Integrated geoarchaeological methods for the determination of site activity areas: a study of a Viking Age house in Reykjavik, Iceland

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Abstract

For over a decade, geoarchaeological methods such as multi-element analysis and soil micromorphology have been used to identify and interpret activity areas on archaeological sites. However, these techniques, along with others such as magnetic susceptibility, loss on ignition, and microrefuse, artefact and bone distribution analyses are rarely integrated in the study of a single site, even though they provide very different and potentially complementary data. This paper presents a comparative study of a wide range of geoarchaeological methods that were applied to the floors sediments of a Viking Age house at the site of Aðalstræti 16, in central Reykjavík, Iceland, along with more traditional artefact and bone distribution analyses, and a spatial study of floor layer boundaries and features in the building. In this study, the spatial distributions of artefacts and bones could only be understood in the light of the pH distributions, and on their own they provided limited insight into the use of space in the building. Each of the sediment analyses provided unique and valuable information about possible activity areas, with soil micromorphology proving to have the greatest interpretive power on its own. However, the interpretation potential of the geochemical methods was dramatically enhanced if they were integrated into a multi-method dataset.

Key Words:

Activity areas
Soil micromorphology
Loss on ignition
Electrical conductivity
Magnetic susceptibility
ICP-AES
Viking Age houses

1. Introduction

The understanding of the spatial organisation of activity areas is of prime importance to the archaeological interpretation of settlement sites. It provides information about how individuals, households and communities organised the wide range of social and economic practices that constituted daily life, how they perceived and managed different types of waste products, and what living conditions were like in and around their dwellings and work places. To identify activity areas archaeologists not only use features such as hearths, cooking pits, storage pits and middens, and the spatial distributions of artefacts and bones, but increasingly they are making use the most minute residues of human and animal activities: microrefuse (bones and artefacts under 1-2 mm in size), plant phytoliths, organic residues and associated elements and isotopes that accumulated on presumed occupation surfaces (e.g. Sampietro and Vattuone, 2005; Shahack-Gross et al., 2008; Smith et al., 2001; Sullivan and Kealhofer, 2004; Terry et al., 2004; Vizcaíno and Cañabate, 1999; Vyncke et al., 2011). Samples for these micro-residue studies are normally in the form of loose bulk samples in which the occupation deposits are homogenised, even though it has long been recognised that occupation surfaces are usually palimpsests, comprising the residues of multiple, super-imposed events (Malinsky-Buller et al., 2011).

The interpretation of artefact, microrefuse, and geochemical distributions on archaeological sites is dependent on a clear understanding of the complex depositional and post-depositional processes that created and subsequently impacted the occupation deposits under study (Carr, 1984; LaMotta and Schiffer, 1999; Wandsnider, 1996). Human actions frequently result in the deposition and/or removal of particular artefacts and residues, especially objects over 1-2 cm in size, which are commonly kicked aside, removed during cleaning, or dumped or cached during site abandonment (Lange and Rydberg, 1972; Stevenson, 1982; Tani, 1995; Wilk and Schiffer, 1979). There is also a wide range of natural processes that alter the composition of occupation deposits over time as they become subject to the same physical, chemical, and biological processes affecting local landforms and soils (e.g. Johnson and Hansen, 1974; Rolfsen, 1980; Schiffer, 1996; Stein, 1983). It is therefore essential to develop a framework for interpreting activity areas that incorporates an assessment of cultural and natural processes that may have affected the formation of occupation surfaces. The ability of soil micromorphology to resolve minute lenses representing super-imposed events and to identify post-depositional processes has been well attested (e.g. Macphail and Crowther, 2007; Matthews et al., 1997; Milek, 2012; Milek and French, 2007; Shahack-Gross et al., 2005; Shillito et al., 2011), but the method continues to be underused in comparison to geochemical methods.

In order to assess the relative contributions that artefact and bone distributions and different geoarchaeological analyses can make to the interpretation of site activity areas, an interdisciplinary study was conducted on a house dated to the late 9th and 10th century AD, which was excavated in central Reykjavik at Aðalstræti 16 (formerly 14-18) (Fig. 1). The house was well preserved, and its turf walls, internal features (hearth, post holes), and 25 distinct floor layers were readily identified in the field (Fig. 2; Roberts et al., 2003; Snæsdóttir, 2004). The distributions of artefacts and bone fragments, organic matter and carbonates (loss on ignition), pH, soluble salt content (electrical conductivity), magnetic susceptibility, and multiple elements (ICP-AES), were compared to each other and to the results of soil micromorphology, in order to evaluate the relative contribution that each technique made individually, and as part of an integrated dataset, to the interpretation of the use of space in the Viking Age house.

