

**Modelling European ancient settlements – their composition and morphology.
Contributions from soil micromorphology and associated geoarchaeological techniques,
with special attention given to the contrasting sites of the Chalcolithic tell of Bordușani-
Popină, Borcea River, Romania and the Viking Age coastal settlement of
Heimdaljordet, Vestfold, Norway.**

By

Richard I Macphail*¹, Jan Bill², John Crowther³, Constantin Haită⁴, Johan Linderholm⁵,
Dragomir Popovici⁴, Christian Løchsen Rødsrud²

[*: corresponding author, r.macphail@ucl.ac.uk](mailto:r.macphail@ucl.ac.uk)

1: Institute of Archaeology, University College London, 31-34, Gordon Sq., London, WC1H
0PY, UK; 2: Cultural History Museum, University of Oslo, Norway, 3: Trinity St Davids,
University of Wales, Lampeter, UK; 4: National Museum of Romania History, București,
România; 5: MAL, University of Umeå, Sweden.

Abstract

Specific soil micromorphological and broader geoarchaeological (and environmental archaeology) signatures of settlement activities and land use have been identified from numerous case studies across Europe – from Romania to western Norway. In order to demonstrate how such investigations contribute to our understanding of settlement morphology and its wider landscape, a new model has been created (Macphail and Goldberg in prep/2016). Activities and land use are divided into ‘Within Settlement’, ‘Peripheral to Settlement’ and ‘The Settlement’s Wider Landscape’. Major themes identified are: Constructions (and materials), Trackways and paths (and other communication/transport-associated features), Animal Management, Water Management, Waste Disposal (1:

middening; 2: human waste), Specialist Domestic and Industrial Activities and Funerary Practices. In the case of trackway deposits, their characterisation aids the identification of intensely occupied areas compared to rural communications, although changing land use within urban areas has also produced ‘rural signatures’ (e.g. as associated with animal management), for example in Late Roman cities. Specialist activities such as fish and crop processing or working with lead and other metals, in-field and within-wall manuring, stabling and domestic occupation floor-use evidence, and identification of different funerary practice – cremations, boat graves and other inhumations and excarnation features – and peripheral features such as boat-houses, are also noted. In addition to also reviewing data from the published London Guildhall site, new information from the Chalcolithic tell site of Bordușani-Popină, Romania and seasonally occupied Viking settlement of Heimdaljordet, Norway, are given.

1. Introduction

Attempts to study the integrated relationship between an urban settlement and its hinterland in complex societies has been a focus of interest for decades, for example in the cases of nearby constructional material quarrying in Paris, France and the discovery of ‘rural’ signatures within ‘urban’ space in English cities (Ciezar et al., 1994; Macphail, 1994). Although use of space investigations within the built environment were also given special attention (Cammis, 1994; Matthews and Postgate, 1994), agriculture (cultivation and animal husbandry) was more likely to be studied in isolation (Courty et al., 1991; Gebhardt, 1992; Macphail et al., 1987). It is therefore timely to suggest models that could aid our understanding of activities and use of space within a settlement, and how the nearby and more distant managed landscape functions as a whole (Table 1; Macphail and Goldberg, Submitted/2016). This requires that unusually, road systems, water management and funerary practice, for example, are also characterised alongside use of space within structures and areas given up to artisan/industrial and middening practices. When deposits are well-preserved, such investigations are relatively straight forward, but when post-depositional processes have been active, whether these are natural or anthropogenic in nature, such characterisations of original deposits and use of space can be challenging (Courty et al., 1989). In order that major episodes in the life of cities are not ignored there has been therefore a long campaign to study the resulting enigmatic deposits, or ‘dark earth’. In fact, dark earth simply represents the result of different or atypical uses of urban space (Galinié, 2004). Much reconstruction of land use has been carried out using dark earth as a resource (Borderie et al., 2014a; Devos et al., 2013; Macphail, 2014).

The paper gives examples from Table 1 and in addition, briefly presents relevant data from case studies, namely:

Case 1: The Chalcolithic tell site of Borduşani-Popină, Borcea River, Romania (Figs 1-2), and

Case 2: The Viking coastal settlement of Heimdaljordet and associated Gokstad ship burial mound, Norway (Figs 3-4).

The fully published early medieval occupation at the London Arena site (London Guildhall East/GYE) is also given particular attention (Bateman et al., 2008; Bowsher et al., 2007).

2. Methods

The methods employed in the various case studies are geoarchaeological techniques combined with other palaeoenvironmental disciplines, where sampling has been carefully correlated with soil micromorphology. Often small bulk samples were taken from the same monoliths used for soil micromorphology; bulk sampled layers were then studied in thin section (Goldberg and Macphail, 2006). In addition to chemistry and magnetic susceptibility, palynology, diatom, phytolith and microfossil studies have been integrated, sometimes utilising identified fossils and microfossils within the thin sections themselves (Devos et al., 2009). Lastly, traditional soil micromorphology (using plane polarised light, crossed polarised light, oblique incident light for optical testing) has been complemented by fluorescence microscopy, and microchemical and micro-mineralogical approaches (SEM/EDS, Microprobe, micro-XRF, micro-FTIR) (c.f. Karkanas, 2006, 2007; Karkanas et al., 2000; Shahack-Gross and Finkelstein, 2008; Shahack-Gross et al., 2004). At the London Guildhall site fifty 80-150mm-long thin sections, forty-eight bulk samples and thirty-one palynological samples were selected from the total number collected for the medieval study, after an assessment (Macphail et al., 2007a, b; Macphail et al., 2004).

3. Elements that make up a settlement

In the suggested model (Table 1), a number of elements and activities have been selected that can be investigated through geoarchaeological techniques, focused around soil micromorphology (Macphail and Goldberg, Submitted/2016).

- *Constructions* – some elements of constructions can be best aided by soil micromorphological investigations. These provide insights into landscaping and ground-raising, the formation of post hole-, ‘pit house-’ and ditch-fills; fire installations are also constructed. Natural- and manufactured-building materials can be linked to quarries, which themselves may be used as dumping grounds, or to the contemporary landscape (see Heimdaljordet and Gokstad turf mound, below). The razing (burning down), collapse, destruction, and weathering of constructions is also an important area of study (e.g. employing ethnoarchaeological cases; (Friesem et al., 2014a; Friesem et al., 2014b). In urban areas, where space is restricted, such debris is often utilised for ground raising – hence the formation of tells. The Borduşani- Popină Tell case study provides some details concerning alternating construction/destruction and also identifies use of space according to different types of occupation surfaces.
- *Trackways and roads* – these are given special attention here because there are few thematic studies in the literature (Engelmark and Linderholm, 2008; Gebhardt and Langohr, 2015). Cattle paths from the byre to the local fields, droveways employed for long distance transhumance, and sedimentary signatures allowing the differentiation of ‘urban’ and ‘rural’ road use, all contribute to the understanding of how a cultural landscape is organised.
- *Animal management* – although stabling and byre floor formation has been described from experiments and settlement sites, herding and the effect of stock concentrations

within and around settlements needs to be investigated in view of their specific sediment and soil types. Naturally there is some overlap between road and trackway deposits registering animal passage, and on how transhumance routes can be studied. In addition, this section on animal management notes the special cases of pig husbandry.

- *Waste disposal* – this includes both a) discard in general, which can come under the generic term of ‘middening’ (e.g. spreads, mounds and tertiary pit and ditch fills, harbours) (Waste Disposal I), and b) specific studies on human waste (e.g. cess pits, latrine outlets) (Waste Disposal II).
- *Water management and control* – typically irrigation canals, drainage ditches, reservoir, millponds and moats have been studied, but much can also be gleaned from the examination of well and water hole sediments, especially when both their primary and tertiary fills are examined.
- *Funerary features* – part or parts of a settlement (usually peripheries) are given over to dealing with human remains, namely inhumations and cremations; on occasion excarnations (exposure of bodies) are also placed within occupied areas, as for example during the British Iron Age and in some Viking sites.
- *Specialist domestic, artisan and industrial activity* – often the accurate characterisation of ‘human materials’ leads to either hints or clear identification of this kind of activity; examples include iron and non-ferrous metal and alloy working, as well as giving instances of the use of lead. Glassy and fuel slags, ore preparation (e.g. tin) and salt working detritus have also been recognised. It should also be possible to note evidence of food processing (kitchen waste, cooking pit fills, cereal residues and grain driers; fish and meat butchery and activities such as smoking and blubber boiling) and associated constructions such as hearths, ovens and furnaces.

3.1 Constructions

Constructed floors and hearths often required the importation of coherent clay loams or similar materials, such as fine sandy and silt loams. Typical natural materials used in this way are wetland clays and till, respectively on Iron Age sites in Vestfold, Norway and the town of Uppåkra, near Lund, Scania, Sweden (Viklund et al., 2013) (Fig 5). In the UK, Clay-With-Flints was used at Late Saxon Winchester while brickearth was chosen at Roman Canterbury and at Late Saxon and early medieval London; brickearth was also used to construct Roman London's arena (Bateman et al., 2008; Bowsher et al., 2007). Till was employed in the East Anglian Templar site of Cressing Temple, Essex, to construct the 12th century barn floors. Further evidence of ground-raising employing earth-based materials (Case 1) and turf mound building (Case 2) is given below.

The fills of some constructional features also provide a rich source of geoarchaeological information on middening practices, use of space and building materials. At the Early Saxon (see below) settlement at Eye, Suffolk, a post hole within an aisled building included fragments of thin layers cob adhering to daub. Cob is formed by pounding chalk, and when used as a plaster, small amounts of calcite recrystallisation occur; it is not a lime plaster *sensu stricto*, however. More commonly in Scandinavia, however, long house post hole fills have provided macrofossil evidence permitting the modelling of how space was organised. Long houses were often built on a shallow slope, with domestic food and activities (e.g. hearth) located upslope, with the animal byre and fodder stored downslope; animal waste thus drained away from the area of human occupation (Engelmark, 1985). Phosphate, organic matter (LOI) and magnetic susceptibility mapping data are also consistent with this model (Viklund et al., 2013). Early and Middle Saxon settlements dating to ~AD 400-800 ('Migration Period') in Europe are often characterised by sunken feature buildings (e.g. Grubenhäuser); often their fills are the only source of data for palaeoenvironmentalists.

Fifteen sites have been studied from England and Scania, and these have provided evidence on the use of turf as a constructional material, and the economy, lifestyle and farming at these sites (Macphail and Goldberg, Submitted/2016). Rare instances of primary fills suggest local soils were managed and manured; at the site Lyminge, Kent an iron plough coulter was found towards the base of the sunken feature fill (Thomas, 2010). SEM/EDS studies suggest that the iron coulter was laid on the original suspended wooden floor (Fig 6). More commonly, tertiary fills contain plant and meat processing residues (phytoliths, bone), hearth debris (ashes and burnt mineral material), craft working inclusions (loam-based loom weights at sandy sites for example), and animal (charred and ashed dung) and human (coprolitic bone and Fe-Ca-P infills and nodules) waste (Macphail, In press; Macphail et al., 2006).

3.2 Trackways and Roads

These can occur within settlements, between settlements and also link settlements with areas of extra-mural activities and local fields and pastures, for example; one major use is connecting sources of manure *sensu lato*, with cultivation fields. In cultivated soils, manuring materials include both minerogenic (burnt daub, burnt flint, ash, charcoal) and organic (dung) settlement waste, which can produce an enhanced magnetic susceptibility and raised organic phosphate content, respectively (Adderley et al., 2006; Engelmark and Linderholm, 1996; Macphail, 1998; Viklund et al., 2013). These additions can sometimes be identified in thin sections, and at Whitefriars, Canterbury, amounts of manure for infields more than doubled between the pre-rampart Roman (3rd century; see Fig 10, CW12) and medieval periods. This is reflected in the LOI, P, heavy metal and magnetic susceptibility data (Goldberg and Macphail, 2006, 202-210. Manuring with dung was also a characteristic of medieval infields in Brussels, Belgium (Devos et al., 2009).

One of the characteristics of road deposits is their homogeneity, general lack of porosity, and where pores are present these are often partially infilled with matrix coatings. These features stem from wheeled, human and animal traffic continually churning muddy road fills. Sediment wetness and periodic waterlogging also leads to characteristic mobilisation of Fe and P, which stain textural pedofeatures and/or form nodules (Figs 7-8). At Sharpstone Hill, Bayston, Shropshire road constructions took place in the Iron Age; the route later became a Roman road (Malim and Hayes, 2011). Prehistoric roads of a similar muddy trackway character also preceded Roman roads at Ware, Essex and Brougham Castle, Cumbria. Here traces of dung, and dung spherulites at Sharpstone Hill testify to tracks being used for animal traffic, giving them a 'rural' signature, with overall only small amounts of phosphate concentrations and negligible magnetic susceptibility signatures. In Scania, the wheel rut and area between wheel ruts was examined in an Iron Age road (Engelmark and Linderholm, 2008). The supposed animal/draft animal-trampled area between the ruts included areas of abundant dark coloured, well oriented clay void coatings and phytolith-rich dung residues (possible layered examples could be from cattle/oxen). The direct input of animal dung and perhaps spillage from carts led to this context being having a higher phosphate content and magnetic susceptibility, compared to the wheel ruts. At the Iron Age site of Bamble, Vestfold, Norway, often compact and layered trackway sediments occur, with dung fragments either testifying to animal traffic or spillage of manure being taken to the fields (Fig 9).

