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## Diatoms as bioindicators of site use: locating turf structures from the Viking Age

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## ABSTRACT

Diatoms recovered from archaeological features on a Viking Age farmstead excavation in the Mosfell Valley in southwestern Iceland are utilized as microscopic indicators of turf-based structures. Eroded turf can be difficult to distinguish macroscopically from naturally occurring sediments because turf foundations erode and melt into the landscape over time, leaving minimal evidence of site use. Turf was a principle building component in Iceland until the early 20th century. Turf strips and blocks were harvested from lowlands where organically rich peat and abundant water contributed to the development of bog plants with thick root mats that produced premium turf. Diatoms embedded in turf reflect the ecological conditions of the peat-bog at the time of deposition. Turf was cut from the bog and transported to higher elevations where drainage was more conducive to house construction. Siliceous diatom frustules are resistant to decay and preserve well archaeologically. The presence of diatoms in archaeological sediments is considered a marker of sediment provenience and an indication of human site use and anthropogenic modification of natural substrates. This paper demonstrates how diatom analysis can determine the presence and delimitation of archaeological features otherwise difficult to distinguish with the naked eye.

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## 1. Introduction

## 1.1. Background

Diatoms are unicellular phytoplankton that can exist in colonies on wet or submerged surfaces (benthic) or as solitary cells in open water (planktonic) (Round et al., 1990). Most are photosynthetic and require light exposure for growth, limiting them to shallow depths (Du Buf and Bayer, 2002:12). Some live on moist terrestrial surfaces such as soil, plants or rocks. *Frustules*, the cell walls of diatoms, are comprised of hydrated silica (SiO<sub>2</sub>) and are resistant to diagenetic deterioration, preserving well in the archaeological record. Frustules exhibit a broad diversity of morphologically distinct shapes and patterns that allow for taxonomic differentiation, often to species or sub-species level (Battarbee, 1988; Du Buf and Bayer, 2002). Given these durable and distinctive properties, they are valuable forms of evidence for reconstructing past environments. In archaeology, diatoms have been used as ecological biomarkers for sourcing materials and environmental modeling (see Battarbee, 1988; Cameron, 2007; Juggins and Cameron, 1999; Mannion, 1987 for reviews). Diatoms sourced specifically from peat sediments

have been utilized to evaluate environmental and climatic changes in freshwater or brackish ecosystems (i.e. Brugram and Swain, 2000; Denys and Verbruggen, 1989; Ryu et al., 2008). This study utilizes freshwater diatoms preserved in peat/turf as ecological biomarkers to make inferences about resource use and to locate archaeological structures.

Turf is defined here as the top layer of semi-dried wetland bogs that includes the thick root system of bog plants. Turf has been used by humans as a construction material for millennia. As a durable, renewable, and readily available resource, turf is an efficient architectural medium, especially in northern climates where its insulating qualities are particularly practical. There is evidence, both circumstantial and empirical, that turf has been used in house construction by a variety of cultures across Europe and the circumpolar north since at least the Neolithic in places such as Scotland, Ireland, England, Wales, mainland Scandinavia, the Orkneys, Shetlands, Hebrides, and Faroes as well as Iceland, Greenland, the Canadian Arctic and was later introduced to the North American prairies as *soddies* by Scandinavian immigrants (i.e. Loveday, 2007; Sigurðardóttir, 2008; Urbańczyk, 1999: 120–122; van Hoof and van Dijken, 2008). Unfortunately, turf's biodegradable properties also frequently render it almost invisible in the archaeological record. Subjected to tectonic and taphonomic forces of wind, rain, deposition and time, eroded turf features can be virtually