2. Study Area

Aðalstræti 16 is situated 1.95-2.15 m above sea level, at the base of a moderately steep slope that rises to the west. The climate in Reykjavik is cool and wet, with an annual mean temperature of 5°C (-0.4°C in January, 11.2°C in July) and an average of 805 mm of rainfall per year (Þórarinsson 1987, 8). The site was well drained, however, because it was located on an ancient pebble beach on which a thin andosol (2-4 cm) had developed, derived from aeolian silt and fine sand of volcanic origin. Both the *in situ* andosol below the house and its turf walls contained the so-called *landnám* tephra layer, which had erupted from the Veiðivotn system in either AD 871±2 (GRIP ice core; Grönvold et al., 1995) or AD 877±4 (GISP2 ice core; Zielinski et al., 1997), providing a *terminus post quem* for the site. AMS dates on eight charred barely grains (*Hordeum Sativum*) from the hearth fills indicate that the site could have been occupied no later than AD 890 (Sveinbjörnsdóttir et al. 2004), and the datable artefacts from the floor of the house, including a polychrome glass bead (Callmer Type B6100) and a glass vessel fragment with 'grape' decoration, support a late 9th-10th century date (Hreiðarsdóttir 2005; Mehler 2002). The house used in this study had suffered only minor damage of its walls from the foundation trenches of 19th-century factory buildings, but an annexe that abutted the southern end of the building was severely truncated by later building activity and only fragments of its walls and its central hearth had survived (Nordahl 1988).

3. Methods and Materials

3.1. Excavation and Sampling

Each of the 25 occupation layers found between the post-abandonment turf roof/wall collapse and the underlying *in situ* soils was recorded separately and sampled on a 1 m grid (Fig. 3; Table 1). Small bulk samples (c. 200 ml) for geochemical and magnetic analyses were taken from each grid square, while the remainder of the sediment in each square was taken for floatation and wet sieving with 1 mm mesh. All bone material over 1 mm in size was counted and identified if possible (Tinsley and McGovern, 2002; see Supplementary Data Table 1). Artefacts found during excavation were 3D recorded, and those found during wet sieving were given the coordinate of the centre of the grid square. The house was excavated in a checkerboard pattern using sextants, and eight undisturbed block samples for micromorphological analysis were taken from the exposed sections using 12x6x5 cm aluminium tins (ff. Courty et al. 1989) (Fig. 3).

3.2. Sediment analyses

Bulk samples were air dried, gently powdered with a mortar and pestle, and sieved to remove inclusions larger than 2 mm. Loss on ignition was conducted at 550 ºC and 950ºC following Nelson and Sommers (1996). Magnetic susceptibility was tested in 10 ml plastic pots using a Bartington MS2 magnetic susceptibility meter with a low frequency sensor. Electrical conductivity and pH were tested in triplicate on three separate subsamples using DiST WP3 and pHep 3 meters immersed in 10:25 ml soil:water suspensions and the mean values were accepted as representative of that grid square. Inductively coupled plasma atomic emission spectroscopy (ICP-AES) was conducted on the <180 µm fraction digested with nitric acid–aqua regia. This near-total digestion regime was chosen because Icelandic andosols have very strong P fixation, necessitating the analysis of total P (Arnalds et al., 1995). The geochemical data are summarised in Table 2, and the complete dataset, including grid coordinates, is provided in Supplementary Table 1.

Statistical analyses using SPSS were employed to examine the probability distributions of the geochemical data, correlations between different element concentrations, and correlations between element and soluble salt (EC) concentrations (Table 3). Spearman's rank correlation coefficient (r_s) for non-parametric data was chosen as the most reliable correlation statistic because only some of the probability distributions approximated the normal curve while others were positively skewed. Interpretations of geochemical data were aided by a survey of the physico-chemical properties and possible sources of elements, as well as a survey of the elements that had previously been identified in modern reference materials (Supplementary Data Tables 3-4).

Micromorphology samples were dried using acetone replacement of water, impregnated with crystic polyester resin and thin sectioned following the method of Murphy (1986). Thin sections were first scanned on a flatbed scanner and then analysed with petrographic microscopes at magnifications ranging from x4-250 with plane-polarized light (PPL), cross-polarized light (XPL) and oblique-incident light (OIL) following Bullock et al. (1985) and Stoops (2003). Key micromorphology descriptions are summarised in Table 4, and full descriptions of all micromorphology samples are provided in Supplementary Data Table 2. The identification of anthropogenic materials such as bone, dung, and ash was aided by modern reference collections (Supplementary Data Table 5).

3.3. Data presentation

Geochemical data and artefact locations were plotted using ArcGIS. Fourteen of the 36 elements determined by ICP-AES had clustered, non-random patterning (Al, Ba, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S, Sr, Zn), of which Ba, Ca, Cu, Mg, P, K, Na, Sr and Zn were selected for presentation here due to their potential contribution to the interpretation of activity areas. A few floor layers overlapped in, and in this case, for ease of presentation, the uppermost sample from the affected grid square was chosen for display. Although geochemical data are often graphically represented by surface contours based on data interpolations, this study presents point data because numerous floor contexts are displayed at the same time, and data from different contexts cannot be interpolated. After experimenting with different ways of binning geochemical values in the GIS, it was noted that the standard deviations from the mean, rather than the raw values, showed more pronounced patterning (greater differences in symbol sizes), and this was therefore the preferred method for graphical presentation of the ICP-AES data in Figs. 6-8. The raw data are presented in Table 2 and the complete original dataset is available in Supplementary Data Table 5.