Of further note, are Late Roman road deposits in the cities of Canterbury and Winchester, which also have the same kind of rural signature, which testifies to an atypical, low intensity urban land use at this time (Macphail, 2010). At Whitefriars, Canterbury the road deposits of the Late Saxon and 'Norman' town can be compared to Roman agricultural soils and Late Roman dark earth deposits. Soil micromorphology and bulk analyses

demonstrated small amounts of manuring in late 3rd Century infield soils (Fig 10, CW12). Two Late Saxon/Norman lanes were also studied. Fig 10 (CW21E and CW21W) shows road sequences over Roman soil and Late Roman dark earth. The road fills are composed of occupation debris: ashes, charcoal, food waste such as shell and bone, strongly burnt minerogenic materials of likely industrial origin, dung and various forms of amorphous phosphatic waste – some as Ca-Fe-P and some as Ca-Fe-Mn-P complexes according to microprobe quantitative and mapping studies. Such notable amounts of anthropogenic input have greatly concentrated carbonate (e.g. from high ash content), phosphate and heavy metals, such as lead, and magnetic susceptibility values can be very strongly enhanced. Clearly such road fills have an ‘urban’ signature.

Animal management

As shown above and in the following section, geoarchaeological information on animal husbandry can be found in refuse deposits and within road and trackway sediments. Where preserved, floor deposits where animals were housed (byres, stables, compounds) also produce a distinctive deposit type that easily contrasts with occupation floors used domestically (Cammis, 1994; Courty et al., 1994; Gé et al., 1993; Macphail et al., 2004; Shahack-Gross et al., 2003). It may be possible to suggest that soils with mull humus horizons could be grazing lands close to settlements, especially if they record enhanced levels of organic phosphate (from dung inputs). The study of many Neolithic and Bronze Age barrow-buried soils and turves within the barrows along the River Nene at Raunds, Northamptonshire found anomalous amounts of dark coloured moderately well oriented clay void coatings and infills, and internal slaking pans in what were originally surface soils. These features were not found in any of the five tree-throws that were also studied in detail. P was concentrated in these pans and clay coatings according to microprobe analysis, and apparently responsible for the enhanced levels of phosphate overall found in bulk samples. It

seems reasonable to suggest from these soil studies and background studies of pollen, insect, plant macrofossils and bones (including cattle skulls), that the valley of the Nene was an area of animal grazing and stocking – especially by cattle (Harding and Healy, 2011; Healy and Harding, 2007).

At the larger scale, transhumance routes may have soils containing exotic pollen from lowlands deposited in dung (Moe, 1983). The ashed cave deposits formed by overwintering of stock by Neolithic pastoralists in the Mediterranean region are of special interest because sheep and goats were foddered on ‘leaf hay’ – twigs and leaves of Evergreen Oak (*Quercus Ilex*), for example (Angelucci et al., 2009; Macphail et al., 1997). Deposits include dark charred dung-stained bedding layers of twigwood material, and overlying ashed layers that include calcite dung spherulites, calcium oxalates relict of leaves, for example, and pseudomorphs of wood and sheep-goat coprolites. In contrast, in the semi-desert region of the Negev Highlands, Israel, studies including pollen and organic chemistry of several rock shelters along the Ramon Crater area indicate that goats were only stabled episodically when pastoral nomads took advantage of plant growth associated with Spring rains (Rosen, 1988; Rosen et al., 2005; Rosen pers. comm.). Compared to recent Bedouin stabling deposits, the rapidly accumulated Early Bronze Age deposits are totally dominated by dung spherulite accumulations and associated phosphate concentrations, due to the partial oxidation of the organic component of dung pellets at the Atzmaut site, for example (Macphail and Crowther, 2008; see also Shahack-Gross, 2011). EDS on two other rock shelter sites found that burning of dung produces even higher concentrations of P (Macphail and Goldberg, Submitted/2016).

Byre deposits have been studied in great detail from Roman, Late Saxon and Medieval London, including both *in situ* floor accumulations in stables and as dumped byre waste. The organic, horizontally oriented plant fragment-rich deposits in byres differ completely from minerogenic domestic floor accumulations, as noted chemically (e.g. higher

LOI), in thin section and palynologically; magnetic susceptibility is also generally markedly lower in stabling waste (Macphail et al., 2004). At both the Butser Ancient Farm experiments and at the London Guildhall site, what pollen is present in domestic floors can be highly diverse, whereas byre deposits are dominated by grass, cereal and herb pollen types typical of foddering, sometimes with a possible special diet (Bowsher et al., 2007; Macphail et al., 2007a) (Figs 9-10). Wooden artefacts and the high concentrations of byre waste with a palynological spectra which is only indicative of local foddering are both consistent with the early medieval settlement being focused upon dairy production, presumably to supply the local London market as a whole.

Waste disposal

It can be seen from the examples given above, that roads and disused sunken featured buildings were readily used as sites for dumping refuse, including latrine waste. Road side areas in 1st century Roman London (No. 1 Poultry) were particularly employed for dumping byre waste according to the soil micromorphology, chemistry and macrofossils, testifying to London being a centre of communications during the continued conquest of Britannia (Macphail et al., 2004; Rowsome, 2000). Studies of dark earth formation at Roman Southwark, London and medieval Norwich also shows that any empty house shell could be a location for dumping ash and other detritus (Macphail, 2003, 2005). In fact, at The House of Amarantus, Pompeii (I, 9, 11-12) one room was simply filled with dumped hearth ash (Fulford and Wallace-Hadrill, 1995-6). The concentration of ash and refuse at some Late Bronze Age-Early Iron Age has produced hectares of midden deposits up to >2m thick, so that the settlement's chief function has been difficult to interpret (Lawson, 2000; McOmish et al., 2010). The organisation of latrine waste disposal has always been a challenge when populations become concentrated. One way has been to construct cess pits where human faecal waste typically becomes mineralised under anaerobic conditions as a carbonate

hydroxyapatite (EDS and microprobe mapped as Ca-P) that is highly autofluorescent under BL (blue light) (Macphail, In Press; Macphail and Goldberg, 2010). Associated microfossil (palynology including nematode eggs) and macrofossils (including insects) also testify to such deposits being cess. They also often have high organic matter and very high phosphate contents.

Water management and control

The chief features associated with European settlements are waterholes, wells and drainage ditches, although exceptional sites such as the Tower of London managed the tidal River Thames to create a massive defensive moat. The fill of this reflected natural inputs of sediment and minerals from the underlying geology (pyrite-rich London Clay), phosphate-rich effluent and heavy metals from the castle, especially in post-medieval times when The Mint and Royal Ordnance was based there (Macphail and Crowther, 2004). A well and drainage (parcel) ditches characterised Case 2 (Heimdaljordet). At Whitefriars, Canterbury a Roman well had a secondary use as a cess pit, while the Middle Saxon villages of Stratton, Biggleswade, Bedfordshire and West Heslerton, North Yorkshire had shallow wells, which were wood lined. Both showed localised muddy trampling, with dung inputs recorded chemically, in thin sections and in pollen analyses (Cruise and Macphail, 2000). Sometimes, the lowermost fills of wells record use of the well, rather than its secondary use and tertiary fills. At the sites of East Heslington (York) and Turing College (Canterbury), UK and at Hesby, Vestfold, Norway relatively clean fine minerogenic and microlaminated sediments apparently record use when collecting clean water caused only minor disturbance of the well's sides. At Hesby, these sediments are in the form of microlaminated cyclothem; later infills are dung-rich and includes dumped ash as shown by the micromorphology, chemistry and beetle analyses (Viklund et al., 2013).

Funerary Features

Past studies on the relationship of urban dark earth and Late Roman inhumations have shown that as city regulations broke down, burials which were once only allowed outside the cities limits, took place in any convenient waste ground – even within the town’s original precincts (Cowan, 2003; Dalwood and Edwards, 2004). Pedological reworking of urban deposits and dark earth soil formation after these inhumations led to the masking of the grave cuts (Macphail, 1994). Three main types of burial practices can be listed – inhumations and cremations, and excarnations, where bodies are exposed. These activities are generally located peripherally to settlements, although excarnations seemed to have occurred within some British Iron Age sites. At Oxley Park, Milton Keynes, UK, a posthole fill, presumably associated with an excarnation platform, included high amounts of coprolitic bone and a tooth of a neonatal/young human. These remains seem to have resulted from raptor activity (Macphail and Crowther, 2008). Viking excarnations were more likely to consist of bodies exposed within wooden grave chambers, which in one case showed inwash of ploughsoils into the decaying wood. Bioworked body stains also occur, with amorphous ferruginous microfeatures having a Fe-Ca-P chemistry at Hesby, while grave mounds at Hørdalen, another Vestfold site include inserted cremations; strongly burnt calcined bone (EDS data: 32.6-40.1% CaO; 17.9-19.9% P₂O₅, *n*=7) is resistant to dissolution (Viklund et al., 2013). In contrast, human remains in Iron Age burials in poorly drained soils at Bjørnstad, Sarpsborg, Østfold, Eastern Norway, seem to be recorded simply as amorphous phosphate staining of the wooden coffin remains, and as associated vivianite (Rødsrud, 2007).

Specialist domestic, artisan and industrial activity

Both the presence of micro-artefacts and the nature of the occupation floor deposits may provide information on specialist activities. For example, evidence for the working of non-

ferrous metals includes finding droplets of copper (Cu) alloys, lead-bronze (Cu-Sn – copper-tin with small amount of added lead) and enhanced amounts of Pb (lead) in ashes. Although the last could imply use of pewter ware, a tin alloy which included copper and lead in the past. Sometimes lead droplets are sealed within a halo of red lead oxide and lead carbonate possibly from lead soldering of lead pipes (Borderie et al., 2014b). Such evidence has been found in medieval Oxford and Late Roman Leicester, UK. Lead-enriched bronze droplets at 13th century Magdeburg were linked to bell founding for the Cathedral (Macphail et al., 2007a). Ore preparation is more likely to be found near the source of raw materials, such as in small settlements on Bodmin Moor, Cornwall where aggregates of cassiterite (tin) were evidence of processing, and these were found alongside the remains of sand-based crucibles (Macphail and Crowther, 2008). Fragments of microlaminated hammerscale, iron droplets/spheroids (Fig 13) and vesicular slags characterised by dark dendritic patterns (e.g., wüstite, FeO) and neo-formed iron-rich olivines such as fayalite ([Fe, Mg]2SiO₄) and other features of high temperature furnaces, may be seen as indicating iron working (Berna et al., 2007; Macphail and Goldberg, 2010). Siliceous glassy slags often have another origin, however, as fuel ash waste or the result of conflagrations burning grain (e.g. grain stores); even low temperature fires can melt plant opal (phytoliths) when plant processing waste is strongly burnt. At the Romano-British salt-working site of Stanford Wharf, on the River Thames in Essex, UK, local coastal wetland plants such as *Juncus Maritimus*, were used as a low temperature fuel and as a daub temper, and occurs both as charred and ashed remains; the latter as partially melted siliceous stem pseudomorphs (Macphail et al., 2012; Turner, 2012). It was suggested that lead vessels mainly took the place of briquetage for boiling brine during Late Roman times across Europe, and at this site floor deposits came under particular scrutiny. Bulk analyses found very strong concentrations of Pb, while ‘iron-staining’ features in the mud floors were found to be dominated by lead (49.1% lead by EDS). Food processing

also leaves important remains, which in the case of bone can be particularly difficult to exactly interpret.

Experiments and a review by (Pearce and Luff, 1994) on the taphonomy of cooked bone compared boiled and roasted bone. Boiled bone (1-8 hours of boiling) was found to be less liable to fracture compared to roasted bone; this helps explain the common presence of fine fragmented bone in hearth debris and associated trampled floor deposits. The latter developed colours associated with roasting temperature: matt black (250°C; soft tissue had become glossy black), ashen grey (500°C) and ‘chalky white’ where calcined (750-1000°C), although the authors in their review emphasise that colour is not a definitive guide to cooking temperature. The review also makes the useful observation that dehydrated roasted bone is essentially inert in soils whereas the remaining soft tissues in boiled bone would “attract greater bacterial action before and after deposition” (Pearce and Luff, 1994, 55). Brickearth constructed domestic floors at the London Guildhall featured thinly laminated beaten occupation deposits characterised by ash, fine charcoal, burnt fine mineral material, eggshell and (rubefied) bone, all consistent with the archaeological interpretation of 12th century cook shops being located at this part of the settlement (Bowsher et al., 2007). Findings from cooking experiments are also important when comparing inhumations and cremations.

Case Studies

Case 1: The Chalcolithic tell site of Bordușani-Popină, Borcea River, Romania (Tables 3a-3c)

This site is an important example of a compact urban settlement through time, because being a tell, a very wide variety of use of urban space – passageways, floors, byres, and outside areas of stocking, middening, food processing and latrine waste disposal – are recorded (Figs

1-2, 14-17, Tables 3a-3c). There are also destruction levels, ground-raising and levelling episodes which preserve these land use signatures.