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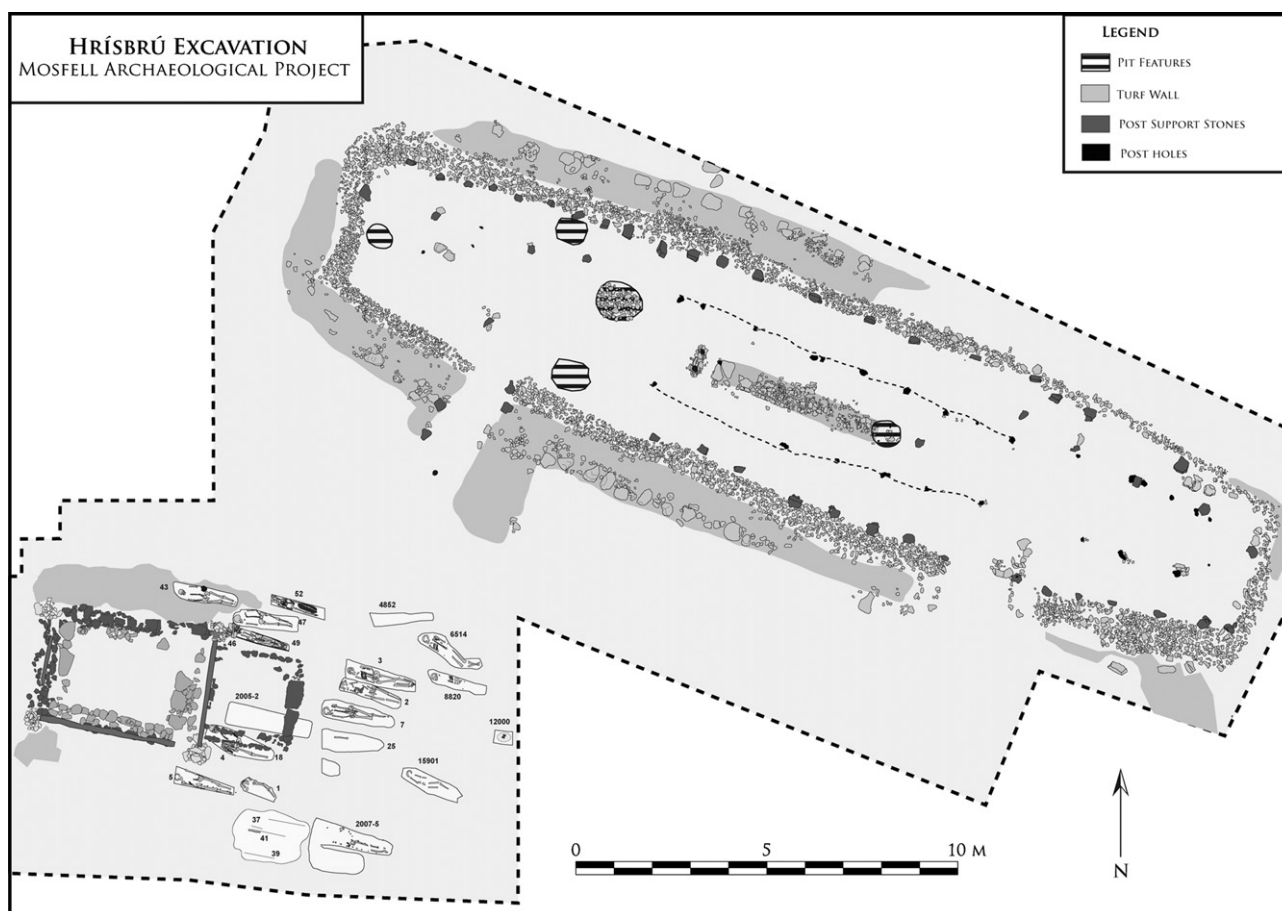
indistinguishable from other sediments, at least at a macroscopic level. But this pilot project has found that microscopic ecofacts embedded in turf, such as diatoms, provide a means of differentiating turf from other sediments.

The 9th through the 11th centuries mark the height of the Viking Age in northern Europe: the age of Norse expansion. The first permanent human settlers on Iceland were Norse and British Isle immigrants who arrived *ca.* AD 870. The maritime subarctic climate prior to colonization supported slow-growth boreal scrubland/forest species such as willow (*Salix callicarpaea*; *Salix herbacea*; *Salix lanata*; *Salix pylicifolia*), rowan (*Sorbus aucuparia*), juniper (*Juniperus communis*) and primarily birch (*Betula nana*; *Betula pubescens*) (Hallsdóttir and Caseldine, 2005). Wood resources were utilized quickly and were slow or unable to replenish (Dugmore et al., 2005; Hallsdóttir and Caseldine, 2005), rendering the island almost tree-less for centuries. Ethnohistoric records of the nineteenth and twentieth century, historic documents, narratives such as the Icelandic sagas, and archaeological evidence establish that turf was exploited as a construction material in Iceland from the earliest colonization period. Until the mid 20th century, up to 50% of Icelandic dwellings were at least partially comprised of turf (van Hoof and van Dijken, 2008; Ólafsson and Ágústsson, 2003). Excavations of a 9–11th century farmstead at Hrísbú in Mosfellsdalur (Mosfell Valley), just east of Reykjavík, offered the opportunity to test whether diatoms could be useful for demarcating obscure archaeological turf-based features (Fig. 1).