4. Results

4.1. Field evidence for activity areas

The house at Aðalstræti 14-18 was 16.70 m long and 3.74-5.81 m wide, with 1.27-1.72 m thick turf walls faced with stones (Figs 2-3). There was one entrance towards the northern end of the eastern long wall and a narrower one in the southwest corner of the house. The northeast entrance was stone-paved, and an antechamber was later added to it that extended the length of the entrance passage to 4.8 m. Within the entrances were alignments of post holes, and the fact that context boundaries respected these alignments suggests that the posts supported partition walls separating small entrance rooms – possibly acting as wind breaks. Context boundaries also respected an area in the northwest corner where there were three rows of stake and post holes oriented perpendicular to the western long wall, and an area in the southeast corner where there was a row of post holes perpendicular to the southern end wall; both corners therefore appear to be discrete spaces surrounded by partition walls. The large central hearth was lined with curb stones and contained a flat stone slab that had been blackened, reddened, and cracked by heat. There was a rectangular setting of four stake holes towards the northern end of the hearth, which may represent a wooden superstructure that had been suspended over the fire, perhaps for a grill or spit. The post hole cluster south of the central hearth probably represents a series of post replacements, while most posts were in rows parallel to the long walls of the house, dividing the space into three aisles (Fig. 3).

The occupation deposits varied considerably in colour, texture and inclusions, enabling 25 to be distinguished (Table 1). The layers in the central aisle were very compacted and rich in charcoal and ash, suggesting the spreading and trampling of hearth waste in this space. Context 844, in the northwest corner of the building, was noted to be particularly organic. In the middle of the western side aisle the occupation deposit was so thin and patchy that no context was recorded, and the excavators suggested that this area might have been covered by a wooden platform.

4.2. Artefact and bone evidence for activity areas

The distribution of artefacts and bones in these occupation layers provided additional information about the locations of activity areas (Fig. 4). There was a concentration of artefacts such as beads, nails, a spindle whorl and a fragment of vessel glass (rare in the Viking Age) around the central hearth, suggesting this was a focus for daily activities. The quartz stones east of the hearth might have been used as gaming pieces for the Viking Age board game *hnefatafl*, which is known from medieval written sources (e.g. *Friðþjólf's Saga*, *Hervör's Saga*, *Saga of Gunnlaug Serpent-Tongue*). Clusters of jasper flakes and strike-a-lights around the northern half of the hearth provide a good indication of where the fire was lit. The piece of pumice, the knife and the spindle whorl in the eastern side aisle suggest that this may have been a sitting and working area, while the four loomweights clustered in the southern part of the western side aisle suggest the location of an upright loom. The cluster of quartz stones in a post hole in the northeast corner can be interpreted as a foundation or closing deposit rather than an every-day activity area.

In the eastern side aisle northeast of the hearth there was a cluster of unburnt bones, which could have been the location of a butchery area, but they could also have been placed there for storage or disposal after the meat had been consumed. Every part of the house except for the western side aisle appears to have received the deposition of hearth waste and burnt bones. The largest cluster of burnt bones outside the hearth was at the southwest entrance, indicating that hearth waste was deliberately dumped or swept there.

4.3. Geochemical evidence for activity areas

4.3.1. pH

Conditions in the central hearth and the deposits around it were alkaline (pH 7-8), and most of the floor deposits were neutral to alkaline (Fig. 5a). Since pure water in equilibrium with atmospheric CO_2 has pH 5.6, the hearth and floor deposits with pH >5.6 acted as a base, contributing alkali salts such as Ca^{2+}, Na^{+}, Mg^{2+}, or K^{+} to the soil solution. A common source of alkali salts in domestic contexts is wood ash (Evans and Tylecote, 1967; Pierce et al., 1998), and inclusions of wood charcoal were also found in most of the floor deposits in variable quantities, suggesting that wood ash was spread from the hearth throughout the building. The distribution of alkaline pH values, like the distribution of burnt bones, which travelled with the hearth waste, is therefore not indicative of specific activity areas in the building but of a floor maintenance practice that involved the intentional spreading of ash – a practice used until the early 20th century in Iceland to keep floors dry and smooth (Milek 2012).

While most grid squares contained sediment that was neutral or alkaline, there were several grid squares with extremely low pH values (4.5-5.0), notably a 1 m wide strip south of the hearth. This strip was located below a 19th-century foundation trench that had contained wet, organic sediment, and its pH can be attributed to the accumulation of organic acids. Any bone originally deposited in this area had little chance of surviving (Fig. 4c).

4.3.2. Electrical conductivity

The electrical conductivity of the floor sediments was generally very low, but context 871, in the southeast corner, had electrical conductivity values ten times higher than most other contexts, indicating very high nutrient or soluble salt levels (Fig. 5b). Since soluble salts are susceptible to leaching, the original concentrations must have been even higher. Identification of the salts present required elemental analysis (section 4.3.5.).

4.3.3. Loss on ignition

Organic matter content estimated by loss on ignition at 550ºC was significant throughout the occupation deposits (Fig. 5c). Concentrations were notably high in the central aisle around and north of the hearth (12-25%), in the northwest corner of the building (19-22%) and especially in the eastern side aisle (22-25%), indicating the locations of activities, flooring materials or organic furnishings (e.g. bedding material) that resulted in accumulations of organic matter. Since ignition at 550ºC combusts both charred and uncharred organic remains, and both plant- and animal-derived materials, interpretations about specific activities or furnishings required additional data from micromorphological analysis (section 4.4.).