The Chalcolithic Gumelnița culture (~4500 cal BC) tell site of Bordușani-Popină, Borcea River, Romania, is located in the wetland area of Balta Ialomiței, paralleling the River Danube (16 recent ¹⁴C assays range between 4000-4700 cal BC) (Figs 1-2). The mud brick and wattle framed daub wall constructed tell (Fig 14) was built on an erosional remnant of the Borcea river terrace where there are alluvial soils and soils formed on loess-like sediments. The tell, which forms a mound with a 15 m relative altitude, also has evidence of La Tène cultural activity after Chalcolithic abandonment (Popovici et al., 2003). The 2003 pluridisciplinary report by Popovici et al. records charred and charcoal remains of mainly *Populus-Salix*, *Populus*, and *Ulmus* (poplar-willow, poplar/aspens and elm, respectively; Tomescu, 2003), and bone of domestic cattle, sheep/goat, pig and dog, as well as wild mammals; sheep/goat data suggest these stock were used for milk production (Bălășescu et al., 2003). Other wild foods were composed of fish, mainly those from lakes and ponds, including a high amount of carp (although this interpretation may be a taphonomic/processing artefact; Fig 15), shellfish (Radu, 2003), and wild birds, predominantly Mallard duck (Gál and Kessler, 2003). The soil micromorphology component to this study by Constantin Haită (Haită, 2003) identified 'passage', 'domestic waste' and 'activity' areas.

In 2012, 22 monoliths were sampled by Haită and Macphail from four successive trenches cut into the tell (at the base Area 3 to Area 6 towards the top, and below later disturbances). In addition, reference samples were taken from natural loess subsoils and an alluvial palaeosol exposed by the River Borcea. A charred barley grain gave the palaeosol a historic date. In all, some 80 microlayers were described and characterised from the 30 thin sections analysed – which also involved SEM/EDS (Scanning Electron Microscopy/Energy Dispersive X-Ray Spectrometry) examinations (Table 3c). These studies were also supported

by 19 bulk organic matter (LOI) and total and fractionated phosphate analyses by John Crowther (University of Wales, Trinity St David) (Table 3b). Other samples were studied for magnetic susceptibility, particle size, clay mineralogy, and palynology (C. Haită, pers. comm.).

The chief findings corroborate the different area uses suggested by Haită (2003) (Haită, 2003), and show how much history of various occupational activities can be packed into just a few mm of tell stratigraphy. Some examples are given in Table 3a. In part, this preservation is due to oxidation of organic components (such as mud brick/daub plant temper, domestic floor mats and byre animal bedding and fodder remains) and compaction induced by successive tell layers and the weight of this overburden; such post-depositional burial processes are discussed elsewhere (Courty et al., 1989; Macphail and Goldberg, Submitted/2016).

Typical microstratigraphic sequences found at Borduşani-Popină tell include deposits evidencing different uses of space:

- Loose silt-dominated micritic mud brick and daub remains from previous constructions were biologically worked and weakly stained by humic (material?); they were exposed to weathering in *open areas* or used for *ground raising/levelling* (Fig 16). In addition, middening (see below) may have also affected these originally calcareous deposits.
- A succession of plant tempered ('adobe') mud brick layers represent *floor constructions*. These often contain very thin series of microlaminated articulated phytoliths, weak humic staining, and inclusions of fine charcoal, bone, and ash. These components indicate small amounts of *domestic occupation* debris that have been trampled in place.

- *Middening in passage ways* and other *open areas/disused space*, coprolitic bone-rich layers and amorphous phosphate-rich cess outflows occur (see Table 3c); a concentrated layer of fish processing waste was also recorded (M11B/30052 – Figs 15-16).
- Both dung spherulite-rich (calcitic) weakly humic silts and patchy layered remains of partially ferruginised reddish amorphous organic matter and plant residues occur – some as pseudomorphs of dung and as ashed remains – indicate areas of *animal enclosures* and *animal management* in general (Fig 17).
- Dung and phosphate-stained floors more likely record *in situ stabling* within structures, which can occur on mud-brick floors. While (deposits and mud brick floors only contain ~1.00% organic matter and <2 mg g⁻¹ P, one purported animal stocking layer in Area 3 (at the base and at the edge of the site) was more humic and phosphate-rich (Fig 17; see Tables 3a-3c). Partially ferruginised organic byre floor deposits include dung spherulites (see SEM/EDS). Such concentrations of calcium and phosphate have been found by EDS in oxidised dung spherulite-rich rock shelter stabling deposits elsewhere – (e.g., Early Bronze Age rock shelters in the Negev Highlands, Israel (Macphail and Crowther, 2008; Rosen et al., 2005; Macphail unpublished reports to S. Rosen).
- *Destruction levels are variously* composed of rubefied (burned) mud-brick floors and collapsed walls and unburned silty material with ferruginous stains (see Fig 14); in some cases they including ashed remains of wooden roofs and thatch (coarse wood charcoal and semi-melted phytoliths), similar to those reported from fire-razed buildings in the UK (Norwich and London) and China (Loess Plateau) (Goldberg and Macphail, 2006; Macphail and Crowther, 2007; Shelley, 2005).

Overall, the analysis of ~80 microstratigraphic layers identified in the thin sections through this tell and local geological and soil profiles, permitted the characterisation and comparison of natural sediments, loessic alluvial soils, and nine broad categories of spatial use in an urban tell settlement. This scenario is consistent with other studies of southern European and Near Eastern earth- and mudbrick-based urban accumulations (Cammis, 1994; Matthews, 2010; Matthews et al., 1996; Matthews and Postgate, 1994). Moreover, it provides specific information on the Chalcolithic lifestyle at Borduşani-Popină, which includes use of food resources gained by fishing and hunting in the local wetland, and management of domestic stock (sheep/goats and possibly also cattle).

The settlement's peripheral zone is dominated by the presence of a river stream surrounding the loess remnant, completely isolating it from Borcea River terrace, marshy areas, lakes and higher areas with alluvial soils and woodlands. Possible activity areas, such as for fish and cereal processing are indicated by thin laminated ash accumulations in a small lake some 100 m east of the tell. Within a broader zone, another tell settlement is located on an erosional remnant (*popina*), near the confluence of Borcea River with Ialomiţa River. An additional *popina* tell site is situated a few km to the South, but there is no Chalcolithic occupation, only an Iron Age necropolis. The pottery was made from the alluvial clay from the vicinity of the settlement, but hard rock (limestone) quarries were located on the eastern side of Danube, in Dobrogea (territory between the Danube and the Black Sea shoreline). This limestone was utilized for tool and weapon making, and some limestone fragments were also employed for the construction and fitting out of the combustion structures (together with burned daub and pottery fragments in order to help maintain elevated temperature in the central part of the ovens).

Case 2: The Viking coastal settlement of Heimdaljordet and associated Gokstad ship burial mound, Norway (Tables 3a-3c)

Unlike many similarly dated settlements, such as Coppergate, York, the London Guildhall site and Odense, Denmark, the pattern of occupation at Heimdaljordet (near modern Sandefjord, Vestfold, Norway) is uncomplicated by later occupations and constructions. At this recently discovered Norwegian site preliminary dating (artefacts, e.g. dirhams, and radiocarbon) suggests occupation between 800/850 to 1000, but with use in the second half of the 10th century only indicated by radiocarbon dates; an end date of AD 920/950 apparently relates to a cessation in the use of bullion on the site (Bill and Rødsrud, In Press). The settlement was made up of parcels (parcel ditches) around an east-west running path or road (Figs 3-4), and although occupation deposits only remain in these parcel ditches and a supposed large well feature, these provide much information on the organisation of the site and its character (Figs 18-22, Tables 4ac).

Like its near neighbour Kaupang, another coastal Viking settlement some 9 km to the south-west (Skre, 2007), Heimdaljordet was probably occupied seasonally. The parcel ditches, which are cut through beach sands into intertidal clay loam sediments not only divided up the settlement but were also probably utilised to manage the site's poor drainage and likely seasonal (winter/spring?) marine flooding (Fig 18). The site was located just above sea level in Viking times (Sørensen et al., 2007), and diatom death assemblages within the parcel ditches show that they were water-filled at times. SEM/EDS analyses (Table 4c) found the coincident presence of Ba (barium) and S (sulphur) infer that the secondary mineral barite of intertidal marine origin is present (Mees and Tursina, 2010). Storm surges probably affected the Oslo Fjord, flooding the local Sandefjord inlets that allowed Heimdaljordet's population to access the sea. The beach on the south side of the settlement is the most likely landing place; at the Royal Manor of Avaldsnes, Karmøy, on the west coast of southern Norway (near Haugesund, Rogaland) turf-walled boat houses were constructed just above sea level (Bauer and Østmo, 2013). Within one boat house the sea seems to have deposited

alternating sand and gravel beach deposits. In addition occupation floor deposits contained wood fragments, possibly from boat maintenance (Macphail and Linderholm, Submitted).

Boat graves are ubiquitous in Scandinavia as funerary features (Müller-Wille, 1969), and these occur on the peripheries of both Kaupang and Heimdaljordet. One example from Heimdaljordet was studied in detail (Feature 5529), and ferruginised boat wood was preserved by rusting nail residues (cf. Sutton Hoo ship burials; Carver, 1998)). At the 5529 boat grave, in the pelvic region of the body stain where the sword hilt was located, mineralised faecal remains were well-preserved as Ca-P and Ca-Fe-P compounds (Macphail et al., 2013).

While the buried topsoils and turf walls of the boathouse at Avaldsnes were informative about likely near-shore grazing, the ~50 m wide and ~5 m high, ~AD 900 Gokstad Ship Burial Mound some 500 m north of Heimdaljordet produced far more palaeoenvironmental information (Linderholm et al., 2013). It also marked the Heimdaljordet location as one of the most important in Norway during Viking times (Cannell, 2012; Nicolaysen, 1882). In terms of construction and building material studies, intertidal clay loam was employed to seal the Gokstad longship and grave chamber within a turf mound. The clay loam produced anaerobic conditions, and as a consequence the wooden ship and burial artefacts were preserved. Macrofossils, palynology, chemical and magnetic susceptibility logs (240 samples) and micromorphology (38 thin sections) sequences through the mound established that a probable grazed sedge pasture with a laminated mull topsoil was the main turf component. It therefore seems likely that the chief land use around Heimdaljordet was grazing.

As noted above, the parcel ditches included waterlaid sediments (Fig18), some of which have diatom concentrations. Some are also dominated by amorphous orange-coloured

latrine waste, in which fishbone is present alongside rare occurrences of embedded nematode eggs(?) (Tables 4a-4c); a separate parasitological analysis confirmed the presence of nematode eggs – such as *Ascaris spp* and *Trichuris trichiura* (Flammer, 2015). Such high concentrations of amorphous phosphate suggest *in situ* outflow from outhouses for example into the parcel ditches. In one example the bulk phosphate content measured 3470 ppm P₂O₅ and SEM/EDS X-Ray microchemistry measured 8.97% P and an associated 21.4% Fe. These contexts seem to infer *some* planned management of human waste, although human coprolitic remains are ubiquitous at the site and in one instance a grave mound ditch was utilised for latrine waste disposal. Casual disposal of human waste is the norm for early medieval settlements such as at Coppergate, York (Kenward and Hall, 1995). At the London Guildhall site ditch dumps of byre waste can also include 10mm-thick layers of pure cess with a Ca-P chemistry and nematode eggs (Macphail et al., 2007b).

In addition, anthropogenic inclusions such as charcoal, charred barley, vesicular silica slag (fuel ash), burned sand and gravels, and burned bone, (and a burned basalt possible grindstone) are common indicators of hearth and food processing residues (Fig 21); fishbone within cess indicates the use of this expected food resource (see Fig 20, Tables 4a-4c). Iron stained charcoal can be associated with latrine waste, although some iron stained charcoal also occurs alongside instances of strongly burned sands and iron slag, indicating industrial/artisan activity; the SEM/EDS identification of an example of copper also indicates possible non-ferrous metal (copper-alloy) working as demonstrated by small artefact recovery (see below). Lastly, different context includes very rare instances of preserved leather fragments, again indicating artisan practices/clothing remains (Fig 22). Excavation and metal detecting have produced large numbers of dirhams, copper-alloys, amber, metal- and textile-working indicators, and food processing waste, which allows some zoning of this trading settlement (Bill and Rødsrud, In Press). This zoning, as at the trading site of Kaupang (Skre,

2007), also locates funerary features; graves and grave mounds, including the well-studied boat grave (see above), are on the north-west periphery of the Heimdaljordet site. The contemporary Gokstad Ship Burial mound, however, was constructed 500 m to the north and dominates the site as a whole.

Conclusions

Geoarchaeological information can greatly contribute to the overall understanding of settlement morphology; use of space within the settlement, and how land peripheral to settlements and in the wider landscape functions; the last includes both pastoral and cultivation practices (Table 1). The model also shows how tracks and roads, water management, middening, latrine waste disposal, food processing and industrial activity can also help the comprehension of a locality for a single cultural period (Bordușani-Popină and Heimdaljordet), or over longer time scales (London Guildhall). The latter site has been fully investigated using soil micromorphology, chemistry and exactly correlated palynological studies. The Bordușani-Popină and Heimdaljordet sites are works in progress, and geoarchaeological and associated environmental data are currently being integrated with archaeological stratigraphic, dating and finds recovery in order to produce multi-proxy assessments of how the settlements function within their own specific time frames and landscape.