The excavations of the Mosfell Archaeological Project (MAP) were initiated in 1995 and have been directed by Jesse Byock of the

University of California, Los Angeles and the late Phillip Walker from University of California, Santa Barbara. The aim of the multi-disciplinary project has been to reconstruct the pattern of human habitation and environmental change in the Mosfell Valley from initial human settlement (Byock et al., 2005). Mosfellsbær (Mosfell Town) is a municipality of the Greater Reykjavík Area. The community encompasses the Mosfell Valley, a soil-rich basin shaped by a melt-water glacial lagoon during the last glacial maximum. The Icelandic place name *Mosfell* translates to “moss hill/mountain,” and refers to the 276 m hill that dominates the landscape on the northern side of the valley. The lowest elevation of the valley is 39 m above sea level (MASL), where the Kaldavísl River still cuts through the basin to drain into the Atlantic at Leiruvogur (Clay Bay). The MAP has focused its excavations on Hrísbú, a farm situated at the northwestern entrance to the Mosfell Valley. Over the past decade, a graveyard and two contemporaneous Viking Age buildings – a church and longhouse – have been excavated at Hrísbú. The focus of the 2006–2008 field seasons was to uncover the longhouse (*skáli*) in its entirety. The Viking Age structures at Hrísbú were situated at an elevation of 65 MASL on a slope formed by the erosion of Mosfell mountain, 26 m above the lowest point in the valley floor.

Turf used for building and wall construction often contains remnants of dissipated ash, or tephra, from volcanic eruptions. Tephrochronological sequences can provide a *terminus post quem* for turf structures, as most major volcanic discharges on the island have been dated by a variety of methods including stratigraphic relationships, ice cores and  $^{14}\text{C}$ , written sources, thermoluminescence and geochemical signatures (Boyle, 1999;



**Fig. 1.** Hrísbú excavations, 2008. Locations of the longhouse, church and churchyard excavations at Hrísbú in Mosfellsdalur in 2008. Batch samples of archaeological sediment were taken from the turf walls and floor. Roof collapse samples were taken from sediments that overlaid the floor.

Hafliðason et al., 2000; Grönvold et al., 1995; Larsen et al., 2001; Newton et al., 2007; Óladóttir et al., 2008; Stothers, 1998; Thorarinnsson, 1970; Thordarson and Larsen, 2007). Ash from the volcanoes settled onto soil and grass surfaces in Mosfellsdalur and was subsequently incorporated into turf cuttings. Stringers of macroscopically distinct olive green *Landnám* tephra (Landnámslagið or Vö-871) were incorporated into turf blocks used to construct the Hrísrú longhouse walls, establishing that the structure was built after the substantial co-eruptions of the Veidivötn and Torfajökull volcanoes in southern Iceland in AD 871 ± 2, during the time of settlement (*Landnám* – land taking). Four black, glass “eye” beads found in the western gable of the longhouse are of a style consistent with trade beads excavated from Viking Age Ribe, in Denmark. Beads of this type (B088/090) are dated by seriation between AD 960 and 980 (Callmer, 1977), suggesting the longhouse was an early period settlement occupied prior to and probably exceeding the Christian conversion of the island in AD 1000.

## 2. Turf utilization in Iceland

In places across Europe where turf was used in construction, turf bricks were cut from local bogs or along the edge of cultivated fields (Loveday, 2007:84). In Iceland, the preferred source for turf has been lowland bogs where sedges (*Carex*), peat mosses (*Sphagnum*) and other bog plants grow deep roots, fed by organically rich and perennially moist peat (Gestsson, 1982; Steinberg, 2004). These wet ecosystems proliferated with phytoplankton which were subsequently incorporated into the turf blocks. In the Mosfell Valley, we anticipated that turf bricks were cut from the bog in the valley floor south of the habitation site, and transported for use at higher elevations where there was better natural drainage for house construction.

The Icelandic word *torf* is a cognate of the English turf, but these terms do not have the same meaning. In Icelandic, turf is differentiated from sod, the latter of which is composed of dry-land grasses (*Poaceae*). Dry-land grasses grow on and stabilize turf house roofs, but only after the wetland plants die (Sigurðardóttir, 2008: 7). Peat is the partially decayed vegetation and organic material that accumulates in wetlands and is prevented from completely decaying by anaerobic, acidic, and waterlogged conditions. Turf grows on top of peat, utilizing it as a food source. So the Icelandic definition of turf incorporates the root mat and sediment, including peat and peat mosses attached to this root mat, where diatoms are incorporated.

