung als eher schlecht zu bezeichnen. Es scheint, dass sie durch Begehung fragmentiert und verschleppt wurden. Auch eine Verwitterung durch Erosionsprozesse ist denkbar.

Ferner wurden in den Profilen 1007 und 1015 mehrere kleinste Bruchstücke von Koprolithen gefunden, die aus einer Ansammlung stark fragmentierter, organischer Reste (20-150 Mikron) bestehen und ein schwammiges Gefüge (15% Porosität) besitzen (Abb. 10f). Nebst den unorientierten braunen Partikeln finden sich stellenweise auch Sandkörner, während Holzkohlen und Knochen fehlen. Aufgrund der oben beschriebenen Merkmale dürfte es sich um Koprolithen von Omnivoren handeln, wobei sowohl Mensch als auch Schwein in Frage kommen.

Weitere Reste aus den Siedlungsablagerungen

In den mikromorphologischen Proben sind ferner Fischreste und Fragmente grösserer Tierknochen nachgewiesen, die jedoch nicht genauer identifiziert wurden (Abb. 10g und 10h; dazu Deschler-Erb und Marti-Grädel 2004; Hüster-Plogmann 2004). Ebenfalls nicht näher eingegangen wird auf die in den Dünnschliffen nur selten vorkommenden Keramikfragmente.

Lehmaggregate, die ausschliesslich in den Siedlungsschichten auftreten, sind eine weitere Kategorie, die hier nur summarisch behandelt wird. Es handelt sich dabei um abgewitterte Baumaterialien, die als kleine Brocken im Wasser leicht gerundet wurden. In Schichten, die viele umgelagerte organische und mineralische Partikel aufweisen, kommen sie besonders häufig vor, was dafür spricht, dass Baulehm vermutlich bei starken Regenfällen erodiert und verlagert wurde.

Beschreibung und Interpretation der einzelnen Fazien

Die verschiedenen Sedimenttypen werden in stratigrafischer Abfolge behandelt. Details zu den Schichtbeschreibungen lassen sich der Tabelle 2 am Ende dieses Beitrages entnehmen.

Seekreideschicht 500 (Abb. 11a)

Die Seekreide an der Basis der Stratigrafie besteht zur Hauptsache aus Kalziumkarbonat (80%), wobei je rund die Hälfte als Mikrit (Abb. 8b und 11a) und als Karbonatkörner vorliegt (Abb. 8a).

Sandlagen enthalten 5 bis 12% an Sand (hauptsächlich Quarz). Der Sand wurde periodisch durch Flüsse in den Bodensee eingebracht und durch die Strömung verlagert, wodurch teilweise *coatings* um die Sandkörner entstanden (Abb. 8a). Generell sind Armleuchteralgen (Abb. 8b und 8c), Muschelkrebse sowie Molluskenschalen (Abb. 8d) häufig und meist gut erhalten.

Anhand der Zusammensetzung und des Gefüges der Seekreide lässt sich das Bildungsmilieu abschätzen. Die Ausfällung von Seekreide benötigt eine Wassertiefe von minimal 0,5 m und maximal 6 m (Brochier 1983, 250). Algenbewuchs und *coated grains* weisen auf eine ufernahe Zone hin, wobei auch hier eine Wassertiefe von über 0,5 m Voraussetzung ist (Muckle 1942, 61). Das Ablagerungsmilieu muss zudem relativ ruhig gewesen sein, da ansonsten Bänderungen von Mikrit und Sand nicht erhalten wären. Aufgrund der guten Konservierung der Mollusken und Muschelkrebse ist anzunehmen, dass die Seekreide nicht der Luft ausgesetzt, sondern konstant von Wasser bedeckt war.

Geologische Aufschlüsse innerhalb der Bucht von Arbon zeigen, dass die holozäne Kalksedimentation, zusammen mit dem Eintrag terrigener Sande, zu einem bis über 70 m mächtigen Paket aus limnischen Beckensedimenten geführt hat (Leuzinger 2000, 24).

Sandschicht 400

Das unmittelbar unter der Kulturschicht liegende Sandband 400 (entspricht nicht der Schichteinheit 7 von Magny, siehe Abb. 7 und Kap. ‚Geologische Situation‘) lässt sich im Bereich der mikromorphologisch untersuchten Profile in zwei übereinanderliegende Abschnitte 400A und 400B aufteilen (Abb. 11b):

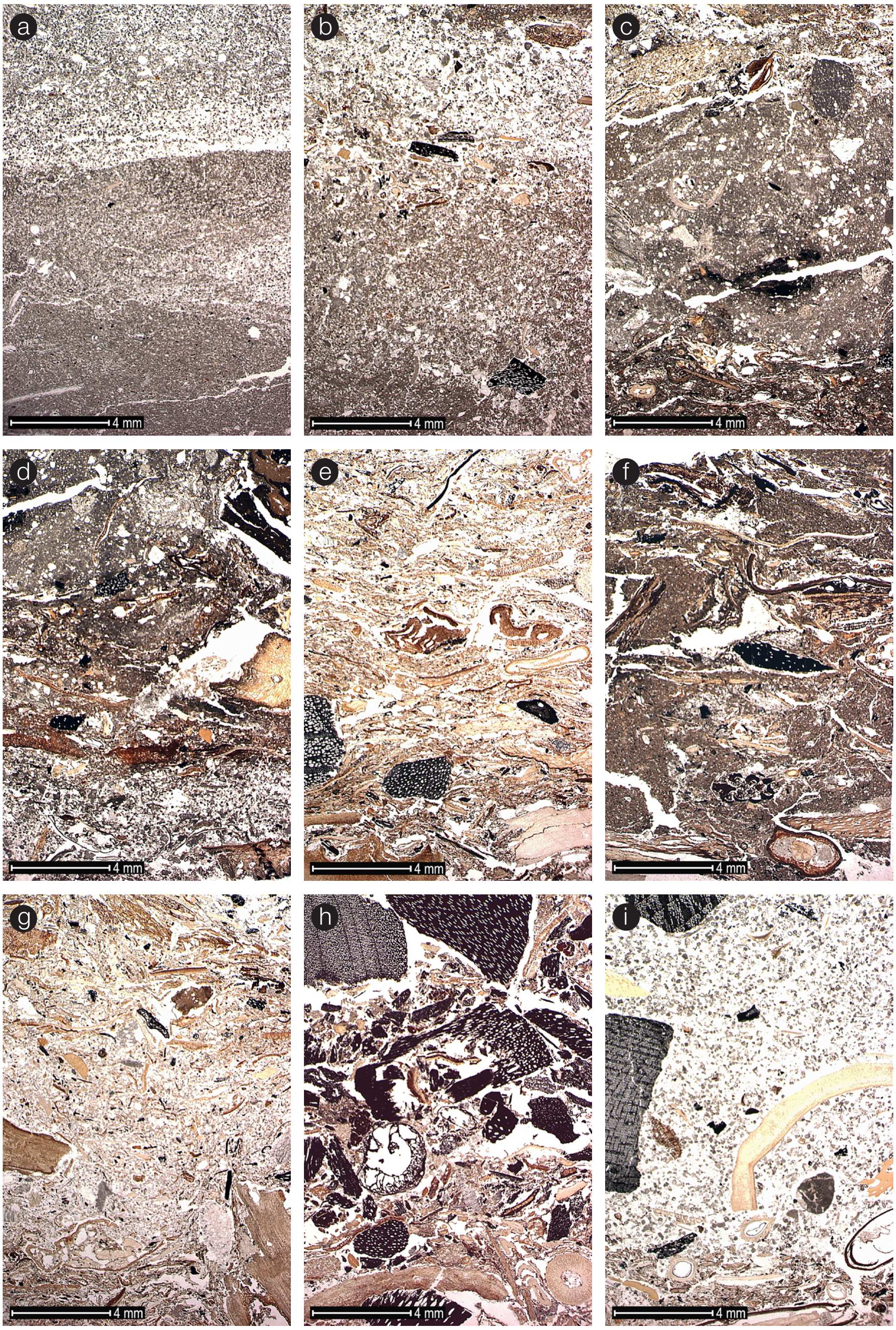

Abb. 11: Mikroskopische Aufnahmen der Charakteristika der Sedimente (mit parallelen Polarisationsfiltern aufgenommen):

a) Seekreideschicht 500 mit sandigen und mikritischen Intervallen (Probe 1029).

b) Litorale Sandschichten 400B (unten) und 400A (oben), organisches Material und Mollusken enthaltend (Probe 1029).

c) Baulehmschicht, bestehend aus dichtem sandigem Mikrit, oben mit organischem Material durchsetzt, vermutlich durch Trampling (Probe 1036).

d) Auf dem litoralen Sand 400A liegt ein 1 cm mächtiger Installationshorizont (Bildmitte), versetzt mit organischen Resten (braun bis gelb). Im oberen Drittel graue, kompakte Baulehmschicht (Probe 1036).
e) Organische Kulturschicht mit 2 Schaf-/Ziegenkoprolithen, gut geschichteten organischen Resten und Holzkohle (Probe 1030).

f) Organische Schicht mit Detritus; pflanzliche Reste und Holzkohle, eingebettet in einen stark organischen Mikrit. Grosses Baumrindenfragment im oberen Drittel rechts (Probe 1030).

g) Sandband durchsetzt mit sortiertem pflanzlichen Material, entstanden durch eine Bachüberschwemmung, die die ältere organische Schicht kappt (Probe 1028).

h) Brandschicht 303; Gemisch aus gerundeten Holzkohlen und einem verkohlten Getreidekorn (rund, Mitte links), durchsetzt mit unverbranntem pflanzlichen Material (Probe 1015).

i) Limnische Sandschicht 290, die die darunter liegende organische Schicht an der Oberfläche gekappt hat (Probe 1029).

400B

Die untere Sandschicht 400B besteht aus einem mikritischen Fein- bis Mittelsand, der eine Schrägschichtung aufweist (Abb. 11b). Der Kalkgehalt beträgt durchschnittlich 70%, wobei Mikrit und Karbonatkörner je etwa die Hälfte ausmachen. Quarzsand ist mit 15% in einer grösseren Konzentration vorhanden als in der Seekreide, und auch *coated grains* sind vergleichsweise häufiger. Mollusken kommen oft vor und weisen charakteristische Verwitterungsspuren auf (Abb. 8d). Zudem fanden sich auch einige seltene Köcherfliegenlarven (Abb. 8e) darin.

Die Zusammensetzung der Schicht 400B unterscheidet sich nur geringfügig von der darunter liegenden Seekreide. Mikroskopische Untersuchungen verdeutlichen aber, dass dieser Sand einer durch Wellenschlag aufgearbeiteten, sandigen Seekreide entspricht und somit einen Reduktionshorizont darstellt. Der Sand hat sich im Flachwasserbereich nahe dem Ufer abgelagert. Erst infolge einer Senkung des Seespiegels konnte die Seekreide durch Wellen aufgearbeitet werden, so dass der Kalkschlamm teilweise erodiert wurde, während sich schwerere Bestandteile wie Quarz- und Karbonatkörner anreicherten. Der oberste Teil der Seekreide 500 erscheint gekappt, was auf eine Lücke im Schichtaufbau hindeutet. Diese vermutet auch M. Magny (Abb. 7; EF2).

Die häufig vorhandenen *coated grains*, Köcherfliegenlarven und die Verwitterungsspuren an den Molluskenschalen deuten darauf hin, dass die Sandschicht unter geringer, aber ständiger Wasserbedeckung entstanden ist (Ostendorp 1996, 225, 231). Verwitterte Mollusken könnten allerdings auch von der nahen Strandzone in den Flachwasserbereich eingetragen worden sein.

400A

Direkt über der Schicht 400B liegt das dünne Sandband 400A, das sich durch eine noch grössere Konzentration an Sand (Quarzgehalt 20%, Karbonatkörner 35%) und einen geringen Mikritgehalt (10%) auszeichnet (Abb. 11b). Es finden sich hier ebenfalls grosse Mengen an *coated grains*, viele verwitterte Mollusken und seltene Köcherfliegenlarven. Zudem ist immer ein kleiner Anteil an organischem Material und Mikroholzkohlen vorhanden.

Bei Schicht 400A handelt es sich um ein gegenüber 400B stärker aufgearbeitetes Sediment: Leichtere Quarzkörner und Mikrit wurden durch Wellenschlag unter niedriger Wasserbedeckung erodiert. Woher das hier vorliegende organische Material stammt, ist schwer zu sagen. Das Vorhandensein eines Installationshorizontes (siehe unten), pollenanalytische Ergebnisse (Brombacher und Hadorn 2004) und auch die Untersuchung der Mollusken (Thew 2004) sprechen eher gegen vertikale Vermischungen. Vielmehr ist ein anthropogener Eintrag von einer nahe liegenden Kulturschicht zu vermuten, möglicherweise aus einem Teil der Siedlung Arbon-Bleiche 3, der mit der Grabung nicht erfasst wurde.

Auch hier ist davon auszugehen, dass ein Teil des Sandbandes 400B erodiert ist und somit eine Schichtlücke zwischen 400B und 400A besteht. Schicht 400A entstand also bei noch niedrigerem Seespiegel als Schicht 400B. Die Siedlung wurde nach einer weiteren Seespiegelabsenkung errichtet, vermutlich auf der freiliegenden Strandplatte.

Als Fazit lässt sich feststellen: Die Sandschicht 400 entstand in zwei Etappen, wobei mindestens zweimal eine sandige Seekreide aufgearbeitet und wieder abgelagert wurde. Damit sind im Minimum zwei Schichtlücken vorhanden, deren Dauer sich nicht näher eingrenzen lässt. Verwitterungserscheinungen an Molluskenschalen und fehlende Bodenbildungsanzeiger lassen auf eher kurzfristige Ereignisse im Rahmen von höchstens wenigen Jahren schliessen. Auch bei anderen Fundstellen am Bodensee wie Hornstaad (D) Hörnle I und Allensbach (D) Strandbad konnte ein dünner Sandhorizont unterhalb der Siedlungsablagerungen erfasst werden. Ähnlich wie in Arbon wird dies von Ostendorp als Reduktionshorizont angesprochen (1990, 297).

Lehmschichten

Baulehm (Abb. 11c)

Beim untersuchten Baulehm aus Arbon-Bleiche 3 handelt es sich meist um Überreste von Materialdepots oder beim Hausbau verschleppter Baustoffe. Die Baulehmschichten sind immer sehr ähnlich zusammengesetzt; sie bestehen aus ungeschichteter, kompakter Seekreide, die vereinzelt *coated grains* und Reste von Mollusken enthält. Hinzu kommt ein besonderer Quarzsand (Anteil 15%), der in seiner petrografischen Zusammensetzung (viele Kalzitkörner) und seiner Korngrösse leicht vom limnisch überprägten Sand abweicht. Während der im Bodensee umgelagerte Sand eine recht homogene Korngrösse in der Fein- bis Mittelsandfraktion aufweist, ist der im Baulehm vorkommende Sand schlechter sortiert, d.h. es kommen alle Kornklassen von Fein- bis Grobsand und Feinkies vor.

Der im Baulehm enthaltene Sand stammt ursprünglich aus dem Hinterland und wurde vermutlich in einem Flussbett oder einer Sandablagerung in Siedlungsnähe abgebaut. Seekreide vermischt mit diesem Sand hat man als Wandlehm verwendet. Diese Befunde zeigen, dass beim Wandlehm nach Möglichkeit lokal vorkommende Baustoffe Verwendung fanden. Die Bauhorizonte zeichneten sich als dünne Lehmlinsen ab, die durch Begehung verdichtet und verlagert wurden.

Installationshorizont 320B (Abb. 11d)

An der Basis der Siedlungsschichten findet sich eine spezielle lehmige Ablagerung (mit Ausnahme der seenahen Proben 1007 und 1015). Es handelt sich um einen kompakten Kalkschlamm (Anteil 40%), der ein plattiges Gefüge besitzt und einen Sandanteil von 25% führt (Quarzsand 10%, Karbonatkörner 15%). Organisches Material, das teilweise aus organischem Detritus besteht (Abb. 9h), macht ebenfalls 25% aus. Vereinzelt sind auch grössere pflanzliche Reste, wie Samen und Holzfragmente vorhanden. Isolierte *coated grains*, Mollusken und seltene Armleuchterreste deuten auf einen schwachen limnischen Einschlag hin.

Die offenbar durch Begehung verdichtete, mit organischem Material und verschleppter Seekreide (und verlagertem Baulehm?) durchsetzte Schicht dürfte beim Bau der Häuser auf der Strandplatte entstanden sein. Diese Schicht entspricht somit einem Installationshorizont. Aufgrund von Beobachtungen während der Grabungen befanden sich an der Basis der anthropogenen Ablagerungen oft Abfälle von Holzverarbeitung, die durch das Zurichten von Pfählen für den Hausbau anfielen (Leuzinger 2000, 38, 116–118). Bei zwei in Seenähe liegenden Kolonnen 1007 und 1015, die diese Schicht nicht aufweisen, wurde der Installationshorizont vermutlich bei Überschwemmungen des Bodensees abgetragen.

Archäologisches Schichtpaket 310/320

Organische Schichten (Abb. 11e)

Die organischen Ablagerungen bestehen zu über 50% aus pflanzlichen Resten, die meist leicht sortiert und geschichtet in wenig sandig-mikritischer Matrix eingebettet sind (Anteil Mikrit 5%, Quarzsand 10%). Das organische Material umfasst das gesamte Spektrum von kleinen Ästen, Rinden, Tannennadeln, Moosen über Holzkohle, Samen, Koprolithen bis hin zu Tierknochen; dies können Säuger-, Reptilien-, Amphibien-, Vogel- und Fischknochen sein. (Abb. 8f bis 10h). Ihre Erhaltung ist im allgemeinen ausgezeichnet, mechanische Beanspruchung, z.B. infolge Begehungen, scheinen sich minimal ausgewirkt zu haben. Erfahrungsgemäss zeichnen sich Begehungsspuren vor allem in feinkörnigen und minerogenen Sedimenten ab (Wallace 1999, 133; Rentzel und Narten 2000). Sie sind in Arbon-Bleiche 3 auf die Baulehmschichten und Installationshorizonte beschränkt. Organische Ablagerungen in feuchtem Milieu konservieren die Kompaktionsspuren schlecht, da sie, ähnlich wie Torf, rasch wieder aufquellen.

Die mikroskopischen Sedimentuntersuchungen sprechen insgesamt für eine Ablagerung in feuchtem Milieu unter Sauerstoffmangel, wobei die organischen Reste aufgrund ihrer sehr guten Konservierung offensichtlich nie ausgetrocknet sind. Hinweise auf Verwitterung unter Luftzufuhr, Bioturbation oder beginnende Bodenbildung fehlen. Da auch sehr feine organische Partikel vorhanden sind, dürften die archäologischen Schichten auch kaum verlagert sein. Allerdings spricht die leichte Sortierung der Reste lokal für eine schwache Aufschwemmung, was vielleicht durch Überflutungen oder oberflächlichen *run-off* verursacht wurde. Die nachgewiesene Kappung der organischen Kulturschichten dürfte hingegen auf mehrere Überschwemmungsereignisse des Baches zurückgehen (siehe Kap. ‚Schichtbildungsprozesse‘).

Organische Schichten mit Detritus (Abb. 11f)

In nahezu jeder Kolonne kommen spezielle Schichten mit organischem Detritus vor, bei der die fein fragmentierten pflanzlichen Partikel in eine mikritische Matrix eingebettet sind. Die Erhaltung der organischen Reste ist auch hier ausgezeichnet, und wie die oben beschriebenen Ablagerungen, sind auch diese Detritusschichten oft gekappt.

Die Entstehung dieser Sedimente, insbesondere deren Gehalt an Kalkschlamm und feinsten organischen Partikeln, kann durch verschiedene Prozesse verursacht worden sein. Es ist denkbar, dass hier spezielle Überreste von Holz- oder Rindenverarbeitung vorliegen, die zusammen mit weiteren organischen Materialien einsedimentiert wurden. Möglicherweise handelt sich aber auch um ein spezielles Verwitterungsprodukt, das – wie schon bei den Installationshorizonten festgestellt – mit unverwitterten organischen Resten durchsetzt ist.

Sandige Schichten

Innerhalb der archäologischen Schicht treten mehrere dünne Bänder auf (Abb. 11g), deren Sandgehalt insgesamt über 40% beträgt (Quarzsand 25%, Karbonatkörner 15%). Organisches Material ist mit 30% relativ schwach vertreten, der Mikritanteil liegt bei nur 5%. Holzkohlen sind meist stark fragmentiert und gerundet, was zusammen mit den häufig festgestellten verrundeten Lehmaggregaten auf eine Umlagerung hindeutet (vergleichbare Befunde liegen auch für Hagnau (D) Burg vor; Ostendorp 1996, 234). Vereinzelte limnische Anzeiger, wie *coated grains* und Mollusken sind sporadisch vorhanden. Die Sortierung der pflanzlichen Reste ist gut, allerdings sind sie schlecht eingeregelt.

Aus sedimentologischer Sicht stellt das Sediment eine Mischung aus feinkörnigem fluviatilem und gröberem limnischem Sand dar. Letzterer stammt vermutlich aus einer mächtigen, molluskenführenden Sandablagerung, die 10 m oberhalb der Siedlung ansteht. Dabei handelt es sich wohl um die Fortsetzung der Strandablagerung (Schicht 400; siehe oben), die landeinwärts an Mächtigkeit zunimmt (Abb. 6).

Die Entstehung dieser Sandbänder scheint im Zusammenhang mit dem nahen Bach zu stehen: Dieser ist wahrscheinlich bei extremen Ereignissen (starken Regenfällen?) über die Ufer getreten und hat den im Hinterland erodierten Sand in der Siedlung wieder abgelagert. Dabei dürfte die Oberfläche der anthropogenen Schichten partiell gekappt und mit Sand vermischt worden sein. Anhand der Korngrössenzusammensetzung scheinen die fluviatilen Ereignisse von eher geringer Erosionskraft gewesen zu sein. Verrundung und Fragmentierung der Holzkohlen zeigen jedoch, dass Teile des organischen Materials bewegt wurden. Bei den Lehmaggregaten handelt es sich wahrscheinlich um abgewitterten Wandlehm.

Eine Korrelation der Sandbänder zwischen den untersuchten Profilkolonnen lässt mindestens 2 bis 3 grössere Überschwemmungsereignisse vermuten, die innerhalb der 15 Jahre dauernden Besiedlung stattgefunden haben.

Schicht 303

Die Brandschicht 303 war nur in Kolonne 1015 vorhanden (Abb. 3 und 11h), in allen anderen untersuchten Proben ist sie erodiert oder mit Seesand vermischt als Schicht 290 abgelagert worden.

Unter dem Mikroskop erkennt man eine Ansammlung aus horizontal eingeregelten Holzkohlen bis knapp 1 cm Kantenlänge, die relativ schwach fragmentiert, jedoch meist verrundet sind. Das locker gepackte Sediment besitzt eine hohe Porosität (40%) und liegt mit deutlicher, welliger Untergrenze auf dem organischen Kulturschichtpaket auf. Letzteres zeigt weder einen erkennbaren Brandrötungssaum, noch eine oberflächliche Lage verkohlter Makroreste. Die Matrix der Brandschicht besteht aus unverbrannter, sandiger Seekreide und ist infolge des markanten Anteils an Mikroholzkohlen dunkel verfärbt. Organisches Material kommt ebenfalls vor, meist als verkohlte Partikel. Ferner finden sich auch wenige verbrannte Koprolithen, die stark fragmentiert und abgerundet sind.

Die in Profil 1015 analysierte Brandschicht entspricht nicht einem *in situ* liegenden Brandschutt, sondern stellt aufgrund der oben beschriebenen Merkmale eine durch den See aufgeschwemmte Ablagerung dar. Die nach dem Brandereignis erfolgte Transgression wird unter anderem durch die scharfe Schichtgrenze, aber auch durch das lokale Fehlen der Brandschicht dokumentiert. Im Verlauf dieses Erosionsprozesses hat eine schwache mechanische Beanspruchung sowie eine selektive Anreicherung des verkohlten Materials stattgefunden. Hinweise auf Verwitterungsvorgänge, die auf ein langandauerndes Offenliegen der Brandruinen deuten würden, existieren hingegen nicht.

Schicht 290

Die Schicht 290 besteht aus einem schwach gebänderten Sand, der mit organischen Resten durchsetzt ist (Abb. 11i). Es lässt sich eine Zweiteilung der Schicht in eine obere (290A) und eine untere Ablagerung (290B) feststellen. Der organische Gehalt nimmt gegen oben ab (von 40% auf 5%) und der Sand entsprechend zu (von 35% auf 70%). Das Sediment ist reich an *coated grains*, Armleuchteralgen, verwitterten Mollusken und enthält auch einige Köcherfliegenlarven.

Die Zusammensetzung und die Bänderung der Schicht weisen auf eine limnische Entstehung hin. Es handelt sich dabei um in Ufernähe überprägten Sand, der sich im Zuge eines raschen Seespiegelanstiegs kurz nach der Brandkatastrophe abgelagert hat (Leuzinger 2000, 27). Dabei wurden ein beträchtlicher Teil der Brandschicht 303 und vermutlich auch Partien der darunter liegenden archäologischen Schichten erodiert und mit Sand vermischt.

Rekonstruktion der Schichtgenese

Limnische und terrestrische Ablagerungen

Wie eingangs erwähnt, besteht eines der Hauptziele der mikromorphologischen Untersuchungen in der Rekonstruktion des Ablagerungsmilieus einer archäologischen Fundstelle. In Seeufersiedlungen stellt sich unter anderem auch die Frage, ob terrestrische Elemente effektiv an Land oder unter Wasserbedeckung einsedimentiert wurden.

Aussagen über die ehemals herrschenden Sedimentationsbedingungen lassen sich im Fall von Arbon-Bleiche 3 aufgrund von verschiedenen Indizien erzielen, die hauptsächlich die Schichtzusammensetzung betreffen. Sind z.B. limnische Elemente, wie *coated grains*, Algenreste, Kalkschlamm und Mollusken (Abb. 8a bis d) in grösseren Mengen als *in situ* liegende Bestandteile vorhanden, so lässt dies darauf schliessen, dass die entsprechende Ablagerung unter Wasser entstand. Andererseits manifestieren sich terrestrische Einflüsse generell in Form von Verwitterungserscheinungen. Dazu zählen Oxidation und Abbau des organischen Materials, Humifizierung der pflanzlichen Reste sowie Störung des Schichtaufbaus infolge bodenwühlender Organismen. Diese Verwitterungserscheinungen stehen jeweils am Beginn einer Reihe von bodenbildenden Prozessen, welche letztlich archäologische Befunde zerstören können (Wood und Johnson 1978). Ferner wurde bereits wieter oben (siehe Kap. ‚Archäologisches Schichtpaket 310/320‘) dargelegt, dass sich auf mineralischen Substraten auch die Auswirkungen menschlicher Begehung besonders deutlich abzeichnen: Sie führen durch die Prozesse von Anreicherung, Verlust, Neuverteilung und Umwandlung zur Bildung einer archäologischen Schicht (Gé et al. 1993).

Als bemerkenswertes Ergebnis der Mikromorphologie gilt, dass die untersuchten Siedlungsablagerungen in Arbon-Bleiche 3 weder eindeutige limnische Anzeiger noch Hinweise auf terrestrische Prozesse geben. Dies lässt auf ein dauerfeuchtes Ablagerungsmilieu schliessen, wobei die organischen Reste jedoch nicht unter grosser Wasserbedeckung eingebettet wurden. Auch aufgrund sedimentologischer Überlegungen ist davon auszugehen, dass die Anreicherung von organischem Feinmaterial und die Bildung von Baulehmlagen nur ohne Wasserbedeckung möglich waren, da sonst die feinsten Bestandteile weggeschwemmt und somit nicht vorhanden wären. In die gleiche Richtung weisen auch die stellenweise häufigen Pilzsporen (Abb. 9g): Sie bestätigen das Bild einer sehr feuchten organischen Ablagerung. Ebenso kann das Fehlen von deutlich ausgebildeten trampling-Anzeigern – die entsprechenden Verdichtungen waren vor allem in den minerogenen Installationshorizonten und in Baulehmablagerungen sicher fassbar – durch den hohen Wassergehalt der organischen Schichtpakete erklärt werden. Im Fall einer Begehung waren diese Sedimente offensichtlich zu weich und zu elastisch, als dass sich markante Spuren der Begehung durch Mensch und Tier überhaupt hätten erhalten können.

Schichtbildungsprozesse

Akkumulation von Siedlungsresten

Aus der archäologischen Befundsituation geht hervor, dass sich – mit Ausnahme des Installationshorizontes – die mikromorphologisch untersuchten Siedlungsschichten unterhalb von abgehobenen Hauskonstruktionen oder im Gassenbereich gebildet haben, wobei auch letzterer aufgrund von Pfahlstellungen als erhöht liegender Steg rekonstruiert wird (Leuzinger 2000, 120). Wie die archäologischen und die naturwissenschaftlichen Untersuchungen belegen, haben wir uns die Siedlungsschichten als komplex entstandene Anreicherungen von Baumaterialien, Abfällen von häuslichen und handwerklichen Tätigkeiten, Dung, Essensresten sowie Gegenständen des täglichen Gebrauchs vorzustellen.

Mikromorphologische Untersuchungen präzisieren, dass sich die Bauhorizonte in Form von speziellen Lehmlinsen aus sandiger Seekreide und Resten der Holzbearbeitung abzeichnen. Betreffend der nur lokal in grösseren Mengen vorkommenden Koprolithen (z.B. in Probe 1030) bieten sich mehrere Erklärungsmodelle an: Vieh hat sich nicht regelmässig im Zentrum der Siedlung aufgehalten oder ein Teil des Viehs wurde in kleineren Pferchen gehalten. Möglich wäre auch, dass der anfallende Dung sich nicht erhalten hat oder entfernt bzw. benutzt wurde (z.B. als Dünger oder Brennstoff, hierzu auch Kühn und Hadorn 2004).

Erosionen

Innerhalb der Siedlung lassen sich mehrere Ablagerungsbereiche fassen, die unterschiedlich stark der Erosion ausgesetzt waren. In ufernahen Zonen hat der Bodensee, vermutlich während der jährlich wiederkehrenden Hochwasser in den Sommermonaten (Geyer 1930, 140), Teile der Siedlungsablagerungen erodiert. Es scheint, dass dabei nicht die gesamte Kulturschicht abgetragen, sondern nur jeweils der oberste Teil gekappt wurde. Belegt wird dies durch das Ausdünnen der Siedlungsschicht in den seenahen Proben 1007 und 1015 (3 cm bzw. 6 cm Schichtmächtigkeit). Erosion ging aber auch vom Bach aus, der etwa 30 m nördlich der Fundstelle durchfloss, bei starken Regenfällen über die Ufer treten konnte und dadurch Teile der organischen Schichten abtrug.

Zur Schichtbildung

Man kann also festhalten, dass die vorgefundenen Schichtreste ein komplexes Puzzle aus Ablagerung und geringer Erosion darstellen. Voraussetzung für die Konservierung dieses Puzzles sind die ausserordentlich guten, dauerfeuchten Erhaltungsbedingungen als Folge der unmittelbaren Nähe des Sees. Möglicherweise war die Erhaltung der pflanzlichen Abfälle deshalb so gut, weil eine organische Deckschicht, die der Verwitterung ausgesetzt war, die darunter liegenden Reste schützte.

Der Zeitraum, in dem sich die Siedlungsreste akkumuliert haben, lässt sich anhand der Mikromorphologie nicht bestimmen. Hinweise auf Saisonalität, d.h. zyklische Sedimentationsabfolgen mit gleichartig zusammengesetzten organischen Ablagerungen, sind in den Bodenproben nicht fassbar. Vielmehr sind in allen Schichten ähnliche Zusammensetzungen vorhanden. Es ist aber denkbar, dass die landseitig stark aufgefächerten Sandschichten zyklisch wiederkehrende Überschwemmungsereignisse des Baches repräsentieren.

Es stellt sich die Frage, ob die organischen Schichten jeweils nur im Sommer gebildete Ablagerungen darstellen. Im Winter akkumulierte organische Reste waren vermutlich infolge tieferem Seespiegel des Bodensees einer stärkeren Oxidation ausgesetzt. Zudem fiel wohl in der kalten Jahreszeit auch weniger pflanzliches Material an, was mit ein Grund sein könnte, weshalb die organischen Pakete insgesamt relativ dünn sind. Dass sich jedoch die Schaf-/Ziegen- und vom Rind stammenden Koprolithen erhalten haben, die nachweislich während des Winters oder frühen Frühjahrs abgesetzt wurden, spricht eher gegen eine schlechtere Erhaltung der organischen Reste während der Wintersaison (Kühn und Hadorn 2004).

Die Kolonne mit der längsten Sequenz (Probe 1030) weist eine 15 cm mächtige Siedlungsablagerung auf. Dies würde eine durchschnittliche Akkumulation von mindestens 1 cm organischem Material pro Jahr bedeuten, was – selbst unter Berücksichtigung der Setzung der Reste – nicht gerade eine grosse Menge ist. Aus mikromorphologischer Sicht gibt es aber keine Hinweise, dass die organischen Sedimente jährlich beim Seespiegelhochstand im Sommer überflutet oder grossflächig erodiert wurden.

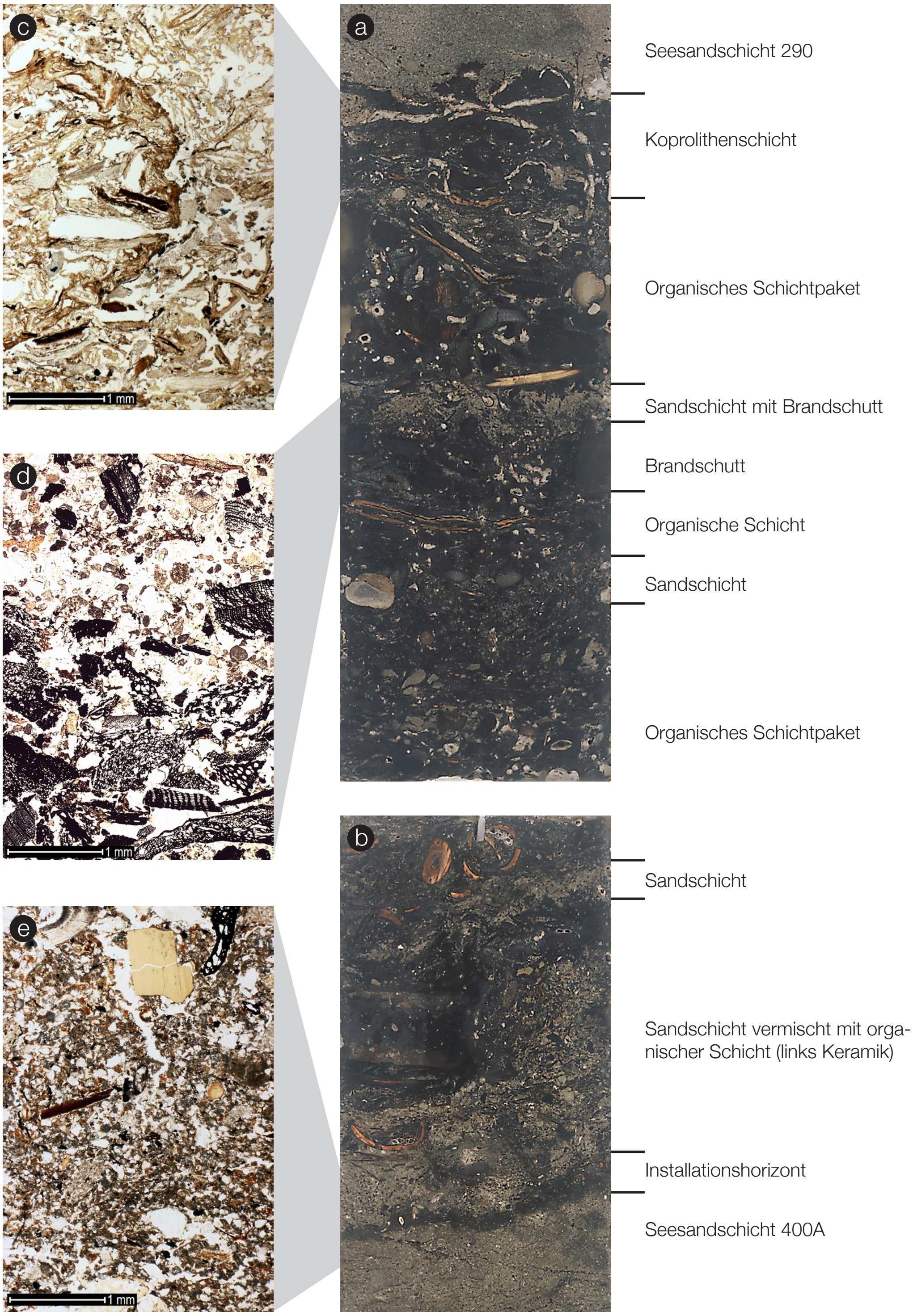

Abb. 12: Anschliffe und Dünnschliffe der Probe 1030, Haus 1; Originale Schichtabfolge (a, b), Höhe 30 cm, und dazugehörige mikroskopische Ausschnitte (c-e). Zur Ereignisabfolge siehe Kap. ‚Spezielle Abfolgen in den Proben'. Fotos Archäologische Bodenforschung Basel-Stadt und K. Ismail-Meyer.

Mögliches Szenario der Sedimentation

Die neolithische Siedlung wurde nahe des Bodenseeufers auf einer sandigen Seeablagerung errichtet. Der Siedlungsbeginn manifestiert sich durch einen Installationshorizont, der sich, ausser in den seenahen Proben 1007 und 1015, in jeder Kolonne zeigt. Diese erste deutlich fassbare archäologische Schicht entstand durch Begehung im Zusammenhang mit dem Hausbau, indem verschleppte Seekreide mit Holzabfällen und weiteren pflanzlichen Resten stark verdichtet wurde (Schichtmächtigkeit 0,5 bis 2 cm).

Oberhalb des Installationshorizontes lagerten sich organische Schichten (310/320) ab, die aus Nahrungsabfällen, Überresten von Baumaterialien, Abfällen handwerklicher Tätigkeiten oder Koprolithen bestehen. Vermutlich erfasst man mit den organischen Ablagerungen nur einen Bruchteil der ursprünglich akkumulierten Reste (mindestens 1 cm Material jährlich). Mehrfach wurden wahrscheinlich bei intensiven Regenfällen oberflächliche Bereiche der Kulturschicht durch den Bach abgetragen und vermischt mit erodiertem Sand einsedimentiert (Sandschichten / Sandband 312). Es lassen sich mutmasslich zwei bis drei Überschwemmungsereignisse fassen.

Nach 15 Jahren brannte die Siedlung ab, was durch einen Brandhorizont (Schicht 303) dokumentiert ist. Er besteht zu einem grossen Teil aus Holzkohle und verbrannten organischen Resten. Kurze Zeit nach dem Brand muss der See ziemlich rasch angestiegen sein. Dadurch wurden die Siedlungsreste überschwemmt, die Brandschicht an vielen Stellen durch Wellenschlag erodiert und vermischt mit Sand wieder abgelagert (Schicht 290).

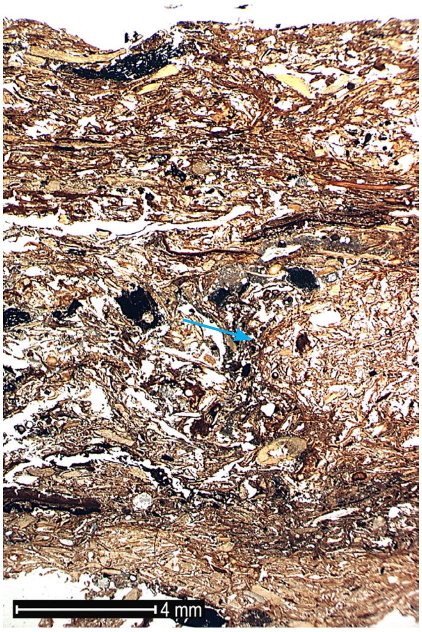

Abb. 13: Mistschicht aus Haus 3; am oberen und unteren Bildrand fast reine Koprolithenschichten, getrennt durch eine seekreide- und holzkohlehaltiges Niveau mit einem isolierten Schaf-/Ziegenkoprolith (Pfeil; Probe 5055).

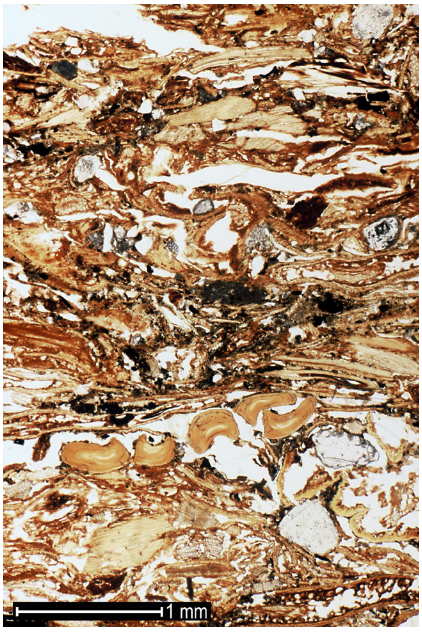

Abb. 14: Haus 3, Detailansicht aus dem mittleren Niveau; in der unteren Bildhälfte sind 5 Fischknochen und unten rechts vereinzelte Mistelreste erkennbar (Probe 5055).

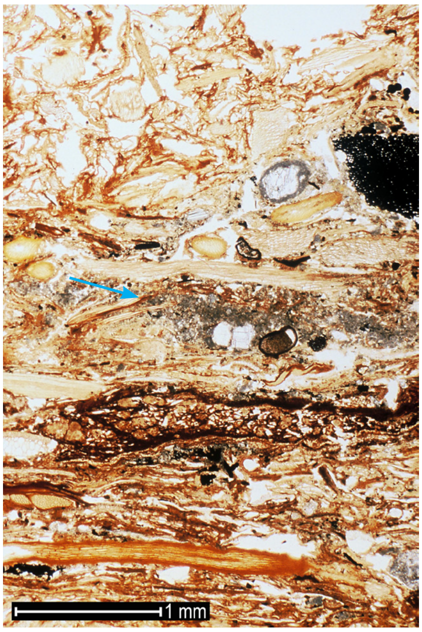

Abb. 15: Haus 3, Detailansicht aus dem mittleren Niveau; mit Seekreide durchzogener Bereich (Pfeil), oben reine Dunglage aus Schaf-/Ziegenkoprolithen (Probe 5055).

Vergleich des Schichtaufbaus zwischen den einzelnen Kolonnen

Die mikromorphologische Auswertung basierte auf der Analyse von 5 Kolonnen aus Hausgrundrissen und 2 Proben aus Gassenbereichen. Im Allgemeinen sind die einzelnen Schichtabfolgen individuell ausgeprägt. Dennoch lässt der Aufbau der Siedlungsablagerungen gewisse Gemeinsamkeiten erkennen:

- an der Basis ein Installationshorizont
- Sand einer Bachüberschwemmung
- organische Ablagerungen
- Sand einer weiteren Bachüberschwemmung
- organische Schicht (im landseitigen Bereich konnten die organischen Schichten durch keilförmige Sandschichten noch zusätzlich aufgefächert sein; Leuzinger 2000, 24 und Abb. 6)
- Brandkatastrophe und anschliessende Überdeckung durch Seesand

Grosse Ereignisse, wie zum Beispiel heftige Gewitter und Überflutungen, dürften sich auf das gesamte Siedlungsareal ausgewirkt haben. Während landwärts die Ablagerungen durch den über die Ufer tretenden Bach beeinflusst wurden, konnten seenahe Bereiche durch einen raschen Seespiegelanstieg erodiert werden. Grundsätzlich lassen sich die Proben aus Hausgrundrissen nicht von den Gassenproben unterscheiden.