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Table 11.1: A model of settlement composition including numerous soil micromorphological examples

THE SETTLEMENT		
Within the settlement	Peripheral to the settlement	The settlement's wider landscape
<p>Constructions</p> <p>Remains and residues of occupation surfaces (see Chapter 10) and use of manufactured lime floors, mortar, daub, adobe/mudbrick etc. (see Chapter 7); storage pits, wells (also below), 'pit house' (e.g. Grubenhäuser) and post hole fills, hearth deposits, urban gardens; and roofs (for roof collapse and razed buildings see Chapter 12).</p>	<p>Ramparts and walls (earth and turf constructions); moats, ditches, millponds, paddy fields (potential fish source), grain dryers, baking ovens and cooking pits; landscaped gardens; fairs and markets.</p>	<p>Monuments – tumuli, grave mounds and other features - Cursuses (see below and Chapter 7); road systems, animal enclosures (see below); arable fields, and associated constructions-ridge and furrow (see Chapter 9); soft and hard rock quarries, field and forest boundaries.</p>
<p>Trackways, roads and paths</p> <p>'Rural' signatures – dung traces, minor P concentrations.</p> <p>'Urban' signatures – food, food preparation and domestic waste, with hearth and industrial residues, and concentrated faecal materials</p>	<p>Chiefly 'rural' in character, in and out of settlement, linking local waterholes, 'infields', stockyards and pastures ('cattle paths' of Norway); some spillage of organic and settlement waste manures; stock and vehicle movements.</p> <p>Slipways, waterfront and harbours - shallow water sediments sometimes rich in refuse.</p>	<p>Chiefly 'rural' in character, linking major settlements (Bronze and Iron Age precursors of British Roman road system in places); accessing wider landscape – woodland resources and arable fields (see Chapter 9), with animal passage along droveways (e.g. transhumance) and pastures.</p>
<p>Other transport (harbours and waterfronts)</p>		

<p>Animal management</p> <p>Stabling activity and byres, including tripartite longhouses (see Chapter 10); specialised features from pig and bird husbandry (e.g. dovecotes).</p>	<p>Enclosures and corals, and associated shallow waterholes.</p>	<p>Pasture soils and effects of stock concentrations (grazing, browsing and woodland pig husbandry); rock shelter stabling; accessing ponds and wetland.</p>
<p>Water management</p> <p>Sediments of well use and disuse; other features – moats and ditches; lead pipes (Pb traces).</p>	<p>Aqueducts, canals, ponds/fish ponds, reservoirs and millponds; irrigated fields (see Chapter 9) and drainage ditches.</p>	<p>(For examples of hunting and gathering around natural water sources – see Chapter 8)</p>
<p>Waste disposal 1; middening</p> <p>Street-side and street dumping; middening, pit and other feature fills and ‘farm mound’ creation; expedient refuse disposal within structures (see Chapter 10)</p>	<p>Major manuring with dung and settlement waste of ‘infield’ horticulture (see Chapter 9), with spillage along trackways.</p>	
<p>Waste disposal 2: latrines and cess pits</p> <p>Occurrence of concentrated human waste (see Chapter 7) in cess pits and outflows (~sewers).</p>	<p>Human waste as manure.</p>	
<p>Specialist Domestic and Industrial activity</p> <p>High temperature burned sediments and fuel waste, ferrous and non-ferrous metal working, with leather and wood crafts, and use of lead</p>	<p>Furnaces, lime kilns, grain dryers, and salt working; industrial waste in minerogenic manures and as recycled for constructions</p>	<p>Fuel and raw material gathering and management of resources (woodland coppicing; iron, limestone, flint, clay for</p>

<p>(e.g. alloys and construction) (see Chapter 7); storage and pitfills, food processing (cereal, fish and meat ‘butchery’, smoking, blubber boiling) and salt working.</p>	<p>(temper in lime plasters and mortars, and daub – ‘clay walls’).</p>	<p>ceramics and floor constructions; intertidal plants and sediments for low temperature fuels/salt-processing)</p>
<p><i>Funerary practices</i> Burials not normally found <i>within</i> Roman settlements, but Late Roman graves do occur; graveyards in ecclesiastical space; excarnation features in Iron Age settlements. Tomb re-use</p>	<p>Graves, cremations and excarnation features; grave mounds juxtaposed to settlements, including boat graves and ship burials.</p>	<p>Tumuli, grave mounds, ship burials and excarnations.</p>

Table 2: Examples of soil micromorphology and integrated bulk data. 2a: AD 5th century Iron Age longhouse floor at Uppåkra, near Lund, Scania, Sweden (Fig 5); 2b: Early medieval (AD 1050-1140; dendrochronology) London Guildhall Yard East (GYE) byre waste (Figs 11-12) deposits

Sample	Depth	Context/summarised results (bulk, EDS and pollen data)	Interpretation
<i>2a: Uppåkra</i> M1 (UPP1)	0-40 mm	Despite broad and very broad burrowing, several occupation layers are distinguished. The lowermost characterised by very fine compacted and fragmented charcoal (possibly under damp conditions – forming blackish fine fabric). Layer contains much fine bone and burned bone, and some fine ash, with a spread of clay and sand. Upwards there are relict laminar structured ash-rich beaten floor deposits with possible cereal processing ash in it. At the top, coarse clasts of burned soil, subsoil and chalky till floor fragments are present. An example of possible human coprolite is present. There are increases in LOI (~05.% to ~2.0%), phosphate (<100 to >800 Cit P mg P ₂ O ₅ /100g) and magnetic susceptibility enhancement (MS=~40 to ~100 χ If 10 ⁻⁸ m ³ kg ⁻¹) when comparing the constructed floor and occupation layer.	Upper (Occupation floors) Sequence of moderately biworked floor/occupation deposit formations, which are composed of charcoal and bone-rich domestic hearth rake out interbedded with charcoal, bone and ash (some cereal?). These are beaten (trampled) floor deposits typical of a domestic use of space.
M1 (UPP1)	40-75 mm	Compact and massive, with crack and channel microstructured very dominant mixed chalky till floor layer (compact mixture of fragments of chalky soil-sediment chalk and chalk fossils, subsoil loam, with small amounts of poorly weathered coarse micaceous sand and clasts of sandstone and clay). A 4 mm-size pale stained bone fragment and probable	Lower (Constructed Floor) Essentially a well-made longhouse floor constructed from chalky till. Relict humic soil at the base (burrow mixed) may be of grazing land origin. Floor shows horizontal cracking from use and thin ‘ironpanning’ from use/water movement; floor shows general iron and probably some P

		<p>sand-size human coprolite are embedded in the floor. Broad burrow-mixed humic soil occurs at the base of the floor.</p>	contamination.
<p><i>2b: GYE samples</i> 251, 687, 755, 977 and 978 monolith, thin section and pollen series</p>	<p>11 x 130mm-long thin sections and 26 palynological analyses (see Fig 12).</p>	<p>Very dominantly organic, with a) intact horizontally layered Poaceae tissues, commonly with abundant phytoliths and long articulated phytoliths; b) sometimes with dark brown humified plant material, c) intercalated with silt, autofluorescent under blue light, layered Ca, P and K distribution (microprobe); d) sometimes inclusions of amorphous organic matter with calcium oxalate crystals. Moderate to very high LOI (range, 10.3-43.4%, $n=13$). Mostly non-calcareous (maximum, 2% carbonate). Clear to strong indications of phosphate (phosphate-P, range = 5.79-20.7 mg g⁻¹), and possible to strong evidence of heavy metal enrichment (especially Pb and Cu). Often no χ enhancement in some samples.</p>	<p>Well-preserved highly organic stabling refuse: Palynology: High concentrations of well-preserved, dominantly cereal t. and Poaceae pollen. Samples with >30% grass should be viewed as relatively undiluted stabling refuse, with major inputs from animal feed, bedding and dung (see Fig 12); samples with <30% grass contain very high amounts of cereal t., possibly as special feed. Weed assemblage probably indicates 'local' animal husbandry. Micromorphology and chemistry: fodder and bedding, b) dung of herbivores; c) stabling floor crusts and d) omnivore (pig?) dung. These deposits have been very little biologically worked before or after dumping. It can be noted that there is also a strong statistical correlation between LOI and phosphate-P, showing phosphate enrichment is due to animal husbandry. There is also strong evidence of the link between phosphate-P and heavy metal concentrations.)</p>

Table 3a: Bordușani-Popină tell; examples of soil micromorphology and integrated bulk and SEM/EDS data – some layered deposits – summarised information from Thin Sections M15C and M18A in Area A4

Sample	Depth	Context/summarised results (bulk, EDS and pollen data)	Interpretation
Area A4 (studied by 6 monoliths – 9 thin sections). Thin section M15C	0.860-0.905 m	<p>Layer 1 – mixed loessic mudbrick/slab material with mixed in coprolitic fine bones and many ash nodules.</p> <p>Layer 2 – Once- microlaminated, but now mixed by mainly thin and rare broad burrowing; very ash rich, with pseudomorphic micritic plant ash remains present, along with occasional bone, fishbone, coarse silty loess clasts, abundant pot fragments (max 9mm thick, >35mm long), rare (x4) fine (max 2mm) humic dung fragments (sheep/goat?) – brownish, humified (still cellulose is present), but any spherulites have been dissolved (finely dotted iron mottling); in addition many thin (100-300 µm) organic fragments with embedded silt occur – probable byre/stable floor crust fragments. (BD: x15/30023 (ash) – 1.59% LOI, 7.74 mg g⁻¹ phosphate-P)</p>	<p>Layer 1 – mixed dump of loessic building debris and anthropogenic material including fine bone and ash nodules – part of the trampled passageway spread.</p> <p>Layer 2 – mixed midden dump of ashes, loess fragments, coarse pottery fragments, fine bone etc, but including humified (uncharred) sheep/goat dung and humic stable/byre floor fragments – only minor biotixing; weak iron staining of dung. Partially cemented ash residue and midden layer; upper part of the trampled passageway spread. Strong phosphate enrichment from both ashy and fish processing waste.</p>
Thin section M15C, <i>continued</i> .	0.905-0.935 m	<p>Layer 3 – Sharp upper boundary (very long fish bone >30mm) to layer totally dominated by strongly BL autofluorescent bone/fish bones, with pale yellow tissue – with moderately low autofluorescence – fish flesh? in different layers), with ferruginous staining in places as dotted parts in others; very thin organo-mineral excrements mixing in loose silt and matrix material.</p> <p>Layer 4 – Weakly calcitic massive loess, traces of</p>	<p>Layer 3 – outside space (?)/passage way with fish preparation waste comprising only fish bone and tissue (flesh/skin?) – some of which also shows ferruginous staining (typical of butchery waste); minor burrowing within network of bone, by very small invertebrate mesofauna.</p> <p>Layer 4 – loess slab layer, affected by minor</p>

			anthropogenic inclusions, with channels (rooting traces) and burrows, with upwards, slightly more humic, darker grey (weathered?) loess as very broad burrow infills; matrix pans and infills at top, with rare iron staining. (BD: xM15/ 30024: 3.15 mg g ⁻¹ phosphate-P.)	subaerial weathering and broad (earthworm?) burrowing. Minor inwash and slaking effects from deposition of layer 3, above. Layer shows phosphate enrichment
Thin section M18A	0.890-0.925 m (30051)	0.890-0.925 m (30051)	Heterogeneous with poorly preserved layers of silty and micaceous loessic mudbrick soil, with remains of semi-intact microlaminated spherulite-rich humified and oxidised dung remains. Strongly burrowed with very abundant thin and many burrows. Lower part includes many charcoal (max 3mm), with very abundant oxidised dung traces, with example of stained and partially altered/cemented patch (2.5mm) of dung spherulites/dung trace, with occasional fragments of Ca-P ccess, rare coprolitic bone, rare microcrystalline and semi-cemented micritic calcite – ash residues/weathered ash clasts(?), rare fragments of humified organic matter (from stabling layers?).	Layer 30051 Mixed layers of exposed and burrowed remains of stabling horizons and middening in open area – several phases, with possible in situ stabling.
<i>Thin section M18A, continued</i>	0.925 -0.965 m	0.925 -0.965 m (30052)	SM: essentially homogeneous SMT 6a becoming more oxidised and layered spherulite-rich (SMT 6b) upwards; <i>Microstructure</i> : compact (25% voids), massive with microlaminated mainly upwards, with fine channels (trace of roots); <i>Coarse Mineral</i> : C:F, as SMT 6a – well sorted silts; <i>Coarse Organic and Anthropogenic</i> : rare amorphous yellow ‘cess’ within laminated laminae; trace of charcoal, fine coprolitic bone and weakly burned bone; occasional	Layer 30052 Area of continued animal (sheep/goats) stabling, with possible trace of cattle dung (layered humified organic matter). (Small to high concentrations of Ca, with P, S and Fe associated with ashed, partially ashed and oxidised/humified – dung spherulite-rich – layers; Table 2c) Stabling activities include a period of some burrow mixing and trace of rooting, before a seemingly unbroken period of stabling left