Carbonate content measured by loss on ignition at 950ºC was highest in the hearth (c. 4%), where it was probably derived from $CaCO_3$ in wood ash and calcined bones (Canti, 2003). Individual grid squares in the eastern and southern edges of the building where carbonates were also in the region of 3-4% (Fig. 5d) are probably also places where wood ash and calcined bones were concentrated, an interpretation supported by the distribution of burnt bones (Fig. 4d).

4.3.4. Magnetic susceptibility

High magnetic susceptibility values were limited to sediments in and adjacent to the hearth, with slightly elevated values also present in the eastern side aisle next to the hearth (Fig. 6a). Since wood ash, charcoal and bone are not magnetic, the magnetic enhancement of the hearth ash indicates the presence of soil particles, pebbles and/or iron nodules that were magnetically enhanced by heating. This suggests that peat and/or turf was used as fuel in addition to wood or that heated soil material from the base of the hearth was mixed with the ash residues sampled in and near the hearth.

4.3.5. Multi-element analysis

Levels of P, Ca, K, Mg, Zn, Ba, and Sr were highest in the central hearth deposits at three or more standard deviations above the mean (Figs 6-7). However, all of these elements also had elevated concentrations in the central isle around and north of the hearth, and in the eastern side aisle east of the hearth, in areas that also have significant organic matter content. These elements are either plant macronutrients or are trace elements commonly present in ground water (Sr), which are taken up by plants and pass through the food chain to animals (Suppl. Data Table 3). They are incorporated into hard and soft organic tissues and are present in elevated levels on archaeological sites wherever plant or animal tissues or their ashes are deposited (Wilson et al., 2008; Misarti et al., 2011). The metals Cu and Ni, which had the same distribution as organic matter and its associated elements, had clearly followed the same depositional pathways (Figs 8b-c).

The multi-element data were interrogated by the visual comparison of distribution maps and statistical correlations in order to determine which soluble salts might be responsible for the high electrical conductivity values in the southeast corner of the house (context 871). None of the element distribution plots were identical to the EC distribution, but Ca and Na both showed slight elevations in this area, and Mg was higher overall in the southern end of the house than in the northern (Figs 6b-d, 8a). Spearman's rank correlation coefficient (r_s)

showed a strong positive correlation between EC and Mg, which was statistically significant at the 0.01 level (Table 3), and which points towards the presence of Mg^{2+} salts. However, some common salts, such as chloride (Cl^-), bicarbonate (HCO^{3-}), ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-), cannot be detected by ICP-AES.

4.4. Micromorphological evidence for activity areas

4.4.1. North end

Analysis of thin section AST01-80 confirmed the high organic content noted in context 844 in the field and in the loss on ignition data, and provided more information about its origin. Four separate lenses were identified in thin section (Suppl. Table 2.14), and although these had been heavily reworked by soil fauna, it was possible to see the original horizontal bedding of the organic matter in localised areas (Fig. 9a). The uppermost and lowermost lenses of the occupation deposit, 844.1 and 844.4, were stained dark brown by organic acid pigmentation and contained 20-30% dark brown, partially decomposed plant matter and 10-30% phytoliths (Table 4). The phytoliths included short, broken strands of articulated silica skeletons that are distinctive of grasses that have been chewed by animals, indicating the presence of herbivore dung (Fig. 9b). Any faecal spherulites, if produced, did not survive. Faecal spherulites have not been found in any reference dung samples or stabling deposits in Iceland, and they are either not produced in Iceland or were rapidly dissolved by liquid excreta (Canti, 1999).

Lens 844.3 was composed primarily of phytoliths and very pale brown amorphous organic matter, and also contained 2-5% charcoal, 2-5% small bone fragments and an unusually high concentration of fungal spores (2-5%) (Fig. 9a). The bone fragments were smaller than 5 mm and highly weathered, with abundant pits and cracks and class 0-1 weathering rims (cf. Bullock et al., 1985). The presence of minute, chemically weathered bone fragments, the yellowish/pale brown colour of the fine organo-mineral matrix in which they were embedded, and the abundance of fungal spores and phytoliths (some in discrete aggregates) suggest that this layer contained a mixture of omnivore and herbivore dung, while the charcoal indicates that wood ash was occasionally sprinkled here. Lens 844.2 was a thin lens of turf containing the *landnám* tephra layer. This lens had not been identified in the field, and may have been a localised inclusion. If the turf was intentionally deposited, it may have served as bedding material.

4.4.2. Central aisle

The layer captured in sample AST01-71, just north of the hearth, contained only 2-5% charcoal and it did not contain any of the ash or burnt bone that had characterised the central aisle contexts in the field, microrefuse and chemical analyses (Table 4). Where it was thin sectioned, floor context 864 contained 40-50% amorphous, decomposed organic matter, an unusually high concentration of fungal spores (5-10%), and a high proportion of phytoliths (40-50%). About 20% of the layer consisted of small (<5 mm) grey aggregates of phytoliths, which were tightly packed together in randomly oriented, short, articulated segments characteristic of sheep or goat dung (Fig. 9c). The deposit did not show any evidence of compaction by trampling and is therefore interpreted as the remains of dung that had been stored next to the hearth for use as fuel.