Proben aus Hausgrundrissen

Die hier behandelten Proben stammen zum grössten Teil aus Zonen unter Hausgrundflächen (Proben 1015, 1028, 1030, 1036 und 1049; Abb. 3). Ältere Häuser weisen generell dickere Ablagerungspakete auf, was vermutlich mit der längeren Besiedlungszeit zusammenhängt. Am deutlichsten ist dies beim ältesten Haus 1 ersichtlich (Probe 1030), das im Jahr 3383 v.Chr. erbaut wurde. Hier ist während der Besiedlung ein 15 cm dickes organisches Paket entstanden (Sandschichten nicht einberechnet). Im Vergleich dazu weist das jüngste beprobte Haus 15 (3380 v.Chr. erbaut) eine maximal 6 cm dicke Siedlungsablagerung auf. Vermutlich geht die kürzere Abfolge hier auch teilweise auf die Lage nahe am Bodenseeufer zurück. Dadurch wurde der Installationshorizont und auch weitere Bereiche bei Hochwasser abgetragen.

Die Zusammensetzung der organischen Schichten scheint recht homogen zu sein. Selten lassen sich Elemente konzentrierter fassen, wie z.B. in den Kolonnen 1028, 1030 und 1049, wo Fischknochen häufiger vorkommen. Konzentrationen von Koprolithen kommen im Bereich der Häuser 1 und 3 vor (siehe auch unten).

Proben aus dem Gassenbereich

Aus Gassenbereichen stammen die Proben 1007 und 1029 (Abb. 3). Spezifische Informationen bezüglich des Ablagerungsgeschehens lassen sich aber nicht entnehmen, da sich die betreffenden Sedimente nicht von denjenigen der Hausgrundrisse differenzieren lassen. Ausserdem lag die Kolonne 1007 dem Seeufer so nahe, dass man von einer intensiveren Erosion durch den Bodensee ausgehen muss.

Die archäologischen Sedimente der zweiten Gassenprobe 1029 wurden während der Besiedlung stark durch Wasser aufgearbeitet. Die Schichtabfolge besteht zu einem grossen Teil aus verstürztem Wandlehm und einer Sandschicht, die durch den Bach eingebracht worden ist. Möglicherweise wurde der Wandlehm in der Folge heftiger Niederschläge erodiert.

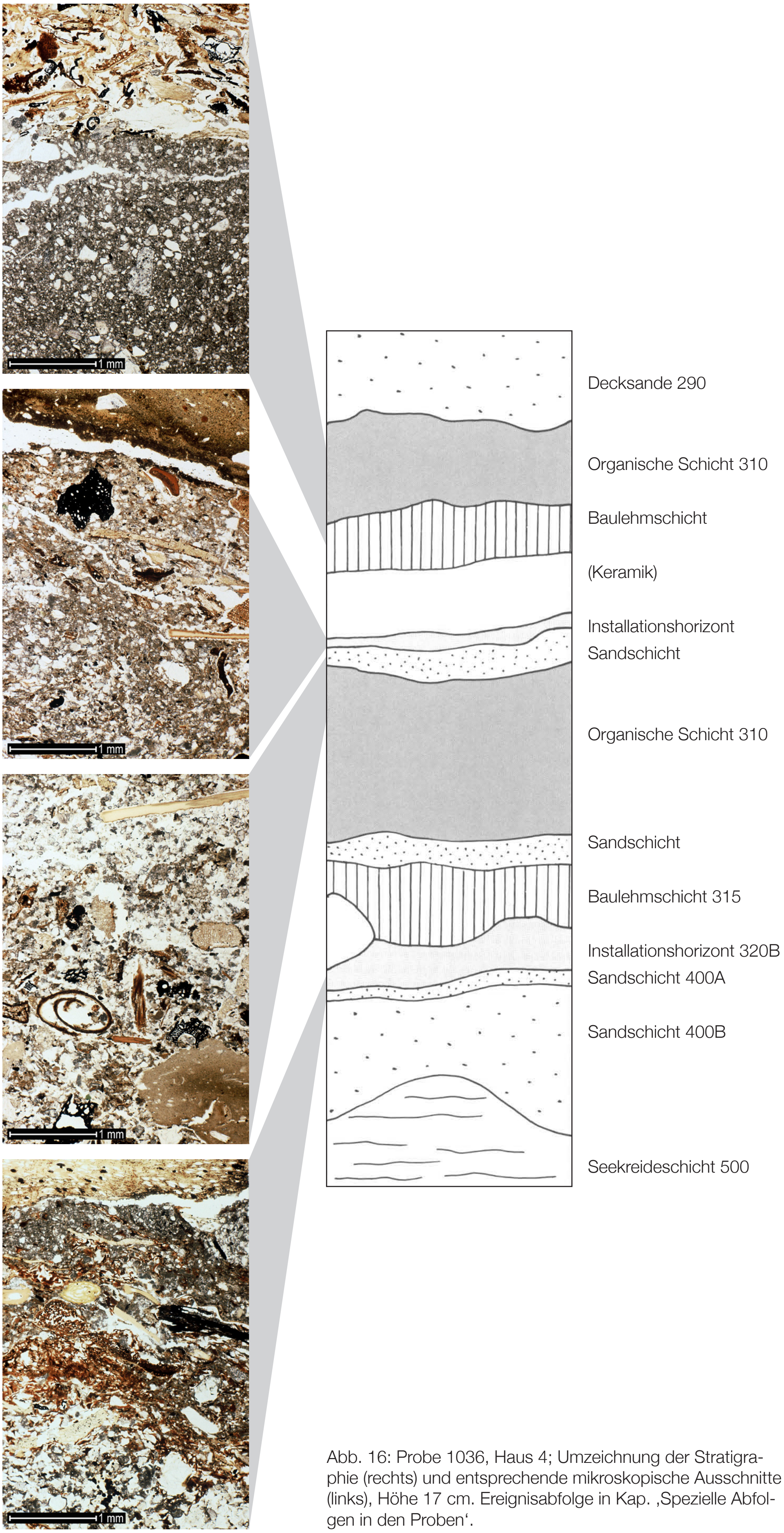

Abb. 16: Probe 1036, Haus 4; Umzeichnung der Stratigraphie (rechts) und entsprechende mikroskopische Ausschnitte (links), Höhe 17 cm. Ereignisabfolge in Kap. ‚Spezielle Abfolgen in den Proben'.

Spezielle Abfolgen in den Proben

Haus 1; abgebrannt und als Viehpferch weiterverwendet

Das älteste Haus 1 (Probe 1030) besitzt die mächtigste Schichtabfolge (Abb. 12). Über dem Installationshorizont liegt eine über 10 cm mächtige Sequenz von organischen Schichten, die durch Sandbänder unterbrochen ist. Als bemerkenswerter Befund ist ein Brandhorizont zu nennen, der oben durch eine Bachablagerung partiell erodiert ist. Abgeschlossen wird die Abfolge durch eine 7 cm dicke organische Schicht, die in den obersten 4 cm grosse Mengen an Schaf-/Ziegenkoprolithen und Misteln enthält.

Aus der archäologischen Befundauswertung geht hervor, dass das Haus im Jahr 3384 v.Chr. erstellt wurde, worauf sich infolge der Besiedlung organische Schichten bildeten. Während Schlechtwetterperioden lagerten sich jeweils dünne Sandbänder ab. Noch vor 3375 v.Chr. brannte das Haus ab, wurde aber anschliessend offenbar wieder instandgestellt, indem man neue Pfähle einsetzte. Vermutlich wurde es danach weiterhin bewohnt (Leuzinger 2000, 63). Zu einem späteren Zeitpunkt musste das Dach eingestürzt sein, was eine Aufgabe des Wohnhauses andeutet. Die anschliessend akkumulierte Dungschicht spricht dafür, dass das Areal weiter genutzt wurde und hier zeitweise Schafe oder Ziegen untergebracht waren. Die Zusammensetzung der Koprolithen zeigt, dass die Ablagerung in den Wintermonaten entstand, wobei die Tiere u.a. mit Misteln gefüttert wurden (Brombacher und Hadorn 2004).

Reste einer Dungschicht in Haus 3 (Abb. 13 bis 15)

Während der Ausgrabungen wurde unter Haus 3 ein mehrere Zentimeter dickes, kompaktes, organisches Schichtpaket angetroffen, das sich durch seine Beschaffenheit von der Umgebung abgrenzte. Die Ausdehnung des speziellen organischen Sedimentes betrug etwa 15 auf 24 cm, umfasste also nur einen kleinen Bruchteil des Hausgrundrisses.

Im Vordergrund der geoarchäologischen Untersuchungen stand die Frage, ob es sich bei diesem Sediment um einzelne Kuhfladen handeln könnte, was durch drei an verschiedenen Stellen entnommene Bodenproben (5055.1–5005.3) verifiziert werden sollte. Die mikromorphologischen Ergebnisse lassen sich dabei wie folgt zusammenfassen:

Die Ablagerung besitzt im allgemeinen eine ausgeprägte Horizontalschichtung und besteht zur Hauptsache aus dicht gelagerten (Porosität: 10-20%), gut eingeregelten organischen Resten (Abb. 13). Dieser Befund deutet auf eine starke Verdichtung der Ablagerung als Folge intensiver Begehung. Die Proben 5055.1 und 5055.2 weisen zwei übereinanderliegende, je rund 1 cm dicke und kompakte Dunglagen auf, die durch eine leicht seekreidehaltige und mit diversen Kulturresten wie Fischknochen, Holzkohlen, Sand usw. durchsetzte Schicht voneinander getrennt sind (Abb. 14 und 15). In beiden Dunglagen finden sich viele Hinweise auf Koprolithen von Rindern sowie Schaf/Ziegen. Im Fall des Rinderdungs handelt es sich um bis 5 mm lange organische Reste, die von einer gelben organischen Grundmasse umgeben sind. Häufig kommen darin auch feine, deformierte (angedaute) Holzpartikel, Tannennadeln, Pilzsporen und Moosblättchen vor, was in guter Übereinstimmung mit bereits publizierten Befunden von Kuhfladen aus Arbon-Bleiche 3 (Akeret und Rentzel 2001) und weiteren, zu dieser Fundstelle dargestellten Ergebnissen steht (Kühn und Hadorn 2004). Isolierte Exkremente von Schaf/Ziege (Abb. 10b) und auch gut erhaltene Fetzen von Rinderdung (Abb. 10c) zeigen, dass bei beiden Koprolithentypen primär kein mineralischer Sandanteil vorhanden ist. Dünnschliffanalysen weisen jedoch eindeutig darauf hin, dass innerhalb der Dungschichten die bestimmbaren Fäkalienreste von mineralischen Partikeln und von grossen Mengen an unstrukturiertem organischem Material umgeben sind. Letzteres stammt mit grösster Wahrscheinlichkeit von aufgelösten und verwitterten Koprolithen. Stellenweise treten auch kleine, flach gepresste Brocken von Seekreide oder Sandpartikel auf (Abb. 15), was als Hinweis für Begehung bzw. Eintrag von Bodenbrocken ‚unter den Hufen' zu werten ist.

Die mikromorphologischen Analysen verdeutlichen somit, dass die unter Haus 3 vorgefundenen Sedimente nicht eigentliche Kuhfladen enthalten, sondern als Reste einer kompakten Mistschicht von Rindern sowie von Schaf/Ziegen zu bezeichnen sind. Nach der Anreicherung einer ersten rund 1 cm mächtigen Dunglage folgte eine Phase mit gemischter Akkumulation von sowohl Koprolithen als auch diversen Siedlungsresten, was durch die Fischknochen, Holzkohlen und Aschen (Abb. 10a) dokumentiert wird. In einer letzten Phase sedimentierte erneut Dung, der infolge Begehung mit Seekreide durchsetzt ist. Aufgrund der Tatsache, dass es sich um ein grosses Fragment einer Mistschicht handelt, ist es möglich, dass der Dung sekundär verlagert ist und sich somit der urspüngliche Viehstandplatz an anderer Stelle befand.

Reparaturen an Haus 4

Probe 1036, die aus Haus 4 stammt, enthält eine interessante Abfolge aus mehreren Baulehmschichten (Abb. 16). Auf dem Installationshorizont liegt ein etwa 1 cm mächtiger Baulehm, der im obersten Bereich mit organischen Resten durchsetzt ist. Über einer direkt anschliessenden Sandschicht folgt eine organische Sequenz, die von einer weiteren Sandlage abgelöst wird. Ein wenige Millimeter messender zweiter Installationshorizont wird von einer 1 cm dicken Baulehmschicht überdeckt. Die gesamte Abfolge endet mit einem organischen Paket.

Haus 4 ist im Jahr 3381 v.Chr. konstruiert worden. Der dabei verwendete Baulehm wurde durch Begehung und Benutzung oberflächlich stark verdichtet und mit pflanzlichen Resten verunreinigt. Anschliessend sedimentierte während 4 Jahren ein organisches Paket von 2,5 cm Dicke. Aus dem archäologischen Befund geht hervor, dass an diesem Haus im Jahr 3377 v.Chr. Reparaturen stattgefunden haben (Leuzinger 2000, 65). Erstaunlicherweise schlagen sich diese Arbeiten auch in der Mikrostratigrafie nieder: Der zweite, obere Installationshorizont und die dazugehörige Baulehmschicht dürften von diesen Ausbesserungen zeugen. Danach wurde das Haus noch mindestens 6 Jahre weiter bewohnt, bevor es durch die grosse Brandkatastrophe zerstört wurde.

Schlussfolgerungen

Aus der Siedlung Arbon-Bleiche 3 konnten sieben Profilkolonnen mikromorphologisch untersucht werden, die Hinweise zu den Sedimentationsbedingungen und den Schichtbildungsprozessen lieferten:

Die Seespiegelabsenkung unmittelbar vor der ersten Besiedlung ist durch einen Reduktionshorizont, die Sandschicht 400, dokumentiert. Die Ablagerung besteht aus aufgearbeiteter Seekreide und bildete die Strandplatte, auf der der ausgegrabene Teil der Siedlung ab dem Jahr 3384 v.Chr. entstand.

An der Basis der meisten Proben liess sich ein Installationshorizont feststellen. Dabei handelt es sich um ein dichtes sandig-mikritisches Niveau, das mit organischem Detritus und pflanzlichen Resten durchsetzt ist. Er entstand infolge des Hausbaus durch Verschleppung und Verdichtung von Baumaterial.

Die organischen Ablagerungen, die während der Besiedlung anfielen, weisen eine optimale Erhaltung auf. Sie haben sich vermutlich kontinuierlich unter feuchten Bedingungen abgelagert und wurden kaum durch Wasser aufgearbeitet, höchstens leicht aufgeschwemmt. Ein Bach, der in Profilen aus dem nördlichen Grabungsteil erfasst wurde, ist bei heftigen Gewittern ab und zu über die Ufer getreten. Er erodierte dabei Feinsediment aus einem mächtigen Sandpaket, das sich in der Nähe des Bachlaufs befand. Die organischen Schichten wurden dadurch leicht erodiert, worauf sich jeweils eine sandige Schicht, durchsetzt mit organischen Resten, abgesetzt hat.

Seltener lassen sich sandig-mikritische Lagen feststellen, bei denen es sich um Baumaterialdepots handelt. Das Material, das zum Abdichten von Wänden verwendet wurde, besteht aus Seekreide, die mit Flusssand vermischt wurde.

Vermutlich erfasst man in den bearbeiteten Profilkolonnen jeweils einen ähnlichen Ausschnitt, der erhalten geblieben ist. Der grobe Ablauf der Siedlungsgeschichte lässt sich folgendermassen zusammenfassen:

Die Siedlung Arbon-Bleiche 3 wurde auf einem Sandstrand nahe des Bodenseeufers errichtet. Infolge des Hausbaus hat sich an der Basis ein kompakter Installationshorizont gebildet. Durch eine Bachüberschwemmung wurde dieser Horizont leicht erodiert und mit Sand überdeckt. Darauf lagerte sich eine organische Schicht als Folge der Besiedlung ab, die anschliessend durch eine erneute Überschwemmung erodiert wurde. Möglicherweise erfolgten im Anschluss an dieses Ereignis Reparaturen an einzelnen Häusern. Nach der Sedimentation eines weiteren organischen Paketes brannte die Siedlung nach insgesamt 15 Jahren ab, wurde rasch vom See überschwemmt und mit Seesand überdeckt.

Probe	Dünnschliffe	x-Koordinate	y-Koordinate	Höhe OK (m ü.M.)	Lage
1007	1007.1-2	64.10	195.12	394.09	Gasse zwischen Haus 21 und 18
1015	1015.1-3	64.18	203.90	394.31	innerhalb Hausgrundriss 15
1028	1028.1-3	64.22	12.27	394.61	innerhalb Hausgrundriss 3
1029	1029.1-4	67.21	212.34	394.53	Gasse zwischen Haus 3 und 5
1030	1030.1-6	59.23	214.9	394.96	innerhalb Hausgrundriss 1
1036	1036.1-5	67.38	217.26	394.67	innerhalb Hausgrundriss 4
1049	1049.1-3	63.90	224.10	394.96	innerhalb Hausgrundriss 2
5055	5055.1-3	61.85	208.36	394.60	Einzelprobe aus Haus 3

Tabelle 1: Probeliste der mikromorphologisch untersuchten Profilkolonnen.

								Zusammensetzung					Sand						Matrix						Seefauna				Organ. Material				Holzkohle			Knochen			Koprolithen		Ton			Makroresten	
Archäologische Schicht	Dünnschliff	mm-Schicht	Matrix	Wurzeln	Schichtung (/ schräg, B Bänder)	Kompaktion	Grenze gegen oben	Porosität (%)	Quarzgehalt (%)	Karbonatgehalt (%)	Organ. Gehalt (%) mit Holzkohle	Tongehalt (%)	Muskovit	Kalzit	Glaukonit	Chert	Coated grains	max. Korngrösse	Karbonatkörner	Mikrit	Ton	Mikroholzkohle	Organ. Partikel	Eisenausfällungen	Mollusken (x grau, l Lösungsspuren)	Ostracoden	Characeenresten	Trichoptera (Anz.)	Pflanzliche Komponenten	max. Grösse (mm)	Einregelung	Sortierung	Holzkohlengehalt	max. Grösse (mm)	Rundung	Fischknochen	Tierknochen	verbrannt	Koprolithen (Anzahl) K Karnivor, Z Ziege/Schaf, R Rind, M Mensch S Schwein	Erhaltung	Tonaggregate	Keramik (Anzahl)	Wandlehm	Makroresten M Makroresten indet., T Tannadeln, R Rinde, H Haselnussschalen, B Brom/Himbeer-, E Erdbeer-, m Mohnsamen, W Wurmkalzit, I Mistel	Bemerkungen
290B	Anschliff	-	Sand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
310o	M7.1	1	Organ. Partikel, Silt	xxxx	xx	-	xxx	20-25	5-10	15-20	45-60	2	o	o	o	o	-	fK	o	x	-	xxxx	xxxx	xx	-	-	-	-	xxx	12	xx	xx	xxx	21	xx	xxx	x	-	3M 1?	xx	-	-	-	M T R H B I	Moos, Gipskristalle
310s	M7.1	2	Mittelsand	xx	xx	-	xx	20-25	25-30	10-15	30-45	2	o	o	o	o	-	mS	x	o	-	x	x	xx	-	-	-	-	xxx	2	xx	xxx	x	2	xxx	xx	x	-	1?	xx	o	-	-	M T B I	-
310	M7.1	3	mikrit. f-mS	xx	xx	-	xx	25-30	5-10	20-25	45-50	2	o	o	o	o	o	gS	o	x	o	x	xx	x	-	-	-	1	xxx	8	xx	xx	xx	4	xxx	xxx	x	-	3K	xxx	x	-	-	M T H B m I	-
400A	M7.1	4	f-mS	x	-	-	xx	15-20	25-30	35-45	15	-	o	o	o	o	xx	mS	xxx	x	-	x	x	x	xxx	-	-	-	x	5	xx	x	o	0.5	x	o	x	-	1?	xxx	-	-	-	M H	-
500v	M7.2	5	siltiger Mikrit	x	B	x	xxxx	2-10	5-10	70-80	10	-	-	o	o	o	o	fS	xxxx	xxx	-	x	xx	xx	xxl	xx	o	-	x	4	x	xx	o	1	x	-	x	-	1M	xxx	-	-	-	T R B	Org. Mat. von oben eingetieft
500	M7.2	6	siltiger Mikrit	-	B	-	xx	5-10	2-20	70-90	2	-	o	o	o	o	o	fS	xxxx	xxx	-	xx	x	x	xx	x	xx	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
303	M15.1	1	ton. f-mS	xxx	x	-	-	20-25	10	10-15	40-50	10	o	o	o	o	o	mS	xx	o	x	xxx	xx	x	x	x?	-	-	x	9	x	xxx	xxxx	14	x	xx	-	-	-	-	xx	-	-	M T B E	-
310	M15.1-2	2	organ. Partikel, f-mS	xxx	xx/	-	xx	20-25	20-25	15-20	25-40	5	o	o	o	o	-	gS	o	xx	-	xxxx	xxxx	x	-	-	-	-	xxxx	25	xxx	x	xxx	5	xxx	x	x	-	1Z 1R 1S	x	xxx	-	-	M T R H B E m	an UK platy structure durch Wurzeln
310s	M15.2	3	Feinsand	-	x	-	xx	25-30	25-30	10-15	25-40	-	o	xx	o	o	-	mS	x	-	-	x	x	-	o	-	-	-	xxx	1	x	xxx	x	1	xxx	o	o	-	-	-	-	-	-	T	-
310	M15.2	4	organ. Partikel, fS	xx	x	-	xxx	25-30	20-25	15-20	25-40	-	o	xx	o	o	-	mS	o	xx	-	xx	xxx	-	o	-	-	1	xxx	15	x	xx	x	4	xxx	o	-	-	-	-	-	-	-	M T H I	-
400Av	M15.2-3	5	f-mS	-	B	-	xxx	25-30	25	25-30	15-25	-	o	o	o	o	x	mS	xxx	o	-	x	x	-	xxx	-	-	1	xx	11	x	x	x	1	xxx	xx	-	o	1M	x	-	-	-	T R H	Spültrichter, stw. nur organ. Reste aus Kulturschicht vorhanden
400Bv?	M15.3	6	mikrit. f-mSand	x	-	-	xxxx	10-15	10-15	65-75	5	-	o	o	-	x	x	mS	xxxx	xxx	-	xx	xx	x	xxx	x	x	-	o	3	-	xx	x	0.5	xx	o	o	-	-	-	-	-	-	T	vermischt, umgelagert
400B	M15.3	7	mikrit. f-mSand	-	x/	-	xxxx	10-15	10-15	65-75	5	-	o	o	o	x	x	mS	xxx	xxxx	-	xxx	x	x	xxxl	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
500	M15.3	8	siltiger Mikrit	xxx	B	-	xx	5-8	5	85-90	2	-	o	o	o	o	o	fS	xxx	xxxxx	-	xxx	xx	xx	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290A	M28.1	1	Feinsand	-	B	-	-	15-20	45-55	25-30	5	-	o	o	-	o	xx	mS	xxx	o	-	x	-	-	xxx	x	x	-	o	3	x	xx	x	1.5	xxx	o	o	-	1Z 1M?	xx	-	-	-	-	-
290B	M28.1-2	2	Feinsand	-	B	-	xx	15-20	20-25	20-25	30-45	2	o	o	o	o	xx	mS	xx	x	-	x	x	-	xxxxl	x	xx	1	xxx	13	xx	x	xxx	5	xx	o?	xx	x	3Z	x	x	2	-	M T H B m	-
310	M28.2	3	Silt, leicht mikrit.	xxx	xx	-	xxxx	10-20	10-15	15-20	45-65	-	?	o	o	o	-	mS	x	o	-	xx	xx	xx	-	-	-	-	xxxx	13	xx	xx	xxx	1.5	x	xx	x	x	1R	xx	-	-	-	M T H	viel Moos
310s	M28.2	4	silt. Feinsand	xx	xx	-	xxx	20-25	20-25	20-25	25-40	2	o	o	o	o	o	gS	xx	o	-	xx	xx	xx	xx	-	-	-	xxx	24	xx	xx	xx	1	x	xx	xx	-	1M?	xx	o	-	-	M T R	-
310	M28.2-3	5	mikrit. Silt	xxx	xxx	o	xx	15-30	5-10	15-20	40-65	2	o	o	o	o	-	gS	o	xx	-	xx	x	x	-	-	-	-	xxxx	14	xxx	xx	xxx	5	xx	xxx	x	-	5Z	x(xx)	o	1	x?	M T R H E m	stw. sehr kompakte organ. Reste
312s	M28.3	6	Feinsand	xx	x	-	xxx	10-15	25-30	20-25	25-40	5	o	o	o	o	o	mS	xx	x	o	xx	x	x	o	o	-	-	xxx	8	x	xx	xxx	1	x	xx	o	-	-	-	x	-	-	M	-
320u	M28.3	7	organ. Mikrit	xxx	xx	x	xxxx	20-30	5	35-55	20-30	-	o	o	o	o	o	fS	o	xxxxx	-	xxx	xxxx	xx	o	-	-	-	xxxx	10	xx	xx	xxx	6	xx	-	x	o	1Z	xx	o	-	-	M T R H B I	stw. sehr kompakt, Grenze gegen oben wellig erodiert
400A	Anschliff	-	Sand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290B	M29.1	1	Feinsand	x	B	-	-	10-15	20-25	25-30	30-45	-	o	o	-	o	xx	mS	xx	o	-	x	x	x	xxxl	x	x	1	xx	16	xx	xx	xxxxx	16	xx	o	xx	-	-	-	-	-	-	H I	-
310	M29.1	2	organ. Partikel, fS	x	xx	-	xxxx	25-30	10-15	10	45-55	2	o	o	o	o	-	mK	o	o	-	xx	xxx	xx	-	-	-	-	xxx	6	x	xxx	xx	4	xx	x	o	-	1M 1Z	xx	o	-	-	M T B E	-
310sv	M29.1-2	3	mikrit. Mittelsand	xx	x	-	xx	15-20	15-20	25-30	30-45	-	o	o	o	o	-	mK	o	x	-	xx	xxx	xx	-	-	-	-	xxx	4	x	xx	xx	6	xxx	xx	x	-	-	-	-	-	-	M R T B	stw. Gipskristalle
310s	M29.1	4	Mittelsand	-	x	-	xxx	10	25-30	30-35	25-35	2	o	o	o	o	o	gS	xxx	o	-	xx	x	x	o	-	-	-	xx	3	xx	xxx	x	0.5	xx	o	o	-	-	-	o	-	-	-	-
315u	M29.2-3	5	f-mS Mikrit?	xx	B	x	xxxx	2-5	5-20	70-90	2-5	?	o	xx	o	x	o	fK	x	xxxxx	xxx	xx	-	x	o	-	o	-	x	3	-	x	xxx	18	x	o	-	-	-	-	xxx	-	x?	T	organ. Mat. durch Wurzeln eingebracht?
320s	M29.3	6	fS, leicht mikrit.	xx	x	-	xxxx	20-25	15-20	35-50	15-20	-	o	o	o	o	o	mS	xx	xx	-	xx	xx	x	o	-	-	-	xxx	5	x	xx	xx	1	xx	-	-	-	1Z	x	-	-	-	-	-
320	M29.3	7	organ. Mikrit	-	x	x	xxx	15-20	5	60-65	15	-	o	o	o	o	o	fS	xxx	xxx	-	xxx	xxxx	x	x	-	-	-	xxx	6	xx	xx	xx	1	xx	o	x	o	-	-	-	-	-	M T	Harz, Kirschkern?
400A	M29.3	8	Feinsand	-	x	-	xxxx	15-20	10-15	45-60	15-20	-	o	o	o	o	x	mS	xxxx	x	-	x	x	x	xxxl	-	-	1	x	2	xx	xx	x	2	xx	x	x	-	-	-	-	-	-	M	-
400B	M29.3	9	mikrit. f-mSand	x	x/	-	xxxx	10-15	10-15	65-75	5	-	o	o	o	x	x	mS	xxxx	xxx	-	xx	xx	x	xxxl	x	-	3	o	4	-	-	o	1.5	x	x	-	-	-	-	-	-	-	R	umgelagert?
500	M29.3-4	10	siltiger Mikrit	x	B	-	xx	5-8	2-10	80-90	2	-	o	o	o	o	o	fS	xxxxx	xxx	-	xx	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290A	M30.1	1	Feinsand	-	B	-	-	20-25	35-45	30-35	5	2	o	o	o	o	xx	mS	xxx	x	o	x	x	xx	xxxl	-	-	-	-	-	-	-	-	-	-	o	-	-	-	-	xx	-	-	-	-
310	M30.1	2	wenig silt. Ton	xxx	xx	-	xxxx	30-40	5	2	50-60	5	o	o	o	o	-	mS	o	o	x	x	x	xxx	-	-	-	-	xxxxx	11	xxx	xxx	xx	6	xx	-	-	-	13Z	x(xx)	x	-	-	M T R I	Dungschicht
310	M30.1	3	organ. Part., fS, Mikrit	xxxx	xx	-	xxx	20-25	10-15	20-25	30-45	5	o	x	o	o	-	mS	x	xx	o	xxx	xxxx	xx	-	-	-	-	xxxx	11	xx	xxx	xxx	4	xx	xxxx	-	x	2R 14Z	x(xx)	xxx	-	x?	M T B E m	Dungschicht, Kiemen als Schicht vorhanden
310	M30.2	4	wenig silt.-tonig	xx	xx	-	xx	30-40	2-5	2	50-60	5	o	o	-	o	o	mS	-	-	o	x	x	x	-	-	-	-	xxx	6	xx	xx	xxxxx	8	xxx	x	-	-	1Z	xx	o	-	x?	M T m	Hüttenlehmfragment?
312s	M30.2	5	Mittelsand	xx	x	-	xxxx	20-25	20-25	15-20	30-45	2	o	o	o	o	xx	gS	xx	o	-	xx	x	x	-	-	-	-	xxx	4	x	xx	xx	4	xx	x	-	-	-	-	xx	-	-	E m	Mohn sehr häufig, Zellketten.
320	M30.2	6	wenig mikrit. fS	xx	xx	-	xxx	10-15	5-10	10-15	60-85	2	o	o	o	o	o	mS	x	x	o	xxxx	xx	x	-	-	-	-	o	3	xx	xx	xxxxx	25	x	-	x	-	-	-	-	-	-	M m	-
310	M30.2-3	7	org.P., wenig Matrix	xxxx	xxx	-	xxx	40-50	5	2	40-50	5	o	o	-	o	-	fS	o	o	x	x	xxx	xx	-	-	-	-	xxxx	16	xxx	x	xxx	5	xx	xx	-	-	2Z	xx	-	-	-	M T R B	-
320s	M30.3	8	f-gS	xxx	-	-	xxx	15-25	20-25	15-20	30-50	2	o	o	o	o	o	fK	xx	o	-	x	x	xx	-	-	-	-	xxxx	6	-	xxx	xx	1	xx	xx	xx	x	-	x	xx	-	x?	M T E	-
320	M30.3-4	9	wenig tonig-fS	xxxx	xx	-	xx	25-35	10-15	-	35-50	15	o	o	o	o	-	gS	-	-	x	xx	xxx	xxx	-	-	-	-	xxxx	15	xx	xx	xx	5	xxx	xx	o	-	12Z	x(xx)	xxx	-	-	M T H B E m	-
320s	M30.4	10	toniger f-mS	xxx	x	-	x	20-25	15-20	5	30-40	15	o	o	o	o	o	mS	x	o	xx	xx	xx	x	o	-	-	-	xxxx	30	xx	xxx	xxx	3	xx	o	o	-	2Z	xx	xxx	-	-	M T R H E m	an UK mit vielen Aggregaten, stark mikritisch
320s	M30.4	11	f-gSand	x	x	-	xxx	25-30	25-30	10-15	30	5	o	o	o	o	o	gS	xx	-	-	x	x	-	-	-	-	-	xxxx	2	x	xx	xx	1.5	xx	o	o	-	1R	xx	xx	-	-	M T	-
320uv	M30.4-5	12	mS, stw. tonig, mikrit.	xx	x	-	xxx	20-25	15-20	15-20	30-45	5	o	o	o	o	x	gS	xx	o	-	xx	xx	x	xxl	-	-	1	xxx	13	x	xx	xx	6	xx	xxx	xx	x	4Z 3R	xx	xxx	1	x?	M T R H B I m	viele Aggregate, Schwemmkegel
320s	M30.5	13	f-mS, leicht mikrit.	-	xx/	-	xx	15-20	20-25	25-30	20-35	5	o	o	o	o	x	mS	xx	x	o	x	x	x	xxl	-	-	-	xx	6	x	xxx	x	2	xxx	xx	x	x	1Z	xx	xxx	1	x?	R H I	viele Aggregate, Schwemmkegel
320	M30.5	14	organ. Mikrit	-	xx	x	xxxx	5-10	15-20	45-50	20-25	5	o	o	o	o	o	mS	x	xxxx	-	xxx	xxxx	xx	xx	-	o	-	xx	10	xx	xx	o	1	xxx	xxx	x	x	1Z	-	xxx	-	x?	T R H	Aggregate aus verwittertem Lehm (Molasselehm?)
400B	M30.5-6	15	mikrit. f-mSand	x	x/	-	xxx	5-10	15-20	65-75	5	-	o	o	o	x	xx	mS	xxxx	xxx	-	xxx	x	x	xx	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Schwemmkegel
310	M36.1	1	mikrit. Feinsand	x	xxx	-	-	15-30	10-15	15	40-60	-	o	x	o	o	-	fS	o	x	-	xxx	xxxx	x	-	-	-	-	xxxx	9	xxx	xx	xx	2	xxx	x	o	x	-	-	-	-		M R T m	-
310	M36.1	2	ton. Feinsand	x	xx	-	x	30-40	5-10	2	35-60	5-15	o	x	o	o	-	fS	o	-	x	xx	xx	xx	-	-	-	-	xxxx	12	xx	xxx	xx	3	xxx	x	x	x	6Z 1R	x	-	-	-	M R T	Mistschicht?
310	M36.1-2	3	mS Mikrit	xxx	-	x	xxx	5-15	20-25	60-70	2	-	o	xx	o	x	o	fK	xx	xxxxx	-	xx	x	xxx	-	-	-	-	o	1	-	-	x	0.5	xx	-	-	-	-	-	-	1	x?	W	Umbauphase von 3377 BC?
310	M36.2	4	organ. Mikrit	xxx	xx	x	xxxx	15-30	5-10	20-60	20-40	-	o	o	o	o	o	mS	xx	xxx	-	xxx	xxx	xx	-	-	-	-	xxx	5	xxx	x	xxx	1	xx	xx	o	xx?	-	-	-	-	-	T R	Umbau von 3377 BC? Stw. viel org. Mat., sonst wenig
310s	M36.2	5	Feinsand	xx	x	-	xxxx	30-35	25-30	10-15	20-35	2	o	o	o	o	o	gS	xx	o	-	x	xx	x	-	-	-	-	xx	2	x	xx	xx	1	xx	xx	o	-	-	-	xx	-	-	R	-
310s	M36.2	6	toniger Feinsand	xx	x	-	xx	15-20	20-25	10-15	30-45	10	o	o	o	o	-	mS	xx	o	x	xxx	xxx	xxx	-	-	-	-	xx	3	x	xx	xxx	1	xxx	x	x	x?	-	-	xx	-	-	M T R	-
310?	M36.2-3	7	organ. Mikrit	xxx	xxx	-	xxx	20-25	5	40-50	25-30	o?	o	o	o	o	-	mS	o	xxxx	o?	xxxx	xxxx	xx	-	-	-	-	xxx	40	xxx	-	xxx	4	x	xx	o	x?	1R 1Z	x	-	-	-	M T R	stw. Nester mit Seesand (coated grains)
310s	M36.3	8	f-gS	xx	-	-	xxx	15-20	30-40	10-15	20-40	5?	o	xx	o	o	o	gS	x	x	x	xx	xx	xxx	-	-	-	-	xx	9	-	x	xx	2	xx	-	-	-	-	-	o	-	-	H	Gips, stw. wenig Matrix, an UK viel Fe
315	M36.3	9	mS Mikrit	xxx	xx	x	xxxx	5-10	5-15	55-80	10-20	-	o	o	o	o	-	fK	x	xxxxx	-	xxxx	xxxx	xx	-	-	-	-	xx	2	xxx	xxx	xxx	2	xx	-	o	o	-	-	x	-	-	M T m	Baulehm mit organ. Resten, stw. sandige Schichten
315	M36.3	10	mS Mikrit	x	-	x	xx	2-10	15-20	65-75	5	-	o	x	o	x	-	gS	x	xxxxx	-	xx	o	-	xx	-	-	-	x	2.5	-	-	x	1	xxx	-	-	-	-	-	x	1	x?	T	-
320	M36.3	11	organ. Mikrit	xx	xxx	x	xxx	2-10	2-5	35-65	30-50	-	o	o	o	o	o	mS	xx	xxx	-	xxx	xxxx	xx	o	o	-	-	xxx	15	xxx	x	xxx	1.5	xxx	xx?	?	-	1M	xxx	x	-	-	T	-
400Av	M36.3	12	Feinsand	xx	x	x	xxxx	15-20	10-15	55-65	10	-	o	o	o	o	x	mS	xxxxx	x	-	x	x	x	xx	-	-	1	xx	9	xx	x	o	0.5	xx	x	x?	-	-	-	-	-	-	M R T H	an OK kompaktiert
400B	M36.3-4	13	mikrit. f-mSand	xx	xx/	-	xx	10-15	15-20	60-70	5	-	o	o	-	x	x	mS	xxx	xxx	-	xx	xx	xx	xxxl	o	x	1	o	1	-	xx	o	0.5	xx	-	-	-	-	-	-	-	-	-	umgelagert?
500	M36.4-5	14	siltiger Mikrit	xxx	B	-	xx	5-20	10-15	60-80	5	-	o	o	o	o	o	fS	xxx	xxxx	-	xx	x	x	xxx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290v	M49.1	1	Mittelsand	x	x	-	-	20-25	15-20	15-20	35-50	2	o	o	o	o	xx	fK	xx	o	-	xx	xx	xx	xxxl	o	xx	1	xxx	5	xx	xx	x	5	xxx	x	-	-	2Z 3R	xx	o	-	-	M R T B R	Vermischung mit 310. 303 erodiert
310	M49.1	2	organ. Partikel, mS	xxx	x	-	x	20-25	10-15	5	45-55	10	o	o	o	o	-	mS	o	o	x	xx	xxx	x	xx	-	-	-	xxx	12	x	x	xx	5	xx	xx	-	x	2Z 1R	xxx	-	-	-	R M B E	viele Aggragate, stw. Gipskristalle
310s	M49.1-2	3	f-mS	-	x	-	xxx	20-25	30-35	20	15-25	5	o	x	o	x	o	mS	o	o	o	x	x	xx	-	-	-	-	x	2	x	xxx	o	0.5	xx	x	-	x?	-	-	x	-	-	-	-
310	M49.2	4	organ. Partikel, mS	x	x	-	xx	20-25	15-20	10-15	40-55	2	o	o	o	o	-	mS	o	x	-	xx	xxx	xx	-	-	-	-	xxx	5	xx	x	xx	5	xx	xxx	-	xx	-	-	x	-	-	M T E	-
312s	M49.2	5	Mittelsand	x	x	-	xx	15-20	30-35	25-35	15	5	o	o	o	o	o	mS	xx	o	-	x	x	xxx	-	-	-	-	x	3	x	xxx	x	2	xx	-	o	-	-	-	xxx	-	-	M E W	einige Gipskristalle
315	M49.2	6	organ. Mikrit	x	x	x	xx	10-15	10-15	50-65	15-20	2	o	o	-	o	o	gS	x	xxx	-	xxx	xxxx	xx	xx	-	-	-	x	19	xx	x	o	1	xx	xx	-	x	-	-	xx	-	x	H 2W?	Begehung? Gipskristalle in Matrix
315s	M49.2	7	Mittelsand	x	x	-	xxx	15-20	35-40	35-45	5	2	o	o	o	o	x	mS	xxx	x	-	x	x	xx	xx	-	-	1	o	4	x	xx	o	1	xxx	xx	-	-	-	-	xx	-	-	HE	Sand aus 400A, anthrop. Sand oder Überschwemmung?
315	M49.2	8	organ. Mikrit mit mS	x	x	x	xxx	10-15	15-20	50-60	15	2	o	o	o	x	x	mS	x	xxxx	-	xxx	xxxx	xx	xx	-	-	-	x	7	xx	x	o	0.5	xx	xx	-	o	-	-	xx	-	x	m	Begehung? Magerung aus 400B
400Av	M49.2-3	9	Feinsand	xx	x	-	xxx	15-20	15-20	50-60	10	-	o	o	o	x	x	gS	xxxx	x	-	x	x	x	xxxxl	o?	-	-	o	1	x	xx	x	2	xxx	x	x	-	-	-	-	-	-	T	-
400B	M49.3	10	mikrit. f-mSand	xx	xx/	-	x	10-15	15-20	60-70	5	-	o	o	o	x	x	mS	xx	xxxx	-	xx	xx	x	xxxl	x	x	-	o	1	-	xx	o	0.5	x	x	-	-	-	-	-	-	-	-	stw. Gipskristalle in Matrix

290A	limnischer Sand	v	vermischt	fS	Feinsand (0.06-0.2 mm)
290B	limnischer Sand vermischt mit Kultursch	u	umgelagert	mS	Mittelsand (0.2-0.6 mm)
303	Holzkohleschicht (Brandschutt)	-	nicht vorhanden	gS	Grobsand (0.6-2 mm)
300	organ. Mikrit (Baulehm?)	o	in Spuren vorhanden (unter 5%)	fK	Feinkies (2-6.3 mm)
300	Lehmpaket (Baulehm)	x	selten	mK	Mittelkies (6.3-20 mm)
300	organische KS	xx	durchsetzt	gK	Grobkies (20-63 mm)
310	organische KS mit organischem Detritus	xxx	häufig		
300s	fluvialer Sand	xxxx	sehr häufig		
400A	limnischer Sand mit organ. Resten				
400B	limnischer mikrithaltiger Sand				
500	sandige Seekreide				

Tabelle 2; Mikromorphologische Dünnschlifftabelle

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Zug-Riedmatt: Ausschnitt aus einem Profil mit der basalen Seekreide (unten, hellgrau), organischen Schichten (dunkelgrau) mit Lehmlinsen (hellgrau) und mehreren Pfählen (hellbraun). Gegen oben gehen die organischen Schichten in hellgraue, laminierte Seekreide über (Aufnahme K. Ismail-Meyer, Oktober 2008).

Zug-Riedmatt: Part of a profile with the lake marl at the base (light grey), organic layers (dark grey) with loam lenses (light grey) and several posts (light brown). Towards the top the organic layers fade into a light grey, laminated lake marl (photograph by K. Ismail-Meyer, October 2008).

3 Paludal Settings (Wetland Archaology)

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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 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 in the diet and hygiene of people also (Cole, 1995: 3; Larsson, 2007: 80; Menotti, 2004; Kenward and Hall, 2004: 4, 2008: 585; 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 Boquet, 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 (see Chapter 2, 4 and 5, this book; Krier, 1997; Wallace, 2000, 2003; Lewis, 2007; Karkanas et al., 2011).

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 (see Chapter 5, this book; Menotti, 2012: 267ff.; Heitz-Weniger, 2014; Bleicher, 2014; Pollmann, 2014: Jacomet et al., 2014).

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 (see Chapter 5, this book; Magny, 2004). 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 (see Chapter 2, this book). The auto-fluorescence 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 (see Chapter 2, this book; Babel, 1975, 1985; Stolt and Lindbo, 2010; Ismail-Meyer, accepted). 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 are 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 is useful. The micromorphological sub-sampling of the profiles (anthropogenic and limnic sediments) for further investigations, including archaeobotany and palynology, can be done with smaller plastic boxes.

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 grey, 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 grey, laminated limnic sediments (Photograph by D. Brönnimann, Institute for Integrative Prehistory and Archaeological Science, IPAS, University of Basel).

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 water table and/or lake level, due often to climatic influences, but in Western Europe over the last 7500 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 13 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 Chapter 2, 4 and 5, this book).

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 sub-littoral zone in about 1 to 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 sub-aerial 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. Lakeside settlements were normally placed in areas with no standing water and on an already hardened surface (Chapter 5, this book; Jacomet, 1985). 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).