		<p>relict humic poorly layered dung fragments and many semi-intact oxidized/humified dung areas (spherulite-rich), with upwards examples of individual laminae of semi-articulated single phytoliths (bedding layers?) – also long humified plant length examples, and intact microlaminated oxidised dung layers becoming very abundant/very dominant as a microfabric type (SMT 6b)(intercalated 1mm-thick silt dominated layers between 250-500 µm-thick weakly humic stained dung spherulite dung layers); <i>Fine Fabric</i>: SMT 6b: as SMT 6a, with very dominant calcitic dusty and cloudy greyish brown to dark greyish, spherulite-dominated, with weak humic staining (was amorphous dung layers), with semi-horizontally oriented mica flakes; <i>Pedofeatures</i>: <i>Amorphous</i>: rare amorphous CaP ccess along some microlaminated areas; <i>Crystalline</i>: trace of gypsum – concentrated into patch of relict micritic calcite – ash patch?; <i>Fabric</i>: lower part of unit with abundant thin and occasional broad burrows; becoming much less burrowed upwards (essentially microlaminated). (BD: Weakly humic and strongly phosphate-enriched with 2.49% LOI and 5.27 mg g⁻¹ phosphate-P.) SEM/EDS (10 areas – see selected data in Table 3c)</p>	<p>humified and oxidised dung layers intercalated with animal(?) trampled silt and spherulite-rich layers. Some erosion/reworking of this uppermost deposit (before Layer 30051).</p>
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Table 3b: Bordușani-Popină tell; LOI and phosphate data

Bulk sample	LOI ^a (%)	Phosphate- P _i (mg g ⁻¹)	Phosphate- P _o (mg g ⁻¹)	Phosphate- P ^b (mg g ⁻¹)	Phosphate- P _i :P (%)	Phosphate- P _o :P (%)
Bordușani - Popină Island Borcea river section (soil profile)						
x1(M1)	2.34			0.660		
Excavation profiles from Bordușani-Popină Tell						
<i>Area A6</i>						
x7/1 (M7)	1.05			1.76		
x7/2 (M7)	1.24			3.09*		
x8/2 (M8A)	0.984			2.41		
x8/1 (M8B)	1.00			1.60		
x9/3 (M9)	4.31*			2.35		
<i>Area A4</i>						
xM11A/30023	1.00	5.14	0.163	5.30**	96.9	3.1
xM11B/30024	1.81	10.5	0.307	10.8***	97.2	2.8
xM14/30021	2.86*	4.99	0.109	5.10**	97.9	2.1
xM14/30022	1.18	7.33	0.149	7.48**	98.0	2.0
x15A/30021	3.11*			2.66*		
xM15A/30021	2.12	1.67	0.047	1.72	97.3	2.7
xM15A/30022a	4.19*	14.5	0.311	14.8***	97.9	2.1
xM15B/30022b	0.751	2.90	0.076	2.98*	97.4	2.6
x15B/30023	1.59			7.74**		
xM15/30024	1.12	3.05	0.099	3.15*	96.9	3.1
<i>Area A3</i>						
x30052(M18A)	2.49			5.27**		
x30053(M18B)	1.67			2.63*		
x30054(M19A)	2.23			3.64*		
x30055(M19B)	3.21*			6.18**		

^a LOI: values highlighted indicate notably higher LOI ($\geq 2.50\%$) than the remaining samples

^b Phosphate-P: values highlighted indicate likely phosphate-P enrichment: * = 'enriched' (2.50–4.99 mg g⁻¹), ** = 'strongly enriched' (5.00–9.99 mg g⁻¹), *** = 'very strongly enriched' (10.0–19.9 mg g⁻¹)

Table 3c: Bordușani-Popină tell; selected SEM/EDS data (% element)

Thin section/Feature	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
M8B (Area A6)											
<i>Thin cess layer</i>											
Yellow Ca-P amorphous infill (n=2)		1.01- 1.16	0.0- 1.04	0.0- 0.43	17.4- 17.8	0.0- 0.36	0.0- 3.79	38.3- 39.2			1.14- 1.49
Ditto – Fe-P-Ca		1.90	2.91	8.30	12.1		3.79	10.1			21.1
<i>Loessic mudbrick layer</i>	1.11	1.58	8.01	32.0			3.31	2.84			3.35
M10B (Area A5)											
<i>Fishbone layer (n=2)</i>	0.44- 0.92	0.86- 0.90	0.0- 1.17	0.0- 3.61	16.1- 18.1	0.0- 0.51	0.0- 0.35	34.1- 39.5			0.0- 1.84
M18A (Area A3)											
<i>Oxidised dung (spherulites) (n=3)</i>	0.0- 0.92	2.71- 4.01	4.85- 8.05	12.9- 17.5	1.91- 3.82	0.70- 0.86	1.77- 2.31	18.8- 25.3			5.87- 6.24
Ditto - matrix (silts and spherulites)	1.29	2.42	6.27	28.2	0.82		2.62	8.08			4.50
M19A (Area A3)											
<i>Oxidised dung fragments (including plant fragments; n=2)</i>	1.08- 1.20	6.21- 9.46	3.44- 3.81	8.27- 14.5	1.81- 2.47		1.39- 1.53	27.5- 31.8			4.22- 5.35
<i>Sheep-goat dung (n=2)</i>	0.58- 0.68	4.42- 10.1	1.58- 3.60	7.06- 24.4	1.13- 2.38		0.95- 1.59	17.5- 35.5			2.89- 4.62
<i>Lens of spherulites (n=2)</i>	0.75- 1.09	2.37- 3.07	4.38- 5.06	24.2- 26.4	1.26- 1.46	0.0- 0.39	2.13- 2.20	11.9- 15.1	0.24- 0.33	0.0- 0.31	3.38- 4.02
<i>Calccitic silty soil matrix</i>	0.68	2.37	6.88	26.9			2.77	11.8	0.28		3.41

Table 4a: Heimdaljordet; examples of soil micromorphology and integrated bulk and SEM/EDS data from feature fills - summarised information from Thin Sections M14834B and M14328

Sample	Depth	Context/summarised results (bulk, EDS and pollen data)	Interpretation
Parcel ditch section SC14832, thin Section sample M14834B	140-215 mm	<p>Layer 4</p> <p>Very heterogeneous with dominant dark microlaminated very humic silty clay (waterlain cess) as layers and coarse fragments, and frequent sands and silty sands. Very few fine gravel, very abundant microlaminated cess (silty clay, with very abundant orange stained plant fragments and amorphous phosphate – sometimes with occasional to abundant diatoms, phytoliths present), many amorphous orange cess/faecal material aggregates and nodules (as at Avaldsnes), many coprolitic bone, including likely fish bone (3mm; spine section), many burned sand including granite and strongly rubefied materials, occasional fine charcoal, and rare ferruginised root traces. There are very abundant matrix panning/sedimentation, with trace of very thin dusty clay panning, very abundant orange probable Fe-Ca-P cess layers and reddish Fe-P(?) nodules, many iron staining, hypocoatings, nodules, very abundant thin, very broad and broad burrowing, and many very thin, abundant thin and very abundant broad organo-mineral excrements. Layer 4 is moderately humic (5.8% LOI), very strongly phosphate enriched (3400 ppm P₂O₅), with a very low Pquota (0.9). A small amount of burned mineral material is indicated by moderately high magnetic</p>	<p>Layer 4</p> <p>A now coarse burrowed and fragmented ditch fill, which originally acted as a sewer. Probably the ditch acted as a waterfilled cess-pit/latrine drain, with often high amounts of diatoms being incorporated into the microlaminated cess deposits; location of privy(?). These are also high in amorphous organic matter and unidentified plant remains. Some cess variants are totally mineralised and resemble house ditch deposits at A10 Avaldsnes. Waterlain, cess is associated with very high P with very low PQuota, and fish appears to be a part of the diet. Background charcoal and burned mineral material also occur. Burrow mixed boundary to:</p>

<p>Feature 14031. Section 3C14274, Thin Section sample M14328</p>	<p>35-110 mm</p>	<p>susceptibility enhancement (MS=212 χIf $10^{-8} \text{m}^3 \text{kg}^{-1}$); EDS shows P-staining (Table 3) Burrow mixed boundary to: Layer 2 More minerogenic layer 2 includes much fragmented Layer 4 material, and is weakly humic (3.8% LOI), phosphate enriched (1040 ppm P_2O_5), with a moderately low Pquota (1.5). A small amount of burned mineral material is indicated by MS enhancement.</p>	<p>Minerogenic ditch silting, now burrow mixed with overlying latrine disposal deposits.</p>
		<p>Layer 2 Heterogeneous with common very humic yellowish silts, with dominant fine and coarse charcoal-rich silts and sands and few sands. It is very poorly sorted with frequent small gravel (max 3.5mm) and sediment clasts; there are common inclusions of minerogenic anthropogenic materials. Layer 2 is characterised by very abundant charcoal including coarse wood charcoal (max 7.5mm) with both broadleaved and conifer wood –, and a rare trace of FeP stained wood charcoal, and abundant charred seeds (barley grains? — max 4.5mm), abundant coprolitic bone (some charred — max >8mm), occasional FeP cess nodules and cess impregnated sediment fragments, occasional rubefied and calcined burned bone, many burned mineral grains and abundant vitrified and vesicular silica ‘glass’ fuel ash waste? (max. spheroid 6mm), and trace of very thin roots. Rare example of silty clay infill (fine root channels), many generally fine-size Fe-P nodules, many very thin, abundant thin, very abundant broad and very broad burrowing, and</p>	<p>Layer 2 Very phosphate and charred grain-rich deposit, wood charcoal, burned sand and high concentration of vitrified siliceous fuel ash waste (e.g. 31.5-36.7% Si) indicating hearth or grain store fire debris. Background sediments are rich in human faecal waste, indicative of localised latrine drainage that has stained charcoal (3.17 P, 22.5% Fe). Charred grain has absorbed the heavy metal copper (0.0-2.27% Cu) – either from biological concentration (cess) or from copper alloy working. The coincident presence of Ba (barium) and S (sulphur) infer that the secondary mineral barite of intertidal marine origin is present.</p>

		<p>many very thin, abundant thin and occasional abundant broad organo-mineral excrements, were recorded. Layer 2 contains the highest amounts of organic matter (13.1% LOI), is very strongly phosphate enriched (3470 ppm P_2O_5), with a low Pquota (1.0). A burned mineral content is indicated by MS, while MS550 reflects secondary iron staining (mainly FeP staining coprolitic remains in thin section); EDS data in Table 3c.</p>	
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Table 4b: Heimdaljordet; Chemistry and magnetic susceptibility – selected data from Linderholm et al. (in prep.)

Context	Thin section	MSif	MS550lf	CitP°	CitPOI°	ppm P ₂ O ₅	PQuota	%LOI
14031, 3C14274								
Layer 2	M14328	29	160	759	795	3470	1.05	13.1
14031, SC14832								
Layer 6	M14834A	212	221	256	372	1620	1.45	4.3
Layer 4	M14834B	14	62	921	790	3400	0.86	5.8
Layer 2	M14834B	12	33	160	239	1040	1.49	3.8
5837, Cut 10901								
Layer 5	M11117	9	8	106	106	460	1.00	3.6
Layer 5	M11117	10	10	120	122	530	1.01	2.7
Layer 2	M11117	10	9	115	112	490	0.97	2.8
Layer 5	M11118	10	11	108	104	450	0.96	3.7
Layer 4	M11118	10	8	126	113	490	0.89	2.7
Layer 2	M11118	8	9	102	96	420	0.94	1.5

Low frequency magnetic susceptibility (MS); 2% citric acid extractable phosphate; loss on ignition at 550°C

Table 4c: Heimdaljordet; examples of SEM/EDS data from feature fills - summarised information from Thin Sections M14834B and M14328

Feature	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe	Cu	Ba
M14328												
Vesicular silica slag 1 (<i>n</i> =3)	1.04- 1.80	1.06- 2.78	0.26- 7.52	31.5- 36.7	0.0- 1.38		4.35- 8.16	1.73- 2.66		0.80- 5.65		
Vesicular silica slag 2	2.85	3.76	0.23	33.5	1.25		7.02	4.03		0.38		
Fe-P stained charcoal			13.8	14.9	3.17			3.14		22.5		
Charred cereal grain (<i>n</i> =3)	0.0- 1.03	0.0- 1.55	1.82- 15.1	3.72- 10.6	0.0- 4.27	0.59- 9.95	0.0- 0.95	0.0- 21.6		5.05- 17.8	0.0- 2.27	0.0- 10.6
Calcined bone	0.67		2.20	1.02	18.4			28.6		8.10		
M14834B												
Contaminated/stained silty inwash	1.50	1.03	6.90	30.6	1.34		1.77	1.26	0.92	7.13		
Iron-stained cess (<i>n</i> =2)	0.57- 0.98	0.69- 0.73	8.44- 9.27	12.7- 17.2	7.77- 8.97	0.39- 0.60	1.29- 1.51	1.04- 1.28	0.0- 0.31	17.8- 21.4		
Stained fishbone (<i>n</i> =2)	0.40- 0.48		3.77- 4.45	0.41- 0.76	17.7- 18.1	0.32- 0.36	0.0- 0.17	19.3		15.4- 17.4		
Ditto – local cess- sediment	1.43	0.93	7.89	26.4	3.62		1.88	1.18	0.37	8.99		
Ditto – local silty sediment	2.02	0.76	6.80	32.9	0.86		2.29	1.46	0.49	4.06		

Macphail et al Captions:

Fig. 1: Location map of the Bordușani-Popină tell site in Romania. Landscape map showing the low flood plain of the River Danube (RD) and Danube delta (DD). The site of the Bordușani-Popină tell (B-P; see Fig 2) occurs between the River Danube and River Borcea (RB) in the Ialomița wetland, 150 km to the east of Bucharest.