4.4.3. Central hearth

The two thin sections taken from the hearth deposits, samples AST01-74 and AST01-75, contained lenses with either high concentrations of charcoal or the microcrystallitic $CaCO_3$ granules and rubified iron nodules characteristic of peat and turf ash, as well as lenses that contained a mixture of both wood and peat ashes (Table 4; detailed descriptions and interpretations in Suppl. Data Tables 2.7-2.10). In the alkaline environment of the hearth, the $CaCO_3$ aggregates normally associated with charcoal should have survived, and the low frequency of these aggregates in thin section may be indicative of low-temperature burning (<400°C) (Simpson et al., 2003). In sample AST01-71, there was a lens of burnt fish bone that lay at the boundary between contexts 802 and 831. It is possible that some of the burnt bones in these ash layers were a product of accidental loss during cooking, but most of the bone was probably intentionally thrown into the fire once the meal was consumed as a convenient and sanitary method of waste disposal (Tinsley and McGovern, 2002).

4.4.4. Western side aisle

Sample AST01-67 was taken from the western side aisle, where occupation deposits were so thin and patchy that no floor layer was recorded in the field. In thin section, however, it was possible to see a very thin occupation deposit below the turf collapse: an organic silt loam about 1 cm thick, containing 5-10% charcoal and <2% bone and burnt bone (Fig. 9d, Table 4, Suppl. Data Table 2.1-2.2). The deposit had been heavily reworked by soil fauna, but even where the original fabric had survived bioturbation, neither the organisation nor the microstructure of the sediment showed any evidence of compaction by trampling. This provided independent support for the interpretation derived initially from the field evidence, that there had been a raised wooden platform in this area.

Sample AST01-79 captured a small context, 851, which was very heterogeneous, containing an abundance of charcoal (20-30%) and amorphous organic matter (30-40%), as well as ash (2-5%), burnt bone (2-5%), and bone (<2%) (Fig. 9e). The sediment was porous and uncompacted, and contained relatively large, randomly oriented charcoal fragments (up to 7 mm), suggesting that the layer had not been trampled. It could not have been the product of a one-off dumping event, since there was a lens of very coarse sand and fine gravel running through the middle of this layer, but it could have accumulated away from the main pathway of foot traffic, either underneath or up against a piece of furniture. The horizontal displacement of artefacts by kicking and scuffing, their accumulation on the edges of floors and pathways, and their tendency to accumulate against physical barriers, have been observed in ethnoarchaeological and experimental studies (e.g. Nielsen, 1991; Stockton, 1973; Wilk and Schiffer, 1979).

4.4.5. Eastern side aisle

The floor deposit in the eastern side aisle, context 868, was described in the field as a mixture of brown, black, and grey silt and ash containing only rare charcoal and burnt bone fragments. In thin section AST01-68, however, this layer was composed of a very highly compacted organic silt loam, with horizontally bedded lenses of organic matter, articulated phytoliths, and dark greyish brown organic silts (Fig. 9f). Although it contained the odd charcoal fragment (<2%), the occupation deposit captured in this particular sample did not contain any ash. Instead, it consisted almost entirely of herbaceous plant matter (e.g. grass) that had been heavily compacted and had decomposed, undisturbed, *in situ*. It may be interpreted as compacted bedding material.

4.4.6. Southwest entrance

Sample AST01-94 was taken from deposits that filled the southwest entrance. The uppermost layer in the sequence in the door consisted of medium brown clayey silt with inclusions of the *landnám* tephra layer and occasional charcoal flecks (context 763; Table 4). In the field, this layer was interpreted as turf collapse, but in thin section the lowermost part of it was made up of numerous compact lenses of waterlain silty clay, plant matter, organic soils, wood ash, and peat ash (Suppl. Data Tables 2.17-2.18). Below this occupation deposit the reddish brown soil (context 824) had also been reworked by water, consisting of multiple, fine lenses of well-sorted silt in fining-up sequences such as those typically found in puddles.

5. Discussion

5.1. Interpretation of the use of space in the Viking Age house based on integrated data

In this 10th-century house, activity areas and associated occupation deposits were divided between three aisles defined by rows of roof-supporting posts, as well as three main functional areas: a multi-functional central living room that was centred on the hearth, and two areas with more specialised functions in the narrow ends of the building (Fig. 10). Linking these three main functional areas was the central aisle, which contained very compacted sediments and had clearly been the main corridor for foot traffic down the length of the building. This central aisle had received inputs of organic matter and ash, abundant charcoal and burnt bone inclusions, and chemically it was characterised by elevations in a suite of elements associated with organic matter and its ash.