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 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; see also Chapter 2, 4 and 5, this book; Jacomet et al., 2004). 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 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

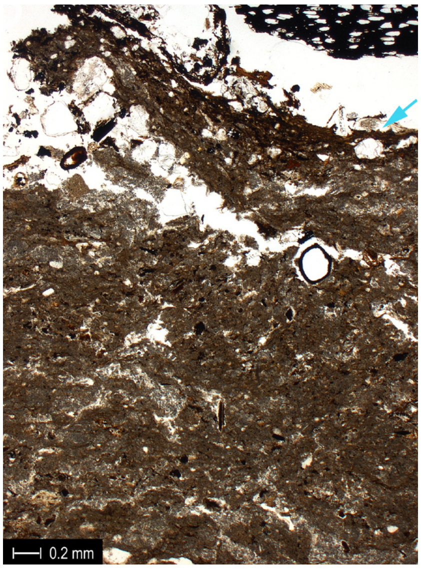


Figure 2. Lake Luokesa, Lithuania, photomicrograph of a thin section in plane-polarized light (PPL): Limnic carbonate (lake marl) overlain by an archaeological deposit. The sediment of the lower part has a heterogeneous aspect due to dense grey lake marl peds enriched with with some brown organic detritus. 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.

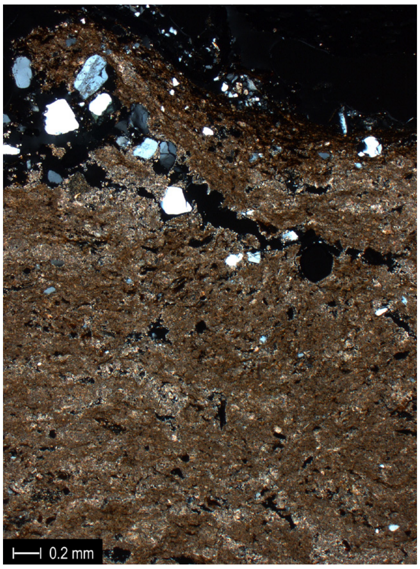


Figure 3. Same section as Figure 2, with crossed polarizers (XPL): The carbonate marl is pale, organic remains appear dark brown to black, quartz grains white and bluish-grey.

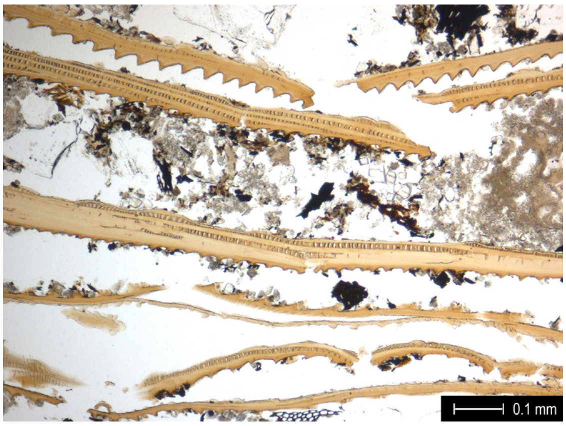


Figure 4. Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): Several well oriented fish remains (gills and scales) in different stages of preservation (well preserved at the top) and showing layers of micropores (possibly due to chemical dissolution) in the rest of the picture.

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 only 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 (see also Chapter 2, this book; Jacomet, 1985: 385). 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 it passes into the waterlogged catotelm. This implies a very slow growth rate of 0.5 to 2 mm per year (Lindsay, 2010: 78; Keddy, 2010: 193). Bones found in peat bogs are tanned with humic acids, often demineralised what can be attributed to lowering of pH or the presence of *Sphagnum* moss ('bog bodies'). Framboidal pyrit in cracks and pores occur and are due to the colonisation of sulphate 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 (Figures 4 and 5). Due to their morphology, wood, bark, foliage leaves, needles, mosses, and some seeds may be identifiable (see Schoch et al., 2004; Ismail-Meyer, accepted). The structure and shape of excrements sometimes allow the identification of the animal (Brönnimann et al., accepted; Brönnimann et al., submitted). Bones of large animals, fish, and amphibians may also be accumulated 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 (see also Chapter 2, this book; 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).

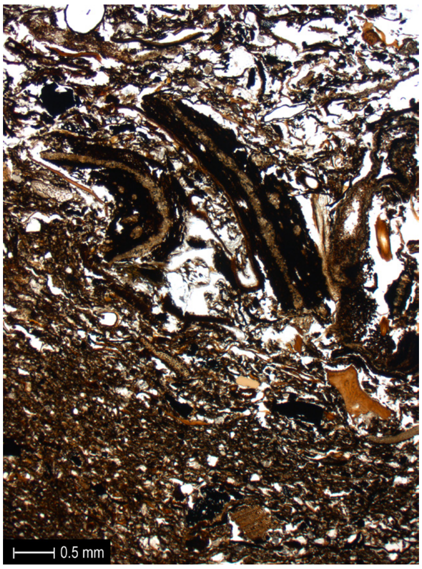


Figure 5. Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): Highly organic anthropogenic deposit, in the lower part a laminated layer composed of highly fragmented organic matter (detritus). The upper, more porous part contains bigger organic remains with many dark brown bark fragments. An example of an outdoor area within a water saturated, paludal depositional environment.

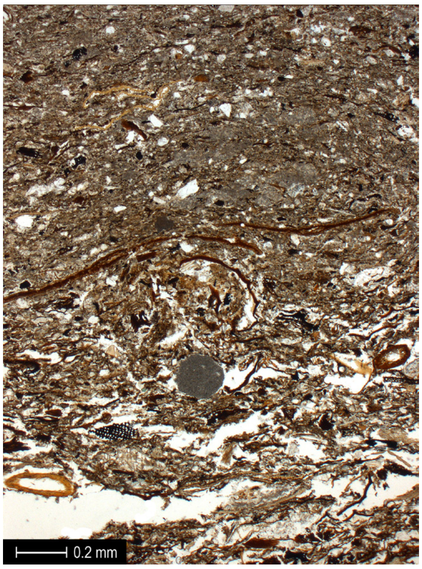


Figure 6. Zug-Riedmatt, photomicrograph in plane-polarized light (PPL): In the lower half of the picture appears an organic cultural layer, truncated and overlayn by limnic sediments with grey lake marl peds mixed with some eroded organic remains. Example of a flooding event after an occupation phase in a paludal environment.

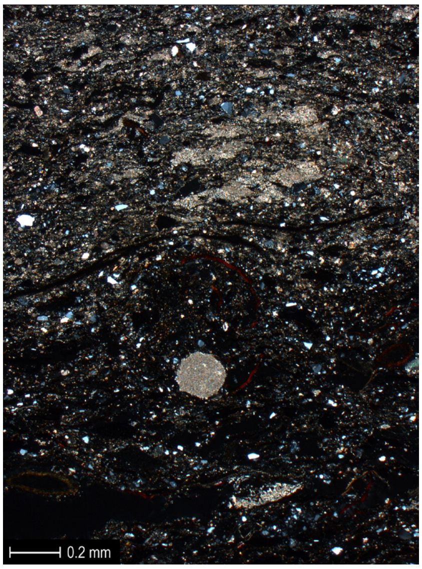


Figure 7. Same section as Figure 6, with crossed polarizers (XPL): In the upper half of the picture, the limnic carbonates appear grey, the layered organic remains are black.

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 three 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 part of a village or in protected, swampy areas beneath raised houses (see also Chapter 2, 4 and 5, this book; Jacomet et al., 2004). Such features demonstrate that, compared to the annual growth rate of a natural peat (see above), 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 pyrit due to sulphate reducing bacteria, tunnelling caused by cyanobacteria and loss of collagen, the organic part 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 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 gravels 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 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 6 and 7).

Micromorphological analyses show that organic layers may be eroded by water movements coming from the lake. Erosion boundaries are difficult to detect, even in 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).

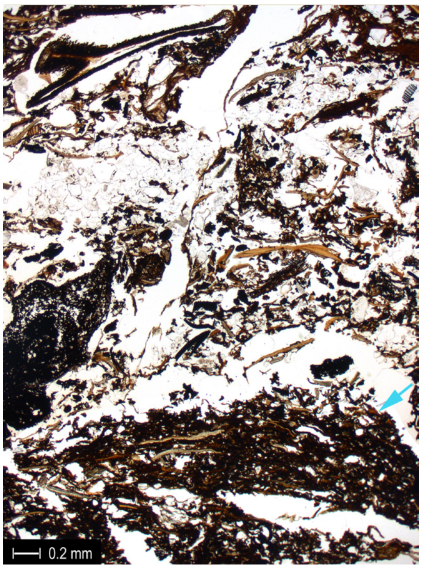


Figure 8. Lake Luokesa, photomicrograph of a thin section in plane-polarized light (PPL): Dense organic crust (arrow) of decomposed organic matter, probably due to desiccation. A sandy layer, possibly an inwash from the hinterland, covered the organic layer.

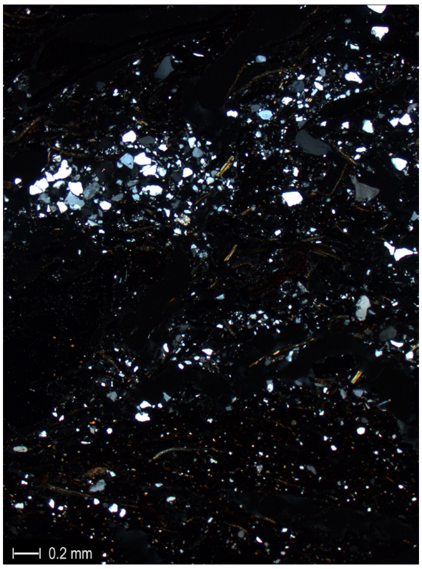


Figure 9. Same section as Figure 8, with crossed polarizers (XPL). The quartz grains from the sandy inwash are visible in white and bluish colors in the upper half of the picture.

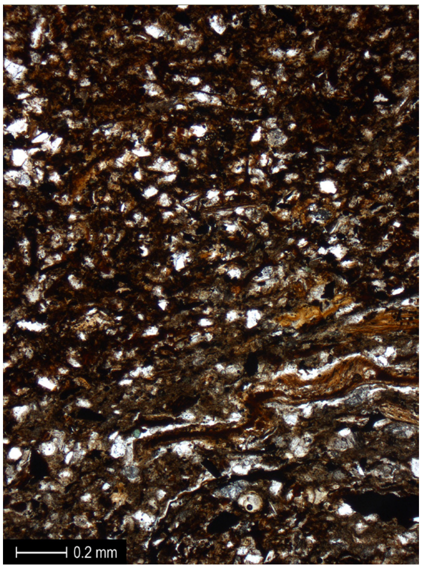


Figure 10. Stansstad-Kehrsiten, Switzerland, photomicrograph of a thin section in plane-polarized light (PPL): Compact organic detritus with fine grained sand – the result of an alteration (desiccation) of the organic matter and runoff from the hinterland.

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 three 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 one 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 8 and 9). 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 (see below).

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 (see also Chapter 2, 4 and 5, this book; Jacomet, 1985; Jacomet et al., 2004). House constructions and on site vegetation may have slowed water movement through the site.

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; 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 finally, 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 micro-organisms that are responsible for organic decay (Lillie and Smith, 2009: 17, 21). Rotting of wood has been observed due to fungi (white, red and soft 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 draw-down in the water table results in an increased load of 10 kg m^{-2} (Lindsay, 2010: 123). Drying out and alteration of bogs, 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). 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 demineralisation, shrinkage and cracking due to the drying and may contain gypsum cristals (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 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 (Figures 8 and 9, see below). Mite 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 10). 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, red and soft 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 droppings of springtails (Collembola) and/or pot worms (Enchytraeidae) may be observed. Due to weathering, sediment can become more minerogeneous (see also Chapter 5, this book). The presence of dopplerite and amorphous organic matter (AOM) seem to indicate drier ore more acidic parts of lakeside settlements, 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 the organic part of bones (collagen), tunnelling as a result of aerobic bacteria and fungi (microfocal destruction or bioerosion), cracking, and signs of dissolution due to chemical weathering. Gypsum crystals in cracks and pores may also occur; the result of the reaction from dissolved calcium with sulphate 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, Chapter 5, this book; Kenward and Hall, 2000: 521).

Post-depositional processes in natural wetlands and lakeside settlements

After burial, only very slow decay, and almost no post-burial alteration (diagenesis) occurs, 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 (see Chapter 2, this book; 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 four meters 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 (Figures 4 and 5; 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 (see also Chapter 2, 4 and 5, this book; Kenward and Hall, 2004: 8; Jacomet et al., 2004). The bones often show very good preservation, and even highly fragile fish gills and scales can be recognized (Figure 4). 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., submitted). 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 (see Chapter 2, this book; Jacomet et al., 2004). Dense organic crusts are not the result of trampling, but refer to phases of acidification/desiccation (Figures 8 and 9; see above and Chapter 5, this book).

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 organic detritus and amorphous organic matter (Figure 10). 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 (see also Chapter 5, this book).

Fire events

Fire events occur regularly in wetlands when the peat surface is sufficiently dry during seasonal or interannual dry 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 (see also Chapter 2, this book; Jacomet et al., 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 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 cal BC and was inhabited until 3370 cal 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 11 and 12). During the occupation, a five to 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 permanently humid but without standing water covering the area. The layers represent a complex puzzle of deposition and erosion. The entire anthropogenic deposit was covered by two meters 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 13). 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 seven-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 beneath it. During the time of settlement, organic layers accumulated, but were repeatedly eroded and covered by thin sand layers, probably during spring floods. After nine years of occupation, House 1 burned down and was subsequently flooded for a short period. A renovation in 3375 cal BC is demonstrated by dendrochronological investigations. Later, the roof collapsed and the house was abandoned. Micromorphological, 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 cal BC, the entire village burned down completely, and shortly after, the area was flooded by the lake (see also Chapter 2, this book; Haas and Magny, 2004; Jacomet et al., 2004).

Figure 11. Arbon-Bleiche 3: Field view of the south profile through House 1. The laminated, grey 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).

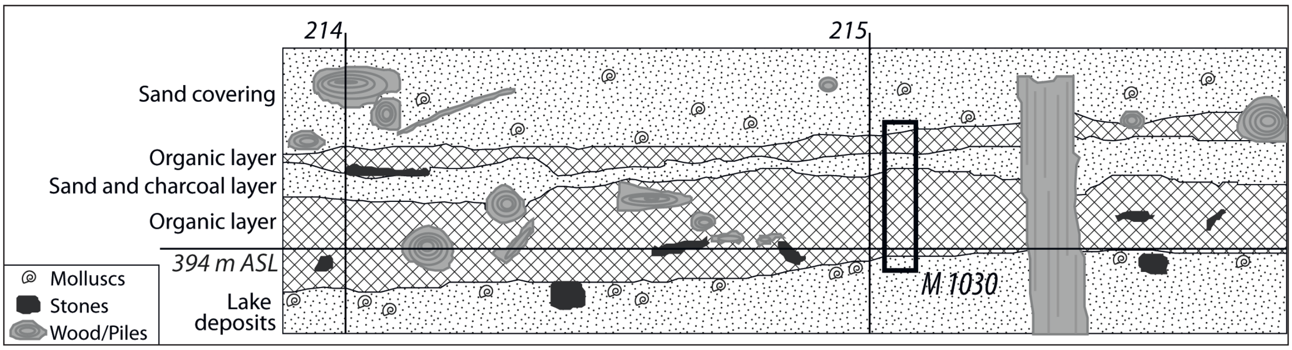
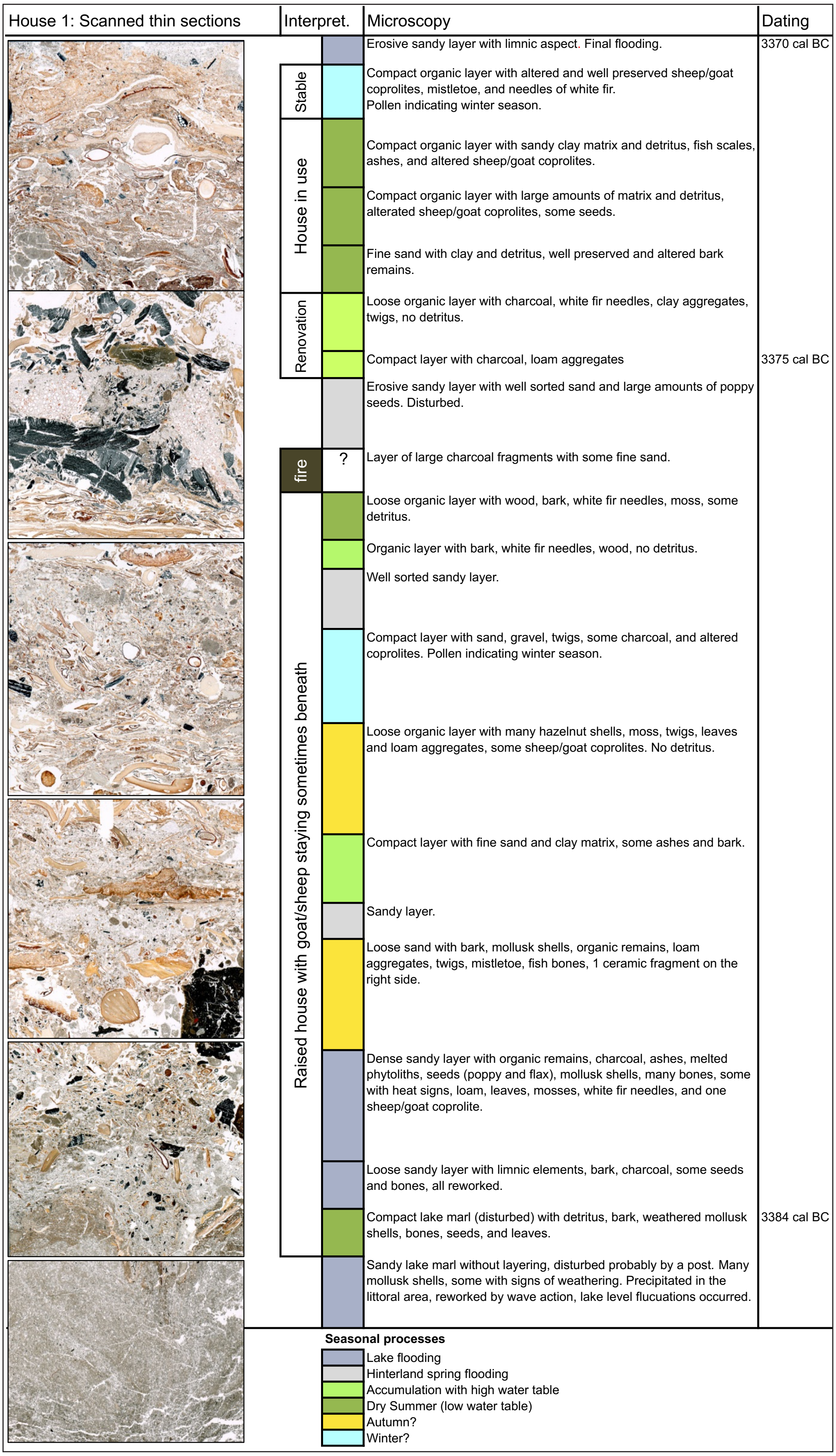


Figure 12. Arbon-Bleiche 3: West profile through House 1 showing the sequence with two main organic cultural layers divided by a charcoal rich sandy layer. The rectangle M1030 corresponds to the micromorphological block sample (see Figure 13) (Drawing by Amt für Archäologie Thurgau, www.archaeologie.tg.ch and K. Ismail-Meyer, modified from Chapter 4, Fig. 2, this book).



House 1: Scanned thin sections	Interpret.		Microscopy	Dating
		🟪	Erosive sandy layer with limnic aspect. Final flooding.	3370 cal BC
	Stable	🟦	Compact organic layer with altered and well preserved sheep/goat coprolites, mistletoe, and needles of white fir. Pollen indicating winter season.	
	House in use	🟢	Compact organic layer with sandy clay matrix and detritus, fish scales, ashes, and altered sheep/goat coprolites.	
		🟢	Compact organic layer with large amounts of matrix and detritus, alterated sheep/goat coprolites, some seeds.	
		🟢	Fine sand with clay and detritus, well preserved and altered bark remains.	
	Renovation	🟩	Loose organic layer with charcoal, white fir needles, clay aggregates, twigs, no detritus.	
		🟩	Compact layer with charcoal, loam aggregates	3375 cal BC
		⬜	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	🟢	Loose organic layer with wood, bark, white fir needles, moss, some detritus.	
		🟩	Organic layer with bark, white fir needles, wood, no detritus.	
		⬜	Well sorted sandy layer.	
		🟦	Compact layer with sand, gravel, twigs, some charcoal, and altered coprolites. Pollen indicating winter season.	
		🟨	Loose organic layer with many hazelnut shells, moss, twigs, leaves and loam aggregates, some sheep/goat coprolites. No detritus.	
		🟩	Compact layer with fine sand and clay matrix, some ashes and bark.	
		⬜	Sandy layer.	
		🟨	Loose sand with bark, mollusk shells, organic remains, loam aggregates, twigs, mistletoe, fish bones, 1 ceramic fragment on the right side.	
		🟪	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.	
		🟪	Loose sandy layer with limnic elements, bark, charcoal, some seeds and bones, all reworked.	
		🟢	Compact lake marl (disturbed) with detritus, bark, weathered mollusk shells, bones, seeds, and leaves.	3384 cal BC
		🟪	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?

Figure 13. Arbon-Bleiche 3, House 1, sample M1030 (see location of sample in Figure 12): A compilation of scanned thin sections with a brief micromorphological description and a suggestion of interpretation of the archaeological layers, including possible seasonal processes (based also on botanical and palynological evidence). Modified from Ismail-Meyer et al., 2013.

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.). 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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Zug-Riedmatt: Vier ausgerichtete Profilproben im Labor vor der makroskopischen Beschreibung und Beprobung. Links die Profile ZGRI 67 (oben) und 68 (unten), rechts ZGRI 66 (oben) und 65 (unten) (Aufnahme K. Ismail-Meyer, Juni 2012).

Zug-Riedmatt: Four positioned profile columns in the laboratory before the macroscopic description and subsampling. Left profiles ZGRI 67 (above) and 68 (below), right ZGRI 66 (above) and 65 (below) (photograph by K. Ismail-Meyer, June 2012).

4 Neolithic Lakeshore Settlements in Switzerland: New Insights on Site Formation Processes from Micromorphology

Kristin Ismail-Meyer, Philippe Rentzel, and Philipp Wiemann

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Abstract

Lakeside settlements can be regarded as a special type of archaeological site, as, thanks to their location near the shoreline, or even in the lake, various kinds of organic remains have been preserved under waterlogged conditions. This paper presents the results of six-studied Neolithic lake-dwellings from Switzerland. A series of natural and anthropogenic site formation processes were identified through micromorphological analysis and have been compared with natural processes in peatlands. The main processes can be summarized as follows: in the littoral zone a carbonate lake marl stratum accumulated prior to construction of the settlement. During lake regressions, the shore platform became dry and the settlements were established. Throughout the period of occupation, anthropogenic processes led to the accumulation of organic layers. The depositional regime can be characterized as paludal, dominated by constant humidity, and rapid covering of the remains. Some parts of the anthropogenic accumulations have been affected by erosion and reworking processes as a result of lake flooding, and runoff from the hinterland. Finally, the degradation of organic matter occurred only during dry phases when the groundwater level dropped. Seasonality was of great importance in this kind of milieu throughout the various processes described above.

Introduction

Lakeside settlements located at the interface between limnic and terrestrial environments are a significant part of the wetland archaeology research (Menotti, 2012). Since their discovery in winter 1853 and 1854, the Swiss lake-dwellings have become one of the best studied prehistoric settlement types in archaeological research of the Circum-Alpine region (Ruoff, 2004; Menotti, 2012). The particular location of these settlements on the shores of the peri-Alpine lakes offers excellent research opportunities as organic remains are often perfectly preserved in waterlogged conditions. However, hiatuses in the archaeological record caused by morphodynamic processes within the littoral zone of the lakes may, at the same time, hinder high-resolution investigations of the stratigraphy. The academic debate as to whether the settlements were built on stilts and platforms above the water or semi-dry land has been resolved - scholars have in fact agreed that both designs existed side by side (Leuzinger, 2000; Menotti, 2001). The anaerobic preservation of organic materials and the various conclusions that can

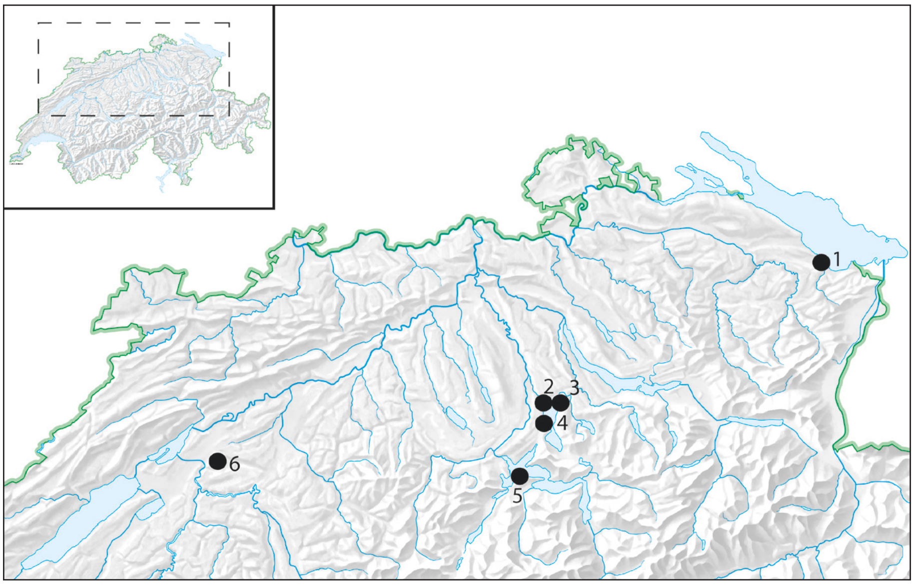


Figure 1: Map of Switzerland with the location of the analysed sites;

1 Arbon-Bleiche 3;

2 Cham-Eslen;

3 Zug-Riedmatt;

4 Risch-Aabach;

5 Stansstad-Kehrsiten;

6 Lobsigesee

(Map data by swisstopo)

Location see Figure 1	Site	Dating	Cultural Groups	Lake marl	Beach plattform	Installation horizon	Loam layers/lenses	Occupation layer on constructed floor	Organic rich cultural layers	Burning layer	Reworked sediments	Degradation horizon	Input of terrigenous sands	Special accumululations	Raised floors	Floors at ground-level	No. samples	No. thin sections	Literature
1	Arbon - Bleiche 3	3384-3370 BC (dendro), 1 settlement phase	Pfyn / Horgen	x	x	x	x		x	x	x		x	Dung layer	x	x	7	26	Leuzinger, 2000 Jacomet et al., 2004 Ismail-Meyer & Rentzel, 2004
2	Cham - Eslen	3985 BC (dendro), 1 settlement phase	Cortaillod	x	x	x	x	x?	x	x	x			Burnt loam (oven?), fish bone rich layers	?	?	12	40	Huber & Ismail-Meyer, 2007 Huber, 2009 Huber & Ismail-Meyer, 2012
5	Kehrsiten	3800 / 3485 BC (dendro), 3 settlement phases	Pfyn and Cortaillod	x	x	x	x		x	x	x		x	Ash layers	x	?	8	29	Hügi, 2006 Michel et al. 2012
6	Lobsigesee	3800 - 3900 BC (typology), 4 settlement phase	Cortaillod	x	x	?	x	x	x	x		x		Bark layers		x	11	24	Hafner & Marti, 2008

Table I: Summary of the samples analyzed in this study.

be made through the application of multidisciplinary scientific analysis remains a main concern of lake-dwelling research (Jacomet, Leuzinger, & Schibler, 2004; Menotti, 2012). Dendrochronological analyses have helped determine the exact dating of various settlement phases, and even individual houses, showing that settlement occupation patterns were often very dynamic. It is only through the reconstruction of formation processes including the depositional environment that the full archaeological potential of lake-dwelling studies can be realized.

Although early lake-dwelling research did take into consideration the various terrains upon which the settlements were built, as well as the specific characteristics of settlement deposits (Vogt, 1955), sedimentological analysis was not applied until the late 1970s and/or early 1980s (e.g., Joos, 1976, 1980; Brochier, 1983, 1989). The main focus of those early sedimentological analyses was to reconstruct the lake level at the time of the settlement, in order to prove/disprove the various theories on house architecture/location. Starting from the early 1990s, there has been an increase in the number of micromorphological studies focused on lake-dwellings (Ostendorp, 1990a; Brochier & Bocquet, 1992; Krier, 1997; Wallace, 1999; Lewis, 2007; Karkanas et al., 2011). The geoarchaeological team at the Institute for Integrative Prehistory and Archaeological Science (IPAS), University of Basel, has had the opportunity to study several lakeside settlements since 1990 (see Chapter 2, this book; Huber & Ismail-Meyer, 2007; Ismail- Meyer, 2010; Huber & Ismail-Meyer, 2012), showing the full potential of micromorphology in archaeological studies (Courty, Goldberg, & Macphail, 1989; Courty & Fedoroff, 2002). As a result, geoarchaeology has joined archaeobotany and archaeozoology as one of the most frequently applied sciences in lake-dwelling research.

Some sedimentological, archaeobotanical, and archaeological studies have identified a set of sediment types, which can occur at lake-dwelling sites (Jacomet, 1985; Brochier & Druart, 1993; Pétrequin, 1997a). During the continuous micromorphological analysis of lake-dwellings, recurrent sediment types were observed. The analysis of a large number of sites from Switzerland (Figure 1; Table I), in association with similar studies from other countries (e.g., Wallace, 1999; Lewis, 2007), have led to the conclusion that some sediment types could be regarded as typical for lake-dwellings on marl lakes. The aim of this article is to describe these sediment types, to present some of their specific forms, and, to reconstruct their formation processes and depositional environment by comparing them with natural peatlands and lacustrine/littoral environments.

Geographic area and regional features of the sites

The results of the hereby-presented study are based on the study of lake-dwellings from the northern Alpine foreland of Switzerland (Figure 1). The lakes, along which most of the settlements were built, formed after the retreat of the Würm glaciers (Hantke, 1978–1983). Fluctuations of the lake levels during the Holocene had a significant influence on the settlement history of the lakeshores (Magny, 2004), showing that lake-dwellings were mainly built during climatically favorable periods, when the lake levels were low and flat moraine shoals near the shore could easily be utilized as ‚empty platforms‘ for constructing settlements (Magny, 1978; Monnier et al., 1991). These areas were probably ideal locations to erect settlements so close to (or even in) the water (Hasenfratz & Gross-Klee, 1995).

The colonization of the lake platforms in Switzerland began in the Neolithic, during the 43rd century BC (Hasenfratz & Gross-Klee, 1995), and, with some intermittent phases of abandonment, lakeshore occupations continued until the end of the Bronze Age (Menotti, 2009, 2012). All sites analyzed in this study date to the Neolithic, with an emphasis on the Late Neolithic Cortaillod and Pfyn culture phases (Jacomet, 2007).

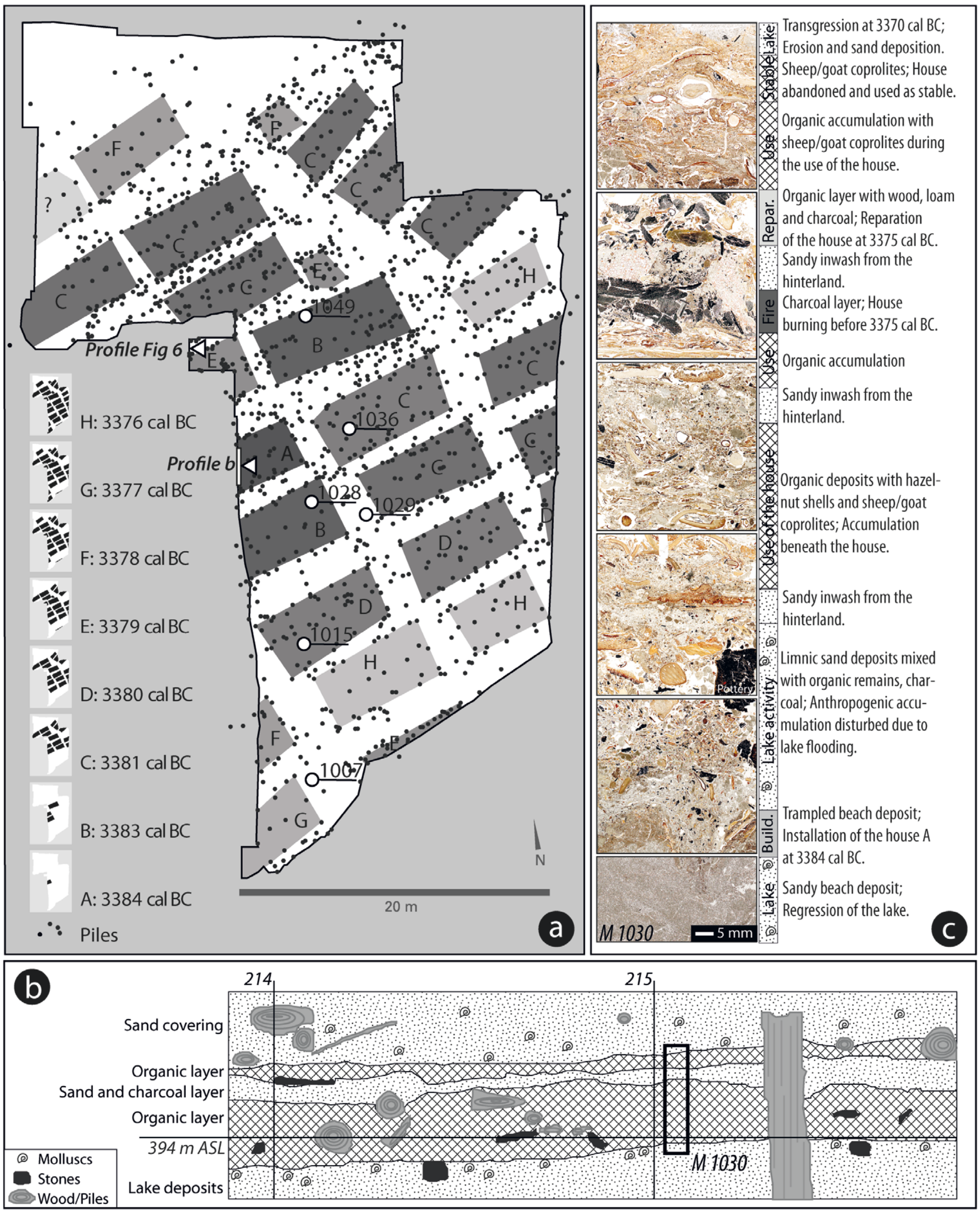
The regional features, the relief of the lakeshore and the hinterland were very influential to the settlements and the people living in them (Figure 1). The site of Arbon-Bleiche 3 (Figure 2) is for instance situated in a flat bay of Lake Constance with a rather even hinterland area (from 400 to 650 m ASL in a distance of 2–3 km inland from the lake). The site itself is not completely leveled, that is 2 m difference within the 50-meter length of the settlement (Leuzinger, 2000). The site of Cham-Eslen (Figure 3), also an underwater excavation, was built on a small island on Lake Zug, 70 meters from today’s shoreline (Huber & Ismail-Meyer, 2012). Also on Lake Zug is the site of Risch-Aabach, which shows highly reworked accumulations by the lake. The site of Stansstad-Kehrsiten (Figure 4), an underwater excavation on Lake Lucerne, was placed at the foot of a steep hillside of the ‚Bürgenstock‘ near the shore, but, after two settlement phases, the remains of the villages slid into the lake (Michel et al., 2012). Finally, the lakeside settlement of Lobsigesee (Figure 5) lies at the former shore of a very small lake surrounded by gentle morainic hills.

Figure 2: The site of Arbon-Bleiche 3;

(a) Site map with the ground floors of the houses and with the eight phases of the village. The position of the profile section b and the profile photograph (see Figure 6) are marked with white arrows.

s(b) The west-profile through house A showing the typical sequence with two main organic cultural layers divided by a sandy layer.

(c) The Arbon-Bleiche 3 thin sections of the column M 1030 with the micrmophologically recognized phases of installation, organic accumulations beneath the house floor and inwash of sand from the hinterland (Pictures by AATG, www.archaeologie.tg.ch and K. Ismail-Meyer).



Methods

For the micromorphological study, 0.5–1 m high undisturbed monoliths were collected in plastic boxes/tubes from the excavation profiles, during archaeological fieldwork and diving campaigns. In the laboratory, the monoliths were first documented with photographs and a geoarchaeological description of all the visible layers. A subsampling of the monoliths into 0.3 m high blocks was subsequently carried out to allowa better handling and further processing of the samples.

Because of the high amount of samples, it was not possible to do an acetone replacement for the elimination of the excessive water – the blocks were instead air-dried over several weeks. This unfortunately made the organic matter shrink (especially wood), leading to an overporosity of organic accumulations. The impregnation was made with an acetone-diluted epoxy resin, and, after drying, the samples were cut into polished sections using a diamond saw. Thirty-eight blocks were studied in an initial assessment of the microstratigraphy, the geometry of the layers, and the geoarchaeological potential of each sample (Table I). For the present study, 119 glass-covered thin sections (47 × 47 or 75 × 50 mm) were prepared by Th. Beckmann, Braunschweig, Germany, and J. Boreham, Cambridge, United Kingdom. The slides were examined optically on a Leitz DM-RXP microscope (using magnification of up to 630×) in plane-polarized light (PPL), crossed-polarized light (XPL), oblique-incident light (OIL), and also using UV-fluorescence (UVL).

Thin sections were described according to Bullock et al. (1985), Fitzpatrick (1993), and Stoops (2003), and reference thin sections of wet-sieved organic material from bulk samples, coprolites and experimentally trampled lake marl sediments were used for comparative analysis (see Chapter 2; Wallace, 1999; Ismail-Meyer, 2010). Bulk samples from lake sediments for a sedimentological and geochemical approach were taken from every site (except Risch-Aabach), and they all show similar characteristics. The methodology applied is described by Braillard et al. (2004), and limnic carbonates were estimated according to Brochier (1983), Magny (2004), and Digerfeldt, Sandgren, & Olsson (2007).

Results

Natural Sediments

Limnic sediments (sub-littoral zone)

The base layer of the studied stratigraphies from Neolithic lakeshore settlements is formed mostly of micrite, a light gray fine crystalline calcium carbonate mud with variable porosity between 10 and 20% (Figure 6; Tables II and III), whereas the carbonate content ($CaCO_3$) is up to 85%; the amount of sand ranging between 5 and 12%. In thin section, algal remains from stonewort (Characeae) such as stems and fruits (Oogonia; Figures 7a and b), fragile sparite chains from algal filaments, diatoms, caddis fly larvae (Trichoptera; Figure 7c) and shells of molluscs (gastropods and bivalves; Figures 7d and e), and shellfish (ostracods) can be easily identified (Freytet & Verrecchia, 2002). Sometimes, scattered organic fine particles, known as detritus or fine particulate matter, can also be detected (see also Sections ‚Organic-rich cultural layers‘ and ‚Decaying Processes‘; Gastaldo & Demko, 2011). The sediment often shows alternating sequences of denser micrite and looser sandy laminations, containing more algal remains and molluscs (Figures 7a and b).

These carbonates, which are found in all the studied sites, were formed by limnic precipitation in many lakes of the temperate zone, are commonly known as lake marl (silty carbonate mud) or – in German – *Seekreide* (Schurrenberger et al., 2003; Muckle, 1942; Brochier, 1983; Magny, 1992). Due to biochemical processes of cyanobacteria (blue algae), stonewort, diatoms, plankton, and algae that grow on leaves and stems of submerged plants (*Potamogeton*, *Najas*), calcite is produced in the form of micrite and chains of sparite due to algal filaments (Platt & Wright, 1991; Magny, 1992; Freytet & Verrecchia, 2002). Lake marl usually forms where the water depth ranges between 0.5 and 12 m (Muckle, 1942; Schindler, 1976; Brochier, 1983); the formation of laminated micrite (deposited on the lake bottom as carbonate mud) is mainly due to seasonal natural processes (Platt & Wright, 1991; Freytet & Verrecchia, 2002). Depending on the geomorphological situation of the riparian zone and the hinterland, changing amounts of fluvial sands can be added to the lake marl. Paleolimnological studies show that the formation of *Seekreide* in Central Europe begins with the warming climate in the Late Glacial interstadial (GI-1e, 12,700 cal BC), and continues throughout the Holocene (Magny, 1995).

Micromorphological analysis of lake marl provides clues to the specific depositional environment (Table III); finely laminated lake marl indicates formation below the wave base in calm sub-littoral conditions (sub-littoral 2 to bentic), whereas homogeneous layers of lake marl with fragmented mollusc shells are formed as a result of reworking by waves in shallow waters (sub-littoral 1) (Brochier, 1989; Digerfeldt, Sandgren, & Olsson, 2007).

Littoral zone

Denser, unlayered micrite layers with higher amounts of sand (up to 20%) and organic matter (up to 15%) usually occur below the dark brown organic accumulations (Figures 7f–h; Tables II and III), and they often contain fragmented and weathered mollusc shells (Figures 7d and e). Single sparite crystals refer to disconnected algal filaments; in the case of Arbon-Bleiche 3, unstratified, sand-rich sediment with many gastropod shells could be observed.

Wave action and currents in the littoral zone cause reworking, reprocessing, and sorting of lake marl; the original laminations are destroyed, terrigeneous detrital sand accumulates, mollusc shells are fragmented, and algal filaments disconnected (see Chapter 2, this book; Brochier, 1983; Pétrequin & Magny, 1986; Ostendorp, 1990a; Digerfeldt, Sandgren, & Olsson, 2007). After the removal of finer particles, sand became enriched and a lag deposit was formed in the instance of a lake regression. At Lake Constance (e.g., Arbon-Bleiche 3, Hornstaad, and Allensbach), a leaching of the fine matrix during the Neolithic period took place, and consequently sandy beach deposits were formed (see Chapter 2, this book; Ostendorp, 1990a, 1990b; see Figures 2b and c). In addition, wave erosion prevents a further accumulation in the littoral zone, leading to the progradation of the shoreline and the formation of a flat surface that can expand toward the lake center with time (Magny, 1978; Pétrequin & Magny, 1986; Platt & Wright, 1991; Magny, 1992).

Climatic fluctuations during the Holocene seem to have been the cause of important lake level changes (Magny, 2004) – the lake levels decreased during longer phases of dry and warm climate so that platforms of lake marl were exposed (Schurrenberger et al., 2003). Experimental observations show that dry, emerged lake marl forms a hard compact surface that may be softened again by rain (Monnier et al. 1991; Jacomet, 2004). Beneath the hardened surface crust the lake marl remains water saturated and plastic, so that piles for house construction can still be rammed down easily (Magny, 1978; Monnier et al., 1991). It has also been observed that, due to nutrient deficiency, only scarce vegetation forms on exposed lake marl (Magny, 1978; Jacomet, 1985; Pétrequin & Magny, 1986), and dry lake marl may weather under atmospheric influence – this is mostly evident in gastropod shells that transform into a porous structure due to solution processes by algae growing on the shells th emselves (Cutler, 1995).

Sandy layers within the cultural sequences

In Arbon-Bleiche 3 and Stansstad-Kehrsiten, we observed repeated thin sandy layers, which divide the cultural sequences into several intervals (Figures 2c, 4c 8a and b; Table II). Those layers show defined lower boundaries, different levels of porosity (5–20%), a high content of well sorted and often graded fine and medium sand (20–40%), some organic matter consisting of wood and bark chips, twigs, mosses, organic detritus (total 20–30%; see also Sections ‚Organic-rich cultural layers‘ and ‚Decaying Processes‘), and also small amounts of loam aggregates (5–10%). In Stansstad-Kehrsiten, these sandy layers show very few freshwater signs (Trichoptera larvae, Figures 7c and f), while in Arbon-Bleiche 3 they contain regularly weathered mollusc shells, coated grains, and micrite aggregates.