Fig. 2: Bordușani-Popină, Borcea River, Romania (near River Danube); a Chalcolithic Gumelnița culture (~4500 cal BC) tell site. A 1:25000 location map showing Bordușani-Popină tell to the east of the River Borcea and the village of Bordușani. A tell settlement within its wider environment – here – wetland that supplied fish such as carp and ducks such as mallard.

Fig 3: Location maps of Gokstad Mound and the nearby Viking coastal settlement of Heimdaljordet, which are located on the outskirts of Sandefjord, between the Norwegian coastal towns of Larvik and Tønsberg. The Gokstad Viking long ship was recovered from the Gokstad Mound, while the equally famous Oseberg long ship was found near Tønsberg. Both are now housed in the Viking Museum, Oslo (Macphail et al., 2013, fig 1).

Fig. 4: Heimdaljordet (Heimdal), Viking coastal settlement near Gokstad Ship Burial Mound, and now on the outskirts of Sandefjord, Vestfold, Norway (see Fig 2a) (after Bill and Rødsrud, In Press). Excavation survey map showing rectangular parcel ditches at the settlement either side of a suspected road. The circular ditches of grave mounds (GM) and the investigated boat grave (BG) are located. Parcel ditches were cut through beach sands occurring over marine mudflat sediments, and were affected by flooding during high tides. The ditches were also employed as convenient latrine outflows.

Fig. 5: Digital flatbed scan of ~5th century AD longhouse floor at Uppåkra, near Lund, Scania, Sweden. Beaten, occupation floor deposits of domestic nature over floor constructed of chalky till (Table 4a). There is a displaced fragment of the chalky till floor-occupation floor (Fr). The floor was constructed over a natural humic topsoil and mesofauna have burrowed upwards into the floor (Bu). Use of the floor led to iron staining of the surface (Fe).

Fig. 6: SEM/EDS BSE (X-ray backscatter) image of thin section B2 (Lyminge, Kent, UK, Sunken Featured Building lowermost fill; Thomas , 2010), focusing on uppermost iron-stained soil attached to the overlying Early Saxon iron coulter. Note presence of probable iron-impregnated knot wood fibres; mean 2.68% Si, 2.40% P, 2.84% Ca, 65.6% Fe. The iron coulter seems to have been laid on a once-suspended wooden floor. Scale bar=1mm.

Fig. 7: Digital flatbed scan of Iron Age road deposits (Context 428 at Sharpstone Hill, Bayston, Shropshire, UK) illustrating massive, compact nature of sediment, effects probably caused by trampling, animal traffic and wheeled transport on wet trackway deposits. This road predated the Roman road following the same route.

Fig. 8: Photomicrograph of Context 425 (as Fig 7, below Context 428); note amorphous, brown and greenish nodular fills, sometimes associated with root channels. Amorphous iron-phosphate (FeP) embeds crystalline iron-phosphate (vivianite). SEM/EDS found 15.7-19.5% P, 34.0-40.1% Fe ($n=5$) in the greenish nodules and enclosed vivianite, while the background sediment included only small amounts of P (7.28-9.23% Al, 32.5-34.1%, 3.50-3.95% Fe; 0.64% P; $n=2$). One source of phosphate in these road deposits is dung, and another layer included relict dung spherulites in addition to finely fragmented humified plant remains. Plane polarised light (PPL).

Fig. 9: Digital flatbed scan of M13145D (Trackway sediments) at Iron Age Bamble, Vestfold, Norway. The sequence includes a partially bioworked 'subsoil' composed of

waterlogged trackway silts, with boundary (blue arrow) to overlying humic trackway sediments (Layer 2) that include a layer of byre waste fragments (arrows).

Fig. 10: Schematic chemistry and magnetic susceptibility diagrams of Roman, Late Roman (dark earth). Late Saxon and medieval 'Norman' sequences at Whitefriars, Canterbury, Kent, UK.

CW12: Late 3rd century AD brickearth-constructed rampart and buried soils; these were infield manured cultivated soils with small inputs of settlement waste manure found in thin section.

Road CW21(E): Late Saxon (AD 850-1060) Eastern Lane section; selected data figure, with chemical and magnetic susceptibility showing road deposits ('Dark Fill') with increased carbonate, phosphate and lead (Pb) content, and material with a strongly enhanced magnetic susceptibility. Calcitic ash, fine shell (carbonate), bone (P), heated soil and artefacts ($\% \chi_{\text{conv}}$) and lead (Pb) contamination are recorded. Minor mixing of anthropogenic materials into, and staining of, the upper buried topsoil is also recorded by this bulk analysis and thin section studies.

CW21(W): Western Lane section composed of two phases of road building and medieval 'Norman' (AD 1175-1250) road deposits ('Dark Fill'). Compared to the dark earth the road fill shows a strong increase in carbonate (ash and shell) and some material with a very strongly enhanced magnetic susceptibility. It is worth noting that phosphate and lead are also moderately concentrated in the dark earth, which was formed in Roman occupation deposits. The very high χ_{conv} (49.8%) in the 'Dark Fill' reflects industrial waste inputs, including iron slag. (Figures by John Crowther, University of Wales Trinity St Davids, Lampeter)

Fig. 11: Digital flatbed scan of M978-2, early medieval (AD 1050-1140) London Guildhall Yard East (GYE); typical horizontally oriented microlaminated plant remains (cereals and grasses) of fodder and animal bedding origin, with high LOI and phosphate content (see Fig 12 and Table 2b).

Fig. 12: Scattergram showing frequencies (%) of Cereal type and Poaceae pollen from the early medieval (AD 1050-1140) London Guildhall Yard East (GYE) in byre waste and stabling deposits including the 978 sampling series (see Fig 11). (Figure by G. M. Cruise; Macphail et al., 2007a).

Fig. 13: SEM/EDS X-Ray backscatter image of vesicular iron spherule containing 42.0% Fe, at Hol (Sudndalslia/Sudndalen), Buskerud fylkes Kommune, Norway, a medieval (AD 1050-1400) iron working site.

Fig. 14: Field photo of Borduşani-Popină, Borcea River, Romania (near River Danube) (see Figs 1-2); a Chalcolithic Gumelniţa culture (~4500 cal BC) tell site. Area A4; an example of the stepped excavation sondages and monolith sampling (2011). 1: ground-raising mixed loess building material and remains of relict floors; 2: intact floors; 3: open area trampled debris spreads – middening – including fish processing waste (Thin section sample M15C; see Fig 15); 4: blackened burnt remains of byre floor deposits, mudbrick and thatch; 5: rubefied burnt mudbrick – which has also been used for ground-raising. (Macphail and Goldberg, Submitted/2016)

Fig. 15: Photomicrograph of M15C (Borduşani-Popină tell, see Fig 14). Here there is a marked concentration of fish bone and unknown yellow material, both of which are highly autofluorescent under blue light (BL) (see Tables 3a-3c). This is a presumed fish processing deposit (fish bones from freshwater pond fish such as carp are common at the site; (Popovici et al., 2003). There is also much reddish amorphous material and bone staining; other

butchery deposits can show reddish stained bone remains. Plane polarised light (PPL). (Macphail and Goldberg, Submitted/2016)

Fig. 16: Photomicrograph of thin section M8B (Bordușani-Popină tell, see Figs 1-2), with tell Layers L3-L5. Layer 3: biologically worked and partially homogenised layer of mud brick and middening debris – an open area; Layer 4: thin (4mm) layer of humic stained material, with humified plant material organs(?) and yellowish orange amorphous cress, embedding leached bone, humified and fine charred organic matter but which is non-autofluorescent under blue light, with 1.6mm size coprolite (records latrine waste disposal episode or drainage from latrine, possibly in a passage way); Layer 5: calcitic silty soil (with plant tempering – not shown) – base of mud brick floor. (SEM/EDS analysis; Yellow cress: 17.4-17.8% P, 0.0-0.36% S, 38.3-39.2% Ca, 1.14-1.49% Fe; ‘Ca-P-Fe’: 12.1% P, 10.1% Ca, 21.1% Fe; Coprolitic bone: 17.5% P, 0.0-0.33% S, 39.5-39.8% Ca, 0.0-0.53% Mn, 3.35% Fe). Plane polarised light (PPL). (Macphail and Goldberg, Submitted/2016)

Fig. 17: Photomicrograph of thin section M18B (Bordușani-Popină tell, see Fig 14), with Layers L1 (Context 30053) and L2 (Context 30052-brown). L1: compact mud brick fragments with fine anthropogenic inclusions and fine mottling (probable Fe-P) - ground raising deposit of mudbrick deposits with weak cress staining and possible mottling from overlying stabling(?) layers; L2: compact and mainly very finely microlaminated weakly humic silts, with very abundant calcitic dung spherulites, and rare examples of layered amorphous dung (4mm and 1mm thick fragmented layer). Overall, bulk analysis found a weakly humic and strongly phosphate-enriched context (2.49% LOI and 5.27 mg g⁻¹ P; 0.527%P) (see Tables 3a-3c). This appears to be an animal (sheep/goats) stabling area, with possible traces of cattle dung (layered humified organic matter) – alternatively ‘floors’ could have been plastered with a series of dung-rich silts. Plane polarised light (PPL). (Macphail and Goldberg, Submitted/2016)

Fig. 18: Photomicrograph of M12054 (Parcel Ditch 11672), at Heimdaljordet, near Sandefjord, Vestfold, Norway. Base of ditch cut into sands (Ss), showing microlaminated clay lens (Cl) associated with standing water after ditch was first cut. Plane polarised light (PPL).

Fig. 19: Photomicrograph of M14834B (Parcel Ditch 14031, Section 14832, Layer 4; Heimdaljordet). Example of pure orange brown amorphous cress deposition (SEM/EDS: 7.77-8.97%P; 17.8-21.4% Fe). PPL.

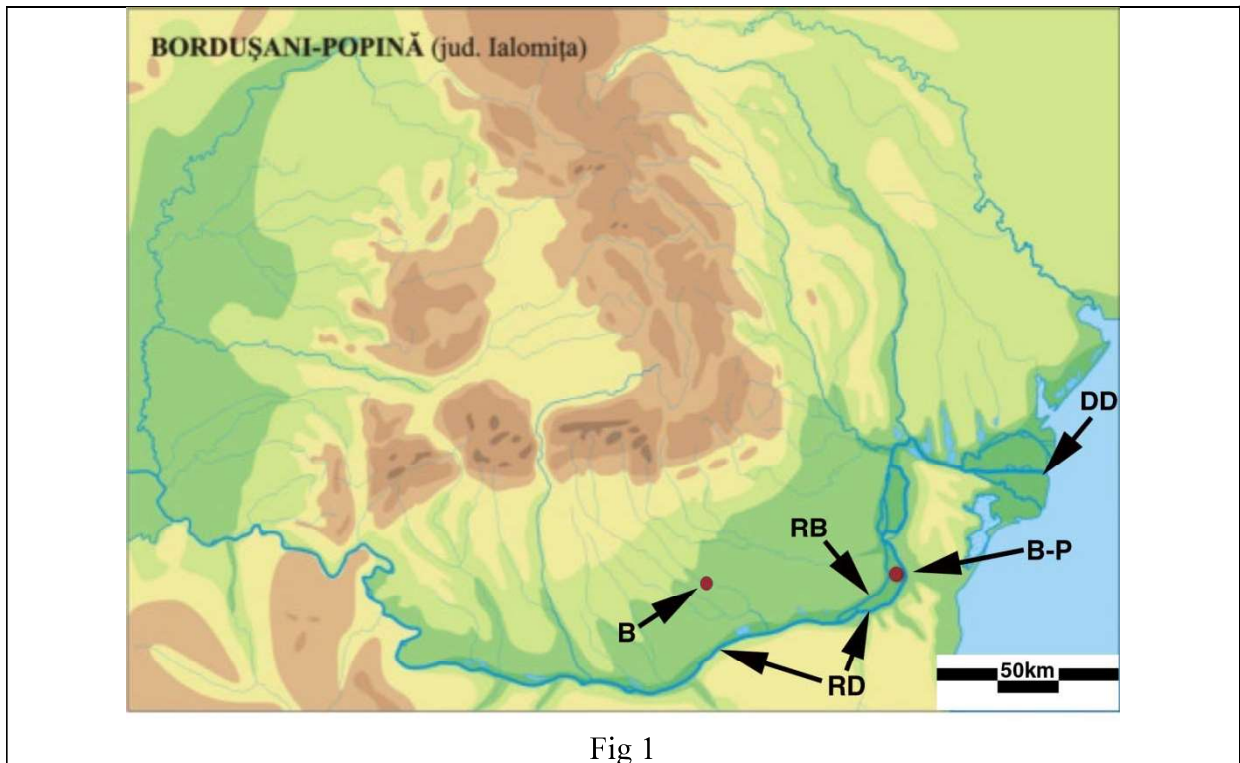
Fig. 20: Photomicrograph of M14834B (as Fig 19). Fish bone found within cress-stained Layer 4 (see Fig 19). Fishbone is probably a precaudal vertebra of a small gadid (Rebecca Nicholson, Oxford Archaeology, pers. comm.). PPL.