While some of the ash in the floor sediments could be from accidental spillage from the hearth and the movement of material by sweeping and trampling, the ubiquity of burnt bones and charcoal throughout the building, including the entrances and areas that had been separated from the central living room area by partition walls, suggests that ash was carried around the house and deposited deliberately. Although modern analogues must be used critically, it is worth noting that in 19th- and early 20th-century Iceland ash was commonly deposited on the floors of turf houses and animal buildings in order to keep them dry and to fill in holes (Milek, 2012). The fine particle size of ash residue enables it to serve as an insecticide, and because it is absorbent it can protect wooden posts and furnishings from fungal decay (Hakbijl, 2002).

The central hearth was the main source of light and heat in the building and must have been the focus for all winter/evening cooking, eating, handcrafts, and social activities. The find spots of the jasper strike-a-lights and flakes indicate that the fire was lit from its northern end. Several different fuels were used, the most important being birch wood and peat, but crumbs of sheep/goat dung found in the thin section taken from the floor just north of the hearth suggest that dung was also used as a fuel. Bones were frequently tossed into the fire after the meat or fish was consumed, which would have had the dual effect of feeding the fire and disposing of bone waste hygienically.

On both sides of the hearth the side aisles contained sitting and sleeping spaces. In the western side aisle this was probably in the form of a raised wooden platform, under and against which hearth and food residues accumulated but were left untrampled. The cluster of abandoned loomweights on the south end of this platform suggests that an upright loom had been located on top of or beside it. In the east side aisle, there was a bed of compacted hay, which, judging from the straight, well-defined context boundaries, had probably been contained by a wooden sill. The artefacts found in the eastern side aisle, such as the pumice, spindle whorl and knife, suggest that everyday craftwork took place on this grassy seat. The cluster of quartz pebbles found in the eastern side aisle also remind us that social activities such as gaming probably took place in this central living room.

In the northwest corner of the house, herbivore excrement identified in thin section indicates that the rows of posts observed in the field defined stalls for housing a few small cows, sheep and/or goats. The presence of omnivore excrement containing small, weathered/digested bone fragments suggests that people might sometimes have used this corner as a lavatory as well. The charcoal inclusions in this deposit indicate that ash was occasionally sprinkled here to absorb moisture or odours. The turf fragment found in this deposit hints at the possible use of turf for animal bedding, as was common in other parts of the North Atlantic region until the early modern period (Fenton, 1978).

In the southeast corner of the house there was a small alcove where the floor deposit contained exceptionally high concentration of salts. Besides the phosphates and nitrates that could have been associated with ash residues and decomposing organic matter – which were actually found in much higher concentrations elsewhere in the house – the salts in this area could have been derived from sea water, seaweed (and its ash), or urine. While urine is especially rich in N_2 it also contains c. 2% Cl^-, K^+, SO_4^{2-}, PO_4^{3-}, and Na^+. Sea water and its associated products and plants are especially rich in Na^+ and Cl^- and also contain Mg^{2+}, SO_4^{2-}, Ca^{2+}, K^+, and HCO_3^-. The fact that there is a strong positive correlation between the high electrical conductivity values and magnesium in this deposit suggests that it is sea salt, seaweed, or seaweed ash that were stored and/or used in this corner.

Salt had various practical uses in Viking Age Iceland. Sea salt obtained by evaporating sea water or burning seaweed may have been used as a preservative for butter, meat, or fish (Shetelig and Falk, 1937, 311). However, from the Viking Age to the present, fish in Iceland has usually been preserved by drying or smoking, and meat has been preserved by smoking or pickling in sour whey (Amundsen, 2004; Krivogorskaya et al., 2005). Ethnographic sources suggest that seaweed ash mixed with water, which produces alkaline lye, was commonly used in the North Atlantic region for cleaning and dyeing wool and fulling cloth until the early 20th century (Buckland and Perry, 1989; Jochens, 1995, 135-140; Shetelig and Falk, 1937, 332-336; Stead, 1981, 1982). One possible explanation for the high concentration of salts in the southeast corner of the house is that seaweed ashes and water were used in this area to wash or dye wool.

5.2. Evaluation of individual geoarchaeological techniques and the integrated approach

This study of the occupation deposits in the Viking Age house in Reykjavík illustrates the potential of a multi-method, integrated approach to the study of activity areas on archaeological sites. The distributions of artefacts and bones, long recognised as being affected by cleaning and abandonment behaviours and scavenging by dogs, are of course also very dependent on soil preservation conditions, which in turn depend on the pH of the soil solution (in the case of bones and bone artefacts), and its salt content (in the case of metals). It is standard practice to take pH spot tests on a site, but this study has demonstrated how variable pH and salt content (EC) can be across a site due to the variable composition of occupation deposits (e.g. plant matter will increase acidity, while wood ash will increase alkalinity), as well as post-depositional conditions (e.g. the quantity and pH of percolating water). These results suggest that on any site where artefact or bone distributions are used to identify and interpret activity areas, pH and EC must be tested systematically (e.g. by sampling on a grid) in order to fine-tune interpretations to micro-scale preservation conditions.