Due to the good sorting, graded bedding and the large extend of these sands, anthropogenic accumulations are unlikely to happen, and natural sources (e.g., the lake and the hinterland) seem more plausible. In Stansstad-Kehrsiten, where caddis fly larvae (typical for lakes and rivers) appeared, the option of hinterland influence was more accurately examined, showing that inland runoff occurs frequently also in gently sloped areas – especially during spring snowmelt. This leads to outwash of sands and silts, a process that can be reinforced in vegetationfree areas, as a result of forest clearing and agriculture, whereby detached sediments are transported downslope and deposited in the bottomlands (Turnbaugh, 1978; French, 2003; Zolitschka et al., 2003). This in-wash process certainly occurred also within lakeside settlements. In Arbon-Bleiche 3, older beach deposits in the hinterland were eroded in this way, and this process of colluviation (triggered by heavy rainfall) was even noticed during the excavation of the archaeological site (Leuzinger, personal communication, 2003).

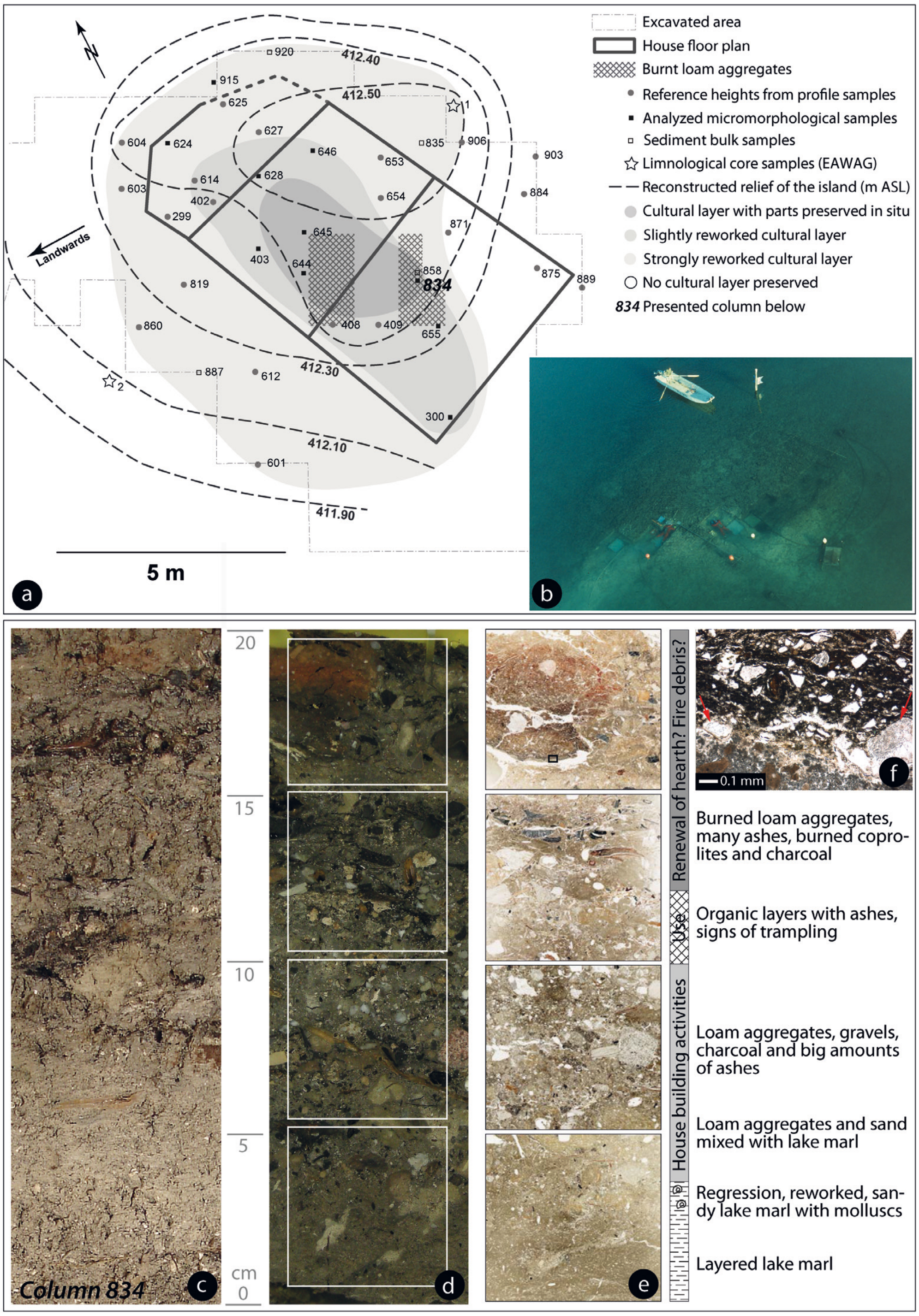


Figure 3: The site of Cham-Eslen:

(a) Overview of the site with the floor plan of the single house and the reconstruction of the small island. The house was constructed in the highest part of the island, but flooding led to reworking of parts of the cultural layer.

(b) Aerial picture of the underwater excavationwith two working divers and the accompanying boat.

(c) Photograph of column 834 (the profiles were documented only through micromorphological samples).

(d) Polished section with the position of the thin sections marked in white.

(e) Scanned thin sections and description of the micromorphological phases and their possible reconstruction. The small rectangle marks the position of the Figure 3f.

(f) Detail of a burned clay aggregate with melted quartz grains (arrows) and gray ashes at the bottom, PPL (Pictures by Kantonsarchäologie Zug, Switzerland, and K. Ismail-Meyer).

Anthropogenic (Cultural) Sediments

Installation horizon

Between the lake marl and the first organic accumulations, a few-millimeters thick, dense (porosity 5–10%) layer can be recognized (Figures 7f-h; Table II); it consists of micrite containing mollusc shells (total $CaCO_3$ amount up to 70%) and sand (up to 15%). Dispersed charcoal, loam aggregates, bones, and aligned organic matter (e.g., tree bark, wood residues, and various seeds) constitute a total amount of 10–20%. This specific compact lake marl has been formed close to the shore (see Section ‚Trampling'), and it represents the transition between the natural limnic sediments and the organic accumulations, which are due to anthropogenic activities. The sharp upper boundary to the cultural layers indicates that the emerged lake marl platform was dry before settlement activities started. A rather good preservation of pollen and mollusc shells give hints of a short hiatus (presumably a few weeks) that occurs just before the settlement was founded (Magny, 1978; Wallace, 1999; Ismail-Meyer, 2010). When human activities started on the platforms, trampling led to a slight compaction of the surface, and an accumulation of wood chips from wood working (Pétrequin, 1997b; Leuzinger, 2007), loam aggregates for floor and wall structures, as well as the remains of food preparation were trodden into the ground surface (see Chapter 2, this book). The main accumulation of other organic matter only started after the houses were erected.

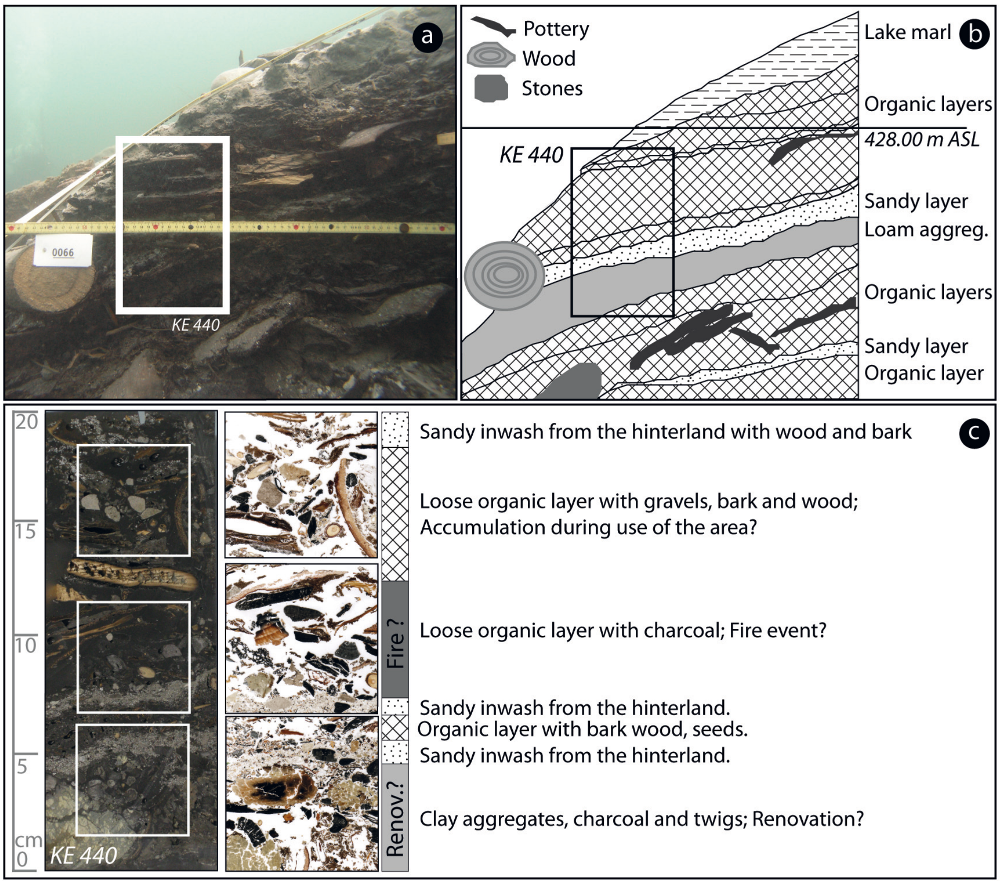


Figure 4: The site of Stansstad-Kehrsiten:

(a) Profile photograph of the underwater excavation with the sample KE 440.

(b) The profile drawing of the same section as in Figure 4a.

(c) Photograph of the sample KE 440 and the thin section position marked in white. In the middle are shown the scanned thin sections with the micromorphological phases and their possible reconstruction (Pictures by Amt für Städtebau, Unterwasserarchäologie Zürich, Switzerland, and K. Ismail-Meyer).

Loam

Loam, a plastic sediment mixture, has been found at all the sites presented in this study (Table II). The loam studied consists of clay and silt (25–45%), purely sorted sand (20–30%) and show different organic matter (including traces of charcoal, ashes, and bones) imbedded into it (content 1–20%). The loam found in the studied sites occurs as compact layers, lenses, or aggregates: loam layers usually measure between 2 and 4 centimeters and show low porosity (5–10%), polyconcave voids and a well-defined, compact surface, sometimes with detached aggregates (Figures 8c-i). A second type consists of loam lenses with lenticular shape; these lenses are thinner and less compact than the above-mentioned loam layers, and show not very clear limits (Figure 8j). Aggregates of loam measure normally several millimeters, have a rather rounded shape (Figures 4c, 8f and g), and occur scattered in organic-rich layers (see Section ‚Organic rich cultural layers'). Burnt loam aggregates are often associated with charcoal and ashes (Figures 3e and f). Petrographic analysis of the loam matrix showed that local sources were preferred (e.g., weathered till material from Al- and Bt-horizons of luvisols); however, molasse clay and lake marl matrix were also exploited.

Loam was mainly used for daub, hearth, and floor construction, and the manufacture of ceramics. The raw material was collected in local outcrops and riverbeds in the vicinity of the sites (Bonzon, 2004). Phytolits represent an organic temper and/or a contamination with anthropogenic residuals, showing that the loam was usually prepared near or in the site itself.
Compact, homogeneous loam layers with sharp upper boundaries can be interpreted as part of the constructed house floors, and they are generally characterized by a massive microstructure with signs of compaction (Courty, Goldberg, & Macphail, 1989). At the sites of Lobsigesee and Cham-Eslen, loam floors seem to have been connected to the perimeter of the houses. The floors of the lake-dwelling were carefully prepared (as traces of subsequent compaction show) (Cammas, 2003). They served as insulation against the rising moisture – some of them had even substructures, such as a timber lattice foundation, or just bark strips (Figures 8c, e, and i). The amount of anthropogenic components (such as microcharcoal, ashes, fine organic material, charred macro remains, and/or artefacts) increases at the top of constructed floors, where they form the base of the occupation layer (Figures 8c, d, f and g; Gé et al., 1993; Matthews, 2010). Loam lenses may also occur as small features within installation horizons, and might have resulted from construction activity, as it is the case of Arbon-Bleiche 3 (Figure 8j; Chapter 2, this book). At Lobsigesee, unburned and very thin lenses of decalcified clay within the organic cultural layer have also been documented (Figures 8d, f, and g). Because of strong similarities with the matrix of ceramic sherds they can be interpreted as the remains of untempered raw material deposits, proving the production of ceramics in the living area. Small aggregates of unburnt clay, sometimes showing organic temper, occur regularly in occupation layers, and are due to natural weathering of daub elements during the lifespan of a house (Cammas, 2003). These aggregates are often the only evidence of wall construction of raised houses, as it is the case in Arbon-Bleiche 3 and Stansstad-Kehrsiten.

Layers with clusters of burnt loam fragments, most likely indicate demolition and/or renovations of hearths (Figure 3e), whereas layers with larger accumulations of loam fragments (that show different degrees of firing) combined with burnt wood, large charcoal fragments, and ashes point to the destruction of buildings during a conflagration. The identification of fire events is however difficult; experimental observations have in fact shown that only part of the loam walls were burnt, the rest consisted of unburnt daub (Goldberg & Macphail, 2006).

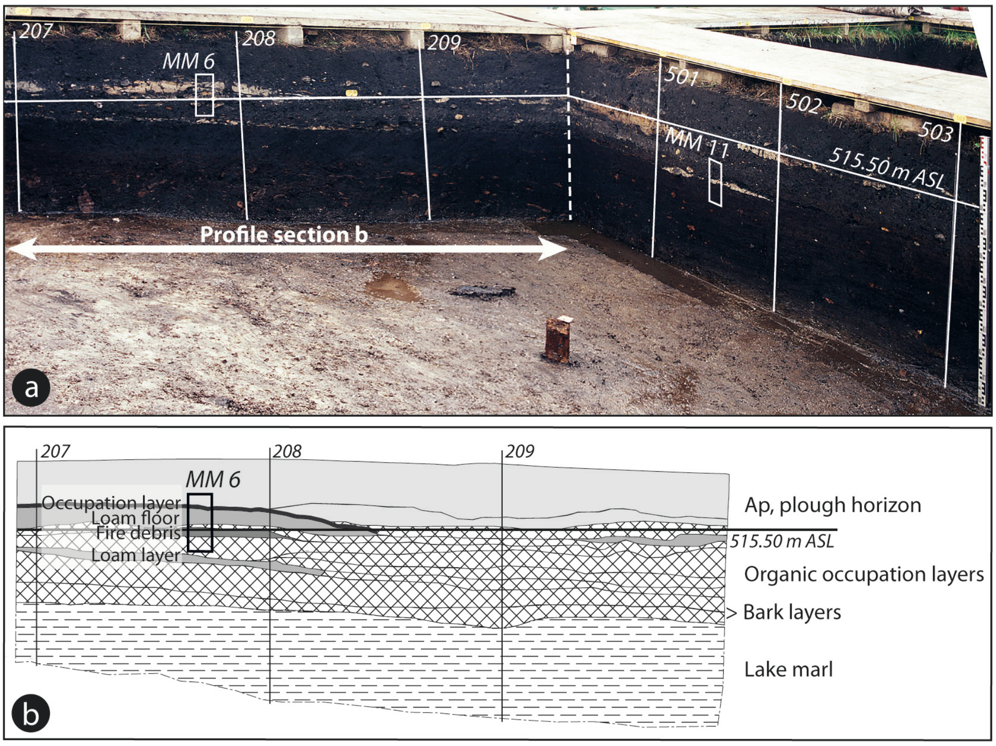


Figure 5: The site of Lobsgesee:

(a) Sight of the west profile and the sample MM6 and the north profile with the sample MM11, presented in the Figures 8d-h and 9i. The sections lie about 10 m from the modern lake shore.

(b) Drawing of the west profile with the sample MM6 (Pictures by Kantonsarchäologie Bern, Switzerland, and K. Ismail-Meyer).

Organic-rich cultural layers

During settlement phases, horizontally bedded complex deposits of variable compositions accumulated, containing large amounts of preserved organic material (30–50%), sand (10–15%), carbonate mud (2–20%), and some clay aggregates (Figures 2c, 4c, 5, 6; Table II). The pH lies between 6 and 8, and it is similar to that of thelake. The size of the organic remains ranges from a few micrometers to several centimeters, and can be micromorphologically identified as wood, bark, twigs, leaves, conifer needles, grass remains (probably straw), mosses, and different seeds. The organic matter shows often an excellent preservation state. Part of the plant material is composed of so-called detritus or fine particulate matter (unidentifiable organic fragments, wood, and bark cells, see Section ‚Decaying processes‘). This detritus appears often combined with well-sorted fine sands and micro-charcoal, and is distributed regularly. Well-preserved organic remains are imbedded in this kind of organic matrix, which also contains pottery and stone tools, charcoal, ashes, bones (including fish bones) loam aggregates, clods of lake marl and different dung remains (Figures 9a-d).

The complex mixture of the organic accumulations is due to different human (and animal) activity, for example food preparation and storage, insolation against moisture and cattle foddering, in, around, and beneath the houses (Figures 9a and b). Accumulations of branches, wood, bark, moss, mistletoe, leaves, and pine needles might derive from the preparation of timber for construction activities, or they could also be insolation material for the floor (Pétrequin, 1997b). Leafy branches and mistletoe can be regarded as fodder for livestock that very likely resided – at least temporarily – within settlements (see Chapter 2, this book; Ismail-Meyer, 2010). Coprolites can be attributed to ovicaprids (sheep/goat; Figure 9b), cattle and less frequently carnivores/omnivores (dogs or foxes and pigs; Figures 9c and d), small rodents (possibly field mouse), and humans – entire layers consisting almost completely of dung can for instance be identified in Arbon-Bleiche 3 (Figures 2c and 9a; see below).

Charcoal and ash most likely formed in/nearby hearths due to cooking and were periodically removed and dumped in other locations. Remains of hazelnut shells and seeds of raspberries or blackberries, strawberries, cereals, flax, and poppy can be interpreted as part of the inhabitants‘ diet – the same applies to the bones of domestic animals, fish, and amphibians (see Chapter 2, this book). Organic detritus is probably the result of desiccation and subsequent weathering of organic accumulations (see Section ‚Decaying processes‘); fragmentation of charcoal may indicate reworking or trampling; and finally, rounding of objects is most probably due to transportation and/or floating in water.

Accumulation of occupational layers on constructed floors in roofed areas

At Lobsigesee and Cham-Eslen loam floors overlain by occupational layers (Figures 8c and d; Table II) differ from the above-mentioned organic layers, because they show a slightly higher compaction rate (15–20%), and contain more loam aggregates (10–15%), sand, and trampled wood ashes. While the grayish, finely laminated layers at Lobsigesee are up to 7 cm thick with traces of erosion on top, the loam floors measure only 2–4 cm in thickness. Their lower boundary is always quite distinct, showing an abrupt contact with the underlying loam floor. The loam floor at Lobsigesee measures several square meters, but the occupational layer was partially destroyed and its extension could not be observed macroscopically.

The composition and good degree of preservation have led us to believe that they represent occupational layers accumulated in the interior of a house. Compared to organic rich layers, the lower porosity may be due to more intense trampling, and the higher amount of loam aggregates can be explained by disaggregation from the loam floor itself. The organic remains accumulated on floors may be interpreted

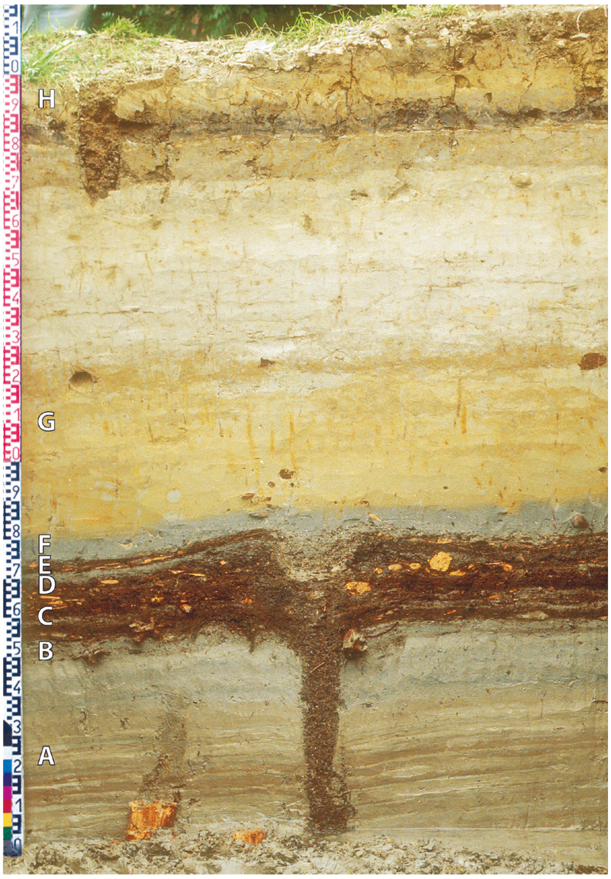


Figure 6: Example of a typical lake-dwelling stratigraphic sequence from Arbon-Bleiche 3 (see Figure 2) with the remainder of a vertical pile in the center of the picture.

(A) Gray laminated lake marl, reworked by wave action in the upper part;

(B) Littoral sand deposit due to regression of the lake;

(C) Organic cultural layer divided into several intervals by thin gray colored sandy inwash;

(D) After the conflagration of the village, a transgression led to erosion and subsequent covering with sand and lake marl;

(E) Reworked cultural layer due to flooding of the ruins;

(F) Lacustrine sandy deposits;

(G) Oxidized limnic sand due to modern drainage; and

(H) Modern plough horizon.

Arbon-Bleiche 3. Picture by AATG, D. Steiner, www.archaeologie.tg.ch.

as daily waste from food processing and cooking (seeds, bones, charcoals, and ashes), fuel (wood, bark, and twigs), and insulation (twigs, mosses, and bark residues) against humidity. In addition, small patches of trodden lake marl may have also been introduced from outside.

Dung layers

Dung-rich layers identified in Arbon-Bleiche 3 (Figures 9a and b; Table II) differ from other layers – they have in fact low sand content (5–10%), and the rest is purely organic (60–70%). A part of the organic matter consists of sheep/goat coprolites, which often show their original shape with a dense margin and convolute internal microstructure (Courty et al., 1991). There are also horizontally aligned organic concentrations with a very high fragmentation rate, which refer to disintegrated herbivore coprolites, possibly from cattle and sheep/goats (Akeret & Rentzel, 2001). Dung spherulites are generally lacking, and the phosphate content is rather low.

Areas with dung layers in settlements are interpreted as cattle stands, which were located outside the houses. Dung spherulithes are not preserved and phosphate only partially, most probably because of the constant outwashing of the accumulations (Canti, pers. comm. 2010). In Arbon-Bleiche 3, the combined results of micromorphology, the analysis of botanical macro remains, and pollen studies showed that the ruins of a house were probably reused as a stand for cattle and sheep/goats during the winter (Figure 2; Chapter 2, this book).

Special accumulations

In addition to the above-described facies, a variety of ‚special‘ accumulations can be found in all studied lakeside settlements. These include, for example, thick ash layers (e.g., at Stansstad-Kehrsiten), which probably accumulated as a midden under, or next to, a house and apparently originate from the cleaning of a fireplace. A layer of burned straw at the same site may be part of a collapsed thatched roof after the house burnt down. In Cham-Eslen, burned aggregates of loam, associated to burned coprolites could belong to a demolished or collapsed fireplace or stove, which was possibly related to fisheries and fish preservation (Figures 3e and f) – this hypothesis is supported by large amounts of fish bones, net sinker, and fishnet remains found (Huber & Ismail-Meyer, 2012).

Discussion of the site formation processes

In this section, the main site formation processes will be discussed by comparing anthropogenic peat layers to natural peatlands. Since ‚anthropogenic peats‘ from the lakeside settlements show some characteristics similar to peats, studying natural peat-forming processes, may give us some clues to understand similar processes that might have occurred in the lake settlements.

Accumulation

Natural peatlands develop in areas with water-saturated surfaces for large proportions of time, and where the rate of accumulation exceeds those for organic-matter decay (French, 2003; Gastaldo & Demko, 2011). The plant parts accumulate only on flat and protected areas and lakeshores, where minimal wave action or flowing water occurs (Keddy, 2010; Gastaldo & Demko, 2011). Peats form due to addition of dead plant material from locally growing plants, as mosses, sedges, and grasses. This loosely packed plant layer called acrotelm, measures from a few millimeters up to several dozen centimeters (depending on the local hydrological conditions). Most of the decay takes place in

Fazies	Dominant microstructure/ bedding	Porosity (%)	Sand (%)	Organic (%) LOI	Carobonate (%) $CaCO_3$	Clay (%)	Compaction	Layering	Sorting of sand	Limnic signs	Bones	Coprolites	Charcoal	Ashes	Seeds	Loam aggregates	Dopplerite	Mite droppings	Spores	Fe-precipitations
Dung layers	Convolute/ horizontal	20-25	5-10	1-5	60-70	1-5	x	x	x	-	xx	xxx	xx	x	xxx	x	v	-	x	x
Organic rich layers	Horizontal	20-25	10-15	2-20	30-50	1-10	-	xx	x	v	xx	x	xx	xx	xxx	x	v	x	x	x
Loam layers	Massive/ aggregates	5-10	20-30	1-10	1-8	25-30	xx	x	x	v	x	-	xx	x	x	xxx	-	-	-	-
Installation horizon	Compact, horizontal	5-10	10-15	45-70	10-20	1-5	xx	x	x	xx	x	x	x	-	x	x	-	v	v	v
Littoral zone	Unlayered, variable	5-15	15-20	40-60	10-15	0	-	x	xxx	xxx	-	-	-	-	-	-	-	-	-	-
Limnic sediments	Laminated	10-20	2-10	50-90	5-10	0	-	xxx	xxx	xxx	-	-	-	-	-	-	-	-	-	-

Legend: - absent; x rare/weak; xx frequent/clear; xxx very frequent/strong; v variable

Table II: The main facies found in the studied sites, and their major characteristics.

this upper layer: organic matter may stay here about 100 years, before dropping below the groundwater table, into the waterlogged, dense organic layer called catotelm. This implies very slow growth rate of peats of 0.5–2 mm per year (Mitsch & Gosselink, 2007; Charman, 2009; Keddy, 2010; Lindsay, 2010). Peats have high water retention and may act as a ‚sponge‘, making the water table raise as a result of high capillarity – peat areas remain wet most of time (Kenward & Hall, 2000; Corfield, 2007; Charman, 2009).

The organic matter in lakeshore settlements derives from plants growing in the vicinity of the settlement, but is formed by human settlement activities. As in peats, the anthropogenic remains could accumulate only on flat and protected areas, with a groundwater table up to the ground surface (without water covering), in order to keep constant permanent waterlogged conditions. The environment can be characterized as very humid, paludal, and supra-littoral depositional (Brochier, 1983; Jacomet, 1985). The anthropogenic sediments showed a higher accumulation rate (i.e., several centimeters per year; see also Section ‚Seasonal Processes‘) than in natural peats. This results in a fast sealing and burial of the remains: in Arbon-Bleiche 3, for instance, Innes (2004) found surprisingly little evidence of coprophilic fungi, which is considered to be a sign of a very rapid coverage of the coprolites. Furthermore, preserved chlorophyll in several lakeside settlements shows that the remains could have been buried in less than 3 days or even within hours (Jacomet, Leuzinger, & Schibler, 2004). Rapid accumulation combined with a high groundwater table is why organic matter is extremely well preserved, and indicators of terrestrial weathering processes, such as iron oxidation, humification, and bioturbation are lacking (Wallace, 1999; Lillie & Smith, 2009; Menotti, 2012).

To sum up, all the investigated lakeside settlements show organic accumulations, indicating well-protected areas with high water table (but no standing water above the ground), where high accumulation rates during the growing season provided rapid sealing of the remains, possibly reinforced by further human and animal trampling.

Flooding processes

Flooding events in wetland areas – and lakeside settlements – are common and seasonally occurring events. Heavy rainfall and rapid snow melting lead to runoff and high lake levels, especially in temperate zones and mountainous areas – large lakes with considerable catchment areas may even have several meters of yearly water level fluctuations (Keddy, 2010). The major effects of flooding are erosion/outwash and redistribution of accumulations, as well as depositions of brought-in sediments from the lake itself, or the hinterland (Turnbaugh,1978).

Because of their internal succession, natural peats react in a special way to flooding events: in the loose organic layer at the surface (the acrotelm), water is lost due to evaporation. Water can move quickly horizontally and vertically, and this layer absorbs precipitations very rapidly (Mitsch & Gosselink, 2007; Lindsay, 2010). Beneath the water table, in the catotelm, plant material is densely packed, and water moves very slowly (Charman, 2009; Baker, Thompson, & Simpson, 2009). When runoffs reach the peatlands, unsaturated parts are quickly filled up (80% of the water discharge moves at the surface and to 98% through the topmost 3 cm), but the catotelm is not influenced by this processes (Holden & Burt, 2003; Baker, Thompson, & Simpson, 2009). Runoff leads also to sediment transfer by surface flow from the hinterland, and this sediment inflow from the catchment area occurs mainly during water discharge in spring (Mitsch & Gosselink, 2007). High lake water tables may also lead to peat flooding, and they too can be exposed to wave action; the consequence is erosion, and removal of fine particles, leaving an aligned and well-sorted coarser substrate such as sands and gravels (Keddy, 2010).

Flooding of lakeside settlements due to surface flow from the hinterland causes erosional processes within anthropogenic accumulations (Jacomet, Leuzinger, & Schibler, 2004). Micromorphological investigation showed that in most cases the uppermost parts of the organic cultural layers were affected by flooding. This fact may be eventually explained by the acrotelm-catotelm-model, indicating that the loose ‚acrotelm‘ of the organic accumulations was faster eroded, while the dense, waterlogged ‚catotelm‘ was not affected by the flooding and

Lake marl depositional environment

Depositional zone	*Littoral zone (beach)* *Supra- and Eulittoral*	*Shallow water zone* *Sub-littoral 1*	*Deep water zone* *Sub-littoral 2 to Bentic*
Estimated water depth	*changing (0-0.5m)*	*up to 0.5m max.*	*up to 6-8m max.*
Criteria			
Charcoal	▨ ■ ▨	□	□
Wave activity	▨ ■	■ ▨	□
Reworked lake marl	▨ ■	■ ▨	□
Caddis fly larvae	▨ ■	■ ▨	□
Sand content	▨ ■	■	■ ▨
Mollusc shell fragmentation	▨ ■	■	■ ▨
Mollusc shell weathering	▨ ■	■	■ ▨
Incrusted algae	▨ ■	■	■ ▨
Sparite algal filaments	□ ▨	■	■
Laminated lake marl	□	▨ ■	■
Mollusc shells	▨ ■	■	■

Legend: strong ■ weak ▨ absent □

Table III: Division of depositional environments and their recognition from the characteristics of lake marl. After Brochier 1983, 1989; Ostendorp, 1990a, 1990b; Platt & Wright, 1991; Magny, 1992; Wallace, 1999; Pétrequin & Bailly, 2004; Digerfeldt, Sandgren, & Olsson, 2007.

remained *in situ* (otherwise a general homogenization of the anthropogenic sequences would have been the consequence). Runoff from the hinterland caused well sorted, graded sandy deposits within the anthropogenic accumulations (Figures 8a and b, 9e), and lake flooding led not only to erosion, but also to the removal of fine particles (Brochier, 1983; Magny, 2004; Digerfeldt, Sandgren, & Olsson, 2007; Macphail et al., 2010). In the studied sites, lake flooding is combined with the deposition of micrite – interesting to notice that, as Brochier (1983) argues, even a short-term transgression of only a few days may cause the accumulation of reworked lake marl up to 10-cm thick. Eroded organic residues (from the ‚acrotelm‘) become suspended and may subsequently be redeposited with micrite, which merges continuously into a pure lake marl deposit.

Layers that contain a dense matrix of organic detritus (see also Section ‚Decaying Processes‘), micro-charcoal and fine sand with embedded, well-preserved organic remains may be the result of desiccation and subsequent surface flow (Figures 8a and b, 9f and g; see also Section ‚Flooding Processes‘). If micrite is part of this matrix, the runoff-sediment was probably transported to an area that underwent a further reworking due to a lake transgression – generally, the lakeward part of the sites were more affected by lake flooding, while runoffs influenced more the landward part of the settlement (Jacomet, 1985; Jacomet, Leuzinger, & Schibler, 2004).

One of the main goals of the archaeological interpretation of wetland sites is to identify whether or not the anthropogenic layers are still *in situ*. As described above, there are several micromorphological features, which indicate flooding, such as reworked layers contain a micrite matrix, or big amounts of well-sorted fine sands, possibly mixed up with organic detritus and micro-charcoal. Archaeological deposits that do not contain any freshwater indicators (mollusc shells, oogonia, trichoptera larvae) can be considered as *in situ*, if they contain fragile components, such as wood ashes or well-preserved coprolites (Huber & Ismail-Meyer, 2012).

The investigated sites show all areas with flooding markers, but also parts that have not been reworked by flooding water, and Arbon-Bleiche 3 and Stansstad-Kehrsiten for instance – both with raised house constructions – contain further regular intercalations of sandy runoff deposits (Figures 2c, 4c, 8a and b). Sediments with a strong limnic influence are quite common in Cham-Eslen, where the outline of a house could be recognized (Figure 3a); sedimentological and micromorphological studies indicate that the single house found was built as a ground-level construction on the top of a small island. Lake flooding led to erosion and reworking of the anthropogenic sediments, but in the central part of the building, archaeological sediments could be considered as *in situ* (Huber, 2009; Huber & Ismail-Meyer, 2012). All the investigated sites are covered by limnic sediments indicating a final flooding event during, or shortly after, the abandonment (Jacomet, 2004).

Trampling

The micromorphological detection of activity on ground surfaces is usually limited to minerogeneous sediments, because this type of sediments retain better the change of microstructure caused by trampling (Courty, Goldberg, & Macphail, 1994; Matthews, 1995; Rentzel & Narten, 2000). This also applies to shore platform sediments, as joint investigations with Wallace (1999) of experimentally trampled lake marl showed that archaeological traces of trampling in lakeside settlements are limited to installation horizons, loam layers (including clay), sandy inwash layers (Figure 9e), and only slightly organic cultural layers. However, highly organic deposits on pathways between houses were (at least temporarily) also walked upon by humans and domestic animals (see Chapter 2, this book). In the case of organic sediments on dry ground, experimental studies on stables, carried out by Macphail et al. (2004), identified various microscopic features of trampling on manure deposits. Research on other types of water-saturated organic layers – such as bogs – show that trampling does cause structural changes and transformations in the sediments (MacDonald, 1998 after Hill, 2005).

Despite the positive results mentioned above, it has to be pointed out that micromorphological evidence of trampling in ductile, waterlogged organic sediments is rather difficult to identify; this may be due to the high moisture content, which causes the sediment to swell quickly again after being walked on – a similar behaviour to peat – and thus almost no irreversible signs of trampling are preserved in this type of sediment (Chapter 2, this book). As previously stated, trampling can be identified within installation horizons, in the form of a compacted layer (porosity 5–10%) of lake marl up to 1 cm thick, at the base of cultural layers (Figures 7f–h; see also Chapter 2, 3 and 5, this book). Since installation layers occur exclusively in the supra-littoral zone that is without indication of a permanent water coverage, they are an important indicator for environmental reconstruction – and support the ‚semi-terrestrial‘ character of the sites. Traces of compression can also be found in beaten earth floors, which show massive microstructure, polyconcave pores and generally low porosity (<5%) (Figures 8c and i). The surface of some floors (e.g., at Cham-Eslen) shows detached blocky peds and a granular microstructure, which is interpreted as an indication of desiccation, walking, and use (Gé et al., 1993; Cammas, 1994). Traces of trampling in covered areas are not only characterized by horizontally skimmed clay floors; they also occur within finely stratified cultural layers from covered areas – in this case, features such as

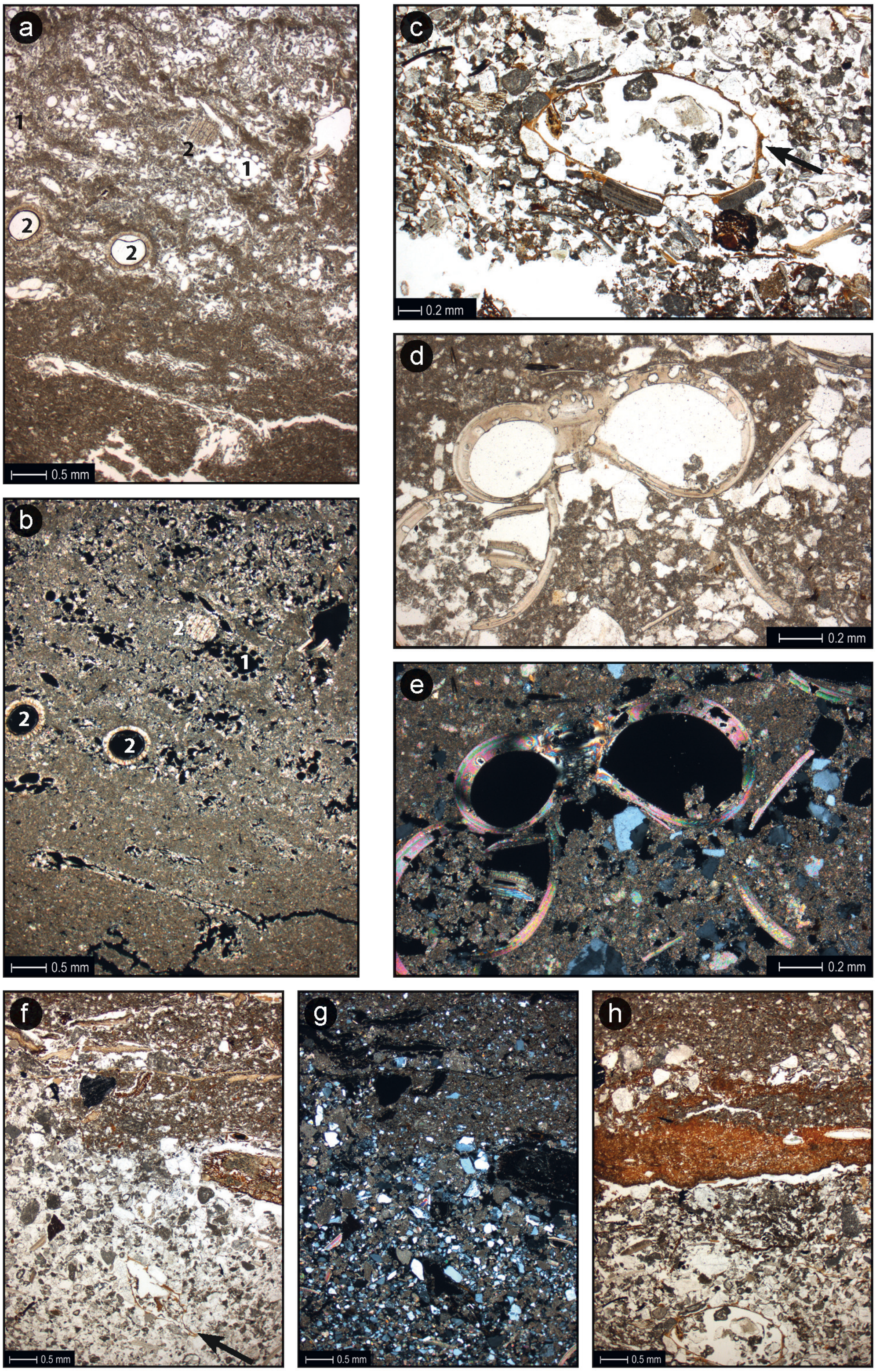


Figure 7: (a) Stratified, carbonate rich lake marl with cross-section through stems of chara-algae (1) and oogonia (2). Zug-Riedmatt M96, plane polarized light (PPL).
(b) Same as (A), the chara stems (1) and carbonate rim of the oogonia (2) are easily recognizable, cross-polarized light (XPL).
(c) Cross-section through a caddis fly larva (arrow), with adherent sand grains. Arbon-Bleiche 3 M1036, PPL.
(d) Weathered mollusc shells in a sandy lake marl. Risch-Aabach M4, PPL.
(e) Same as (d), XPL.
(f) Sandy beach deposit with caddis fly larvae (arrow) and rounded aggretates of lake marl, overlain by the dark gray, trampled installation horizon. Arbon-Bleiche 3 M1029, PPL.
(g) Same as (f), XPL.
(h) Compacted sandy beach deposit, overlain by bark fragments (brown, center) and dark gray trampled peds of carbonatemud, corresponding to the installation horizon. Arbon-Bleiche 3 M1036, PPL.

compacted loam peds, micro-charcoal, fragmented wood ash, horizontally oriented components, and low porosity (15–20%) are the main indicators for *in situ*-preserved activity surfaces (Figure 8h). All studied sites show a compacted installation horizon due to trampling. Concerning trampling features in presumably roofed areas, best examples derive from loam floors and associated cultural layers from Lobsigesee and Cham-Eslen (Huber & Ismail-Meyer, 2012).

Fire Events

In natural wetlands, fire events occur frequently when the peat surface is sufficiently dry (e.g., in the summer when the groundwater table drops), with the major sources of combustion being human activities and lightning (van der Valk, 2006; Lindsay, 2010). However, fire affects only the surface vegetation of a peat producing large amounts of ash, which is easily washed away by rain (Charman, 2009; Lindsay, 2010).