Fig. 21: Digital flatbed scan of M15196B (Parcel ditch 14031, Section 14750, Layer 6; Heimdaljordet). Overall, the fill has an LOI of 11.1%, in part associated with concentration of charred cereal (barley) grains (arrows).

Fig. 22: Photomicrograph of M15196B (14031, Section 14750, Layer 6; Heimdaljordet). An example of leather, as indicative of leather clothing/craft working. Leather is composed of amorphous organic matter with fine channels; leather is dull reddish, isotropic under crossed polarised light (XPL), and very dark brown to black under oblique incident light. PPL.

(Macphail and Goldberg, Submitted/2016)

Figs



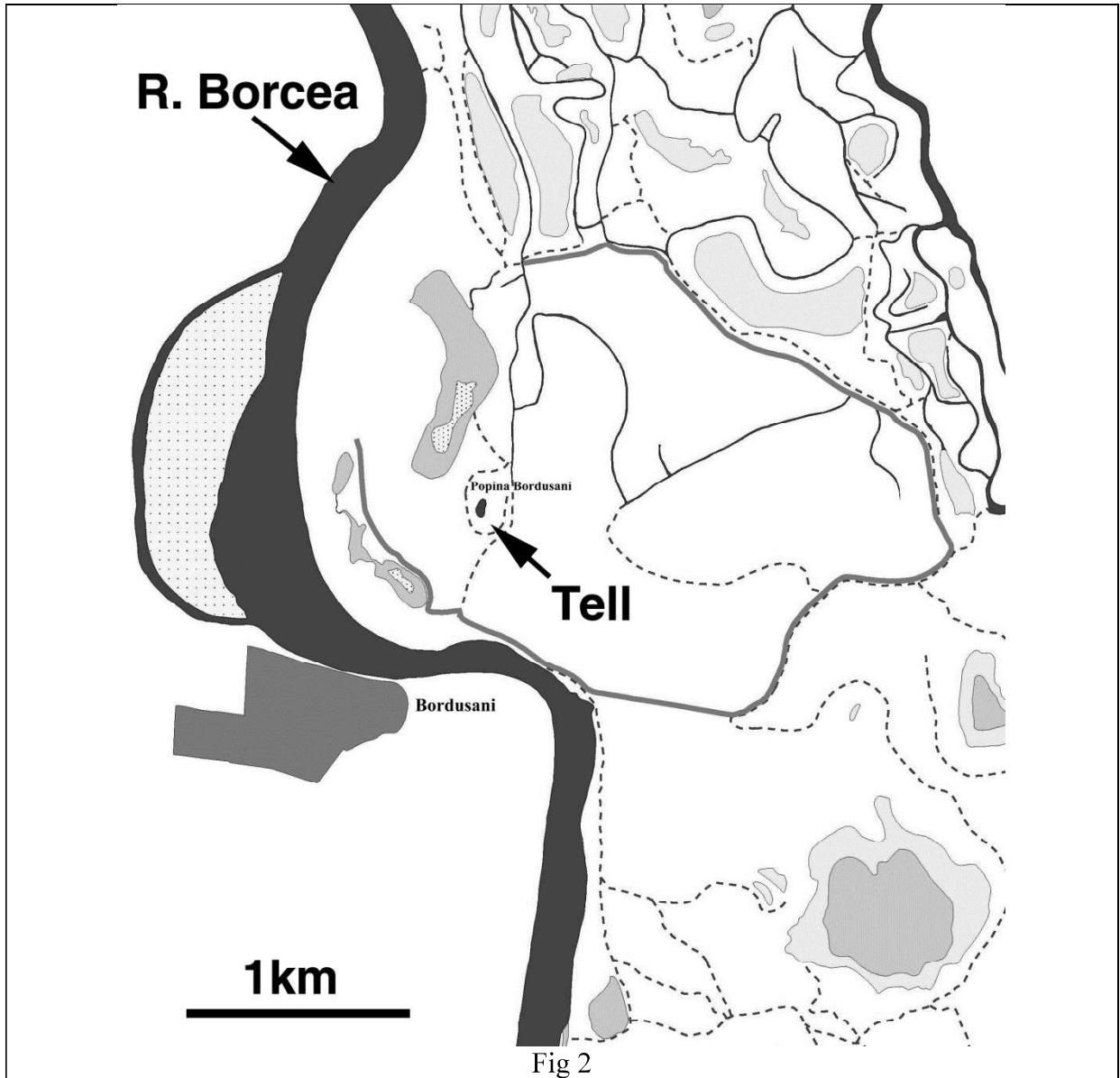


Fig 2

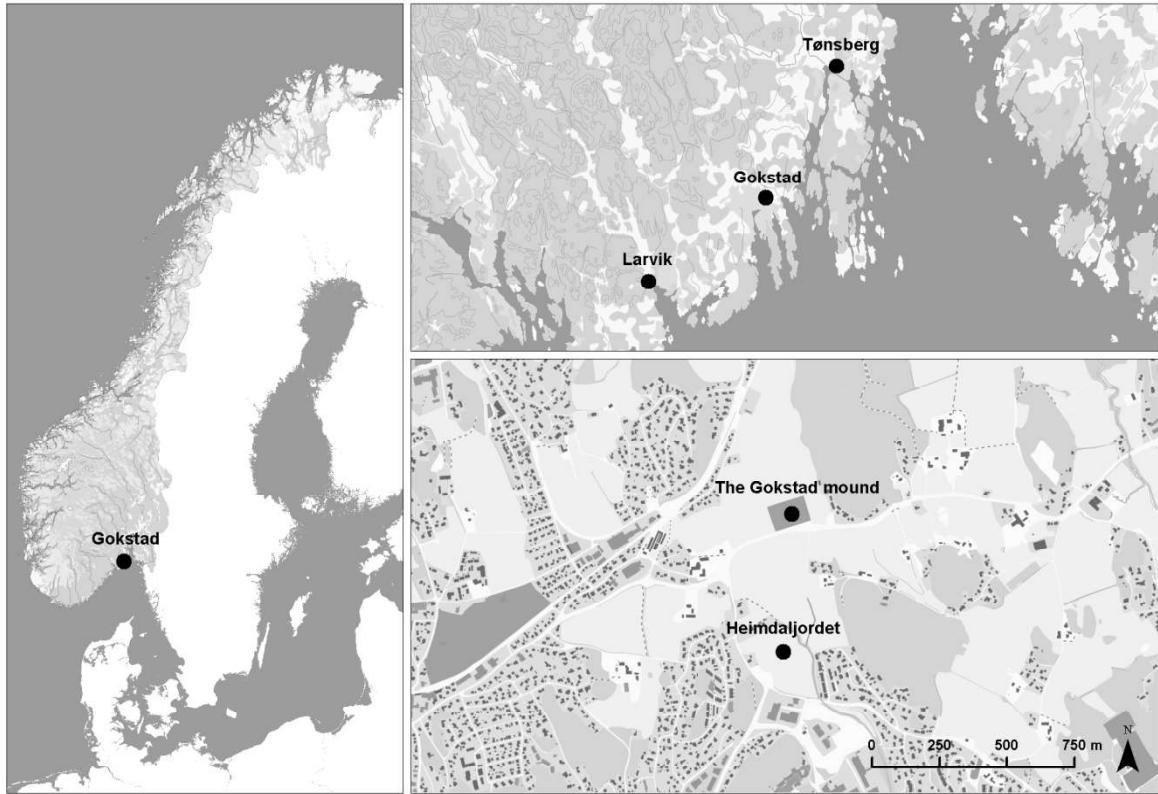


Fig 3

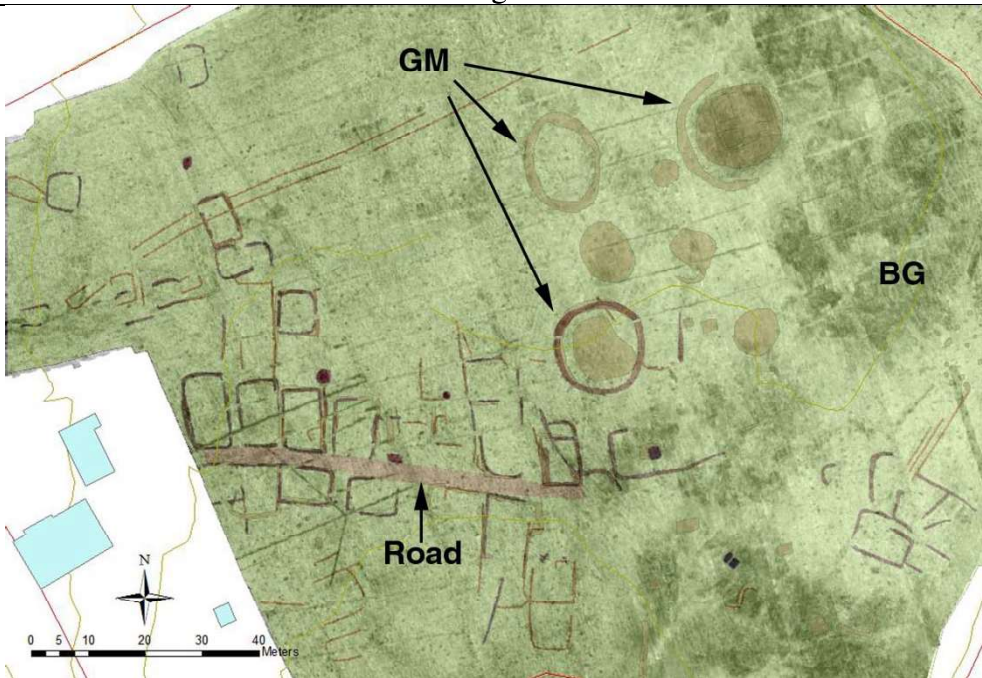


Fig 4

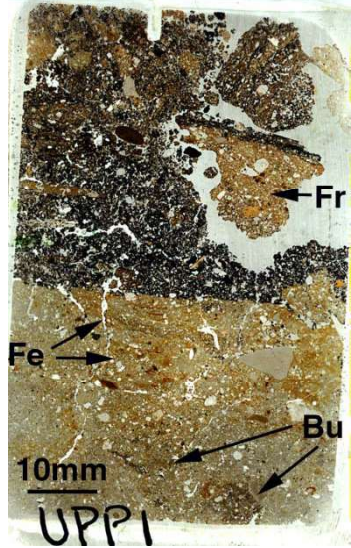