In this case study, artefact and bone distributions used on their own provided only limited insight into the use of space in the building. Burnt bone and charcoal distributions may be used as proxies for ash dumps on the floors of the house, and provide information about floor maintenance activities rather than the use of space. There is no question that with a critical evaluation of the reliability of artefact find spots, certain types of artefacts, such as those associated with craft production (e.g. loomweights, spindle whorls or pumice in this

Viking Age context), fire-starting (e.g. jasper or flint flakes), or gaming can provide a rich source of information about the likely locations of these activities. However, the floors of buildings are not always rich in artefacts, many types of artefacts cannot provide information about activities (e.g. beads, nails) and find spots may frequently be judged to be unrelated to locations of use. In this study, geoarchaeological techniques played an essential role in the identification and interpretation of activity areas, sometimes confirming the field evidence, and sometimes contradicting it, or deriving new information that had not been detected in the field.

In this study, magnetic susceptibility provided little new information about activity areas, merely confirming that *in situ* burning only took place in the central hearth. Likewise, loss on ignition at 950ºC confirmed that the hearth contained a concentration of wood ash ($CaCO_3$), and showed how wood ash and calcined bone had been distributed around the building – a distribution that overlapped with that of burnt bones. Loss on ignition at 550ºC quantified the organic matter and charcoal that had been observed in the field, and pinpointed the parts of the house that had received the greatest inputs of this organic material (the central aisle, the eastern side aisle, and the northwest corner). However, the nature and origin of the organic matter, and the specific activities that took place in these areas, could not be determined by this technique. Likewise, electrical conductivity identified an activity area in the southeast corner that had resulted in a concentration of soluble salts, which in this case had not been identified in the field, but the types of salts cannot be determined by this technique. While these rapid and inexpensive methods provide a spatial overview of the locations of activity areas and spatial variations in preservation conditions, additional, spatially overlapping data are required to interpret the original inputs and thereby the activities that created them.

Multi-element analysis and the determination of statistically significant correlations were instrumental for the interpretation of the types of salts found concentrated in the southeast corner of the building, in this case linking them to sea salts. In addition, the overlapping distributions of the plant macronutrients P, Ca, K, Mg, Zn, Ba, the trace element Sr, and the micronutrients Ni, Cu, all of which are taken up by plants and transferred through the food change to animals, lent further support to the understanding of where there were concentrated inputs of organic matter and ash, which had initially been based on field descriptions and loss on ignition at 550ºC. However, because almost all types of decomposed, charred, and ashed organic matter will result in the elevated concentrations of these elements, and different activities do not have precise chemical fingerprints, multi-element analysis alone does not enable a precise identification of the inputs or the types of activities that occurred in the identified activity areas (see also Wilson et al. 2008). Moreover, because the preservation potential of different types of elements is highly dependent on the pH of the soil solution, the presence of the fixing agents needed to prevent the leaching of some elements (e.g. P fixed to clay, Fe or Ca), and because of preferential loading and possible trapping of elements such as Ca, P, Sr and Zn in charcoal or bone (Wilson et al., 2008), the interpretation of multi-element concentrations must always include a critical assessment of the overlapping data on pH levels, clay content, and the concentrations of other elements, charcoal and bone.

In this study, multi-element analysis on its own gave no indication of herbivore and carnivore excrement in the northwest corner of the house, which were clearly identified in thin section. Phosphorus levels in this area were either at the mean or were elevated above it by only one standard deviation, and the nutrient levels (EC) here were low. Because this deposit was dominated by decomposed organic matter and contained little soil, there was a lack of clay or iron to which phosphorus could fix, and since pH levels were 6-7, phosphorus in this area could have remained in mobile ionic form and leached fairly rapidly. In this case study, the identification of animal and human excrement and the interpretation of the animal stalls in the northwest corner of the building were achieved only through soil micromorphological analysis, with no contribution from multi-element analysis or any of the other geochemical techniques.

Of the geoarchaeological methods employed to detect activity areas in this case study, micromorphological analysis had the greatest interpretive power on its own. Most importantly for this study, in thin section it was possible to identify and quantify different types of organic matter (e.g. phytoliths of grass/hay, charred and uncharred wood and plant remains, animal excrements, etc.), thus enabling the identification of the stabling area, the area north of the hearth where sheep/goat dung was stored for fuel, and the grass/hay bedding in the sitting/sleeping area in the eastern side aisle. The identification of uncompacted microstructures in thin section also supported the interpretation of an untrampled area in the western side aisle that had been protected by a raised platform. In thin section it was also possible to identify the specific types of ashes (e.g. wood ash, peat ash) contained in the central hearth, and to identify waterlain deposits in the southwest entrance area, which had not been identified in the field. The application of soil micromorphological analysis to the study of activity areas is limited by the fact that block samples cannot feasibly be taken systematically across house floors. However, this case study demonstrates that targeted micromorphology sampling could be of utmost importance to the successful interpretation of site activity areas.

6. Conclusion

The results of this integrated geoarchaeological study were fundamental to the interpretation of the 10th-century building at Aðalstræti 16, in Reykjavik, and have been incorporated into the museum exhibit built around the preserved foundations of the house (*Reykjavík 871±2: The Settlement Exhibition*). However, the implications of this comparative analysis of geoarchaeological methods can be applied to the study of activity areas on archaeological sites anywhere in the world.