Micromorphological analyses of building structures in all lakeside settlements in this study have shown traces of combustion, confirming that

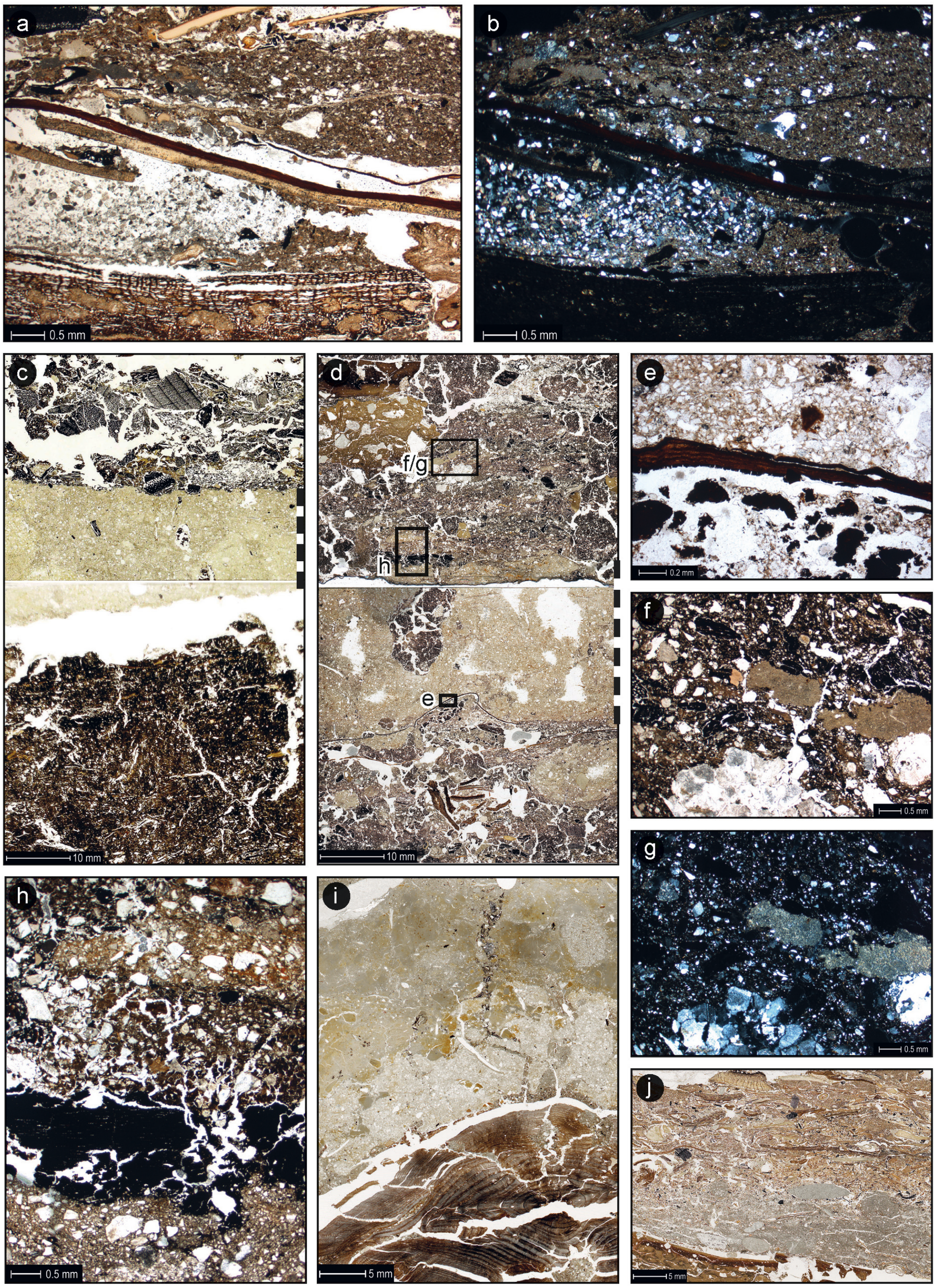


Figure 8: (a) Sorted sand deposit on a top of an erosion surface as a consequence of a sandy inwash from the hinterland. Note also the homogeneous transgression deposit in the upper section. Arbon-Bleiche 3 M1036, PPL.
(b) Same as (a), XPL.
(c) Loam floor (dashed line) on a degraded and shrunken bark layer and charcoal rich occupation layer (top). Lobsigesee M4, scan of thin sections (see also Figure 5).
(d) Yellowish loam floor (dashed line) covered by a horizontally bedded occupation deposit with ash, loam, and a ceramic fragment. The black rectangles mark the position of the microscopic pictures 8 E–H. Lobsigesee M6, scan of thin sections (see also Figure 5).
(e) Compressed bark strip (center) forming the substructure of the beaten earth floor. Lobsigesee M6, PPL.
(f) Charcoal rich occupation deposit containing unburnt clay (center) and crushed granitic temper (base), indicating pottery manufacturing within a roofed area. Lobsigesee M6, PPL (see also Figure 8d).
(g) Same as (f), XPL.
(h) Surface of the beaten floor (bottom), overlain by a horizontally layered occupation deposit, containing trampled loam peds, ashes, and charcoal (see also Figure 8d). Lobsigesee M6, PPL.
(i) Wooden pile grate (below) and compact loam floor (above), Risch-Aabach M18, thin section scan.
(j) Compacted carbonate loam peds indicate construction activities, followed by occupation (layered organic deposits). A ceramic fragment is at the base. Arbon-Bleiche 3 M1036, PPL.

fire management was fairly problematic, especially during dry phases. Traces of conflagrations occur in organic layers (e.g., at Cham-Eslen), in the form of burnt plant material, ashes, and melted phytoliths (Figures 3e and f). Layers of charcoal occur too, but they are rather rare (Figure 9e), because charcoal particles are easily dislocated, fragmented by trampling and removed by flooding events (Macphail et al., 2010). The formation of fire debris of raised wooden dwellings of Arbon-Bleiche 3 and Stansstad-Kehrsiten is always associated with the collapse, tilt and displacement of the affected structures (Hochuli, Schären, & Weiss, 1998). This leads to the formation of heterogeneous accumulations of burned daub aggregates, containing charcoal and ashes. If the ruins were affected by wave action during a subsequent transgression, then removal of charcoal (Macphail et al., 2010), suspension, erosion, and rounding of the components would have subsequently occurred.

In thin sections, some deposit shows a lake marl matrix with micro-charcoal and larger horizontally aligned charcoal and charred organic material. These strata always possess a distinct border with the underlying organic occupation layer, which shows no superficial traces of burning. They may be the result of a major fire event, followed by a lake transgression (see Chapter 2, this book). In sheltered areas, for example under a localized layer of daub, fire debris may contain well-preserved wood ash, burnt coprolites, and even melted phytoliths (Figures 9c and d) – these fragile components are otherwise preserved only under exceptional conditions, such as in burnt dung layers found in caves, or within collapsed stables (Macphail et al., 1997).

Decaying Processes

The preservation of plant material in wetland sites is often related to the height of the groundwater table. Most of the decay occurs mainly before and during deposition; in fact, after burial, ground conditions soon become more or less stable (Kenward & Hall, 2000).

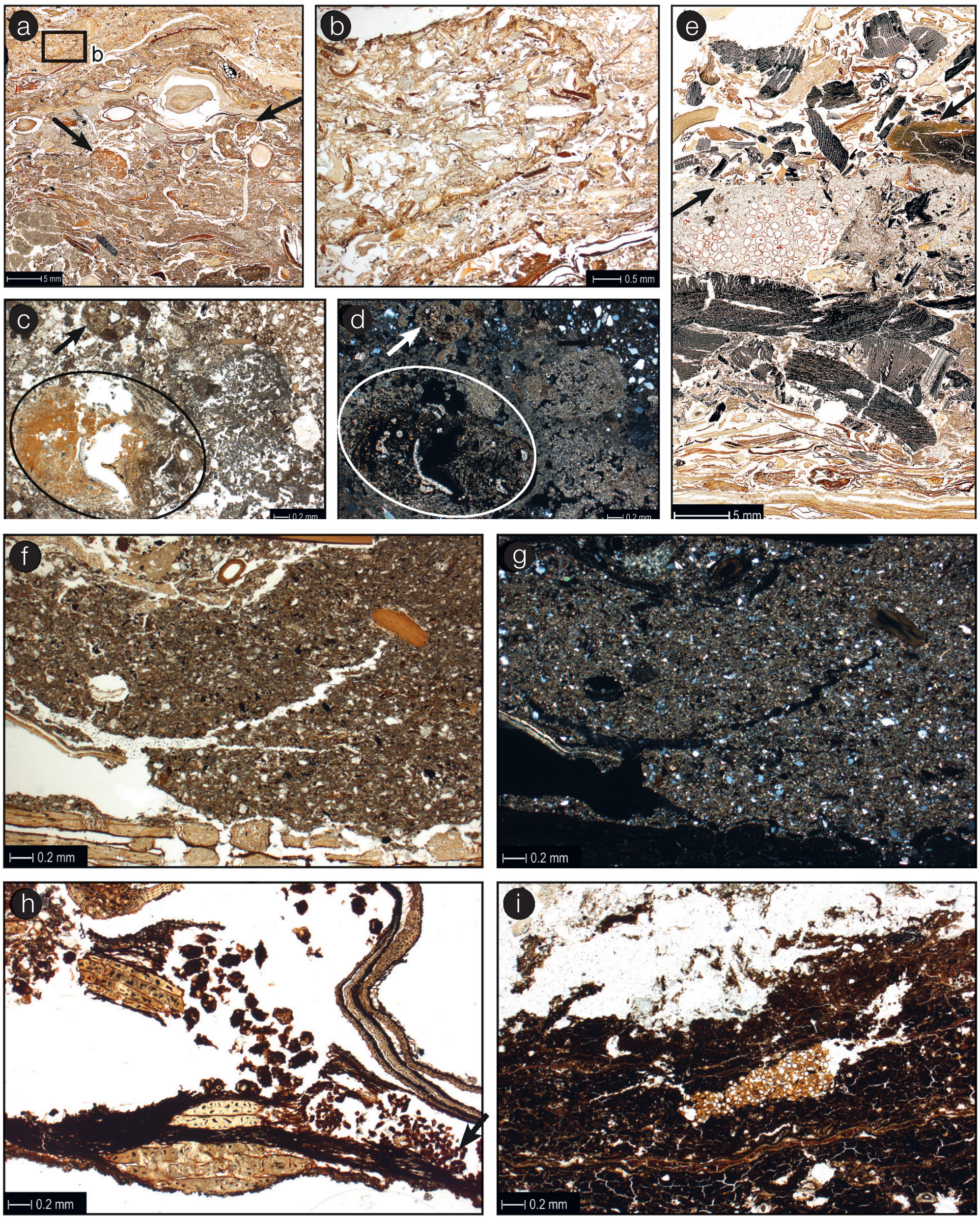


Figure 9: (a) Dung rich stabling deposit, with droppings of sheep/goat (arrows in the central part). Well-preserved animal pen within the area of the abandoned house 1. The black rectangle marks the position of the detail Figure 9b (see also Figure 2c). Arbon-Bleiche 3 M1030, thin section scan. (b) Detail of a well-preserved sheep/goat dropping with the typical convolute internal structure and the dense rim, imbedded in a dung layer (see also Figures 2 and 9a). Arbon-Bleiche 3 M1030, PPL. (c) Concentration of burnt coprolites with melted phytoliths. The brown phosphatic matrix of a carnivore coprolite turns into carbonate to the right side (circle). A further possible burned coprolite shows a bubbly structure (arrow). Cham-Eslen M665, PPL (see also Figure 3). (d) Same as (c), XPL. (e) An organic occupation deposit at the bottom is covered by a charcoal-rich burning layer and an accumulation of inwashed sand from the hinterland, mixed with lots of poppy seeds (disturbed on the right side). The top of the sandy layer is trampled (left arrow) and covered by charcoal, organic matter, and a burnt loam aggregate (right arrow). Arbon-Bleiche 3 M1030, PPL (see also Figure 2). (f) Homogeneous transgression deposit consisting of carbonate, fine sand, and clay containing reworked organic matter,microcharcoal, and bones. Arbon-Bleiche 3 M1036, PPL. (g) Same as (f), XPL. (h) Degraded wood remains with faecal pellets (center) and mite precipitation (arrow). Stansstad-Kehrsiten M440, PPL (see also Figure 4). (i) Dopplerite formation and concentration of modern fungal spores (center) in a strongly degraded bark layer. Lobsigesee M11, PPL (see also Figure 5).

However, if natural peats dry out, the effect of sun and wind leads to the formation of the so-called organic detritus in the upper acrotelm (see Section ‚Flooding Processes‘), without further physical abrasion (Mitsch & Gosselink, 2007; Lindsay, 2010; Gastaldo & Demko, 2011). Detritus particles measure between 0.45 µm and 1 mm, and consist only of the most resistant plant residues, as cuticles, wood, and bark cells containing lignin. Detritus appears after dry summer periods and is mainly transferred through surface flows into bottomlands or may enter streams and lakes during autumn (Lindsay, 2010; Gastaldo & Demko, 2011). Low water tables in peatlands facilitate the intake of oxygen and oxygenated waters, and, as a result of biochemical processes and through fungal and bacterial activity plant parts are reduced (Retallack, 1984; Kenward & Hall, 2000; Gastaldo & Demko, 2011). However, anaerobic bacterial and fungal activity also occurs under reducing conditions in waterlogged areas, leading to moderate organic matter decay and wood rotting (Lillie & Smith, 2009). Further, peats show high amounts of pore space (up to 80%) that are normally filled with water. Low water table leads to rapid subsidence and collapse of the porosity (Mitsch & Gosselink, 2007; Lindsay, 2010).

In lakeside settlements decay of organic matter is supposed to be connected to low water tables. In fact, decay of organic matter could occur in the unsaturated part above the groundwater table (‚acrotelm‘, see Section ‚Flooding Processes‘) at the top of the anthropogenic sequence. In thin sections, poorly preserved organic layers contain plant material of a very dark brown color, a higher rate of compaction due to loss of porosity, and fragmentation until detritus. Mite droppings, fungal spores, and dopplerite – as result of dissolution of organic matter in acidic waters (Stolt & Lindbo, 2010) – are also present, but there are only rare signs of faunal activity (Figure 9h; Pawluk, 1987; Takeda, 1988). If layers with signs of decay are followed by well-preserved ones, decay occurred during the settlement phase, and has been most probably connected to seasonally dry phases during the summer (Kenward & Hall, 2000).

After burial, the settlement features become permanently trapped below the ground-water level, where only very slow decay and almost no postdepositional alteration (diagenesis) occur (Kenward & Hall, 2000) and, if these wet conditions persist, the anthropogenic accumulations from lakeside settlements keep their level of preservation as shortly after burial. Traces of bioturbation are mainly caused by recently grown roots of reeds and rushes from the shore belt – root penetration may lead to changes of the arrangement of the remains, mixing of several layers and the intrusion of younger material into the cultural layers, even if those are covered by 1–2 meters of lake marl (Haas & Magny, 2004).

The major postdepositional effects on wetlands and lakeside settlements are due to human activities, such as agriculture, forestry, artificial lowering of lake levels, drainage systems, stream canalization, dam and dike constructions, mining, water pollution, and groundwater extraction (Mitsch & Gosselink, 2007) – modern drainage often leads to consolidation, compression, oxidation, and pedogenesis, which eventually destroys the wetlands (French, 2003; Lindsay, 2010; Gastaldo & Demko, 2011).

The investigated sites show all an excellent preservation of the organic matter, indicating a general high groundwater table – there are however single levels with signs of desiccation in Arbon-Bleiche 3 and Stansstad-Kehrsiten. Postdepositional processes by reed growth can be seen in all sites, but are rather evident in Cham-Eslen. Modern lake-level lowering has led to a severe decay in Lobsigesee (Figure 9i), and in Arbon-Bleiche 3, the parts above the groundwater table were completely decomposed after a drainage (Leuzinger, 2000).

Seasonal Processes

Sandy inwash from the hinterland during the formation of anthropogenic accumulations are particularly important for the identification of seasonal processes, and, as mentioned above (Section ‚Flooding Processes‘), they occurred mainly during snowmelt from late winter to spring (French, 2003; Zolitschka et al., 2003). The sandy layers are often followed by well-preserved organic layers that accumulated during phases of high groundwater table, whereas organic accretions with signs of decay and detritus formation could have been the result of a dry phase in the summer (Keddy, 2010; Gastaldo & Demko, 2011; see also Section ‚Decaying Processes‘). In autumn, the accumulated detritus floated and redeposited, mixed up with inwashed fine sands from the hinterland and local fresh organic matter (Lindsay, 2010; Gastaldo & Demko, 2011).

During winter, the organic accumulations were well protected because of the low temperature and possible snow coverage – snowmelt of the following spring started a new seasonal cycle with further sandy inwash (Figures 2 and 4).

Lakeside settlements that show signs of seasonal processes and have good dendrochronological dating may even allow a rough calculation of the accumulation rate of the deposits. In Arbon-Bleiche 3, the thickest organic sequence (measuring about 15 cm) represents no more than 15 years, indicating an annual accumulation rate of about 1 cm (see Chapter 2, this book). On the other hand, the detection of four sandy inwash events from the hinterland, suggests four seasonal depositions (and truncation of older sediments); therefore, the accumulation rate in the central area of the site (beneath a raised house) could be estimated to ca. 4 centimeters per year. It is unfortunately not clear which 4 years of the total occupation are represented in the sequences; major erosion surfaces have not been identified either – only further interdisciplinary investigations will be able to shed more light on this fascinating conundrum.

Conclusions

The hereby-presented investigation of four Neolithic lakeside settlements (Arbon-Bleiche 3, Cham-Eslen, Stansstad-Kehrsiten, and Lobsigesee) shows that microstratigraphic analyses can be of great help in the study of depositional and formation processes of natural and anthropogenic deposits. When applied to lake marl deposits, a combination of micromorphology and sedimentology offers an assessment of the limnic milieu, as well as the detection of regression or transgression events. In this context, beach deposits can also be clearly identified by sedimentological parameters, faunal evidence, and/or weathering phenomena. Littoral sediment types are present in all investigated prehistoric lakeshore sites, and generally form the base of the archaeological sequence. The latter comprises organic deposits of anthropogenic origin, resulting from food production and consumption, wood working activities, animal stabling, dumping, and other daily life activities. Inorganic parts of the cultural layers may consist of loam as remains of construction activities, dumped hearths, firing residues, or beaten earth floors. A series of site formation processes such as accumulation, trampling, flooding, decay, and fire events have been identified.

The depositional environment of the cultural layer is, in *sensu stricto*, neither limnic nor terrestrial, but rather paludal (Jacomet, 1985). It can be described as a water saturated, ‚peat-like‘ context, influenced by a high water table. This is illustrated particularly well at Arbon-Bleiche 3, where a multidisciplinary approach has also provided evidence for frequent erosional gaps within the cultural layer and a patchwork-like composition of the deposit (Jacomet, Leuzinger, & Schibler, 2004). This underlines the fact that anthropogenic sediments from lakeside settlements cannot be regarded as an ideal archive, which incorporates continuous sedimentation; as a result, although the archaeological record is of high resolution, it may also be incomplete.

From a methodological point of view, detailed archaeological field observation in combination with methods of micromorphology and archaeobiology, have provided the most significant results for lake-dwelling sites, with dendrochronology allowing a precise chronological framework.

Through this approach, lake-dwellings, with their (often) highly detailed stratigraphies and short occupation spans, can be regarded as an invaluable record, not only for palaeoenvironmental reconstruction, but also for tackling socio-historical research questions (Doppler et al., 2010).

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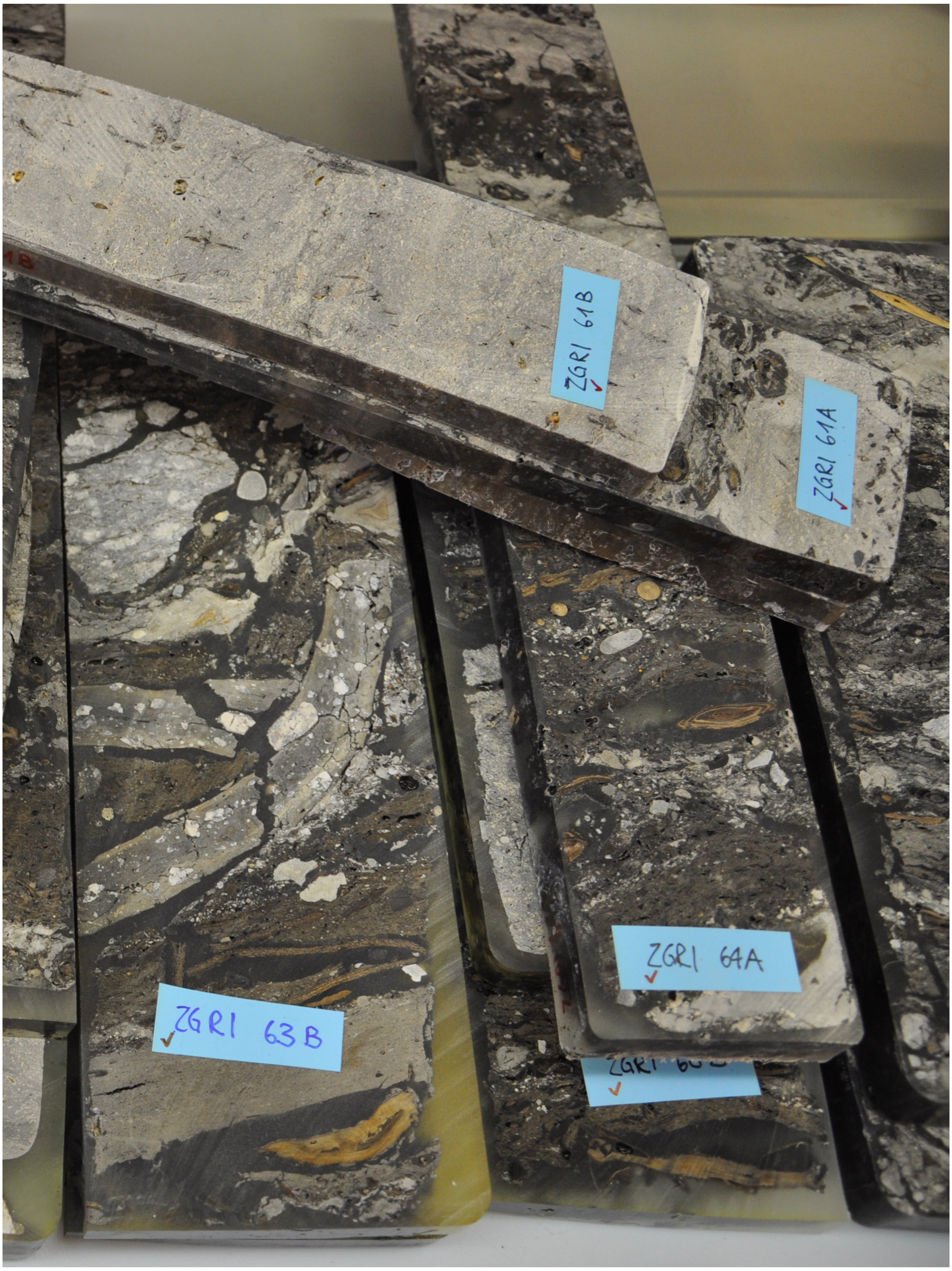

Zug-Riedmatt: Ein Teil der in Kunstharz eingegossenen und aufgesägten Proben, sogenannte Anschliffe (Aufnahme K. Ismail-Meyer, Dezember 2013).

Zug-Riedmatt: Some of the samples, cast into epoxy resin and cut into polished sections (photograph by K. Ismail-Meyer, December 2013).

5 The potential of micromorphology for interpreting sedimentation processes in wetland sites: a case study of a Late Bronze – early Iron Age lakeshore settlement at Lake Luokesa (Lithuania)

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Site formation processes; Seasonality; Human impact; Trampling; Erosion; Geoarchaeology

Abstract

Lake Luokesa lies in the eastern part of Lithuania and is part of a region of lakes formed by the Scandinavian ice-sheet and its melt waters during the last glaciation. During the Late Bronze–Early Iron Age transition, between 625 and 535 cal BC, a lakeside settlement with an onshore palisade was built on the platform of a carbonate bank. A total of five profiles, each comprising an organic occupation layer and lake sediments at its bottom and top, were examined micromorphologically. In this paper, natural and anthropogenic processes that led to the formation of the individual layers are presented; their possible origins are reconstructed and then discussed and compared to lakeside settlements of the circum-alpine region. This includes the emergence of lake marl, accumulation of organic layers in the settlement area as well as their decomposition, erosion and trampling features and inwash of sand through runoff from the hinterland. Due to the accumulation of the up to 60 cm thick culture layers in waterlogged environments, indications of seasonal deposition cycles could be identified.

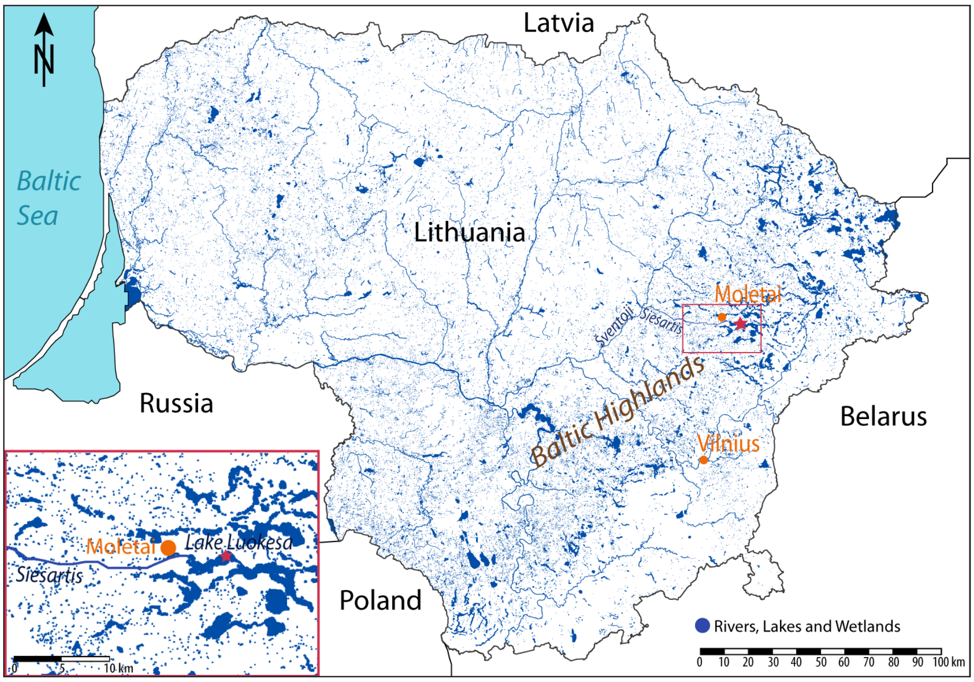

Fig. 1 Map of Lithunia with marked lakes, wetlands and rivers. The site (star) lies near the city Molėtai and is part of a lake district. The detail on the left side shows the lake district and Lake Luokesa with the site Luokesa 1 (map by E. Pranckėnaitė, modified)

Introduction

During the Neolithic and Bronze Age in Central Europe and in the Baltic area even until the Iron Age, people settled on lake shores and built up agricultural and pastoral communities there. Some researchers have shown that platforms were exposed due to fluctuations of the lake water levels during periods of low levels (Magny 2004; Menotti et al. 2005). The unique aspect of lakeside settlements is that a large part of the material brought into the littoral zone by peoples and their domestic animals is well-preserved (Menotti 2012). This is due to a permanently moist environment; weathering and soil formation processes that normally lead to the degradation of organic matter barely took place in these situations. However, in lakeside settlements floods are a limiting factor that can lead to reworking, relocation and erosion of deposits (see Chapter 2, this book; Huber and Ismail-Meyer 2012). At the Late Bronze–Early Iron Age (LBA–EIA) site Lake Luokesa 1 (L1), beside the archaeological investigation, botanical macro remains, pollen, dendrochronological and micromorphological analyses were done contemporaneously, in an interdisciplinary way (Pranckėnaitė 2014; Pollmann 2014a; Heitz-Weniger 2014; Bleicher 2014). This contribution will give an overview of the micromorphological results from the site.

Micromorphological analyses allow the characterization of natural and anthropogenic sediments, which in turn makes possible the evaluation of the site formation processes and the environment in which the deposits were formed. This method of analysis originally evolved from the study of soil, where the practice of casting soil samples in resin and then examining them microscopically has been used since the 1950s (Babel 1975). This technique has been applied to deposits from archaeological sites since the 1970s (Goldberg and Macphail 2006). Since the early 1990s, micromorphological studies have become increasingly popular in the analysis of lakeside settlements (Ostendorp 1990, 1996; Krier 1997; Wallace 1999, 2003; Karkanas et al. 2011). Over the last 10 years, the Institute for Integrative Prehistory and Archaeological Science (IPAS), University of Basel, Switzerland, has had the opportunity to micromorphologically examine several wetland settlements on lake shores (see Chapter 2 and 4, this book; Ismail-Meyer 2010; Huber and Ismail-Meyer 2012). It was the aim of the present study to reconstruct the site formation processes and environment of this settlement. The key issues included whether the settlement was built over open water, how the organic accumulations formed and if the deposits have been reworked. The results of our investigations will be compared with the already existing analysis of five profile samples taken from Lake Luokesa in the years 2007 and 2008 (Lewis 2007; Motuzaite Matuzevičiūtė 2008).

Geographical and geomorphological setting of Lake Luokesa and archaeological basics

Lake Luokesa is part of an area of lakes located in the eastern part of Lithuania in the Molėtai region (Fig. 1). A large area of the country was moulded by the Scandinavian ice sheet during the Nemunas/Weichselian glaciation. Among other glacial forms subglacial tunnel valleys (proglacial valleys) were formed which then filled up with melt water (Guobytė and Satkūnas 2011). The landscape is characterised by hills with plateaux with an altitude of 160–170 m a.s.l. that are covered with dense forests.

Peatlands are often found in the lowlands, at an altitude of approximately 150 m a.s.l. (Motuzaite Matuzevičiūtė 2008). In the area of Lake Luokesa fluvioglacial, sandy–gravelly sediments and moraines formed during the latest stages of the last glacial, referred to as Grūda and Baltija (Bitinas et al. 1995; Guobytė and Satkūnas 2011).

The relief around the lake is characterised by relatively steep slopes which are covered with solifluction deposits (Bitinas et al. 1995). The soils that have formed on these deposits are sandy-clayey brown soils on the hills and peat soils in the lowlands (Motuzaite Matuzevičiūtė 2008).

Lake Luokesa is connected with several other small lakes through streams; it is fed from the east/south-east and drains towards the west (Fig. 2; Menotti et al. 2005). The morphology of the lake (2.4 km long, 0.8 km wide, maximum depth 47.8 m), is dominated by moraine ridges that may have influenced the development of two islands on the lake. Biogenic lake deposits of fine-grained carbonate mud (lake marl) cover large areas of the littoral zone (see Fig. 2). They form a 15–20 cm thick coating on the moraine ridge (Motuzaite Matuzevičiūtė 2008; Menotti et al. 2005). Today there are reed beds located in some places within this area (E. Pranckėnaitė personal communication). A mapping of the lake floor in combination with aerial photographs (E. Pranckėnaitė) shows that an elongated shore platform that connects to the eastern island exists at depths down to about 5 m below the current water level (Fig. 2; Pranckėnaitė 2014). The fortified settlement of L1 developed on this elongated lake marl peninsula at an unknown time between 625 and 535 cal BC (Fig. 3; Bleicher 2014).

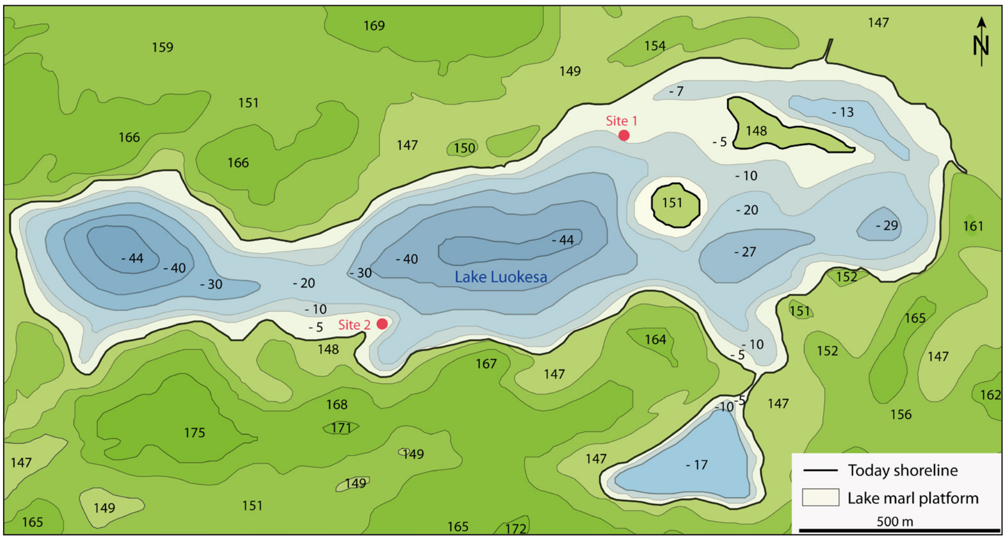

Fig. 2 Topography of the Lake Luokesa and its surroundings with the approximate heights in m a.s.l. The bathymetric heights of the lake are marked as metres below the today lake level. The white beach platform emerges when the lake level drops for about 5 m (Source of the maps: http://kvr.kpd.lt/heritage/, modified)

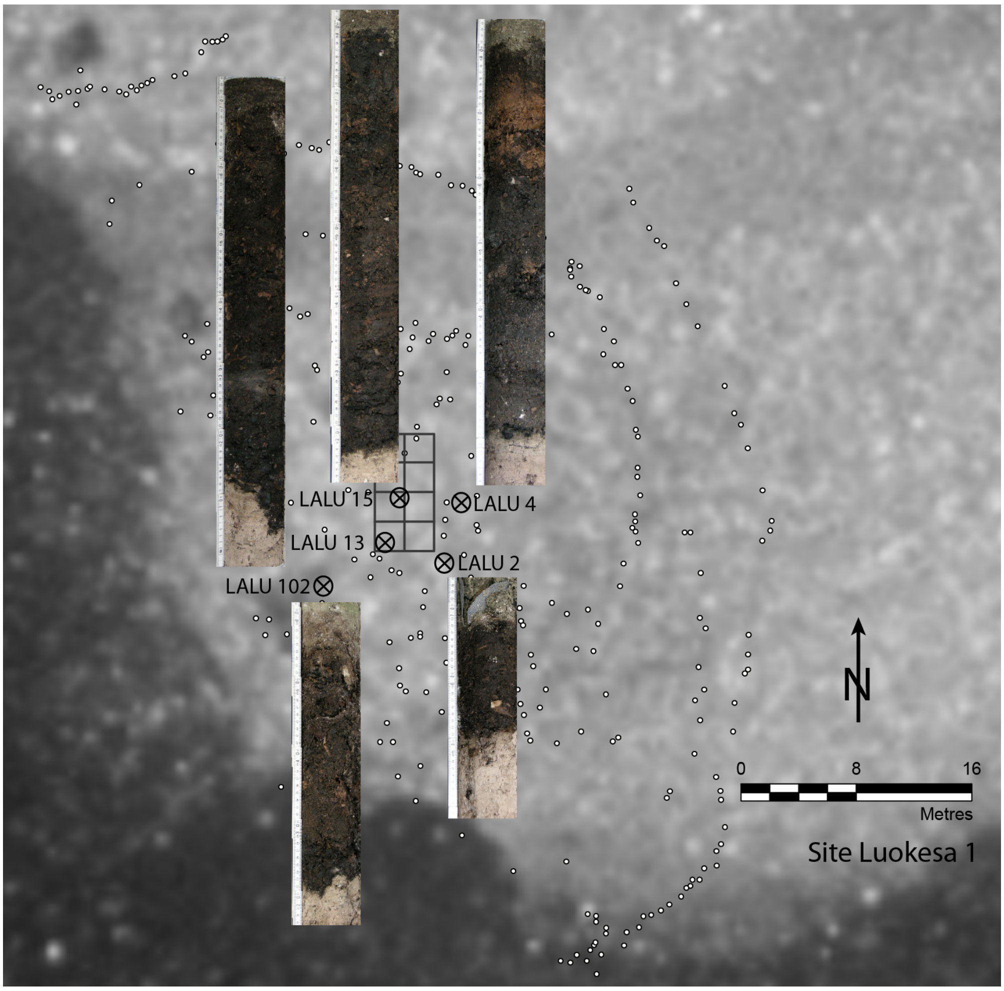

Fig. 3 Lake marl platform (light grey) with the site Lake Luokesa 1, the piles (dots), the measurements grid for the excavation and the micromorphologically analysed profile columns (crosses) with photographs of the opened columns beside (map provided by E. Pranckėnaitė, modified by B. Pollmann)

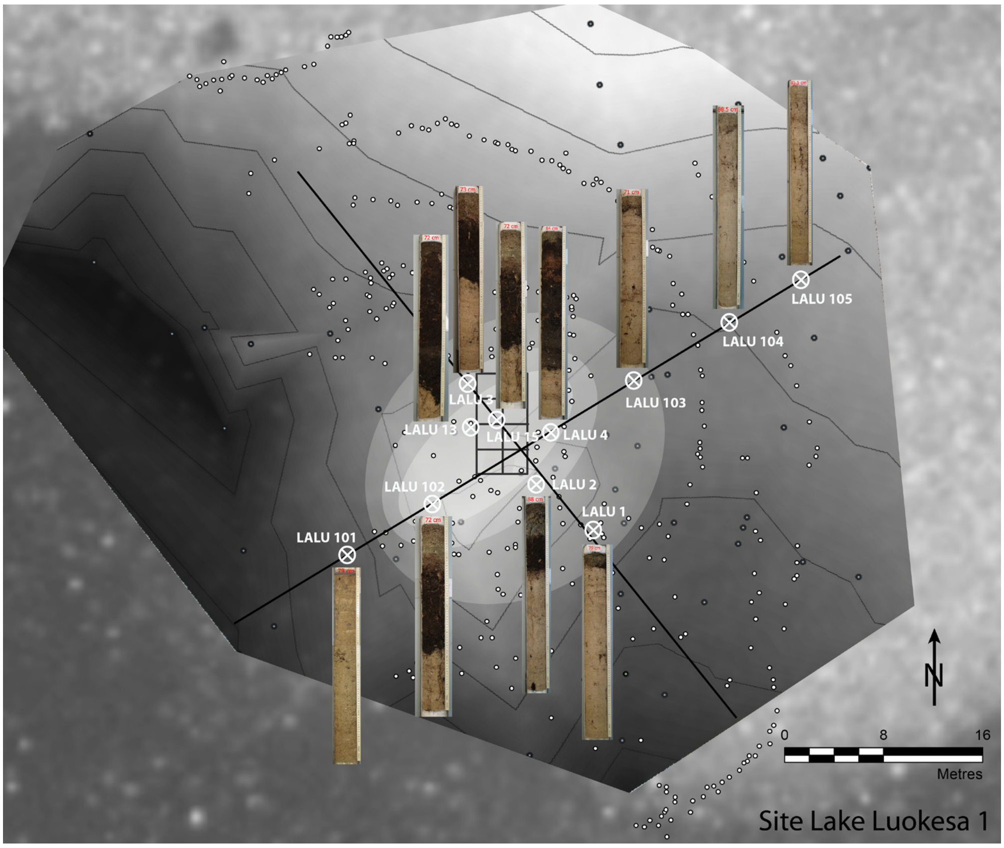

Fig. 4 Geomorphological map of the lake marl platform; higher parts in light grey (99.7 m a.s.l.), lower parts in dark grey (98.9 m a.s.l.). The white dots mark the piles found, the grey ones the measurement points. The crosses mark the column samples with the photographs of each column beside. The ellipses indicate the approximate cultural layer thickness; the big ellipse indicate the area with preserved cultural layer (less than 15 cm layer thickness), the medium ellipse show layer thickness from 15 to 25 cm, the small, central ellipse indicate a layer thickness over 25 cm (maps provided by E. Pranckėnaitė, modified by B. Pollmann and K. Ismail-Meyer)

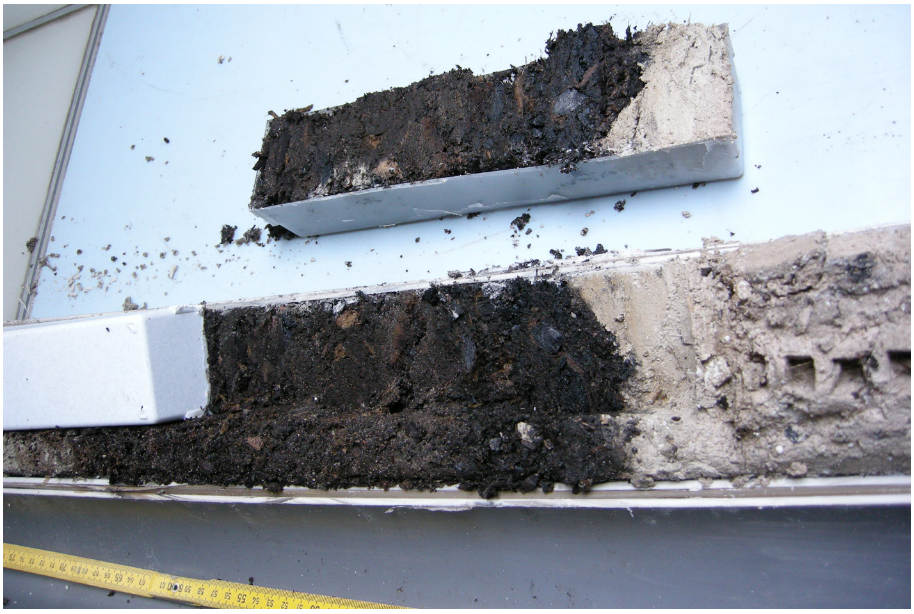

Fig. 5 Cleaned profile column with the basal lake marl (light grey) and the cultural organic layers (dark coloured). The square holes at the bottom of the column are due to the palynological sampling. Above the column there is a micromorphological subsample with the basal part of the cultural section. A second subsample is still on the column (grey box on the left)

The relief of the shore platform near L1 shows that the area with a massive anthropogenic accumulation of organic material is quite small with a size of about 100 m^2 (Fig. 4). This area is located approximately in the centre of the zone enclosed by the palisade and can be regarded as the centre of the settlement due to the dense positioning of the poles and high concentration of archaeological artefacts (Pranckėnaitė 2014). The organic deposit thins out quite rapidly closer to the lake (Fig. 4). This is also the case in the north-east part of the site as the thickness of the organic deposits decreases from 60 cm (profile LALU 4) to 2 cm (profile LALU 103) within a distance of 8 m (Fig. 4; for a section see Fig. 5 in Pranckėnaitė 2014). The reconstruction of the ground floor planes of the houses by dendrochronological analyses was not possible (Bleicher 2014). The absence of clear floor structures, such as compact loam floors, suggests that the house floors were most likely elevated above the ground (Pranckėnaitė 2014).

Materials and methods

During the underwater excavations at Lake Luokesa in the years 2008 and 2009, 12 m^2 were excavated and several profiles in tubes of 10 cm in diameter were collected within the excavation site and the surrounding area for paleoecological study (Figs. 3–5; see also Pranckėnaitė 2014 and Pollmann 2014a). Five profiles with a well-preserved cultural layer (LALU 2, 4, 13, 15 and LALU 102) were selected for interdisciplinary analysis from L1 (Fig. 3; see also Pollmann 2014a; Heitz-Weniger 2014). These profiles originate from the excavation area, covering a small, central part of the settlement of approximately 12 x 5 m (Fig. 3) and a transect (Fig. 4; see also Fig. 3 in Pollmann 2014a and Fig. 3 in Heitz-Weniger 2014). Up to the present it has not been determined whether the profiles were taken from the alleyways or from places within the houses, as the ground floor plans of the houses are not known (Bleicher 2014).

The surfaces of the opened tubes were cleaned and photographed in the laboratory and the recognisable layers were geoarchaeologically described. The pollen sampling was done based on this description (Heitz-Weniger 2014). The entire sequence of occupation layers of every profile was then sampled, including the top and bottom of the adjoining lake deposits, using small plastic containers (Fig. 5). It was important to remove as little material from the columns as possible to ensure that sufficient material remained for the study of macroremains (Pollmann 2014a). After gentle drying of the samples, they were cast in epoxy resin under vacuum, and after curing were sawn into slices, referred to as polished sections (Fig. 6). At the relevant points, 4.7 cm long square blocks were processed into 31 covered thin sections of 0.03 mm thickness (Fig. 7; Beckmann 1997).

The thin sections were correlated with the geoarchaeological layer description of the profiles and described in detail using a polarizing microscope at magnifications from 16x to 630x (after Bullock et al. 1985; Stoops 2003; Table 3). Identification of components, such as minerals, clay, bones, ashes and pottery, were made following literature (e.g. Bullock et al. 1985; Fitzpatrick 1993; Schiegl et al. 1996; Stoops et al. 2010). The state of preservation of mollusc shells was evaluated after Cutler (1995). Organic components were estimated after Babel (1975, 1985) and Stolt and Lindbo (2010), by the use of reference sections and in close collaboration with the archaeobotanist (Pollmann 2014a). Coprolites (excrement) of domestic animals and micro fauna were distinguished by their composition, shape and structure (after Pawluk 1987; Akeret and Rentzel 2001; Karkanas and Goldberg 2010) and according to our own reference sections. Signs of alteration of organic components were described after Babel (1975), Pawluk (1987), Takeda (1988) and Stolt and Lindbo (2010).

For the environmental reconstruction, sediment types (facies), were defined. In order to compare the density of seeds in each facies, we calculated the approximate number of countable seeds in the thin sections per 10 mm x 47 mm strip for each layer.

Results

Lake marl below the cultural layer and post-settlement sediment cover

The base of the profiles contains laminated, light grey calcium carbonate mud containing traces of sand (Tables 1, 3; Figs. 5, 6, 7a). Only a small amount of organic material is present, consisting of wood, bark, leaves, grass (not specifically identifiable remains of Poaceae and Cyperaceae) and roots. Remains of aquatic organisms such as molluscs (i.e. *Bithynia tentaculata*, *Valvata cristata*, *Radix ovata* and *Amiger crista*; Pollmann 2014b), crustaceans (Ostracoda), diatoms, sponge needles and occasionally caddis fly larvae (Trichoptera) are present. Algal residues, usually of stonewort (Charales), can be found in the form of calcified stems and oogonia. These residues are referred to in this paper as limnic elements.