Fig 5

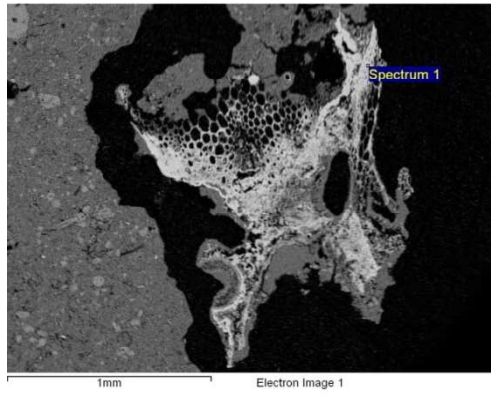


Fig 6



Fig 7

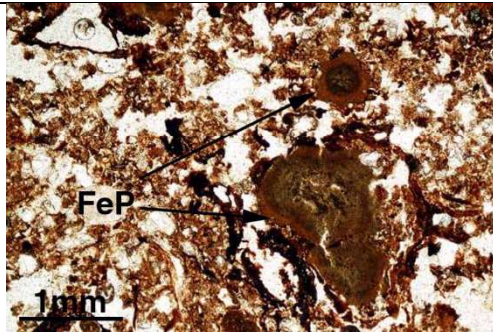


Fig 8

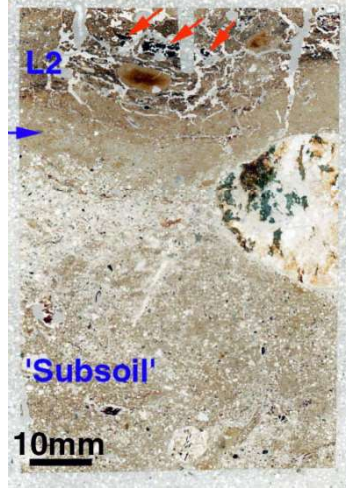


Fig 9

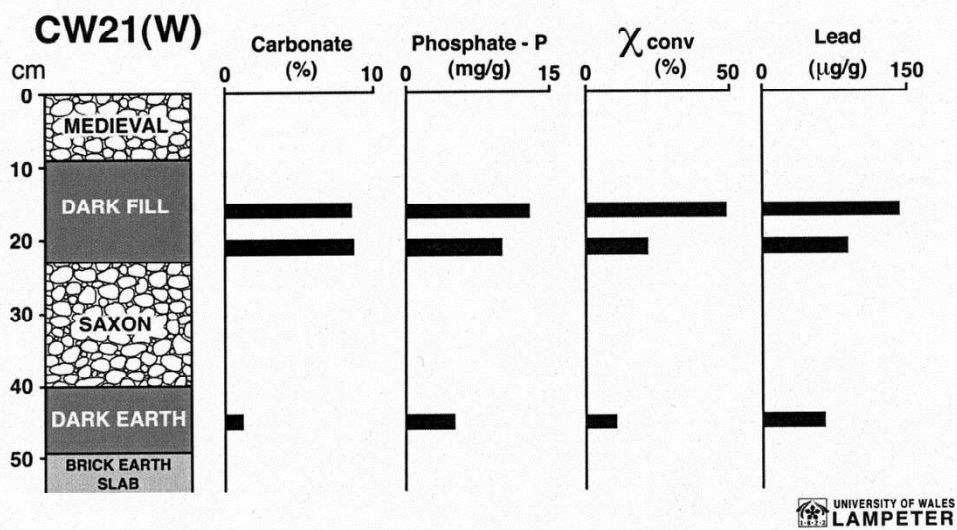
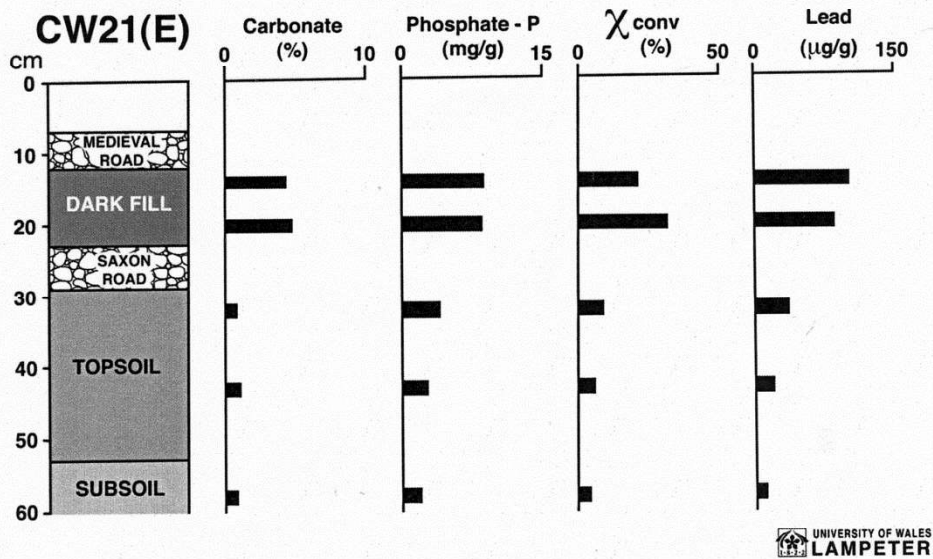
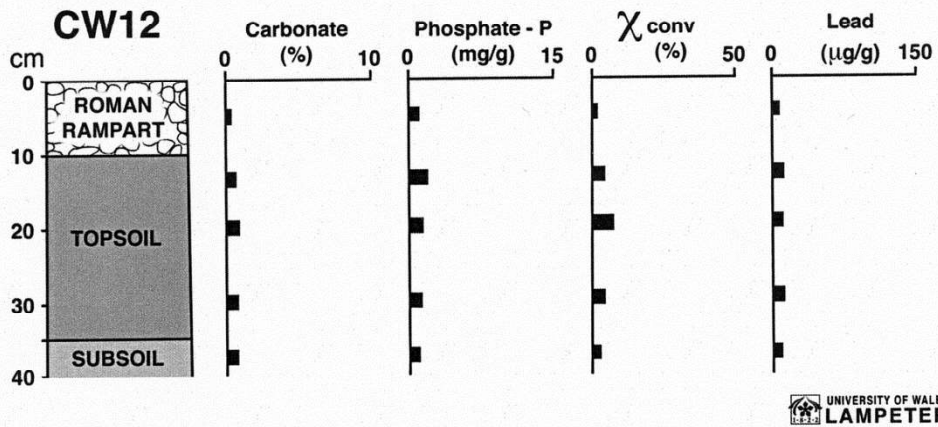


Fig 10



Fig 11

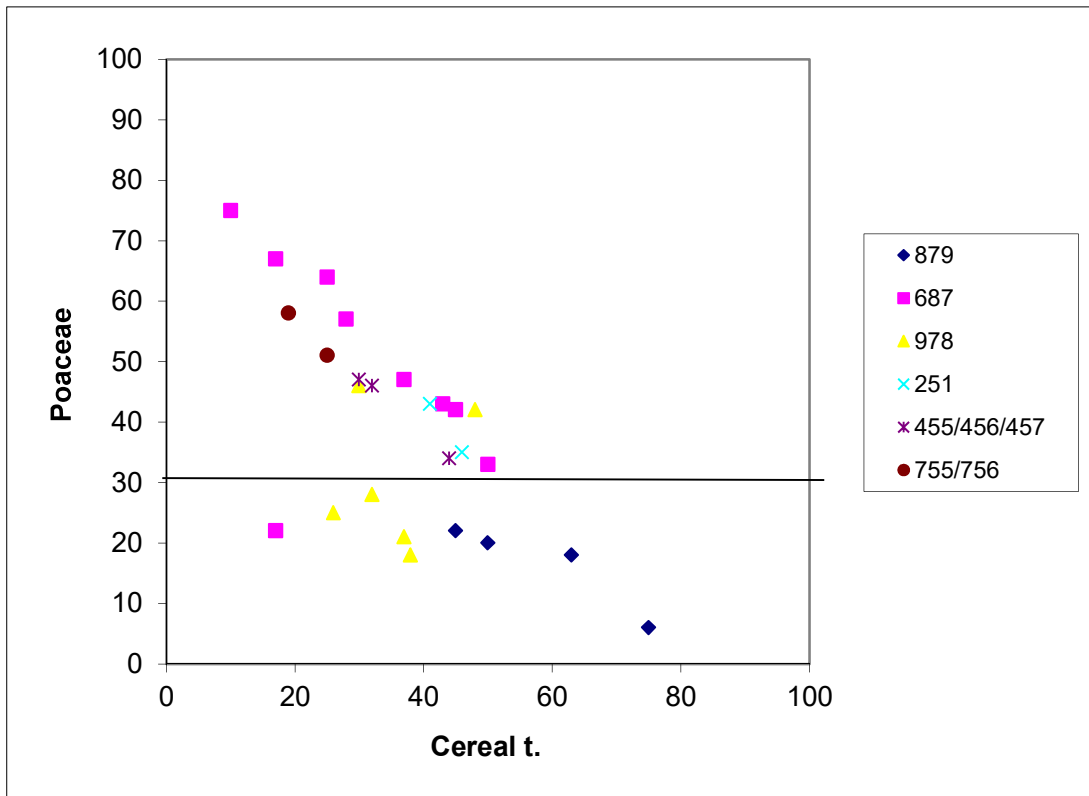


Fig 12

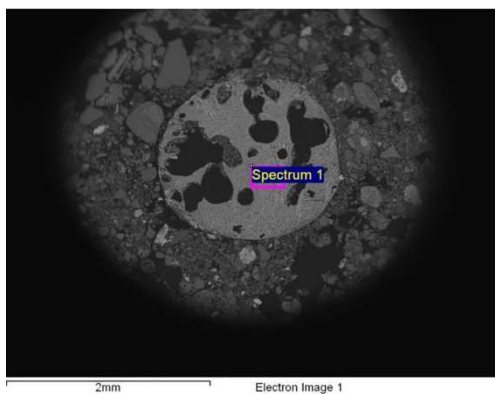


Fig 13

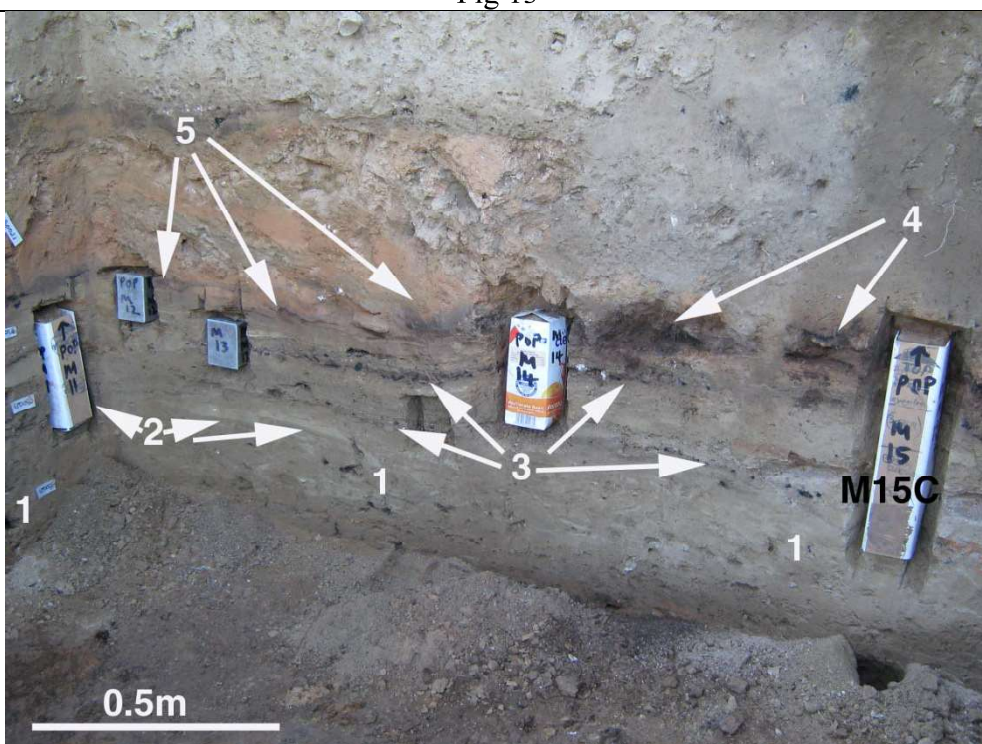


Fig 14



Fig 15

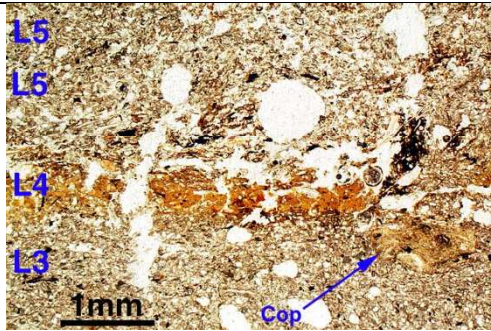


Fig 16

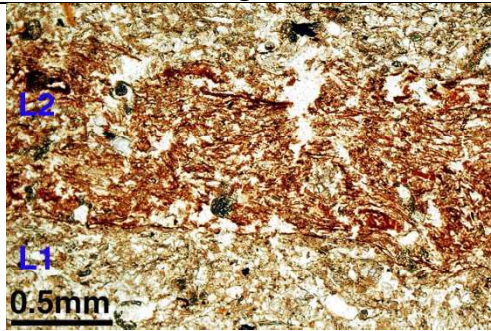


Fig 17

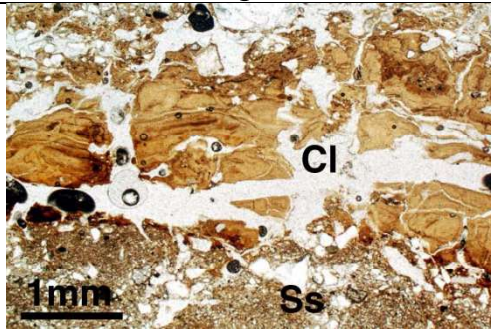


Fig 18

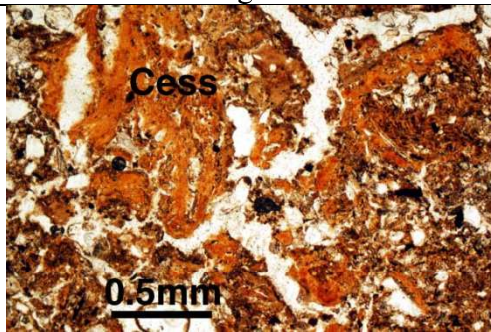


Fig 19

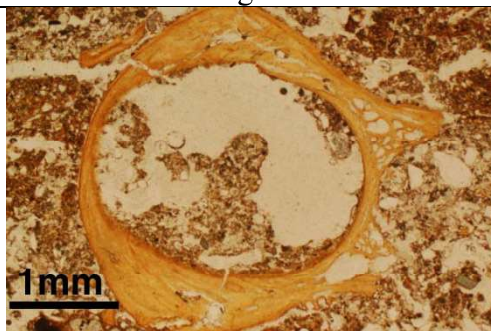


Fig 20

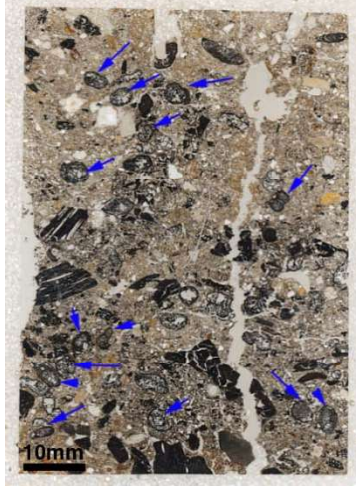


Fig 21

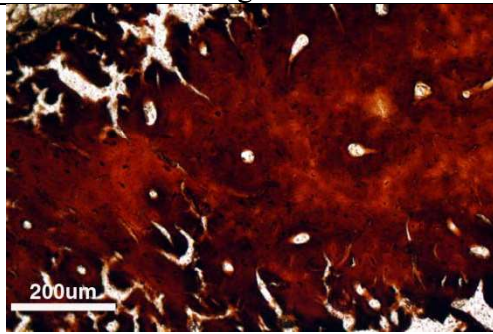


Fig 22