All of the geoarchaeological analyses used in this study enhance field descriptions by verifying or fine-tuning field interpretations, quantifying the components identified in the field, showing the degree to which composition and preservation conditions vary across a single context, and in some cases providing new information about sediment characteristics that cannot be observed in the field. However, while each sediment analysis provides unique and valuable information about activity areas, used individually their interpretive power is limited. In particular, geochemical methods such as loss on ignition and multi-element analysis are effective at pinpointing the locations of activity areas that received elevated inputs of fresh, charred, and/or ashed organic materials, but due to the wide range of possible sources of organic matter, carbonates, and elements, it is not possible to make direct links between the spatially identified activity areas and specific inputs or activities.

The use of multiple, overlapping datasets dramatically increases the interpretation potential of geochemical methods by allowing the determination of correlations between them and the critical assessment of factors that could have affected distribution patterns. Multi-element distributions in particular can only be interpreted following an assessment of the degree to which the compositions of different deposits might have had an effect on element leaching, binding (e.g. to clay, iron, calcium) or trapping (e.g. by charcoal or bone). The most effective way to detect and interpret activity areas on archaeological sites is to integrate as many complementary methods as possible, using multiple geochemical methods to identify the possible locations of activity areas, followed by soil micromorphological analysis to provide detail about the composition, organisation and compaction of the components in each of the identified occupation deposits.

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Figure and Table Captions

Table Captions

Table 1
Descriptions of the occupation deposits used in this study with associated bulk samples for geochemical analyses and block samples for micromorphological analysis.

Table 2
Geochemical, loss-on-ignition, and magnetic susceptibility data.

Table 3
Correspondence analysis based on Spearman's rho (r_s) for electrical conductivity (EC) and multi-element values.

Table 4
Summary micromorphology descriptions of the occupation deposits, with representative descriptions of the overlying turf collapse layers (units 747, 792, 858) and underlying soil and tephra layers (units 824, 910, 913) shaded grey.

Figure Captions

Fig. 1. The location of the Viking Age house (a) in Iceland, (b) in Reykjavík, and (c) on Aðalstræti (drawing by Óskar G. Sveinbjarnarson).

Fig. 2. The Viking Age house at Aðalstræti 16 (formerly 14-18) under excavation, showing (a) the floor layers exposed in 2001 (facing north) and (b) the porch structure discovered when the excavation area was extended in 2003 (facing southeast).

Fig. 3. Plan of the house at Aðalstræti, showing the internal features of the house, the floor layers selected for geochemical analysis and the locations of micromorphology samples (drawing by Howell M. Roberts, Karen B. Milek and Óskar G. Sveinbjarnarson).

Fig. 4. Distributions of (a) artefacts, (b) stone manuports and jasper flakes, (c) bones, and (d) burnt bones on the floor of the Viking Age house. Note that bone distribution data is excluded from context 844, in the northwest corner of the house, because the bones from this context were accidentally lumped together in a single bag.

Fig. 5. Distributions of (a) pH, (b) electrical conductivity, (c) percent loss on ignition at 550°C, and (d) percent loss on ignition at 950°C.

Fig. 6. Distribution of (a) magnetic susceptibility, (b) barium, (c) calcium, and (d) copper.

Fig. 7. Distributions of (a) magnesium, (b) phosphorus, (c) potassium, and (d) sodium.

Fig. 8. Distributions of (a) strontium, and (b) zinc.

Fig. 9. Photomicrographs (PPL) of (a) micromorphology sample 80, context 844.3, showing a localised area with horizonally bedded bone, plant mater, and phytoliths surrounded by sediment disturbed by soil fauna, (b) micromorphology sample 80, context 844.4, showing truncated, articulated phytoliths typical of herbivore dung, (c) micromorphology sample 71, context 864, showing the tightly packed, randomly oriented segments of articulated phytoliths typical of herbivore dung, (d) micromorphology sample 67, showing charcoal, bone and decomposing plant matter in an area where there no floor context was identified in the field, (e) micromorphology sample 79, context 851, showing uncompacted and relatively large fragments of charcoal, bone and burnt bone, and (f) micromorphology sample 68, context 868, showing very compacted, horizontally bedded lenses of phytoliths and decomposing plant matter. b: bone, bb: burnt bone, ch: charcoal, o: amorphous organic matter, ph: phytoliths, v: void.

Fig. 10. Interpretive plan of the Viking Age house on Aðalstræti, showing the original house and the later additions.

Supplementary Data Tables and Figure Captions

Supplementary Data Table 1
Complete bone, bulk soil analyses and ICP-AES dataset, with grid coordinates to enable the data to be imported into a GIS and re-analysed (Excel spreadsheet).

Supplementary Data Table 2
Full descriptions and interpretations of all micromorphology samples.

Supplementary Data Table 3
Properties and possible sources of the elements used in this study.

Supplementary Data Table 4
Elements identified in modern reference materials.

Supplementary Data Table 5
Micromorphological characteristics of modern reference materials used for this study.

Supplementary Figure 1
Georeferenced house plan on the Reykjavik grid (AutoCAD drawing). May be imported into a GIS and used to re-analyse the data provided by Supplementary Data Table 1.