At the top of the lake marl, in the first 10–20 mm below the cultural sequence, the carbonate becomes light brown, dense and sandy (Figs. 7a, 8a, b; Table 1). The colour change is caused by the presence of finely distributed micro-charcoal and very fine plant detritus. Limnic elements such as molluscs and algal remains decrease, while larger pieces of charcoal, bark and grass and the first macro remains of terrestrial origin become increasingly common. The gastropod shells are fragmented; in the western settlement area (in profile column LALU 4) algal boring can be observed (Figs. 4, 8c, d).

The covering layer of cultural deposits also consists of porous lake marl in some parts of the site (Table 1; Fig. 7b). However, in the north-eastern area of the site (columns LALU 2, 13, 15; Fig. 4), the top layer consists of up to 50 % sand. The organic content is very low in the surface layers and almost only consists of roots and reed rhizomes. It is striking that it is in these outer layers that the largest numbers of gastropods, often showing signs of algal boring, are found (Fig. 8c, d).

Organic facies of the cultural layer

Above the lake marl, dark brown organic layers are common (Table 1; Figs. 5, 6). These deposits all consist on average of over 50 % plant residues, while the sand content is at highest 20 % (Table 1; Fig. 7c). Rare limnic components can be observed at the transition to the lake marl. The average carbonate content of 3 % is mainly due to the presence of carbonate wood ash. Further, there are charcoal, burnt aggregates (sometimes containing phosphates) and quartz with melting rims, which can be observed regularly. Gravel and ceramics (Fig. 9a) can also be determined. The micromorphologically identifiable plant remains can mainly be attributed to wood and bark fragments, grass remains (Poaceae and Cyperaceae; Fig. 9b, c), mosses (Bryophyta and *Sphagnum*; Fig. 9d), branches and leaves from foliage (Fig. 9e). There are also numerous glumes and grains of *Panicum miliaceum* (millet, Fig. 9f) and other cereals (Fig. 9g–i), *Fragaria vesca* (strawberry, Fig. 9j) different *Rubus* species, *Camelina sativa* (false flax), seeds of Chenopodiaceae (goosefoot family) and rarer *Corylus avellana* shells (hazelnut, Fig. 10a) as well as a charred *Pisum sativum* (pea, Fig. 10b). In addition, there are different coprolites (Fig. 10c–e). These show different states of preservation and are sometimes fragmented (Pollmann 2014b); dung spherulites are not preserved. Fish bones are rare and some of them are charred (Fig. 10f). Some insect remains could also be recognised (Fig. 10g). Fine organic detritus is quite common. Fungal spores (sclerotia) and droppings of mesofauna, such as Oribatida (mites), Collembola (springtails) and/or Enchitraeidae (pot worms), are rather rare (Fig. 10h; Pollmann 2014b). On occasion dopplerite (dissolved organic matter; Fig. 10i) and organic crusts, i.e. elongated organic aggregates showing poor cell preservation, can be observed. The regular traces of roots and rhizomes can be attributed mainly to reeds (Fig. 10j). The organic deposits can be divided into three sub-facies (Table 1):

Fig. 6 The polished section of the profile column LALU 2; at the bottom the grey lake marl is overlain by the dark cultural layers composed mainly of organic matter. The upper part consists of grey sand

Organic layers with good preservation (Fig. 7c)

The loose organic deposits consist mainly of brownish, horizontally aligned residues showing a spongy structure. They contain around 15 % rather poorly sorted fine to coarse sand. The density of seeds (1.4 seeds per 10 mm x 47 mm strip) is relatively low compared to other facies. Distributed regularly in the matrix are detritus and micro-charcoal.

Organic layers with signs of alteration (Fig. 11a, b)

These compact layers show often a spongy or a fine granular structure. They consist of dark brown organic residues often in the form of detritus. Mesofaunal droppings, dopplerite, sclerotia and organic crusts are also present. The seed density (2 seeds per 10 mm x 47 mm strip) is the highest for the site.

Organic layers with dung remains (Fig. 7b)

The layers show a spongy structure and contain coprolites and concentrations of highly fragmented plant remains of reddish-brown colour. With 8 % sand content these layers have the lowest sand content of anthropogenic deposits while simultaneously having the highest organic amount of over 65 % (average porosity 19–27 %). The seed density is elevated with 1.7 seeds per 10 mm x 47 mm strip. The content of mesofaunal droppings, dopplerite, sclerotia and organic crusts is quite high. The organic spectrum does not differ significantly from the two organic facies described above.

Facies		Avarage layer thickness (mm)	Layering	Compaction	Sharpness of lower boundariy	Porosity %	Sand content %	Carbonate content %	Organic content %	Clay content %	Limnic signs	Burning sings	Charcoal amount	Seed amount (per 10mm)	Org. detritus amount	Coprolites	Preservation	Bioturbation
🟥	Burning layers	11	x	-	x	15	42	6	32	5	-	xxx	xx	1.5	x	x	x	x
🟪	Clay layers	25	x	x	x	14	54	0.5	16	16	-	x	x	0.4	x	-	xx	x
🟩	Sandy layers with detritus	13	xx	x	xx	15	50	2	28	5	-	x	x	1.6	x	-	x	x
🟦	Sandy layers with gravels	6	xx	-	xx	20	43	2	32	3	-	xx	xx	0.6	xxx	x	x	x
🟨	Dung layer	27	x	x	xx	23	8	1	67	1	-	-	x	1.7	xx	xxx	x	x
🟩	Organic layers with signs of alteration	17	xx	x	x	24	18	1	54	3	-	x	x	2	xx	x	x	x
🟩	Organic layers with good preservation	22	x	-	x	28	14	1	57	0.5	-	-	xx	1.4	xx	x	xx	x
⬛	Covering lake marl layer	-	xx	-	xx	23	9	62	6	-	xxxx	-	-	-	x	-	x	x
⬜	Horizon of installation	8	x	xx	x	12	11	61	16	-	xx	-	x	1.8	x	-	xx	x
⬜	Lake marl	-	xx	-	x	12	2	80	6	-	xxx	-	-	-	-	-	xx	x

Table 1 Descriptions of the different facies found at the site Lake Luokesa.

Legend: - absent; x rare/weak; xx frequent/clear; xxx very frequent/strong; xxxx predominant/very strong

Sandy intercalations within the cultural layer sequences

Almost all the profiles – with the exception of LALU 2 located in the south-east – show several sandy intercalations that represent two facies (Figs. 3, 7d; Table 1).

Sandy layers with gravel

Here the components are well aligned and consist of over 40 % fine sand to fine gravel, which is moderately sorted (Figs. 7d, 11c, d). The lower layer boundaries are often pronounced; the surfaces are compact in some cases. The organic content is quite high, at 30 %, which comes from wood, bark, peat moss and rarely grass and leaves. In some layers, very high charcoal amounts and organic crusts can be observed. The seed content is elevated, with 1.6 seeds per 10 mm x 47 mm strip. Ashes and charred aggregates are frequently present. A part of the sand consists of well-rounded medium sand, often showing melting rims and undulatory extinction under polarized light (Fig. 12a, b).

Sandy layers with detritus

There are some striking levels of fine sand, which have a high density and contain a clay matrix with high amounts of organic detritus (Figs. 7d, 11c, d). They are well sorted and show a gradation. Here, the lower layer boundaries are clearly visible also. In addition to a fine sand content of nearly 50 %, the amount of organic remains – compared with the gravelly sand layers – drops somewhat and mainly originates from bark and *Sphagnum*. Micro-charcoal, ash and burnt aggregates are rare.

Clayey layers within the cultural layer

Clay-rich layers in the site L1 are very rare (Table 1). Clay amounts of up to 10 % are found in organic layers with signs of alteration and sandy deposits. They are represented by aggregates of more than 6 mm size, which consist of residual clay (E horizon). Aggregates from clay accumulation horizons (Bt horizon) are less common. Both types occur due to soil formation above a moraine, where in the A horizon clay minerals are washed out (E horizon), translocated to the bottom and accumulated in the underlying Bt horizon. Three clay rich layers with a maximum clay content of 20 % can be determined in the LALU 4 profile column. Additionally, in several layers, a fine sandy-clayey matrix is present (total mineral content between 60 and 70 %) which is mixed with about 15 % organic material (bark and grass remains). In the profile column LALU 13 (Fig. 3), such a layer forms a 3 cm thick, compact level which is overlain by a weathered organic layer (Fig. 11e, f).

Discussion

History of the site reflected in sediment micromorphology

Lake marl formation

The carbonate mud below the cultural layers can be associated with lake marl; formation of it is well known in many lakes in mid-latitudes as well as in the Baltic states (Magny 2004; Novik et al. 2010; Punning et al. 2005). Lake marl started to form during the early Holocene and originates from the biogenic precipitation of carbonates, mainly due to the metabolism of aquatic plants, both macrophytes (*Najas* and *Potamogeton*) and algae like Characeae. The metabolic carbonate products are deposited on the bottom where they form micritic deposits. Within these deposits, remains of flora and fauna such as mollusc shells and calcified algae are present. In undisturbed areas below the wave base, laminations may be observed, consisting of denser micrite layers with loose intercalations of mostly algal remains, probably due to changing types of precipitation (Freytet and Verrecchia 2002). The appearance and composition of lake marl allow a rough estimation of the water level during its precipitation, meaning that fluctuations in the water level, and therefore shifts in the shoreline, become visible. Thus lake marl showing lamination has formed below the wave base in a calm environment (Digerfeldt et al. 2007; Huber and Ismail-Meyer 2012; see Chapter 4, this book). Closer towards the shore in the littoral zone or after a lake regression, fine sands were in-washed by fluvial processes. Wave action led to reworking and leaching of the lake marl, so that a lag deposit may have arisen in the form of unstratified, sandy

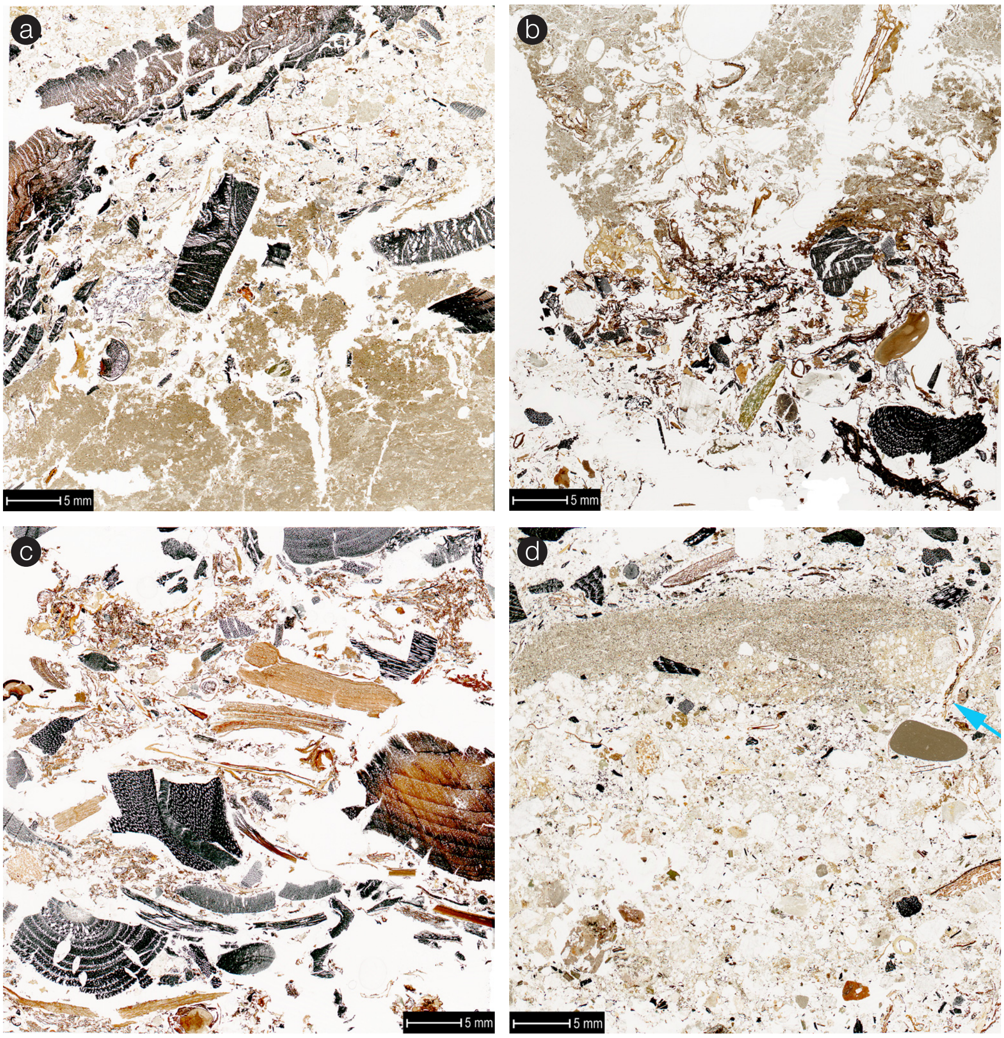

Fig. 7 Scanned thin sections; a) thin section LALU 4.2.3, at the bottom the beige lake marl which is denser in the upper part due to trampling. The limnic sediment is overlain by the basal part of the cultural sequence, consisting here of black charcoal and bark imbedded in sand; b) thin section LALU 102.1.2, a sand layer at the bottom (light grey) is covered by an organic accumulation (dark coloured), possibly a dung layer, which has been eroded and covered by lake marl (grey sediment in the upper half) after the final flooding; c) thin section LALU 102.2.4, organic layers of the cultural sequence consisting mainly of big charcoals, wood, bark remains and detritus; d) thin section LALU 4.2.1, a dense anthropogenic sand layer with gravels. In the top most part there is an inwash of fine sand from the hinterland with detritus (arrow), covered by coarser sand grains containing charcoal

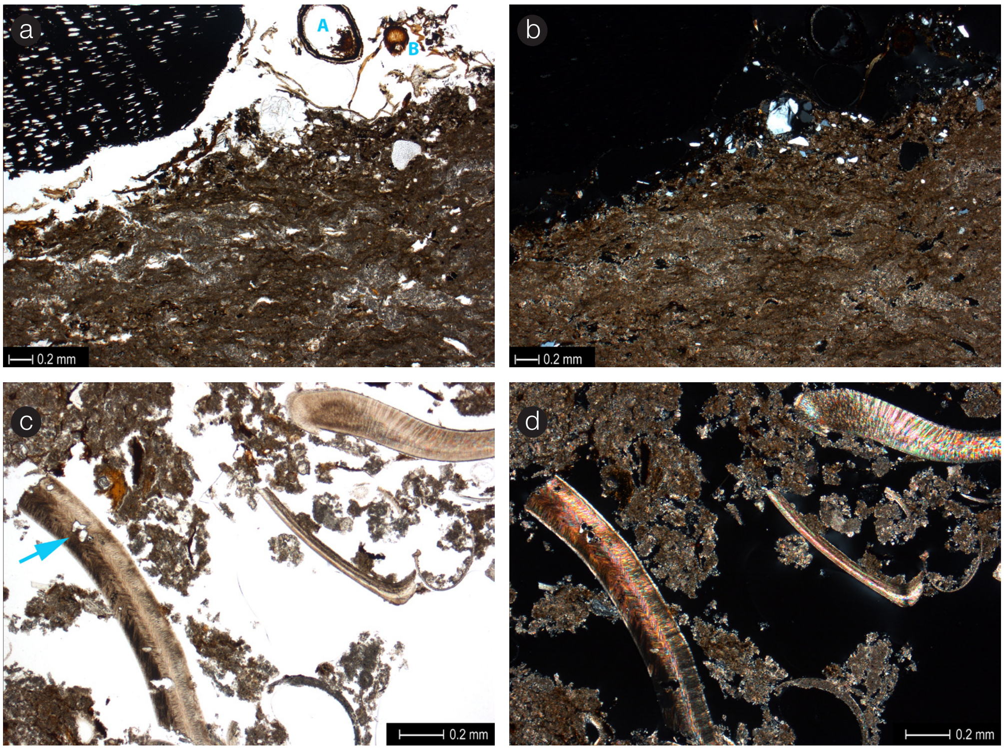

Fig. 8 Photomicrographs of limnic sediments. The pictures in plain polarized light show the carbonate lake marl and mollusc shells in beige to grey, organic remains in brown and black, quartz grains appear transparent. With crossed polarizers the lake marl shows a beige to grey colour, the mollusc shells appear grey, pinkish and greenish and quartz grains white to bluish grey; a) LALU 13.2.4, plain light, compact lake marl of the installation horizon containing organic detritus. At the surface there are anthropogenic remains trampled into the lake marl as quartz grains (see Fig. 8b), a charcoal (top left), a seed (A) and moss (B); b) same as Fig. 8a, crossed polarizers, note the quartz grains; c) LALU 102.1.1, plain light, several mollusc shells embedded in the lake marl. The shells show different stages of preservation as algal boring (arrow) and dark grey, weathered parts. At the top right side, a good preserved bivalve shell; d) same as Fig. 8c, crossed polarizers

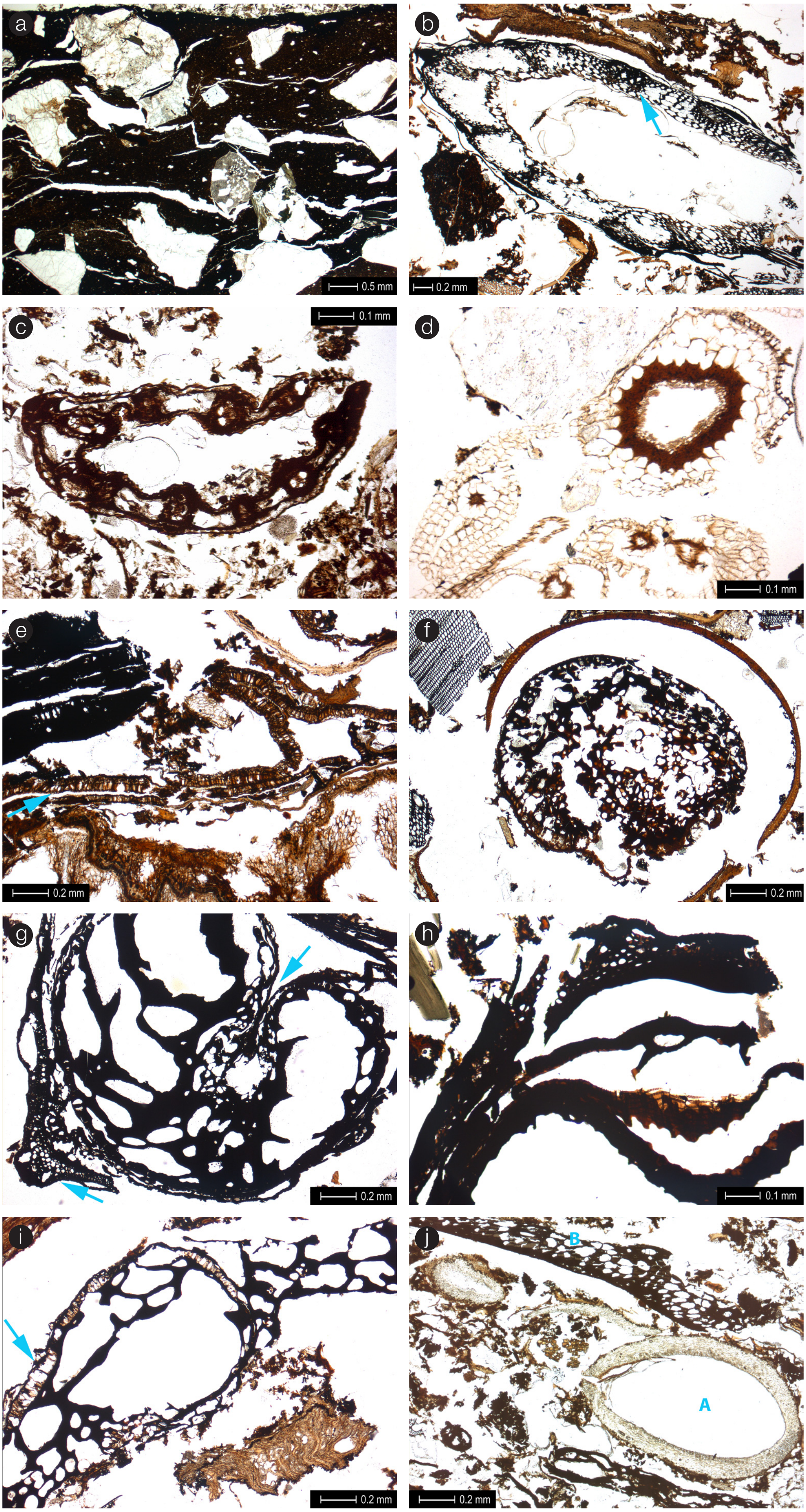

Fig. 9 Selected details I from the Lake Luokesa thin sections, all in plain light;
a) LALU 4.2.2, a cross section through a pottery with coarse tempering (granite fragments);
b) LALU 2.2, a grass stem, probably a cereal, seen in cross section, with the characteristic conduct cells (arrow);
c) LALU 4.1.1, a cyperaceae leaf in cross section (identification by Ö. Akeret, IPAS);
d) LALU 13.2.3, peat bog (*Sphagnum*) with a dark coloured stem and the almost transparent cells of the leaves. In the upper left corner a quartz grain (greyish-transparent);
e) LALU 13.2.1, at the bottom a bark overlain by a dark leaf in the middle with visible palisade tissue (arrow) and a charcoal in the top left corner;
f) LALU 102.2.4, a burnt millet seed (*Panicum miliaceum*) with the black, bursted starch in the middle, encircled by the seed coat;
g) LALU 4.1.3, a burnt cereal grain with the bubbly starch, the seed coat with the marked crease (right arrow) and the glume still covering the grain (left arrow);
h) LALU 4.1.3, burnt glumes;
i) LALU 4.1.3, cereal porridge with a recognizable cereal seed coat (arrow, identification by B. Pollmann, IPAS);
j) LALU 4.1.1, strawberry seed (A) overlain with black grass remains, probably from cereals (B)

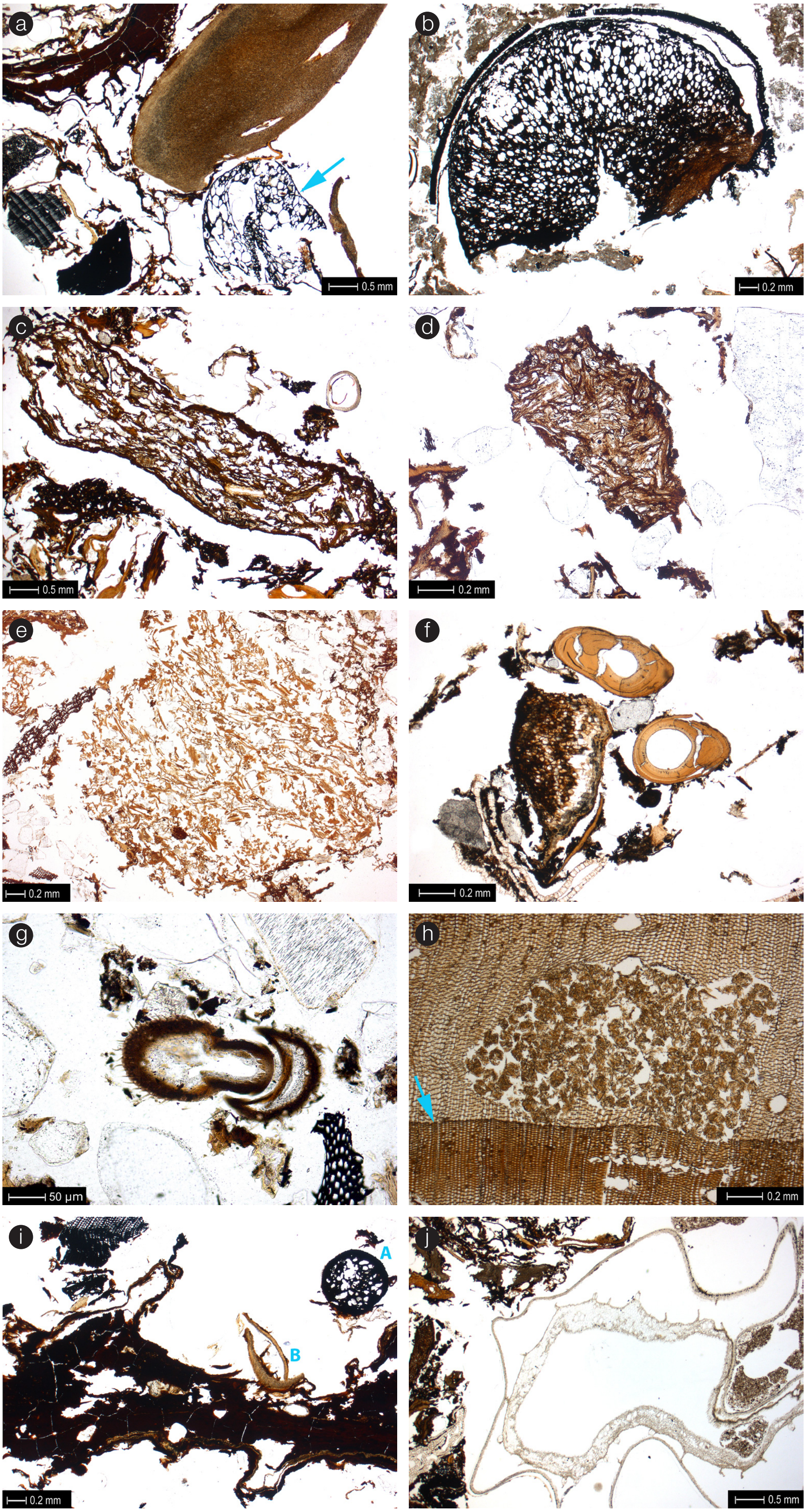

Fig. 10 Selected details II from the Lake Luokesa thin sections, all taken in plain light;
a) LALU 102.2.1, hazelnut shell (top right corner) with 2 resin ducts, below a burned cereal grain without glumes (arrow);
b) LALU 4.2.3, a partially burnt pea (*Pisum sativum*) with the bubbly starch in the middle, surrounded by the preserved seed coat;
c) LALU 13.1.2, a well preserved, whole sheep/goat coprolite with the typical, convolute internal structure and the denser rim;
d) LALU 102.2.1, a coprolite of a small rodent, probably a field mouse, identifiable because of the size and the dense structure;
e) LALU 102.2.4, possible pig coprolite with very high fragmentation rate of the remains (identification by R. Macphail);
f) LALU 13.2.4; two burned fish or amphibian bones (light brown) beside a dark bark;
g) LALU 4.2.4, insect remain with the chitin showing tiny hairs on the left side, embedded in a sandy sediment;
h) LALU 15.1.2, coniferous wood in transversal section showing an annual ring with dense late wood (arrow). In the middle part, in the early spring wood, there are some mite droppings, indicating a slight decomposition of this wood fragment;
i) LALU 102.1.2, dopplerite, the result from decayed organic remains. At the top right corner a burned cereal grain (A) and in the middle a fragmented strawberry seed (B);
j) LALU 2.1, rhizome of a reed, grown through the cultural layers after the settlement phase (identification by B. Pollmann)

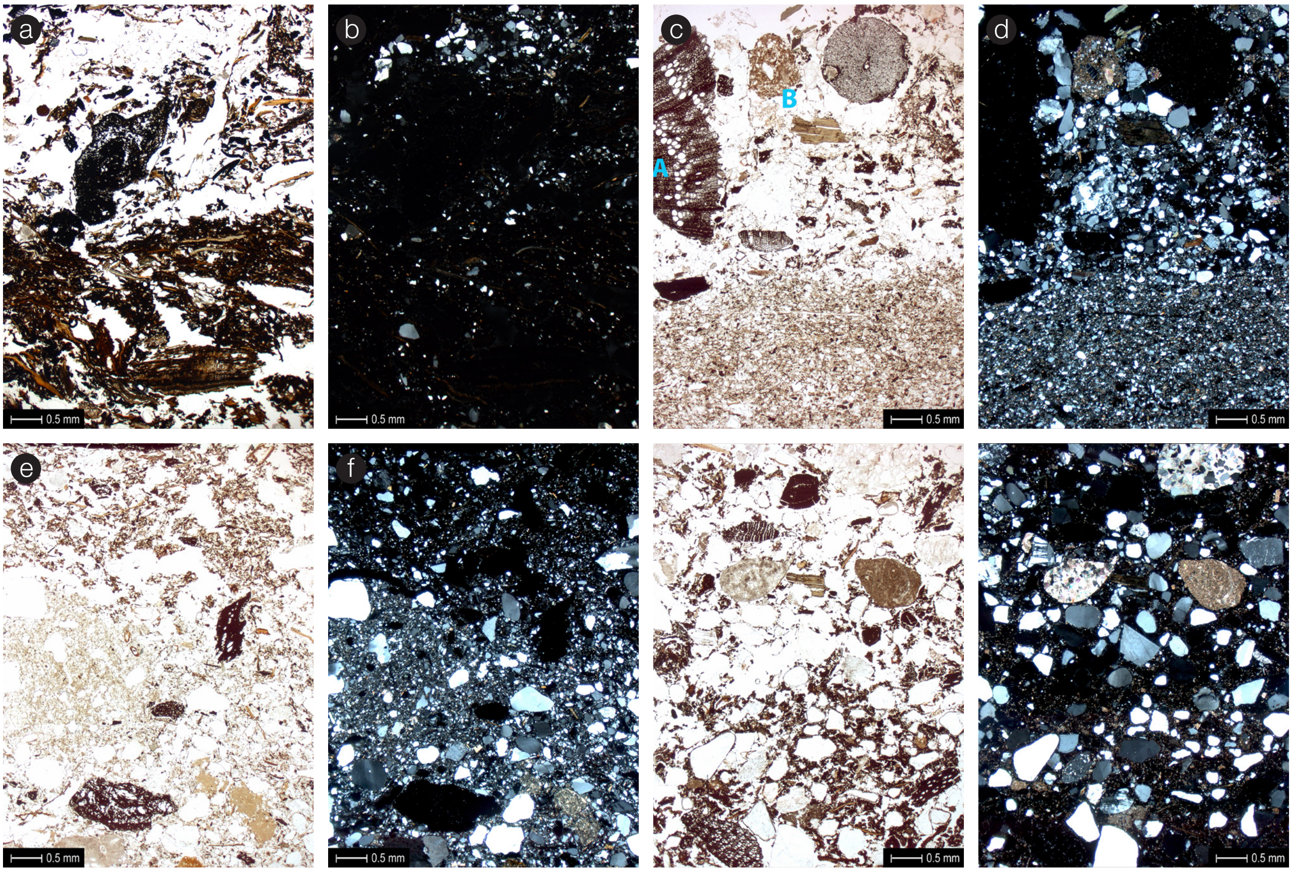

Fig. 11 Photomicrographs from the main facies from Lake Luokesa; the pictures in plain light show organic remains in brown colour, quartz grains transparent to greyish and loam in beige. In crossed polarized light organic remains appear black, quartz in white to bluish-grey and loam shows a fine mottling in grey to black colours with embedded quartz grains;
a) LALU 13.2.1, plain light, organic layer with detritus (lower part) showing signs of desiccation and crust formation. The organic accumulation is overlain by a sandy inwash in the uppermost part (see Fig. 11b);
b) same as Fig. 11a, crossed polarizers, the sand content of this layers is very low;
c) LALU 4.2.1, plain light, inwash of fine sand with detritus (lower part), overlain by coarser sand containing wood remains (A) and a loam aggregate (B). Detail from Fig. 7d);
d) same as Fig. 11c, crossed polarizers, the well sorting of the fine sand in the lower part is clearly visible, the upper sand layer is less sorted;
e) LALU 13.2.2, plain light, a compact clay containing sand, a possible loam floor, overlain by a brown, organic layer rich in detritus, perhaps remains of a weathered functional layer;
f) same as Fig. 11e, crossed polarizers; the dense structure of the clayey sand is clearly visible;
g) LALU 13.2.3, plain light, a burning layer (lower part) with rounded middle sand, scattered micro charcoal (and ashes in the lower half);
h) same as Fig. 11g, crossed polarizers, the scattered ashes in the lower half of the picture are visible as grey dots between the quartz grains

and mollusc rich lake marls (Brochier 1983; Ostendorp 1990; Platt and Wright 1991; Magny 1992; Freytet and Verrecchia 2002; Digerfeldt et al. 2007). If lake marl is exposed to air, a hard, walkable-on crust forms on the surface (Monnier et al. 1991; Jacomet et al. 2004) and exposed mollusc shells are quickly altered by weathering and algal boring (Cutler 1995; Ostendorp 1996).

The laminated lake marl from Lake Luokesa has been precipitated below the wave base and show that before the settlement development the environment was very calm, which is also supported by the presence of gastropods indicating clear, plant-rich water (Werner and Reitner 1989). In the top 1–2 cm the start of a regression can be seen in the form of reworked lake marl (destruction of laminations in the littoral zone). Traces of iron oxide, such as those observed by Motuzaite Matuzevičiūtė (2008) were not apparent in the profiles studied by us. The abrupt transition between lake marl and the cultural layer indicates that the platform emerged as a result of a lower lake level causing its surface to dry out. This led to the exposure of an oblong lake marl platform from the coast to the eastern island (Fig. 2). In the dry zone of the riparian area, the settlement of Lake Luokesa was founded during the LBA–EIA.

Cultural layers

The area was settled only after a hard, accessible surface was formed due to desiccation, and not over open water (suggested by Lewis 2007; Menotti et al. 2005). This is indicated by the sharp transition between the dense lake marl and the organic layers. The good preservation state of the mollusc shells and pollen, such as the lack of ferric precipitations, indicates only a short hiatus in terms of several weeks before the platform was settled (see also Motuzaite Matuzevičiūtė 2008; Heitz-Weniger 2014). There is evidence of a slight superficial compaction of the lake marl surface, which was due to anthropogenic (and animal) trampling during the building activities. The first anthropogenic remains, such as charcoal, seeds, wood and bark chips were trampled into the lake marl and formed a 5–10 mm thick so-called ‚installation horizon', which can be observed in many lakeside settlements (Ismail-Meyer and Rentzel 2004; Huber and Ismail-Meyer 2012; see Chapter 4, this book). The organic layers derive from anthropogenic (and animal) activities and cannot be attributed to natural peat growth (as suggested by Lewis 2007 and Motuzaite Matuzevičiūtė 2008); the exceptions were some onsite growing annual herbs (Pollmann 2014b).

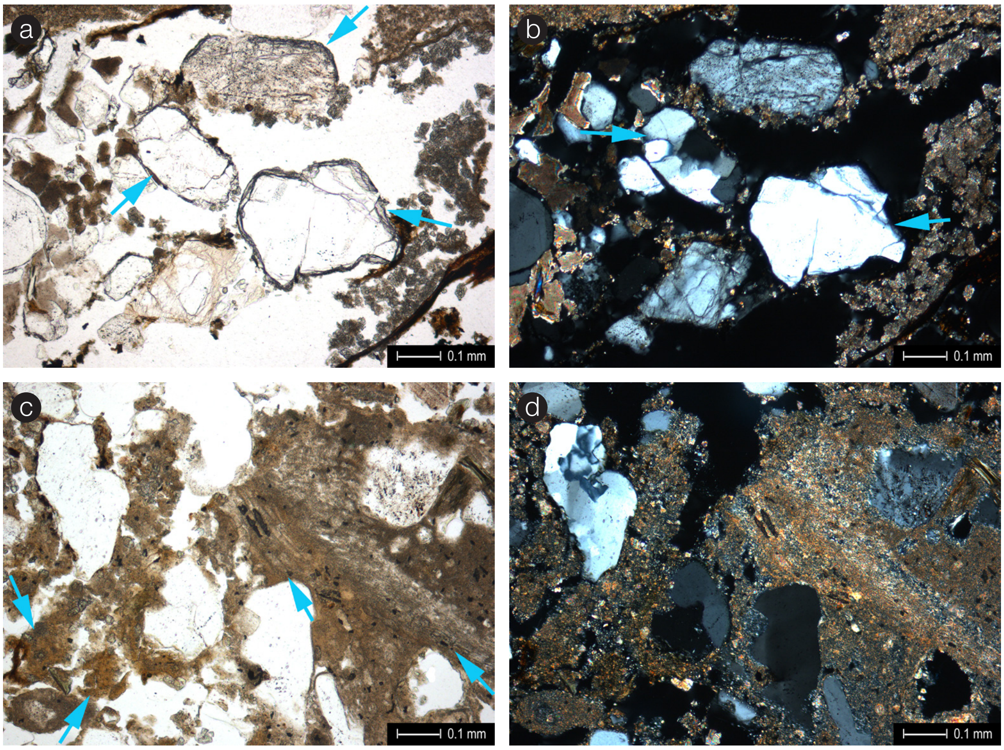

Fig. 12 Thin section pictures from burning features. The pictures in plain light show carbonate ashes in beige to grey colours and quartz grains appear nearly colourless. In crossed polarized light carbonate ash shows beige to brown colours and quartz grains appear white to bluish-grey; a) LALU 4.1.4, plain light, detail from a burning layer with quartz grains showing melting rims (arrows) and carbonate ashes;
b) same as Fig. 12a, crossed polarizers, the quartz grains show an ondulatory extinction (arrows), probably due to heating. The beige coloured ashes are clearly visible;
c) LALU 4.2.2, plain light, compact carbonate ashes showing plant pseudomorphs (right arrows), and brown parts probably containing iron and phosphate (left arrows, perhaps a burnt coprolite);
d) same as Fig. 12c, crossed polarizers, the ashes appear beige to dark grey

Organic layers formed by the inhabitants and animal activities in, beneath and around the houses; coprolites of sheep/goats, small rodents (field mouse?), possibly cattle, pigs and dogs could be recognized due to their composition, shape and internal structure (Fig. 10c–e; Akeret and Rentzel 2001; Karkanas and Goldberg 2010). Dung spherulites, formed mainly in the intestines of herbivores and representing often the only remaining sign of coprolites in terrestrial environments, generally do not occur in lakeside settlements as they have been most probably dissolved (M. Canti personal communication). Activities within the settlement which can be recognized through micromorphological investigations are house building and preparation of timber (wood and bark chips, loam aggregates), crafts (granite boulders as temper for ceramic production, see also Pollmann 2014a), food preparation and consumption (fruits and seeds, threshing, cereal porridge, nut shells, fish and amphibian bones; Fig. 9, 10), stabilization and isolation of the ground (bark, mosses, twigs), and animal husbandry (coprolites, branches, leaves and grass as litter and feed; Fig. 9b, c, e; Pollmann 2014a). The weakly calcareous acid–base balance (pH between 7.4 and 7.8; Pollmann 2014b) ought to have supported fish bone preservation on the site (Lyman 1994) since it can be assumed that fishing was practised at the time (fishnet finds are present, Pranckėnaitė 2014). The fact that they are so rare (20 fish and amphibian bones, of which 6 had burn marks; Fig. 10f) may be explained by an extensive absence of fish related waste, as cleaning, consumption and disposal of fish could have occurred well outside the sampled area. The use of fire is shown by charcoal, calcitic wood ash, burnt aggregates (possibly burnt dung, R. Macphail personal communication) and quartz grains with melting rims (Fig. 12). The latter most probably originate from the so-called Jotnian Sandstones, transported from Sweden by glacial activity (V. Motuza personal communication). They were found in and around fireplaces (E. Pranckėnaitė personal communication). As melting rims on quartz are formed at temperatures from 800° C upward (Courty et al. 1989), we assume that the inhabitants gathered sandstones in the nearby moraines for use as hot stones; the continuous heating and cooling leading probably to the melting features and dismantling of grains (Fig. 12). Cleaning of fireplaces may have led to the formation of sandy layers with strong indications of burning. Sand, as a regular component of anthropogenic layers, may also be interpreted as weathered loam aggregates from house walls and floors (U. Leuzinger personal communication).

Compaction due to trampling can be seen more prevalently on minerogenous deposits (Magny 1978); waterlogged organic layers seem not to conserve visible traces of compaction as they swell up again quickly as peats (see Chapter 2, this book). In the settlement L1 trampling is most clearly distinguishable on the installation horizon (Figs. 7a, 8a, b). Additionally there are several compacted sand levels, which are shown most clearly by the profiles from LALU 4 and 13 (Figs. 3, 7d, 11c, d).

Environmental influences

During the settlement phase organic layers showing good preservation accumulated, indicating waterlogged, anoxic conditions. It is known that organic accumulations can act as a ‚sponge' and raise the local water table, so that a fringe of capillary water is drawn up (Kenward and Hall 2000; Gastaldo and Demko 2011; see also Chapter 3, this book). Further, these accumulations show strong water retention and remain wet for a long time span (Corfield 2008; Charman 2009). A combination of high sedimentation rates and very fast sealing of remains led to an extraordinary preservation. Also phases of falling groundwater levels can be detected by the way that organic layers with signs of decay have arisen and organic detritus formed (organic particles measuring between 0.45 μ m and 1 mm; Mitsch and Gosselink 2007; Gastaldo and Demko 2011).

As waterlogged organic layers, such as natural peats, have about 80 % of their pore space filled with water, desiccation leads to a rapid subsidence and collapse of this pore space (Mitsch and Gosselink 2007; Lindsay 2010). The compact, spongy structure in decayed organic layers may be the result of such a process. In some parts, mesofaunal activities (mites, springtales and/or pot worms) led to microaggregated structures. At least some slightly acidic phenomena occurred, as the formation of dopplerite and organic crusts indicates (Stolt and Lindbo 2010). When anthropogenic, non-graded sand is the major component of a layer, this may be the result of plant matter decay, where sand was secondarily enriched due to soil formation. Many sandy layers from L1 show strong signs of alteration, so that a halt in sedimentation and a small hiatus must be postulated in such cases. Roots and rhizomes of reeds are most probably of recent origin and led to disturbance of deposits, especially in the upper half of the cultural sequence.

Layers can be affected by flooding caused by lake transgression or runoff from the hinterland (French 2003; Goldberg and Macphail 2006; Digerfeldt et al. 2007). From the micromorphological view it is obvious that due to the continuous fine stratification of the deposits, no general reworking of the layers due to lake flooding has occurred; the consequence would have been a general homogenization (see Chapter 4, this book; Huber and Ismail-Meyer 2012). Only the basal 1–2 cm of the anthropogenic layers contain sparse limnic signs, which are most probably due incursions of human and animal trampling. The rest of the anthropogenic sequence up to the top shows no limnic influences.

Runoff from the hinterland onto low ground, with inwashing of sand and silts into lakes and peatlands, is well known, even on gently sloping areas (Turnbaugh 1978; Baker et al. 2009; Zolitschka et al. 2003). Furthermore, forest clearing and human land use enhances destabilisation of slopes, soil erosion and sediment transfer to low ground (French 2003; Digerfeldt et al. 2007; Menotti 2012). Organic accumulations seem to show special behaviour with respect to runoff; 98 % occurs in the topmost 3 cm, while the deeper, water-saturated layers are not affected (Holden and Burt 2003; van der Valk 2006; Charman 2009; Baker et al. 2009). This may be one explanation of why the anthropogenic successions in lakeside settlements are not eroded completely. In the settlement L1, the difference in height between the lake marl platform and the ridge located to the north is about 25 m at a maximum distance of about 500 m (Fig. 2).

During snowmelt it is conceivable that fine sand and silt was eroded from the slopes and washed into the settlement which resulted in well sorted and graded sandy layers (containing no limnic signs), as seen in the profile LALU 4 and 13 (Figs. 7d, 11c, d). This event must have had a certain impact as the distinct lower limits of such sand layers show erosion of the exposed sediments; loose material on the surface was worked up and re-deposited together with sand, while the water-saturated layers below were not affected (see Chapter 3, this book). Since such sand inundation is only present during the occupation phase, it can be assumed that it was probably related to slash and burn land clearing which is known to have been prevalent in the Baltic region after the end of the Bronze Age (Kabailienė 2006; Stančikaitė et al. 2002, 2004; Gaigalas and Dvareckas 2002).

Abandonment of lakeside settlements often occurred due to a fire incident, poor condition of the houses, disuse or persistent flooding from the lake which made further occupancy impossible (Menotti 2012). Micromorphologically, it is difficult to detect the reason for abandonment, as the subsequent flooding also led to erosion of the topmost sediments. The remains of a settlement fire are washed away quickly due to the low specific weight of charcoal (Macphail et al. 2010). Further, water level fluctuations – often due to modern lake level corrections – can cause lakeside settlements to be exposed to terrestrial conditions causing them to be rapidly weathered. The abandonment of L1 was most likely not due to a settlement fire or flooding, but to simple desertion, which is indicated by the poorer preservation of remains observed in the upper part of all the profiles (Pollmann 2014a). After a short period – before a humic horizon could develop – the lake level rose and led to erosion of the topmost layer and the formation of a reworked lag deposit (Fig. 7b).

Does the cultural layer composition reflect climate seasonality?

In the case of lakeside settlements it can be assumed that several natural processes, which may have been connected to seasonal variations, affected the cultural sequences, such as phases of higher and lower groundwater table or inundation from the lake and from the hinterland. Sedimentation rates and loss of volume due to desiccation are also connected to seasons, which seem to have a further influence on the average layer thickness of the different facies as compared between the profile columns (which have been calculated for this project for the first time; Table 1).

Possible dung layers show the highest layer thickness with an average of 27 mm, organic layers with good preservation 22 mm thickness, while the organic layers with signs of alteration are 17 mm and sandy layers 10 mm in thickness. This shows that cattle stands probably had the highest sedimentation rates (litter, foddering and dung), even when they have been affected by desiccation. Organic layers with signs of alteration lost some volume due to desiccation. Sandy layers seem to have lower sedimentation rates (graded fine sands) or have lost almost all the organic matter and have therefore the smallest average thickness. If one compares the average layer thickness through the profile columns, the profile LALU 13 shows the highest values with 22 mm, followed by LALU 15 with 19 mm and LALU 102 with 17 mm. Significantly lower layer thickness can be seen in LALU 4 and LALU 2 with 12 and 6 mm respectively (Figs. 3, 4). The central areas show

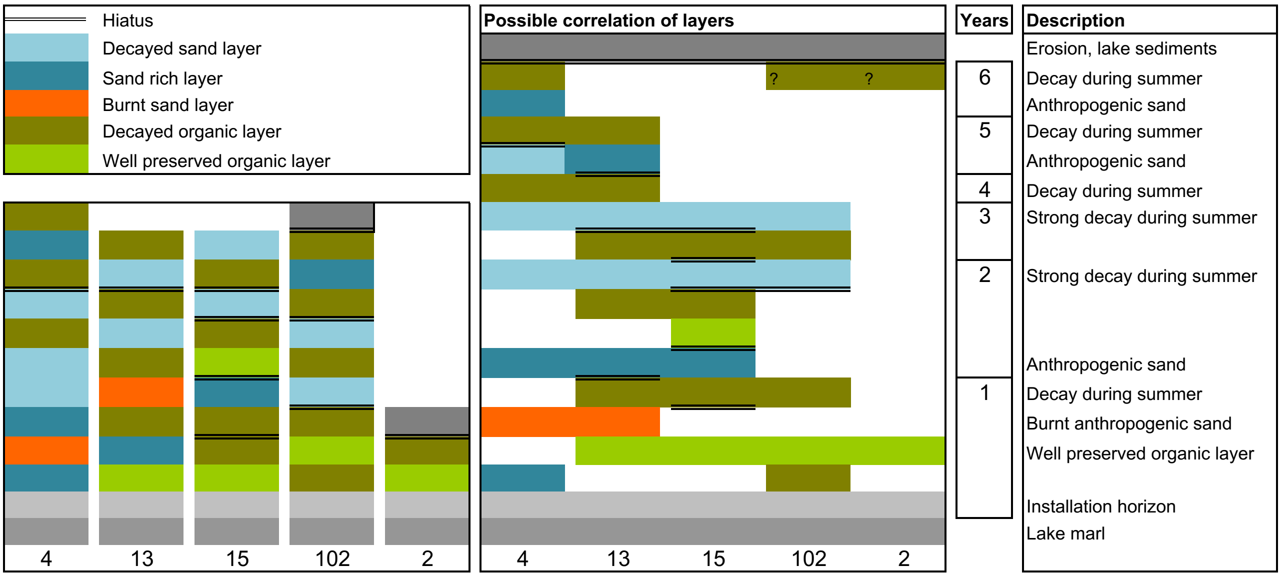

Table 2 Simplified facies sequences of the profile columns (left side), an attempt to correlate the facies (middle part) and a possible scenario with seasonal accumulations during 6 years (right side).

high sedimentation rates (columns LALU 13, 15, 102), where the cultural deposits were at the same time better protected due to dense pile positioning of the buildings and waterlogged conditions. Towards the south, west and east, lake level highs led to erosion of layers (profile LALU 2, 103). Higher areas towards the island in the north-east were more affected by dehydration and runoff. This area may well be regarded as semi-terrestrial, as the preservation of pollen was also comparatively worse (profile LALU 4; Heitz-Weniger 2014). A correlation of the layers fits well for the base of the sequences (Table 2). The natural lake marl shows signs of the lake regression and formation of an installation horizon. A sand layer covered a portion of the site. Above this an organic layer with signs of weathering has formed, which could indicate a short hiatus. From this point onwards the image becomes more heterogeneous, while towards the top several profiles indicate a less good preservation.

It is interesting to note that the sandy layers, regardless of what origin, divide the cultural layers into several intervals. By comparing the sequences of all the columns repetitive cycles could be recognised. Well preserved organic layers show in the upper parts signs of alteration and larger amounts of organic detritus. An accumulation of sand on the organic layer forms the top of the cycle. These successions could be recognised three to four times per column, in LALU 4 even six times (with the exception of profile LALU 2; Table 2). The reason of these cycles is most probably due to seasonal processes; during phases with a high groundwater table (from autumn to early summer) the remains accumulated fast and stayed well preserved. Sandy runoff sediments, as observed in the column LALU 4, can be related to melt water in late spring (Mitsch and Gosselink 2007). During mid-summer the groundwater table could drop due to elevated evaporation rates that led to the decay and soil formation processes in the desiccated part at the surface (Gastaldo and Demko 2011; Mitsch and Gosselink 2007). Sandy layers with strong signs of decay are the result of such a phase of alteration. In autumn the groundwater level increased again and a new cycle started. If this interpretation is correct, then the resulting cultural layers would represent at most 6 years (number of sand inundations in the profile column LALU 4). The settlement period suggested by the dendrochronological dating is between 16 and 20 years (Bleicher 2014), so that one must assume that the cultural layer has not been preserved completely.

Finally, the history of L1 reflected in local environment data can be presented as follows. The area around Lake Luokesa was free of ice after around 14,000 cal BC (Guobytė and Satkūnas 2011). Lake marl began to be deposited in the riparian zones at the latest since the beginning of the Holocene around 10,000 cal BC. The highest water level in Lake Luokesa was most likely during the Atlantic period (Motuzaite Matuzevičiūtė 2008; Kabailienė 2006; Menotti et al. 2005). During the beginning of the Subboreal, in around 3,300 cal BC, a mild climatic phase began and the water level dropped off to a level roughly 3–4 m below the current level (Pollmann 2014a). At around 750–250 cal BC (Sillasoo et al. 2009) a further warming can be postulated, which might have led to the formation of the lakeside platform in Lake Luokesa which was then settled at an unknown time between 625 and 535 cal BC (Bleicher 2014). Settlement activities led to the accumulation of highly organic deposits over several years that were sometimes exposed to desiccation during dry phases (midsummer?). Only after the abandonment of the site a transgression led to erosion of the topmost layers and covering with reworked lake marl. Whether this event is connected to a phase of falling temperatures and rising lake levels towards 150 cal BC (Sillasoo et al. 2009) cannot be answered. In recent times, growth of reed beds led to disturbance of some parts of the cultural deposits due to roots and rhizomes.

Comparison with some Neolithic lakeside settlements of the circum-alpine region show that site formation processes which led to accumulation, erosion and alteration of the deposits are largely the same as those reconstructed for the LBA/EIA site L1. Common features are also construction on water free carbonate platforms, no natural peat growth, fine laminations and sandy intercalations without limnic signs. Desiccation phases during summer were more pronounced at the Lithuanian site, which may be explained by the more continental climate. Some local features, such as topography and position of the site in relation to the lake (and its high stands), were of great importance for all the sites studied by us so far.

Conclusions

Due to a lake regression during the course of the LBA–EIA an extended lake marl peninsula was formed in Lake Luokesa. After drying of the riparian zone, between 625 and 535 cal BC, a settlement surrounded by double palisades was erected and inhabited for a period of up to 20 years (Bleicher 2014). As a result of this construction work an installation horizon, a trampled layer containing wood and bark residues from the preparation of the piles, was formed. During the existence of the settlement organic remains accumulated and remained well preserved due to a waterlogged environment, high accumulation rates and fast sealing. Manure layers show that domestic animals were at least temporarily kept in the settlement. Regularly appearing sand layers are the result of desiccation phases during mid-summer and inwash from the hinterland, indicating approximately 6 years of preserved data. After the abandonment of the settlement, the lake level rose, flooding the village, eroding part of the accumulations and overlaying the site with lake marl and sand. In later times, the lake seems never to have fallen below the level of the settlement, meaning that a further degrading of the organic material did not occur. Recent reeds have in some places disturbed the deposits with their roots and rhizomes.

With the interdisciplinary research at the LBA–EIA site L1 it was possible to combine archaeobotany (Pollmann 2014a), palynology (Heitz-Weniger 2014), dendrochronology (Bleicher 2014), archaeology (Pranckėnaitė 2014) and micromorphology. The detection of seasonal deposits was only possible due to a very close co-operation between these disciplines.

Further, it may be noted that the layer formation processes in the lakeside settlement L1 in the Baltic region seem to be very similar to those found in Switzerland. The topography of the hinterland and the location of the settlement in relation to the lake had a big influence in this context. These are important factors that determine whether cultural layer deposits are preserved or not.

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											Composition					Matrix				Limnic Elements									Clay						Signs of burning						Plant Material				Plant spectrum																		Taphonomic signs									
Profile number (LALU_)	Micromorphological layer	Thin section	Secondary features	Fazies	Structure	Bioturbation	Layering	Compaction (^ at surface)	Layer thickness (mm)	Lower layer boundary	Porosity (%)	Sand content (%)	Carbonate content (%) with molluscs	Organic content (%) with charcoal	Clay content (%)	Organic detritus	Micro charcoal	Distribution	Sand sorting	Gastropods, x weathered	Bivalves	Ostracodes	Characeae stems	Oogons	Trichoptera larvae	Micrite	Single sparite cristals	Sparite chains in connection	Aggregate content	Average size (mm)	Rounding	Clay from E-horizon	Clay from Bt-horizon	Clay, fine sand matrix	Charcoal	Max. size (mm)	Rounding	Wood ash	Quartz with melting rims	Burnt coprolites	Plant remains (without roots)	Max. size (mm)	Horizontal orientation	Sorting	Roots	Wood	Bark	Leaves	Needles	Twigs	Leaf moss	Sphagnum	Div. grass remains	Panicum	Fragaria vesca	Chenopodiaceae	Cereal grains (burnt)	Glumes	Cereal seed coats	Cereal porridge	Camelina	Other seeds	Dopplerite	'Net-like' org. matter	Organic crusts	Fungal spores	Potworm droppings	Springtale droppings	Mite droppings	Fish bones (number)	Insect remains (number)	Coprolites (number)
2	3	2.1		⬛	loose	xx	-	-	4	xx	30-35	40-50	-	20-25	-	x	-	x	x	o	o	-	-	-	-	-	-	-	-	-	-	-	-	-	o	1	xx	-	-	-	x	8	x	x	x	-	x	-	-	-	-	-	o	o	-	-	-	-	-	-	1	-	-	-	-	-	x	x	xx	-	2	-
	4	2.1-2		🟫	spongy	xx	x	x^	51	xx	10-20	5	-	75-85	-	xxx	x	xx	xx	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	x	5	xx	-	-	-	xxxx	10	xx	xx	xx	x	xx	o	-	x	x	xx	x	xx	-	1	1	o?	-	-	4	1?	o	xx	x	o	xx	xx	xx	1	3	dung
	5	2.2		🟩	spongy	x	x	-	17	x	35-40	10	-	50-55	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	8	x	-	-	-	xxxx	14	xx	x	x	x	xx	-	-	-	-	-	xx	xx	-	-	1?	-	-	1	3	1?	-	o	-	-	o	o	-	-	1	-
	6a	2.2		🟩	loose	-	x	-	7	x	40-50	10	-	40-50	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	1	xx	-	-	-	xxxx	4	xx	x	-	x	xxxx	-	-	-	-	-	x	x	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	6b	2.2		⬜	loose	x	x	xx	9	x	20-25	10	35-45	25-30	-	xx	x	xx	x	-	x	-	-	-	-	xxx	x	-	-	-	-	-	-	-	xx	4	xx	-	-	-	xxx	20	xx	x	-	x	xx	-	-	-	-	-	o	-	2	-	2	-	-	-	-	1?	-	-	-	-	-	-	-	-	3	-
	7	2.2		▩	dense	x	x	x	8	-	10-15	5	55-65	20-25	-	o	o	xx	xx	-	-	o	-	x	-	xxxx	x	x	-	-	-	-	-	-	xx	3	xx	-	-	-	xx	10	xx	x	x	-	x	-	-	-	o	-	x	-	-	-	-	-	-	-	-	1?	-	-	-	-	-	-	-	-	-	-
4	3	4/1.1		? 🟫	loose	x	x	-	25	x	15-20	15-20	-	50-60	10	xxx	xx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	xx	21	xx	-	-	-	xxx	19	xx	x	-	x	x	-	-	-	-	x	xx	2	8	1	-	x	-	-	1	-	-	o	-	-	x	x	-	-	-	-
	4a	4/1.1-2		🟪	dense	x	o	x	55	x	10-15	45-55	-	15-20	20	xx	xx	x	x	-	-	-	-	-	-	-	-	-	x	5	xx	x	-	xx	xx	22	xx	-	o	-	x	6	x	xx	-	o	o	o	-	-	-	-	xx	-	1	-	-	x	-	-	-	-	-	-	-	-	-	-	o	-	-	-
	4b	4/1.2-3		▣	loose	-	xx	-	23	x	20-25	35-40	-	30	10	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	5	xx	-	o	o	xx	30	xx	x	-	-	xx	-	-	x	-	-	-	-	-	-	-	-	-	-	1	-	-	o	-	-	-	-	-	-	-	?
	4c	4/1.3		🟫	loose	xx	xx	-	17	x	30-35	10-15	-	50-60	2	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	o	0.5	-	-	o	-	xx	7	xx	o	o	o	xxx	7	xx	x	xx	-	xx	-	-	xx	-	o	x	-	-	1	-	o	-	1	-	-	-	xx	x	-	o	o	-	-	-	-
	4d	4/1.3	🟧	🟫	dense	x	xx	x	7	xx	15-20	5-10	o	70-80	-	xx	xx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	4	xx	o	o	o	xxxx	6	xx	xx	-	x	xx	x	-	-	-	-	x	o	-	1	1	x	-	-	-	-	-	xx	xx	-	-	-	-	3	-	-
	4e	4/1.3-4	🟧	🟫	loose	x	x	-	25	x	35-40	10	o	45-50	5	xx	xx	x	x	-	-	-	-	-	-	-	-	-	o	1	x	-	o	-	xx	12	xx	o	o	o	xxx	5	x	x	x	o	xx	o	o	-	-	-	o	xx	-	2	2	x	-	1	-	2?	-	x	-	-	-	-	-	-	-	dung
	5a	4/1.4		▣	loose	x	x	-	11	x	20-25	25-30	o	35-45	10	x	x	xx	x	-	-	-	-	-	-	-	-	-	xx	2	x	-	xx	-	xx	10	x	x	o	x	xx	2	x	xx	x	-	o	-	-	-	-	-	-	xx	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	1v	-	-
	5b	4/1.4		■	dense	x	x	x	3	xx	15-20	40-50	-	20-25	15	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	xx	5	xx	o	o	-	x	2	xx	xx	x	o	o	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	1	-
	5c	4/1.4	🟥	▣	dense	x	x	-	3	xx	10-15	25	15	45-50	-	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	2	x	xx	x	-	xx	11	xx	x	x	o	x	o	-	o	-	o	x	x	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6a	4/1.4		▣	loose	x	xx	-	7	x	15-20	25-30	-	50-60	-	xx	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	10	xx	o	o	o	xxxx	6	xx	xx	x	-	x	-	-	-	-	x	o	xx	-	-	1	-	o	-	-	1B	-	x	-	-	-	-	-	-	-	1G1C?
	6b	4/1.4		■	dense	x	x	x	5	xx	15-20	50-55	o	20	10	x	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	xx	5	xx	o	-	-	x	2	x	xx	x	-	o	o	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6c	4/1.4		🟫	dense	-	xx	x	7	xx	10-20	15	-	65-75	-	xxx	xxx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	5	xx	-	-	-	xxxx	30	xx	x	-	-	xxx	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	xx	x	-	-	-	-	-	-	-
	6d	4/1.4		■	loose	x	x	-	6	-	20-25	65-75	-	5-10	-	x	xx	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	5	xx	-	-	-	o	0.5	x	xx	x	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
	7a	4/2.1		▣	dense	x	xx	x	4	xxx	10-15	50-60	5	20-25	5	x	xx	x	x	-	-	-	-	-	-	-	-	-	o	1	x	o	-	-	xxx	6	x	o	-	o	x	7	xx	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7b	4/2.1		▣	dense	x	xx	x	1	xxx	5-10	75-85	-	5-10	5	x	xx	xx	xx	-	-	-	-	-	-	-	-	-	o	1	x	-	o	o	xx	1	x	-	-	-	o	1	xx	xx	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7c	4/2.1		🟦	dense	x	xx	x	9	xx	10-15	65-70	-	15	5	xxx	xxx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	x	5	xx	-	-	-	xx	0.5	xx	xx	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7d	4/2.1		■	dense	x	o	x	12	x	15-20	60-70	o	5-10	10	x	xx	x	o	-	-	-	-	-	-	-	-	-	x	1	x	-	o	o	x	1	xx	o	-	o	x	2	x	xx	xx	-	xx	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	xx	-	-	-	-	-	-	-	-	-
	7e	4/2.1-2		■	loose	-	o	-	23	x	30-35	30-40	-	10-20	5	o	o	o	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	x	3	xx	-	-	o	x	15	x	x	x	xxx	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	1R	xx	-	-	-	x	x	o	-	-	-
	8a	4/2.2		🟦	dense	x	x	x	3	xx	20-30	20-25	o	40-55	5	xxx	xxx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	x	3	xx	o	o	-	xxx	2	xx	xx	x	-	x	-	-	-	-	xx	-	x	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-
	8b	4/2.2		▣	loose	-	x	-	4	xx	40	40-45	o	15-20	-	x	x	x	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	1	xx	o	-	-	xx	2	xx	xx	-	-	x	o	-	-	-	o	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
	8c	4/2.2		🟦	dense	-	x	x	6	xx	5-10	60-55	5	20	5	xxx	xxx	xx	xx	-	-	-	-	-	-	-	-	-	x	4	x	x	-	-	o	1	xx	o	-	o	xx	17	xx	x	-	x	xx	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	1	-	-
	8d	4/2.2	🟥	▣	loose	x	x	-	9	x	10-15	60-70	5	10-15	5	x	x	x	x	-	-	-	-	-	-	-	-	-	x	2	x	x	-	-	o	1	xx	o	o	x	x	4	x	xx	x	x	x	o	-	-	o	x	o	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	1	1	-
	8e	4/2.2	🟥	▣	dense	x	x	-	18	-	10-15	55-60	10	10	10	x	x	x	x	-	-	-	-	-	-	-	-	-	x	6	x	x	-	-	o	2	x	x	-	xx	x	15	x	x	x	-	x	o	o?	-	o	xx	o	xx	-	-	-	o	-	2	-	-	-	-	-	-	-	-	-	-	-	2C?
	9	4/2.3		▣	dense	xx	x	-	17	xx	15-20	40-50	5	30-35	2	o	o	o	o	x	o	o	-	-	-	-	-	-	o	1	o	o	-	-	xx	30	xx	-	-	-	xxx	5	x	xx	xx	o	o	-	-	-	-	x	x	x	-	-	1	o	-	1	-	-	-	-	-	-	-	-	o	-	-	-
	10a	4/2.3		⬜	loose	xx	x	-	7	o	15-20	10-15	45-55	20	-	x	x	xx	x	o	-	o	-	-	-	xx	x	-	-	-	-	-	-	-	xxx	13	xx	-	-	-	xx	2	x	xx	xx	o	o	-	-	-	-	o	x	o	-	-	1	x	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	10b	4/2.3		⬜	dense	xx	x	x	9	x	5-10	10-15	55-65	20	-	x	x	xx	xx	x	o	x	-	o	-	xxx	x	-	-	-	-	-	-	-	x	8	xx	-	-	-	xx	5	x	xx	x	x	-	-	-	-	-	o	x	o	1	-	1	x	o	-	-	-	-	-	-	-	-	-	-	1v?	1	-
	11	4/2.3		▩	dense	x	xx	-	11	-	5-15	o	80-90	5	-	o	-	xx	x	xx	x	xx	x	x	-	xxxx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	o	0.5	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1?	-	-	-	o	-	-	-	-	-	-
13	3	13/1.1-2	🟧	🟫	spongy	xx	o	-	75	x	25-30	5-10	-	60-70	-	x	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	3	x	-	-	-	xxxx	9	x	x	xx	x	xx	-	-	xx	-	o	-	xx	1	1	-	-	-	-	-	2?	x	xxx	xx	o	x	x	-	-	-	2G dung
	4	13/1.2-3		🟫	loose	xx	o	-	63	x	30-35	5-15	-	50-65	-	x	x	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	12	x	-	-	-	xxxx	40	x	x	x	xxx	xx	-	-	x	-	-	x	xx	4	1	-	-	-	-	-	-	o	x	-	-	x	x	-	-	-	1C?
	5a	13/1.2		■	loose	x	x	-	3	x	30-35	30-35	-	30-40	-	xx	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	6	x	-	-	-	xx	3	xx	xx	-	-	x	o	-	-	-	-	x	xx	1	-	-	-	-	-	-	1?	-	x	x	-	-	-	-	-	-	-
	5b	13/1.3-2.2		🟫	loose	x	xx	x^	41	x	25-30	5-10	-	60-70	-	xx	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	9	-	-	-	-	xxxx	15	xx	x	x	xx	xx	x	o	x	-	-	o	xx	7	5	-	-	-	-	-	1N	x	xx	xx	-	x	x	-	-	-	-
	5c	13/2.2		🟫	dense	xx	x	x	58	x	20-25	5-10	-	65-75	-	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	8	x	-	-	-	xxxx	15	xx	x	xx	x	xx	x	-	x	-	o	xx	xx	15	7	-	-	-	1	-	1N	x	xx	-	o	-	-	-	2	-	-
	5d	13/2.2		🟦	dense	x	x	x^	4	xx	15-20	25-30	-	50-60	-	xxx	xx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2	xx	-	o	-	xxxx	3	xx	xx	x	-	x	o	-	-	-	-	x	o	1	-	-	-	-	-	-	1?	-	-	-	-	-	-	-	-	-	-
	6	13/2.2		🟪	compact	x	o	x	32	x	5-10	55-60	-	15	20	x	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xxx	x	5	xx	-	-	-	x	7	x	x	x	-	-	-	-	x	-	-	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	13/2.2-3		🟫	dense	-	x	-	14	x	20-25	30-35	o	35-45	5	xxx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	x	2	xx	o	x	o	xxx	7	x	x	-	-	x	-	-	x	-	-	o	x	-	-	-	-	-	-	-	-	-	x	-	o	x	x	-	-	-	-
	8a	13/2.3		■	loose	-	x	-	13	x	20-25	30-35	5	35-45	-	x	x	x	xx	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	xx	8	xx	x?	x	-	xx	7	xx	x	-	x	x	-	-	-	-	-	x	x	2	-	-	-	-	-	-	1?	-	x	-	-	-	-	-	-	-	1G?
	8b	13/2.3		🟫	loose	x	x	-	14	x	25-30	15-20	o	50-55	-	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2	xx	o	x	-	xxxx	6	xx	x	x	-	x	-	-	x	-	xx	x	x	-	1	1	-	-	-	-	-	-	xx	-	o	x	x	o	-	-	-
	8c	13/2.3	🟥	▣	loose	-	x	x	8	x	15-20	40-50	-	25-30	10	x	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	xx	2	x	-	xx	-	x	3	x	xx	-	o	x	o	-	-	-	-	-	o	-	-	-	-	-	-	-	1?	-	-	-	-	-	-	-	-	-	-
	8d	13/2.3-4	🟥	▣	dense	-	x	x	9	x	10-15	25-30	5	50-60	2	x	xxx	xx	xx	-	-	-	-	-	-	-	-	-	o	1	x	-	o	-	xxx	7	x	xx	xxx	-	xx	2	x	xx	-	-	x	-	-	-	-	-	-	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2v	-	1CR
	8e	13/2.4		🟫	loose	x	x	-	8	x	25-30	20-25	o	40-50	2	xx	xx	xx	x	-	-	-	-	-	-	o?	-	-	-	-	-	-	-	o	x	5	x	o	o	-	xxxx	5	x	x	-	-	xx	-	-	-	-	xxx	o	-	-	-	-	-	-	-	-	-	-	xx	-	-	xx	xx	o	3	-	-
	9a	13/2.4		▣	dense	x	x	x	5	xx	10-20	75-85	-	5	-	x	xx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	0.5	xx	-	o	-	o	1	x	xx	o	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-
	9b	13/2.4		🟩	loose	x	x	x	24	xx	10-15	25-30	5	50-60	2	xx	x	xx	x	-	-	-	-	-	-	o	-	-	o	0.5	x	-	o	-	x	5	xx	-	-	-	xxx	30	x	x	x	x	x	-	-	o	x	xxx	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9c	13/2.4		⬜	compact	x	x	xx^	18	x	5	5	85	5	-	x	x	xx	x	o	-	o	-	o	-	xxxx	x	x	-	-	-	-	-	-	o	0.5	xx	-	-	-	o	2	xx	x	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?	-
	10	13/2.4		▩	loose	x	x	-	21	-	20-25	-	75-80	o	-	-	-	-	-	xx	x	xx	-	o	-	xxxx	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	2a	15.1.1		■	dense	xxx	o	-	20	x	10-15	35-40	-	45-55	-	x	xxx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xxx	4	xx	-	-	-	xx	5	o	xx	xxx	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2b	15.1.1		▣	loose	xxx	o	-	16	x	15-20	25-30	-	40-50	10	xx	xxx	xx	x	-	-	-	-	-	-	-	-	-	xx	5	x	x	x	-	xx	8	xx	-	-	-	xx	13	o	x	xxx	o	-	-	-	-	-	xx	o	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-
	3a	15.1.1		🟫	spongy	xxx	o	-	11	-	30-35	5-10	-	50-60	5	xx	xx	xx	xx	-	-	-	-	-	-	-	-	-	x	5	x	x	-	-	x	3	xx	-	-	-	xxxx	7	o	x	xxx	x	x	-	x	-	-	x	-	-	-	-	-	-	-	-	-	-	x	x	-	-	x	x	-	-	-	-
	3b	15.1.2		🟫	spongy	x	x	x^	31	x	30-35	15-20	-	45-55	2	xx	x	xx	xx	-	-	-	-	-	-	-	-	-	o	1	xx	o	-	-	xx	9	xx	-	-	-	xxx	27	x	x	x	x	xx	o	o	o	-	x	-	-	-	-	-	-	-	-	-	1?	-	x	-	o	x	x	o	-	-	-
	3c	15.1.2-3		🟫	spongy	x	x	x^	30	x	25-30	5-10	-	60-70	-	xxx	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	6	xx	-	-	-	xxxx	25	x	x	x	x	xx	-	-	x	-	x	x	x	-	-	-	-	-	-	1	-	-	x	x	o	x	x	o	-	-	1G
	4a	15.1.3		🟫	spongy	xx	x	-	26	x	30-35	15-20	-	40-50	5	xx	x	xx	x	-	-	-	-	-	-	-	-	-	x	5	xx	x	-	-	xx	13	xx	-	-	-	xxx	15	x	x	xx	x	xx	o	-	x	-	x	x	x	1	-	-	-	-	-	-	-	-	-	x	x	-	x	x	-	-	1	-
	4b	15.1.4		🟫	loose	x	x	-	19	x	25-30	15-20	-	50-60	2	xx	x	xx	x	-	-	-	-	-	-	-	-	-	o	1	xx	-	o	-	x	2	xx	-	-	-	xxxx	22	x	x	-	-	xx	o	-	x	-	o	o	x	1	-	-	-	o	-	-	-	-	x	-	-	x	x	-	-	1	-
	4c	15.1.4		🟫	spongy	x	x	-	31	x	30-35	15-20	-	45-55	2	xx	x	xx	x	-	-	-	-	-	-	-	-	-	o	0.5	x	-	o	-	xx	19	xx	-	-	-	xxx	15	xx	x	x	-	xx	o	-	x	-	-	-	x	1	2	-	-	-	-	-	-	x	xx	x	-	xx	xx	-	-	-	-
	4d	15.1.4-2.1		🟫	loose	x	x	-	12	x	30-35	5	-	60-65	-	xx	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	7	xx	-	-	-	xxxx	15	xx	x	-	xx	x	-	-	x	-	o	o	x	2	1	-	-	-	-	-	-	-	xx	x	-	x	x	-	1	1	1R
	5a	15.2.1		■	spongy	x	xx	-	39	xx	20-25	20-30	-	45-60	2	x	x	xx	xx	-	-	-	-	-	-	-	-	-	o	1	xx	-	o	-	x	5	x	-	o	-	xxx	32	xx	xx	x	-	xxx	o	-	-	-	o	-	-	-	1	-	-	-	-	2	-	-	x	xx	-	x	x	-	-	-	-
	5b	15.2.2		🟫	spongy	x	x	x	17	xx	5-25	5-10	-	65-85	-	xx	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2	xx	-	-	-	xxxx	15	x	x	x	x	xx	o	-	x	-	x	x	-	2	1	-	-	-	-	-	-	-	x	xx	o	-	-	o	-	1	dung
	5c	15.2.2		🟫	loose	x	x	-	33	x	30-35	5-10	-	55-65	-	xx	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	4	x	-	-	-	xxx	30	x	o	x	x	xxx	o	-	-	-	x	x	-	-	-	-	-	-	-	-	-	x	x	x	o	x	x	o	-	1	-
	6a	15.2.2-3		🟩	loose	xx	x	-	20	x	30-35	5-10	-	55-65	-	xx	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	10	xx	-	-	-	xxx	18	x	x	xx	x	xxx	-	-	-	-	x	x	o	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	1	-	-
	6b	15.2.3		■	dense	xx	x	x?	21	x	10-15	30-35	-	50-60	-	xx	xx	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	5	xx	-	-	-	xxx	20	xx	x	xxx	x	xx	o	-	-	-	x	-	o	-	-	2?	-	-	-	-	-	xx	x	x	o	-	-	-	-	-	-
	6c	15.2.3		🟫	dense	x	xx	x?	8	x	10-15	10-15	o	70-80	-	xxx	xx	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	10	xx	-	-	o	xxxx	3	xx	x	-	x	xx	-	-	-	-	x	x	o	1	1	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-
	6d	15.2.3-4		🟫	dense	x	xx	x?	5	x	15-20	5-10	-	70-80	-	xxx	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2	xx	-	-	-	xxxx	3	xx	xx	x	x	xx	xx	-	-	-	xxx	x	x	-	1	-	-	x	-	-	1?	-	x	x	-	x	x	-	-	1	dung
	6e	15.2.4		🟩	loose	x	x	-	7	x	20-25	10-15	-	60-70	-	x	o	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	5	x	-	-	-	xxxx	15	xx	x	-	-	xx	x	-	x	-	o	x	x	-	-	-	-	-	-	-	1?	-	-	-	-	x	x	-	-	-	1?
	6f	15.2.4		🟩	loose	x	x	-	16	x	25-30	15-20	10	40-50	2	xx	x	xx	x	-	-	-	-	-	-	o	-	-	o	0.5	xx	-	o	-	x	1	x	-	-	-	xxx	3	xx	x	x	-	x	x	-	-	-	o	x	x	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	7	15.2.4		⬜	compact	x	x	x	4	x	10-15	15-20	55-65	10	-	xx	x	xx	x	-	-	-	-	-	-	xxx	x	-	-	-	-	-	-	-	x	2	xx	-	-	-	x	1	xx	xx	x	-	-	-	-	-	?	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8a	15.2.4		▩	dense	x	xx	-	4	xx	10-15	o	85-90	o	-	o	-	xx	xx	-	-	xx	o	-	-	xxxx	x	xx	-	-	-	-	-	-	-	-	-	-	-	-	o	1	xx	xx	-	-	-	-	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	-	o	-	-	-	-	-	-
	8b	15.2.4		▩	dense	xx	xx	-	8	-	5-10	o	80-90	5-10	-	x	-	xx	xx	x	-	xx	o	o	-	xxxx	x	x	-	-	-	-	-	-	-	-	-	-	-	-	x	5	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	-	-	-	-	-	-
102	2	102/1.1		⬛	loose	x	xx	-	3	x	25-30	o	70-75	o	-	-	-	-	x	xxx	x	x	x	x	-	xxxx	x	xx	-	-	-	-	-	-	o	2	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	102/1.1		⬛	dense	x	xx	-	13	xx	15-20	o	80-85	-	-	-	-	-	x	xxx	x	x	x	x	-	xxxx	x	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	102/1.1		⬛	loose	x	xx	-	20	x	25-30	o	70-75	o	-	x	-	xx	x	xxx	x	x	xx	x	-	xxxx	x	xxx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5a	102/1.1-2		⬛	loose	x	xx	-	13	x	20-25	o	70-75	5	-	x	-	xx	x	xx	x	x	x	x	-	xxxx	x	xxx	-	-	-	-	-	-	-	-	-	-	-	-	o	4	-	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5b	102/1.2		⬛	loose	x	xx	-	9	x	15-20	-	65-75	10-15	-	x	-	xx	-	xx	x	x	-	x	-	xxxx	x	xxx	-	-	-	-	-	-	-	-	-	-	-	-	x	9	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5c	102/1.2		⬛	dense	xx	xx	-	6	xx	10-15	o	60-70	20-25	-	xx	-	xx	xx	xx	x	x	-	x	-	xxx	x	xx	-	-	-	-	-	-	-	-	-	-	-	-	xx	2	xx	xx	x	-	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	1	-
	6a	102/1.2	🟧	🟫	dense	xx	x	x?	13	x	15-20	5-10	-	70-80	-	x	x	xx	xx	-	-	-	-	o	-	-	-	-	-	-	-	-	-	-	xx	6	xx	-	-	-	xxxx	6	xx	xx	xx	x	x	-	-	-	-	o	o	x	-	1	1	-	-	-	2	1H1?	xx	xxx	-	-	x	x	-	-	2	-
	6b	102/1.2-2.1		▣	loose	x	x	-	23	x	25-30	25-30	-	40-50	-	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	11	xx	-	o	-	xxx	15	x	x	-	xx	xx	-	-	-	-	-	-	x	1?	3	2	-	-	-	-	4H1?	-	-	-	-	-	-	-	-	-	-
	6c	102/2.1		🟫	loose	x	x	-	16	x	25-30	15-20	-	50-60	-	xx	x	xx	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	13	xx	-	x	-	xxx	18	x	x	x	xx	x	o	-	-	-	o	-	x	1	3	-	-	-	-	-	1?	-	x	-	-	-	-	-	-	-	-
	6d	102/2.1-2		■	loose	xx	x	-	29	x	20-25	35-40	o	35-45	2	x	x	x	o	-	-	-	-	-	-	-	-	-	o	1	x	o	-	-	x	3	x	-	x	o	xx	5	x	x	xx	o	x	o	-	-	-	o	o	x	1	6	-	-	-	-	1	2B2?	-	xx	xx	-	-	-	-	-	-	-
	6e	102/2.2		🟫	loose	x	x	-	16	x	20-25	15-20	o	55-65	-	xx	x	xx	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	3	xx	-	x	o	xxx	18	x	x	x	x	xx	-	-	-	-	x	o	xx	1	5	-	-	-	-	-	2B2?	x	xxx	-	-	-	-	-	-	-	1G
	7a	102/2.2-3		■	loose	x	x	-	14	x	20-25	35-40	o	35-45	-	x	x	x	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	7	xx	-	x	o	xx	17	xx	x	x	x	x	-	-	-	-	o	-	-	-	1	-	-	-	-	-	1N	-	x	-	-	-	-	-	-	-	-
	7b	102/2.3		■	loose	xx	xx	-	20	x	20-25	30-35	o	40-50	2	x	x	xx	xx	-	-	-	-	-	-	-	-	-	o	1	-	-	o	-	x	4	x	-	xx	o	xxx	8	xx	xx	xx	x	xx	-	-	o	-	x	x	-	1	2	-	-	-	-	-	-	-	xxx	-	o	x	x	-	-	-	-
	8a	102/2.3-4		🟫	loose	-	x	-	18	x	25-30	25-30	-	40-50	-	x	x	xx	xx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xx	15	x	-	x	-	xx	21	x	x	-	x	xx	-	-	o	-	o	x	x	1	-	1	-	-	-	-	-	-	xxx	-	-	-	-	-	-	-	-
	8b	102/2.4		🟫	loose	x	x	-	30	x	20-25	20-25	-	50-60	2	xx	x	x	x	-	-	-	-	-	-	-	-	-	o	1	xx	-	o	-	xx	10	x	-	o	-	xxx	14	xx	x	x	xx	xx	o	-	-	-	x	x	x	-	2	1	-	-	-	-	-	-	xx	-	-	x	x	-	-	-	1P?
	8c	102/2.4-5		🟩	loose	x	x	-	13	x	20-25	20-25	o	50-60	-	x	x	x	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	xxx	15	x	o	-	-	xx	10	x	x	x	xx	x	-	-	x	-	x	o	o	-	-	-	-	-	-	-	-	x	-	-	-	-	-	o	-	-	-
	9a	102/2.5		🟩	loose	x	x	-	14	x	20-25	15-20	o	55-65	-	xx	x	xx	x	-	o	-	-	-	1	-	-	-	-	-	-	-	-	-	x	7	xx	-	-	-	xxx	11	xx	x	-	xx	xx	x	-	-	-	xx	o	-	-	-	-	-	-	-	1	1R	-	-	-	-	-	-	-	1	-	2 beetles?
	9b	102/2.5		🟫	dense	x	x	x	5	xx	5-10	10-15	55-65	20	2	xx	x	xx	x	o	-	o	-	-	-	xxx	o	-	o	1	xx	-	o	-	x	1	x	-	-	-	xx	2	xx	xx	x	-	x	-	-	-	-	-	o	-	1	-	-	-	-	-	-	-	-	x	-	-	x	x	-	-	-	-
	9c	102/2.5		⬜	dense	x	x	x	5	x	5-10	5-10	70-80	10	2	-	o	o	x	x	-	x	o	x	-	xxxx	xx	x	o	1	x	-	o	-	o	2	x	-	-	-	o	2	x	xx	-	o	o	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	o	-	-	-	-	-	-
	10	102/2.5		▩	loose	x	xx	-	32	-	10-20	o	75-85	5	-	-	-	-	xx	xx	-	x	x	x	-	xxxx	x	x	-	-	-	-	-	-	-	-	-	-	-	-	o	15	x	x	x	o	o	o	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	o	-	-	-	-	-	-

Legend

Facies
- 🟩 Organic layers with good preservation
- 🟫 Weathered organic layers
- 🟦 Natural sand with detritus
- ▣ Anthropogenic sand with gravels
- ■ Anth. sand with strong decay
- 🟪 Loam layers
- ⬛ Covering layers (lake marl or sand)
- ⬜ Horizon of installation
- ▩ Lake marl
- 🟥 Burning layers
- 🟧 Possible dung layers
- ═ Hiatus

Quantity
- \- absent
- o very rare/weak
- x rare/clear
- xx frequent/strong
- xxx very frequent/very strong
- xxxx predominant

Other seeds
- B Brassicaceae
- H Hazelnut shell
- N Nymphaceae
- R Rubus

Coprolites
- G Goat / Sheep
- C Cattle
- CR Carnivore
- P Pig
- R Rodent

Table 3 Layer description

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Institut für Integrative und Naturwissenschaftliche Archäologie (IPNA) an der Universität Basel; Leica Mikroskop DMRXP mit Dünnschliffen der Fundstelle Zug-Riedmatt (Aufnahme K. Ismail-Meyer, August 2015)

Institute for Integrative Prehistory and Archaeological Science (IPAS) at the University of Basel, Switzerland; Leica microscope DMRXP with thin sections from the site Zug-Riedmatt (photograph by K. Ismail-Meyer, August 2015)

6 Zusammenfassung

Die Seeufersiedlungen Mitteleuropas stellen dank ihrer ausserordentlichen Erhaltung ein einzigartiges Archiv für die Archäologie und ihre benachbarten Wissenschaften dar. Dies wurde auch von der UNESCO anerkannt, welche im Jahr 2011 insgesamt 111 europäische Fundstellen von Seeufersiedlungen in die Welterbliste aufgenommen hat (http://whc.unesco.org/en/list/1363). Diese reichhaltigen Fundstellen bieten viele Möglichkeiten, Ergebnisse aus mehreren Disziplinen zusammenzuführen und so zu einer detailreichen Rekonstruktion der Zeitstellung, Ernährung, Wirtschaftsweise und der beeinflussenden Umweltfaktoren zu gelangen. Die Mikromorphologie versucht, die anthropogenen und natürlichen Prozesse, die vor, während und nach dem Bestehen einer Siedlung die Schichtbildung beeinflusst haben zu rekonstruieren. Dabei spielen Überlegungen zur Taphonomie von diversen Resten eine zentrale Rolle. Aber auch die Zusammensetzung und Struktur der Ablagerungen sind von grosser Wichtigkeit, um Einwirkungen auf die Schichten erkennen zu können.

Mit der hier vorliegenden Arbeit konnte u.a. aufgezeigt werden, dass ähnliche anthropogene Prozesse zur Ablagerung von unterschiedlichen Schichten in Seeufersiedlungen geführt haben, wie die Akkumulation von diversen Resten infolge alltäglicher Tätigkeiten, Begehung und Bauaktivitäten. Diese oft stark organischen Kulturschichten wurden wiederum durch ähnliche natürliche Prozesse beeinflusst; Überflutungen, Aufarbeitung durch Wasser, Erosionen und Trockenfallen. Die im Folgenden formulierten Hypothesen gelten nur für die hier vorliegenden Seeufersiedlungen (wobei sich viele Prozesse auch in anderen Seeufersiedlungen erkennen lassen).

Natürliche Prozesse vor der Besiedlung

Unterhalb der Kulturschichtablagerungen lässt sich jeweils im Litoral ausgefällte Seekreide fassen. Feine Laminierungen zeigen generell ein ruhiges Milieu unterhalb der Wellenbasis an. In der Seekreide enthalten sind Molluskenschalen, häufige mit Karbonat verkrustetete Algenreste von Armleuchteralgen und seltener Diatomeen (Brochier, 1983; Platt and Wright, 1991; Freytet and Verrecchia, 2002; Schurrenberger et al., 2003). Sinkende Seespiegel, wohl in vielen Fällen klimatisch bedingt, führten zur Aufarbeitung von laminierter Seekreide; Feinschichtungen wurden durch Wellenschlag zerstört, fluvial eingebrachter Sand angereichert und fragile Bestandteile aus der Seekreide, wie Molluskenschalen und Algenreste fragmentiert (Digerfeldt et al., 2007).

Sank der Seespiegel weiter, wurde Seekreide der Luft ausgesetzt; Molluskenschalen verwitterten und Algenbewuchs griff diese noch zusätzlich an. Man muss bei solchen Befunden von einem (kurzfristigen) Sedimentationsunterbruch ausgehen (Cutler, 1995). Bei längeren Unterbrüchen (im Bereich von mehrere Wochen) konnte auf der trockenen, harten Oberfläche der Seekreide eine Pioniervegetation entstehen, wie beispielsweise Moose, was durch makrobotanische Analysen aufgezeigt werden kann (Jacomet, 1985; Monnier et al., 1991).

Anthropogene Prozesse während der Besiedlung

Zu Siedlungsbeginn war die Seekreide in den hier untersuchten Fundstellen jeweils trocken. Dies lässt sich aufgrund von mehreren Beobachtungen feststellen: Infolge von Begehung durch Mensch und Tier fand offenbar kein Einsinken in die Seekreide statt (deutliche Schichtgrenzen vorhanden), es lässt sich vielmehr eine Komprimierung der Oberfläche der Seekreide erkennen, mit ersten anthropogenen Resten, wie Holzkohlen, Rindenschnipseln und Lehmaggregaten, die in die Seekreide eingetreten wurden. Dieses charakteristische Niveau, das rund 5 bis 10 Millimeter mächtig ist, bezeichnen wir hier als Installationshorizont.

Mit der Zeit haben sich infolge Bauarbeiten, Nahrungszubereitung, Handwerk und Viehhaltung Reste dieser Tätigkeiten sowie Exkremente (Koprolithen) von Haustieren neben/unter den Häusern akkumuliert. Unseren Abschätzungen zufolge betrugen die Sedimentationsraten mehrere Zentimeter pro Jahr. Man könnte diese stark organischen Schichten, welche ähnlich wie Torfe agieren und reagieren, auch als eine Art ‚anthropogenen Torf' bezeichnen.

Im Innern der Häuser wurden Lehmböden ausgebracht, die bei ebenerdiger Konstruktionsweise teils noch *in situ* erhalten sind. Diese zeigen im Dünnschliff an der Oberfläche Spuren der Nutzung auf, wie Kompaktionen und Ablösungen von Bodenaggregaten infolge Begehung. Zudem lassen sich darüber jeweils infolge der Nutzung dünne Niveaus an Holzkohlen, Aschen, Moosen und anderen organischen Resten, Fischknochen und Sand fassen. Die meist geringe Grösse der Reste könnte auf Reinigungen der Oberflächen oder eventuell eine Bedeckung mit Matten hindeuten. Bei Erneuerungen der Lehmböden konnten diese Nutzungsschichten regelrecht versiegelt werden.

Bis anhin wurde mit unseren Proben keine eindeutigen Feuerstellen angeschnitten. Akkumulationen von Aschen und Lehmaggregaten mit starken Brandspuren sind jedoch im Zusammenhang mit der Leerung von Feuerstellen zu sehen, wobei auch Brandereignisse mit Verstürzen nicht immer ausgeschlossen werden können.

Synsedimentäre natürliche Prozesse

Die synsedimentären Prozesse wirkten auf die entstehenden anthropogenen Ablagerungen ein und sind von grosser Wichtigkeit für das Verständnis von taphonomischen Prozessen in den Fundstellen; sie entscheiden wesentlich mit, ob und wie viel der anthropogenen Schichtakkumulationen bis heute überliefert werden konnte.

In der unmittelbaren Umgebung von Seen, also da wo sich Seeufersiedlungen teils bis heute erhalten konnten, lassen sich jeweils erhöhte Grundwasserspiegel, teils bis an die Oberfläche feststellen. Organische Ablagerungen haben generell eine Schwammwirkung, wie auch Torfe; sie erhöhen den lokalen Grundwasserspiegel mittels Kapillarkräften. Zudem halten diese Ablagerungen Wasser stark zurück, so dass innerhalb von organischen Akkumulationen oft wassergesättigte Bedingungen herrschen. In solchen Ablagerungen wird Sauerstoff rasch von Bakterien und Pilzen aufgebraucht, so dass die meisten natürlichen Abbauprozesse rasch unterbunden werden (Corfield, 2007; Kenward and Hall, 2008; Lillie and Smith, 2009; Gastaldo, 2011).

Die organischen Ablagerungen der Seeufersiedlungen müssen sich im Grunde ähnlich wie Torfe gebildet haben; an der Oberfläche befindet sich eine Zuwachszone (‚Akrotelm'), die durch anthropogener Akkumulation wächst (in Torfen sind dies absterbende Torfpflanzen). Infolge Überdeckung gelangten die akkumulierten Reste mit der Zeit in die wassergesättigte, sauerstofffreie Zone (‚Katotelm'). Dieser Prozess dauert in natürlichen Torfen rund 100 Jahre (Mitsch and Gosselink, 2007). In Seeufersiedlungen muss dies zeitweise sehr rasch vor sich gegangen sein, im Verlauf von Tagen oder Stunden, was beispielsweise die gut erhaltenen Ablagerungen von Arbon-Bleiche 3 aufzeigen (u.a. Chlorophyllerhaltung, kaum koprophile Pilzsporen; Jacomet et al., 2004).

Das Akrotelm-Katotelm-Modell aus der Torfkunde erklärt, dass sich Wasser in der nicht wasserhaltigen Zuwachszone rasch bewegen kann, während es im wassergesättigten Katotelm nur langsam fliesst. ‚Neues' Wasser von Niederschlägen oder Überflutungen kann nicht in die wassergesättigte Zone eindringen. Während Runoff-Prozessen in Torfen durchfliesst deshalb das Wasser aus dem Hinterland nur den obersten, nicht wassergesättigten Bereich (Baker et al., 2009; Charman, 2009). Überträgt man dieses Modell auf Seeufersiedlungen, bewegte sich Wasser, entweder vom Hinterland her kommend oder infolge Seespiegelhochständen, in organischen Ablagerungen nur durch die durchlüfteten Schichtbereiche an der Oberfläche, während die tieferen, wassergesättigten Bereiche nicht beeinflusst wurden. Dieses Modell könnte auch den Umstand erklären, weshalb Ablagerungen aus Seeufersiedlungen zwar Erosionen und Zonen mit Aufarbeitungen aufzeigen, was aber nur einzelne, teils über grössere Distanzen verfolgbare Lagen betrifft.

Seespiegelhochstände in Seeufersiedlungen haben zur Kappung und/oder Aufarbeitung von durchlüfteten Ablagerungen an der gefluteten Oberfläche geführt. Wenn der See zudem erodierte Seekreide mitführte, konnten Mischzonen aus Kulturschichtresten und Seekreide entstehen. Runoff-Prozesse traten auf, wenn das Hinterland ein gewisses Relief aufweist. Diese waren wohl meist an die Schneeschmelze und/oder intensive Regenfälle gebunden. Sie äusserten sich in Erosionen der durchlüfteten Sedimente (analog zu Seespiegelhochständen) und führten zur Ablagerung von gut sortierten, teils gradierten Feinsanden mit verlagerten, teils frischen organischen Resten ohne jegliche limnischen Anzeiger. Die Sande wurde im Hinterland erodiert, was insbesondere durch Störungen des Bodengefüges infolge Rodung und/oder Landwirtschaft im Hinterland verstärkt werden kann (Mitsch and Gosselink, 2009; Zolitschka et al., 2010); in den untersuchten Fundstellen lassen sich diese charakteristische Sandlagen teilweise feststellen (Arbon-Bleiche 3, Stansstad-Kehrsiten und Lake Luokesa), wobau auffällt, dass diese nur in den anthropogen gebildeten Schichten vorkommen und nicht in den natürlichen Seekreiden.

Infolge jahreszeitlicher Schwankungen von Temperatur (und Evaporationsmengen) bewegt sich der Grundwasserspiegel auf und ab. Bei den organischen Ablagerungen der Seeufersiedlungen konnte es geschehen, dass phasenweise freiliegende Schichten verwitterten, was vermutlich im Hochsommer geschah, wenn die kapillare Wirkung der organischen Ablagerungen nicht mehr ausreichte, um den Grundwasserspiegel bis an die Oberfläche anzuheben (Keddy, 2010; Gastaldo, 2011). In den betroffenen Bereichen führte Wasserverlust zur Verminderung der Porosität und Fragmentierung der organischen Reste bis zu organischem Detritus, während Bodenfauna sich ausbreitete und eine Gelifizierung von organischen Resten (Doppleritbildung, organische Krusten) stattfand (Lindsay, 2010; Stolt and Lindbo, 2010; Gastaldo, 2011).

Eine einzelne Schicht kann mehrere solcher Prozesse durchgemacht haben, wie beispielsweise Eintrocknen, Aufschwemmung, Ablagerung, erneutes Eintrocknen etc. In Schichtabfolgen, innerhalb derer mehrere unterschiedliche Prozesse übereinander rekonstruiert werden können, müssen diese synsedimentär stattgefunden haben, da ansonsten eine Homogenisierung der Ablagerungen hätte stattfinden müssen (Kenward and Hall, 2000). Wenn also eine Schichte mit Anzeigern auf Zerfall von einer gut erhaltenen Schicht überdeckt ist, fand der Abbau der ersten während der Sedimentation statt.

Generell nimmt die Erhaltung der organischen Reste von unten gegen oben ab; am besten erhalten sind die ältesten, auf der Seekreide akkumulierten Akkumulationen. Möglicherweise hängt dies mit der gegen oben abnehmenden Kapillarwirkung zusammen.

Abgehoben oder ebenerdig konstruiert

Die Schichtbildungsprozesse wurden beeinflusst, je nachdem ob eine Siedlung ebenerdig oder abgehoben konstruiert worden ist.

Die als abgehoben rekonstruierten Siedlungen in der hier vorliegenden Arbeit zeigen sehr fein laminierte Schichten, die sich über lange Distanzen verfolgen lassen. Dies scheint auf den Umstand zurückzugehen, dass sich Wasser – von Runoff-Prozessen und/oder Überflutungen vom See her kommend – vermutlich fast ungehindert über grössere Areale bewegen konnte. Die zahlreichen Pfähle haben die Fliessgeschwindigkeit von Wasser sicher stark heruntergesetzt, aber nicht komplett unterbunden. Aufgeschwemmte Kulturschichtreste (aus den durchlüfteten Schichtbereichen an der Oberfläche erodiert) konnten über grosse Flächen eingeebnet werden. Hausaussen- und Innenbereiche (also unterhalb der Häuser entstanden) lassen sich nicht mikromorphologisch differenzieren, da dasselbe Material verteilt wurde. Ausserdem enthalten die hier analysierten abgehobenen Siedlungen generell nur wenig Baulehmreste, die in Form von Aggregaten vorliegen. Diese gehen wohl hauptsächlich auf abgewitterte Bausubstanz zurück. Der Grossteil des wohl ursprünglich vorhandenen Baulehmes muss sich in Wasser aufgelöst haben, am ehesten in der Folge von Regenfällen, Runoff-Prozessen oder Überflutungen.

Ebenerdig konstruierte Siedlungen zeigen weniger fein laminierte Schichtungen und können *in situ*-Befunde, wie Lehmböden, aufweisen (Aussen- und Innenbereiche lassen sich teils differenzieren). Runoff-Sedimente konnten bis anhin nicht ausgemacht werden, vermutlich weil diese Siedlungen zufällig ein weniger hohes Hinterland aufwiesen. Entsprechende Ablagerungen können natürlich auch nicht erhalten sein.

Postsedimentäre Prozesse

Alle hier analysierten Seeufersiedlungen wurden während oder nach ihrer Auflassung von Seesedimenten überdeckt (und Sand im Fall von Arbon-Bleiche 3), die auf eine Transgression zurückgehen. Eigentliche ‚Auflassungsablagerungen' (Brandschichten oder organische Ablagerungen mit Anzeichen von Abbau) sind mikromorphologisch kaum beobachtbar. Dies hängt damit zusammen, dass diese meist infolge der finalen Überflutung vom See erodiert worden sind. Dies ist auch ein Grund, weshalb die Gründe für eine Auflassung mikromorphologisch oft schwierig zu erurieren sind. Vorstellbar wäre ein Feuer, ein Seespiegelanstieg, ‚zerwohnte' Häuser oder dass eine Siedlung nicht mehr benötigt wurde (Menotti, 2012). Infolge der Transgressionen, welche alle vorliegenden Seeufersiedlungen heimsuchten, haben sich sandige oder seekreidige Ablagerungen über den Kulturschichtresten akkumuliert, deren Bedeutung als Erosionsschutz enorm war und noch heute ist.

Es ist bekannt, dass unter wassergesättigten Bedingungen Abbauprozesse aufgrund von Sauerstoffmangel praktisch unterbunden sind. Sobald sich die Reste einmal in diesem Milieu befinden, bleiben sie praktisch in diesem Zustand erhalten. Dies impliziert, dass der Grossteil der Abbauprozesse synsedimentär und nicht postsedimentär stattgefunden hat, sofern der Grundwasserspiegel nachträglich nicht bis auf die Höhe der Kulturschichtablagerungen gesunken ist (Kenward and Hall, 2000).

Die wichtigsten postsedimentäre Prozesse sind Weiss-, Rot- oder Nassfäule, welche Holz degradieren können (Huisman and Klaassen, 2009). Aber auch das Wachstum von Schilfwurzeln und -rhizomen, welche tief ins Sediment reichen, können zu beträchtlichen Störungen im Schichtgefüge führen.

Seespiegelkorrekturen sind wohl die grösste Gefahr für Seeufersiedlungen (Mitsch and Gosselink, 2007). Sobald gut erhaltene Schichtbereiche nach Seespiegelabsenkungen mit Sauerstoff in Berührung kommen, beginnen sie zu oxidieren, was innert Minuten zu Verfärbungen des organischen Materials führt. Danach setzt rascher Abbau durch Bakterien und Pilze ein; die Bodenfauna wird aktiv. Zuletzt bleiben vom reichen kulturhistorischen Erbe nur noch Lehmbrocken, Holzkohlen, Steine, grössere Knochen und Keramik übrig.

Saisonale Ablagerungen?

In mehreren Fundstellen lassen sich regelmässig Runoff-Sedimente beobachten, welche die Kulturschichtabfolge in Intervalle aufteilen können; auf eine sandige Einschwemmung vom Hinterland folgt in der Regel eine gut erhaltene organische Schicht, die gegen oben Anzeichen von Degradierung aufweist. Nach dem momentanen Stand der Forschung gehen wir davon aus, dass die Sandeinschwemmung mit der Schneeschmelze im Frühjahr einhergeht, während der Abbau der Schichten im Hochsommer geschehen sein dürfte. Noch lässt sich nicht sicher aussagen, ob die Hauptakkumulationszeit der organischen Reste während des Winters (Vorkommen von Dung, Nahrung und Streu für im Siedlungsareal befindliches Vieh) oder im Frühjahr in der Hauptvegetationsphase stattgefunden hat, während der das Vieh wohl hauptsächlich ausserhalb des Siedlungsareals gehalten wurde.

7 Ausblick

Seeufersiedlungen waren während ihres Bestehens weder rein limnisch noch terrestrisch und besetzen somit eine Nische mit einem einzigartigen Milieu, dessen Eigenheiten heutzutage, nach Seespiegelkorrekturen und Flussbettkanalisierungen, kaum mehr ‚live' beobachtet werden kann, zumindest in Mitteleuropa. Aas amphibische bot den damaligen Bewohnern offenbar viele Vorteile, was die Unannehmlichkeiten, welche diese Lebensweise wohl ebenso mit sich brachten, offenbar wett machte. Mit hoher Feuchtigkeit, jährlich wiederkehrenden Hochwasserständen und der wohl zeitweise matschigen Seekreide um die Häuser, wo man regelmässig zirkulierte und sich auch zeitweise Haustiere aufgehalten haben, hat man offenbar gelebt. Möglicherweise packte man vor Überschwemmungen alles Notwendige und zog samt Vieh für ein paar Wochen in höher gelegene Gebiete, um danach die Häuser wieder instand zu stellen, wie dies teils noch heute an nicht korrigierten Flussläufen im Herzen Afrikas gehandhabt wird.

Die Erforschung des amphibischen Milieus wird bis heute nicht von einer einzelnen Disziplin abgedeckt, so dass sich multi- und interdisziplinäre Analysen der Seeufersiedlungen anbieten. Seit einiger Zeit legt man deshalb in Forschungsprojekten einen Schwerpunkt auf vielseitige naturwissenschaftliche Auswertungen (was neben diversen Knochenanalysen, Makrobotanik, Palynologie, Mikromorphologie auch Sedimentologie, Geochemie, Entomologie, Parasitologie, Fungologie, Holzkohlenanalysen etc. beinhalten kann). Es wird nun auch vermehrt Wert auf taphonomischen Beobachtungen der Reste gelegt, nicht nur von botanischen Resten und Knochen, sondern auch von Keramik und Molluskenschalen, welche wichtige Informationen zum Milieu liefern können. Das Zusammenbringen der vielseitigen Informationen aus unterschiedlichen Disziplinen birgt mit Sicherheit ein grosses Potential, um dem Verständnis für das Leben in und rund um Seeufersiedlungen und den vielseitigen beeinflussenden Prozessen näher zu kommen. Mit der Methodik der interdisziplinären Analysen beschäftigt sich von Anfang 2014 bis Ende 2016 ein Forschungsprojekt ‚Formation and taphomomy of archaeolgocal wetland deposits: Two transdisciplinary case studies and their impact on lakeshore archaeology', finanziert durch den SNF (Projekt-Nr. CR30I1_149679/1), das sich u.a. mit Fragen, ob man rein interdisziplinär, also getrennt, oder integrativ, also im Austausch untereinander auswerten soll. Es werden Vorgehen und Resultate der Grossgrabung Zürich-Opéra (ZH), welche interdisziplinär analysiert wird mit der Kleingrabung Zug-Riedmatt (ZG), die integrativ im ständigen Austausch zwischen Archäologie, Makrobotanik, Palynologie, Mikromorphologie, Geochemie und Zoologie angegangen wird, verglichen. Beide Ansätze haben ihre Stärken und Schwächen. Der erste, allgemein übliche Ansatz birgt die Gefahr, dass die beteiligten Naturwissenschaften ihre Resultate soweit interpretiert haben, dass eine wirkliche Diskussion kaum mehr stattfinden kann. Mit dem integrativen Ansatz kommen alle Resultate ständig in einer Art Schmelzpott zusammen und es hängt stark von den beteiligten Personen ab, was daraus ‚gegossen' wird. Irrungen, Wirrungen und Zirkelschlüsse sind hier eine Gefahr, es entstehen aber auch zahlreiche wichtige Diskussionen. Ein weiterer Aspekt des transdisziplinären Forschungsprojektes ist es, vorgefertigte Bilder möglichst auszuschliessen und die Analysen soweit als möglich neutral durchzuführen. Allerdings spielen viele Bilder bereits bei der Ausgrabung mit und beeinflussen auch die Beprobungsstrategie, die Auswertungen und Interpretationen. Sich mit diesen Bildern auseinanderzusetzen sollte immer ein wichtiges Thema sein und bleiben, egal mit welcher Methodik man sich einer Ausgrabung annähert (Gross et al. in prep.).

Ein paar aktuelle Fragestellungen, welche möglichst übergreifend angegangen werden sollten, wären:

- Themenbereich Seekreide: Wie verhält sie sich als Baugrund? Wie beeinflusst ein hoher, resp. tiefer Wassergehalt der Seekreide Vorgänge an dessen Oberfläche? Was geschieht mit trockener Seekreide, die wieder überflutet wird? Wie verhält sich Seekreide, die von organischen Resten überlagert ist?
- Wasser oder kein Wasser: Muss sich aufgrund der guten Erhaltung eine organische Schicht unter Wasserbedeckung ablagern? Oder reichen allein die kapillaren Kräfte der organischen Schichten aus, um die Erhaltung zu erklären? Braucht es für eine Gelifizierung von organischem Material Wasser (Bildung von Dopplerit und organischen Krusten)? Was geschieht mit Aschen und trockenen oder nassen Lehmaggregate im Wasser oder in wassergesättigten organischen Ablagerungen mit und ohne Trampling? Kann die Taphonomie von Knochen Aufschluss über den Wassergehalt von Ablagerungen geben?
- Wird es in Zukunft möglich sein, mit interdisziplinären oder integrativen Auswertungen Anzeichen für zyklische Prozesse, also saisonale Ablagerungen zu fassen?

Ob interdisziplinär oder integrativ; sich den Seeufersiedlungen möglichst ganzheitlich und frei von vorgefertigten Bildern anzunähern, mit den kombinierten Resultaten aus den unterschiedlichsten Analysen im Rücken, könnte ein weiterer Schritt zum Verständnis dieser Lebensweise im Spiegel von jahreszeitlichen Vorgänge sein.

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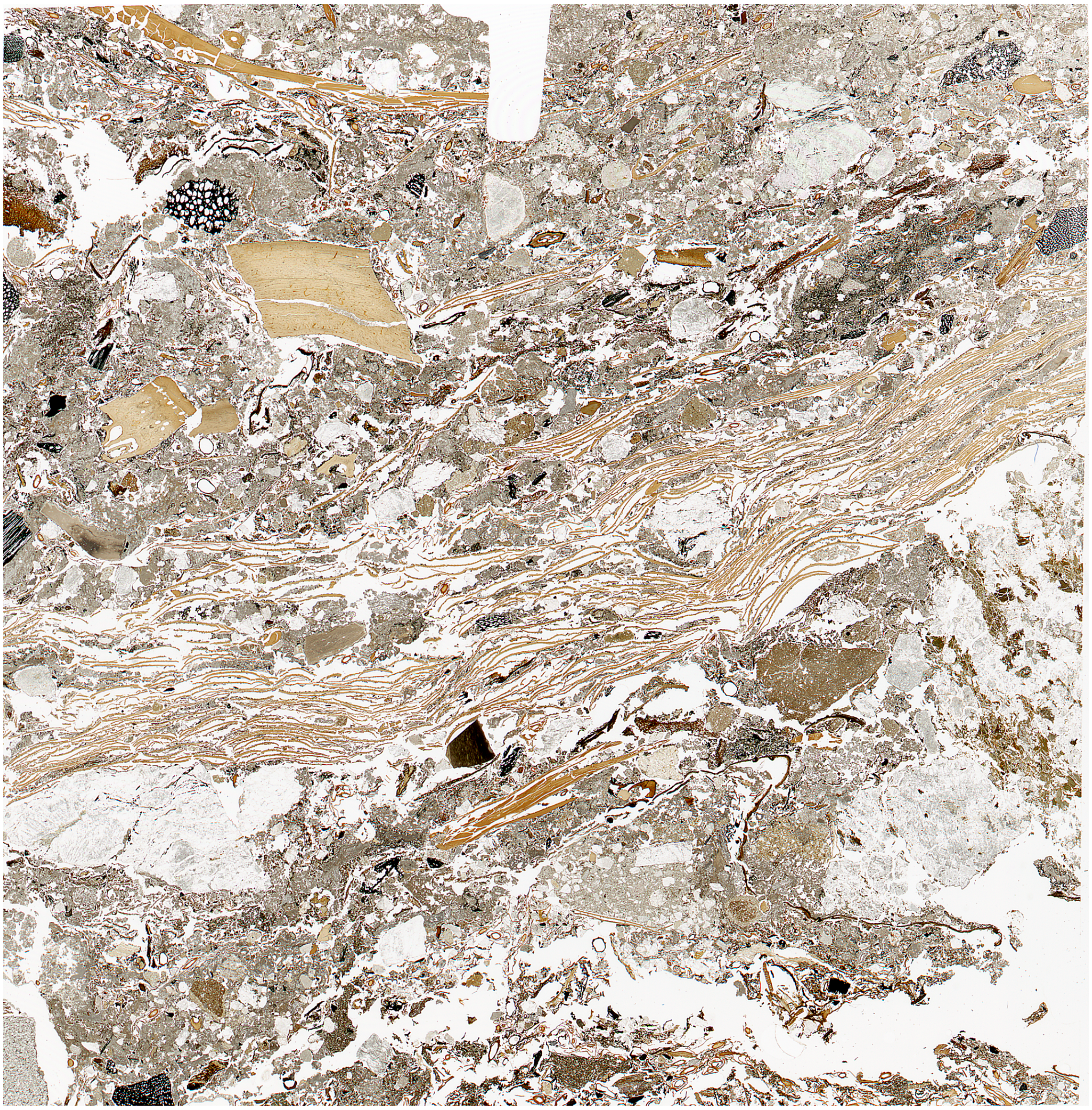

Dünnschliff ZGRI 98.1.5 der Fundstelle Zug-Riedmatt mit einer lehmreichen Schicht im unteren Drittel, einer Lage bestehend aus Fischschuppen und -kiemen in der Mitte und einer aschereichen Schicht im oberen Drittel (Abbildung K. Ismail-Meyer, April 2012).

Thin section ZGRI 98.1.5 from the site Zug-Riedmatt with layer rich with loam at the base, an accumulation of fish scales and gills in the middle and a layer rich with ash in the upper third of the section (illustration by K. Ismail-Meyer, April 2012).

8 Summary

The lakeside settlements of Central Europe constitute a unique archive for archaeology and related sciences thanks to their exceptional state of preservation. This has also been recognised by UNESCO, who added 111 sites to its World Heritage List in 2011 (http://whc.unesco.org/en/list/1363). These sites offer opportunities for inter- or transdisciplinary research, which can lead to a more detailed understanding of their chronology, economy, diet and environmental conditions. Micromorphology attempts to identify and reconstruct the anthropogenic and natural processes, which influenced a settlement before, during its existance and after it was abandoned. Taphonomic considerations are of the utmost importance in this enquiry but the composition and structure of the deposits also play a key role in understanding the processes that led to their accumulation.

The work presented here shows, among other results, that similar anthropogenic processes led to the accumulation of a variety of deposits, such as the deposition of remains resulting from the daily occupation and building activities on lakeside settlements. These 'cultural layers', which often contain much organic material, were exposed to comparable natural processes, including flooding, modification by water, erosion and desiccation. It must be stressed that the hypotheses formulated below only apply to the lakeside settlements presented here (although many such processes are encountered on other lakeside sites).

Natural processes before occupation

Beneath the cultural layers there are layers of carbonate micrite, i.e. lake marl, precipitated in the littoral zone of the lakes. Fine lamination indicates that the lake marl had accumulated below the base of the waves in a calm environment. Molluscs and frequent remains of algae (charophyte – green algae) encrusted with carbonate, and more rarely diatoms, are imbedded in these sediments (Brochier, 1983; Platt and Wright, 1991; Freytet and Verrecchia, 2002; Schurrenberger et al., 2003). Regressions, most probably due to climatic changes, led to reworking of the laminated lake marl; laminations were destroyed by wave action, a part of the micrite washed out, fluvial sand became enriched, and delicate components like algal remains and molluscs were fragmented (Digerfeldt et al., 2007).

If the lake level dropped further, the lake marl was exposed to the air, and mollusc shells became degraded and partially dissolved by algal growth. Such evidence suggests a (short-lived) break in sedimentation (Cutler, 1995). If the hiatus was longer (several weeks), scarce pioneer vegetation such as mosses could spread on the dry and hard surface of the lake marl, as can be shown in analyses of plant macroremains (Jacomet, 1985; Monnier et al., 1991).

Anthropogenic processes during occupation

A number of elements at the sites examined here indicates that when the settlements were established the lake marl was dry: there was apparently no traces of sinking into the sediment due to walking on the lake marl (the interfaces between layers are distinct) after the site had been accessed by people and animals. Rather the surface of the sandy lake marl became compacted and the first anthropogenic remains, including charcoal, bark chips and clay aggregates were trampled into the top of the lake sediment. We call this characteristic level, roughly 5 to 10mm thick, an installation horizon.

With time, building activities, food preparation, craft and husbandry resulted in the accumulation of refuse and excrement (coprolites) of domestic animals around and below the (raised) houses. Our analyses suggest that the rate of such accumulation comprised several centimetres per year. These highly organic sediments act and react similar as a peat and can be described as a kind of anthropogenic peat.

Clay floors were built inside the houses, and some still remained *in situ* if they were constructed on the ground surface. Thin sections demonstrate signs of use, such as the compaction and dissolution of floor aggregates. Above this level further thin layers of charcoal, ash, moss and other organic remains, fish-bones and sand can be identified. The generally small size of the remains may indicate that the floors were swept clean or perhaps covered with mats. These use levels could be literally sealed when the clay floors were renewed.

Hearths have not been encountered in the samples so far analysed, but accumulations of ash with burnt clay aggregates showing strong signs of burning may represent dumped hearth residues. The possibility that fires and the subsequent collapse of houses caused such accumulations is also not excluded.

Synsedimentary natural processes

Synsedimentary processes had an effect on the accumulated anthropogenic sediments; they play a very important role for our understanding of taphonomic processes on individual sites. Indeed they largely determine if and how much of the anthropogenic layers survive.

In the immediate environs of lakes, i.e. in areas where lake settlements have partly survived up to the present day, a high local water table, sometimes as high as the surface of the sediments, can be identified. A characteristic of organic sediments, as well as peat, is a sponge effect caused by capillary forces; they can raise the local groundwater table artificially. Further, they have strong water retention, so that organic accumulations can remain waterlogged over long periods. Under waterlogged conditions oxygen is quickly depleted by the presence of bacteria and fungi, resulting in the rapid suppression of the majority of natural degradation processes (Corfield, 2007; Kenward and Hall, 2008; Lillie and Smith, 2009; Gastaldo, 2011).

Organic accumulations in lakeside settlements have properties that are fundamentally similar to those of peats. On the surface there is an accretion layer (acrotelm); in peats this is caused by dying moorland plants (as peat moss) whereas on lakeside settlement this is created by anthropogenic accumulation. Later deposits caused the accumulated remains to be in a waterlogged and oxygen-free environment (catotelm). In natural peat this process takes around 100 years (Mitsch and Gosselink, 2007). On lakeside settlements this process must have taken place very quickly, perhaps over a few days or even hours, because the accumulation rate was much higher (several centimetres per year) compared to that of peats (a few millimetres per year), as attested by the well-preserved deposits of Arbon-Bleiche 3 (where chlorophyll survived and there were hardly any coprophilous fungi spores; Jacomet et al., 2004).

The acrotelm-catotelm model derived from peat research shows that water can move quickly through the upper, non-waterlogged acrotelm whereas it moves only very slowly in the waterlogged catotelm. 'New' water from rainfall or floods cannot enter the waterlogged zone. Runoff through peats moves mainly on the surface and through the acrotelm (Baker et al., 2009; Charman, 2009). If we adapt this model to lakeside settlements, it implies that water (which came either from the hinterland or was the result of high water levels in the lakes) moved only through the aerated acrotelm-layer on the surface while the waterlogged, deeper parts were unaffected. This model could explain why sediments on lakeside settlements may show instances of erosion and areas that had clearly been reworked, but why these affected only single layers that can sometimes be traced over long distances.

High lake levels in lakeside settlements led to erosion and/or reworking on the surface of the flooded exposed top layers. If the lake brought in lake marl washed out from elsewhere, a mixed horizon consisting of eroded lake marl and reworked cultural remains could form. Runoff can be an issue when the hinterland has a certain relief. Runoff was most probably connected to snowmelt and/or heavy rainfalls. It led to the erosion of aerated sediments (analogous to those caused by high lake levels) and to the deposition of well-sorted sometimes graded fine sands (without any signs of limnic activity), mixed with reworked and fresh organic remains. The sands came from erosion in the hinterland, caused mainly by disturbance to the structure of the terrain by clearance and/or agriculture (Mitsch and Gosselink, 2009; Zolitschka et al., 2010). These characteristic sand deposits could be traced on some of the sites analysed here (Arbon-Bleiche 3, Stansstad-Kehrsiten and Lake Luokesa) where they only occur in the anthropogenic layers and not in the natural lake marl.

Seasonal changes of temperature (and of the amount of evaporation) cause the groundwater table to move up and down. It is likely that among organic accumulations on lakeside settlements exposed layers suffered periodically from erosion and this probably occurred in high summer, when the capillary force of the organic accumulations was insufficient to lift the water table to near the surface (Keddy, 2010; Gastaldo, 2011). In the areas affected, the loss of water led to reduced porosity and to the fragmentation of the organic matter into detritus (very fine organic particles) while the soil fauna spread and jelly-like substances (e.g. dopplerite and organic crusts) formed as a result of the degradation of organic residues (Lindsay, 2010; Stolt and Lindbo, 2010; Gastaldo, 2011).

A single layer may go through several processes, for example desiccation, water transport, deposition, further drying out, resedimentation etc. In layer sequences where it is possible to reconstruct the order of different processes one on top of the other, synsedimentary degradation must have taken place, as otherwise the result would have been a homogenisation of the deposits (Kenward and Hall, 2000). If a layer containing indications of degradation is sealed by a well preserved layer, then the degradation of the earlier layer must have happened during sedimentation. Generally, the preservation of the oldest accumulation above a lake marl is much better than the top organic layers. This may be due to reduced capillary force in the higher layers. If less preserved organic layers overly well-preserved ones, synsedimentary degradation must have taken place (Kenward & Hall 2000).

Houses built above ground or at ground level

The site formation processes were influenced by the kind of settlement it was, especially whether its dwellings were raised above ground or built at ground level.

The sites with houses raised above ground examined here show finely laminated layers, which can sometimes be followed over long distances. This seems to be due to the fact that water – from runoff and/or flooding of the lake – could submerge large areas almost unhindered. The many piles must have slowed the flow of water down considerably but not prevented it. Remains of flooded cultural layers (eroded out of the exposed upper surface) could have been spread over extended surfaces. It has proved impossible to distinguish micromorphologically the interior from the exterior of the dwellings (located under the originally raised houses) because the same material was dispersed. Moreover, there was little clay left from the raised floor of the houses, only some clay aggregates likely to have been weathered building material. Water must have dissolved the greater part of the original clay used for building, most probably in rainfall, runoff and flooding events.

Settlements constructed at ground level show less fine lamination and may contain features preserved *in situ*, including clay floors. The exteriors and interiors of the houses can sometimes be distinguished from each other. Runoff sediments have not been identified so far, perhaps because the sites built on the surface happen to have a less steep hinterland or because the relevant deposits have not survived.

Postsedimentary processes

All the lakeside settlements analysed were covered by lake marl (or sand in the case of Arbon-Bleiche 3) either at the time they were abandoned or later. This indicates a transgression resulting in flooding. Actual ‚abandonment layers' (burnt or organic layers with indications of alteration) are hardly ever encountered in micromorphological analyses. This is owed to erosion caused by the final flooding event. This is also why it is difficult to establish micromorphologically the reasons behind the abandonment of a site; they may include a devastating fire, a rise in the lake level, the poor condition of the houses, or the fact that a settlement was no longer needed (Menotti 2012). Following the flooding events that affected all the lakeside settlements, lake marl or sandy deposits eroded from elsewhere covered the sites' cultural layers and protected them from further erosion by wave action, a circumstance of great importance then and today.

It is well known that in waterlogged conditions the lack of oxygen largely inhibits general decay processes. When remains are in this kind of milieu, they are preserved more or less in the condition they were when they became covered. This implies that degradation processes were mainly synsedimentary and not postsedimentary, provided the lake level did not drop below the height of the cultural layers (Kenward and Hall, 2000).

The most important postsedimentary processes are white, red and soft rot which may attack wood (Huisman and Klaassen, 2009). But roots and rhizomes of reeds, usually of recent origin and which can reach deep into the deposits, can severely disturb the sediment structure.

Corrections of lake levels constitute the greatest danger to lakeside settlements (Mitsch and Gosseling, 2007). As soon as the water level drops, well-preserved cultural layers come into contact with oxygen, and within minutes oxidation causes organic matter to darken. Degradation by bacteria and fungi sets in rapidly and faunal activity in the soil begins. Eventually the rich evidence from organic remains will be reduced to fragments of clay, charcoal, stones, and larger fragments of bone and pottery.

Seasonal deposits?

On several sites runoff sediments, which divide the archaeological sequence into horizons separated by intervals, were routinely detected. Above a sandy inwash from the hinterland there is generally a well preserved organic layer which may show signs of degradation near its surface. Currently the sandy inwash is interpreted as resulting from snow melting in the spring while the degradation may have taken place in midsummer. It is not clear at present whether the main period of accumulation of organic material occurred during the winter (indicated by the presence of dung derived from the feeding and bedding of domestic animals kept on the settlement) or in the spring, i.e. in the vegetation's main growth season with cattle kept mostly outside the settlement; this subject requires further investigation.

9 Conclusion

During their lifetime lakeside settlements were neither exclusively limnic nor purely terrestrial and thus occupy a niche within a unique, amphibious environment. Today, after the lake levels have been artificially corrected and the rivers canalised, it is difficult to observe such milieus, at least in Central Europe. It is apparent that this amphibious way of life offered advantages that compensated for the difficulties people no doubt had to endure. These included high levels of humidity, annual flooding, and at times mushy lake marl around the houses, in areas used as paths and for keeping domestic animals. Possibly all essentials were packed up when floods were expected and the community moved to higher ground for a few weeks, returning to refurbish the houses, as is still the case on unmodified river courses in the heart of Africa.

The study of this special environment cannot be covered by a single discipline; an interdisciplinary approach seems to be the most appropriate way to examine lakeside settlements. For quite some time research projects have focused on multiple scientific analyses, which include not only archaeozoological, macrobotanical, palynological and micromorphological analyses but can also comprise sedimentological, geochemical, entomological, parasitological, mycological and anthracological studies. Taphonomic aspects – not only of the plant remains and animal bones but also of the ceramics and molluscs, which can give important indications about the environment – are given greater consideration. The combination of all these strands of information from different disciplines offers an enormous potential to better understand life in and around lakeside settlements and the many concurrent processes at work.

The methodology that incorporates interdisciplinary analyses has been at the core of a research project entitled ‚Formation and taphonomy of archaeological wetland deposits: Two transdisciplinary case studies and their impact on lakeshore archaeology‘ which runs from 2014 to 2016 and is financed by the Swiss National Foundation (Project-No. CR30I1_149679/1). Questions concerning different approaches, i.e. whether to proceed in a interdisciplinary way (comparing the final results from the different disciplines) or in an integrative manner (exchanging and discussing results during analysis), feature among its objectives. Procedures and results from the large-scale excavations of Zürich-Opéra (ZH) which follow an interdisciplinary approach and the small-scale excavation of Zug-Riedmatt (ZG) which is integrative (involving constant cooperation between the disciplines of archaeology, macrobotany, palynology, micromorphology, geochemistry and zoology) will be compared. Both approaches have their strengths and weaknesses; the more commonly applied interdisciplinary strategy may suffer from the fact that individual scientists have interpreted their results so far that an interdisciplinary discussion can hardly still take place. In the integrative approach all results come together in a kind of melting pot and it depends very much on the scientists involved what the ‚cast’ from this melting process turns out to be. It may lead to errors, false starts, blind alleys and vicious circles, but also to numerous fruitful discussions.

Another aspect of this research project consists of avoiding as much as possible received ideas that influence the analyses and their interpretation and instead conduct our work in as neutral a way as possible. We should be aware that mental pictures emerge as early as the excavation itself and that they play a part in our sampling strategy, analyses and interpretations. Confronting such aspects should be and should remain a significant, no matter what approach is adopted when analysing archaeological sites (Gross et al. in prep.).

Some aspects of site formation processes in lakeside settlements that should be addressed as comprehensively as possible include the following topics:

- Lake marl: What are the properties of lake marl as a building ground and how does it react to construction? How does a high or low water content in the lake marl influence processes at its surface? What happens with dry lake marl, which later becomes flooded? How does it react when overlain with organic matter?
- Water or no water: Does the excellent preservation of organic matter mean that an organic layer formed when covered by water? Or is the capillarity in organic layers sufficient to explain this preservation? Is water essential for the gelification of organic material? What happens to ash and dry or wet clay aggregates in water or waterlogged organic accumulations, with or without trampling? Can bone taphonomy give further information about the water content of sediments?
- Future prospects: Will it be possible to find indicators of cyclic processes, i.e. seasonal accumulations, in interdisciplinary or integrative analyses?

Whether multidisciplinary or integrative, an approach to lakeside settlements that is as holistic and as free of preconceptions as possible and which integrates the results of different analyses represents a step towards the better understanding of this way of life as reflected by seasonal processes.

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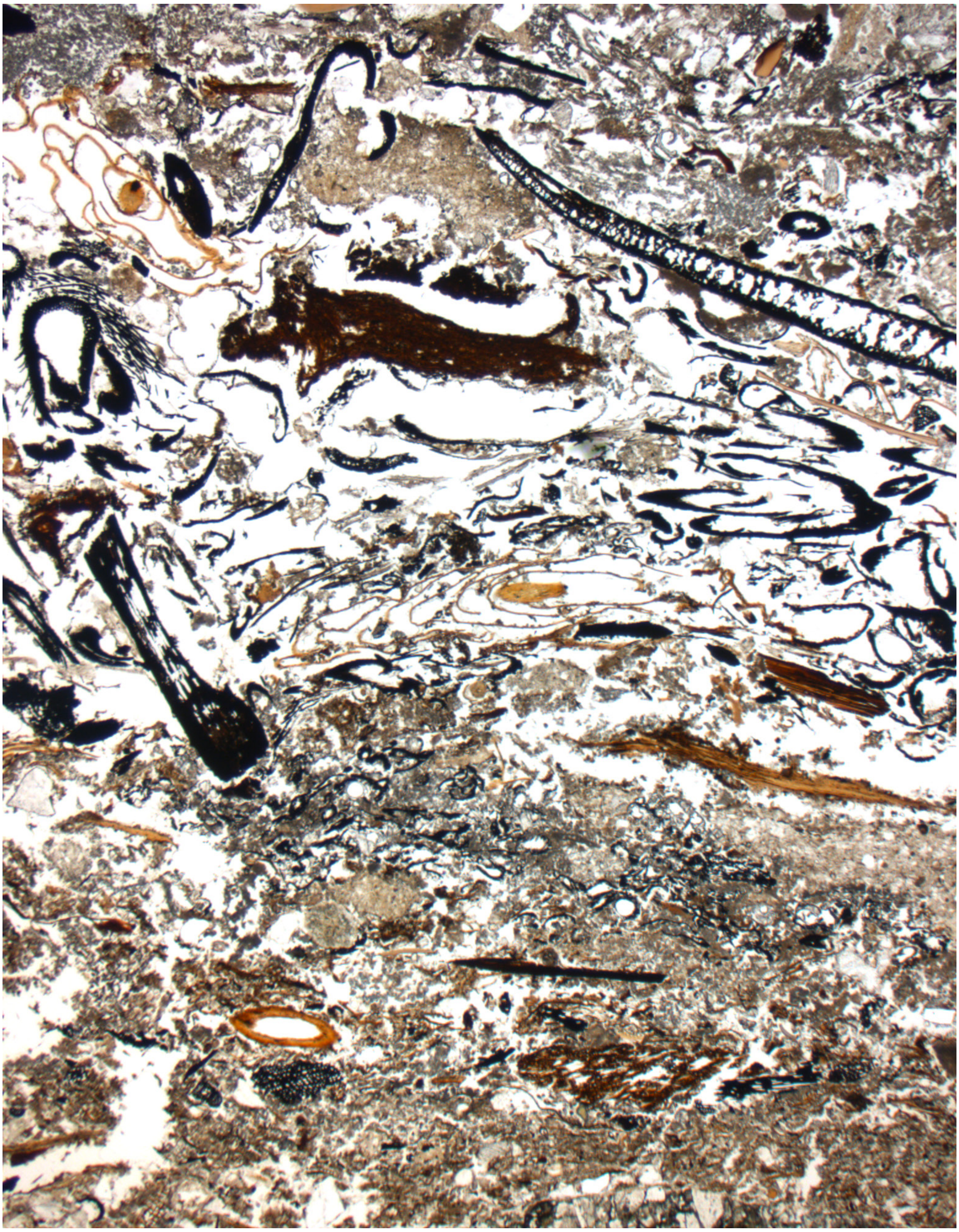

Dünnschliffaufnahme (ZGRI 87.2.2) mit Ascheakkumulationen und Getreidespelzen (in schwarz). Bildbreite: 5 mm (Abbildung K. Ismail-Meyer, August 2011).

Microphotograph (ZGRI 87.2.2) with an accumulation of ashes and husks (in black). Image width: 5 mm (illustration by K. Ismail-Meyer, August 2011).