Turf has had a variety of construction uses in Iceland to the extent that a vernacular has developed to differentiate the types, shapes, and usage (Sigurðardóttir, 2008; van Hoof and van Dijken, 2008). The two main and most easily distinguishable categories of turf differ on the basis of how they are cut and their intended use. Turf cut with a scythe-like tool is called *torfur* (turf) or *strengur* (strip). These turfs are typically long, thin, and wide, incorporating a slim lens of peat sediment. Turf cut as blocks (*hnausar* and *kekki*) with a spade result in thicker sections containing more peat and sediment. There is greater variation in their shape, including clamped blocks (*klambra*), corner blocks (*hornhnaus*) and strip or diamond shaped blocks (*snidda*) (Sigurðardóttir, 2008:4). There are many subdivisions of each category and names for turf sub-types can differ throughout Iceland. Turf walls can be constructed with a variety of combinations of turf blocks, strips, loose wall fill (typically a mixture of turf and soil), and stones (van Hoof and van Dijken, 2008). One common method is to lay long strips of turf between rows of turf blocks, helping to hold the wall together (Sigurðardóttir, 2008: 5).

### 2.1. Turf in the archaeological record

Turf was a major component in all Viking Age and medieval Icelandic domestic structures, including houses, barns, livestock pens, smithies and other workshops (Byock, 2001; van Hoof and van Dijken, 2008; Ólafsson and Ágústsson, 2003; Urbańczyk, 1999). But in archaeological excavations, usually only the bottoms of turf walls are encountered *in situ*. Abandoned structures collapse in various directions and the organic material and air pockets in the turf compress, reducing total volume. Severe erosion over the past 1200 years due to deforestation has resulted in considerable aeolian soil deposition in the valleys and on the mountain slopes, burying a majority of old farms and leaving few surface indications.

Geophysical surveys utilizing resistivity, conductivity, and ground penetrating radar have been successful in locating turf structures (Steinberg, 2003), but these methods are highly specialized and, as yet, expensive. Another method utilized for identifying turf measures the organic content retained in sediment, but has concluded that “buried turf walls without a surface sign, that have a preserved height of less than 25 cm, and have their base close to the subsurface [may have an organic content that is] indistinguishable from the surrounding soil as measured by Lol” (loss on ignition) (Steinberg, 2004: 67). Whereas organic content will decompress over time and turf walls greater than 25 cm in height are rarely preserved nor readily distinguished, siliceous diatoms are more impervious to diagenic forces of decay and are likely to be retained in even thin archaeological sediments as evidence of turf.

## 3. Methodology

### 3.1. Field collection

Sediment for microscopic analysis was collected from 15 archaeological and natural features within and around the longhouse excavation on the Hrísrú farm (Figs. 1 and 2). Archaeological features where turf was most likely to have been used include the longhouse walls, the collapsed roof (which collapsed in a layer overlaying the floor and likely incorporated portions of wall), and the habitation floor (which consisted primarily of trampled soil and ash deposits from the hearth). For comparison, we also sampled features where we did not expect to find evidence of turf, including the natural paleosol outside the longhouse walls and a grave shaft in the nearby church graveyard on *Kirkjuhóll* (Church Knoll) (noted as “2007-5” in the lower left corner of Fig. 1.) Approximately 3 g of sediment was collected in random composite batch samples from each archaeological feature of interest. A single gram sample was drawn, weighed and processed for analysis from each of these batch samples.

Positive and negative control samples were drawn from locations inside a 600 m radius of the excavation site, within an area we considered to have been expedient for turf harvesting (Fig. 2; Table 1). Positive controls were drawn as random batch samples from three separate locations, selected on the basis of the presence of water/wetland and peat. We expected these locations would yield rich quantities and a diversity of diatoms. One sample was drawn from a cut in a natural peat exposure, located approximately 131 m southwest of the excavation at an elevation of 60 MASL, approximately 5 m below the elevation of the longhouse. Other positive control samples were drawn from sediment next to a natural spring cutting through the peat, at an elevation of 65 MASL, 78 m southwest of the excavation. A small, warm, thermally heated spring 87 m south of the excavation and east of the peat exposure at an elevation of 64 MASL was also sampled.

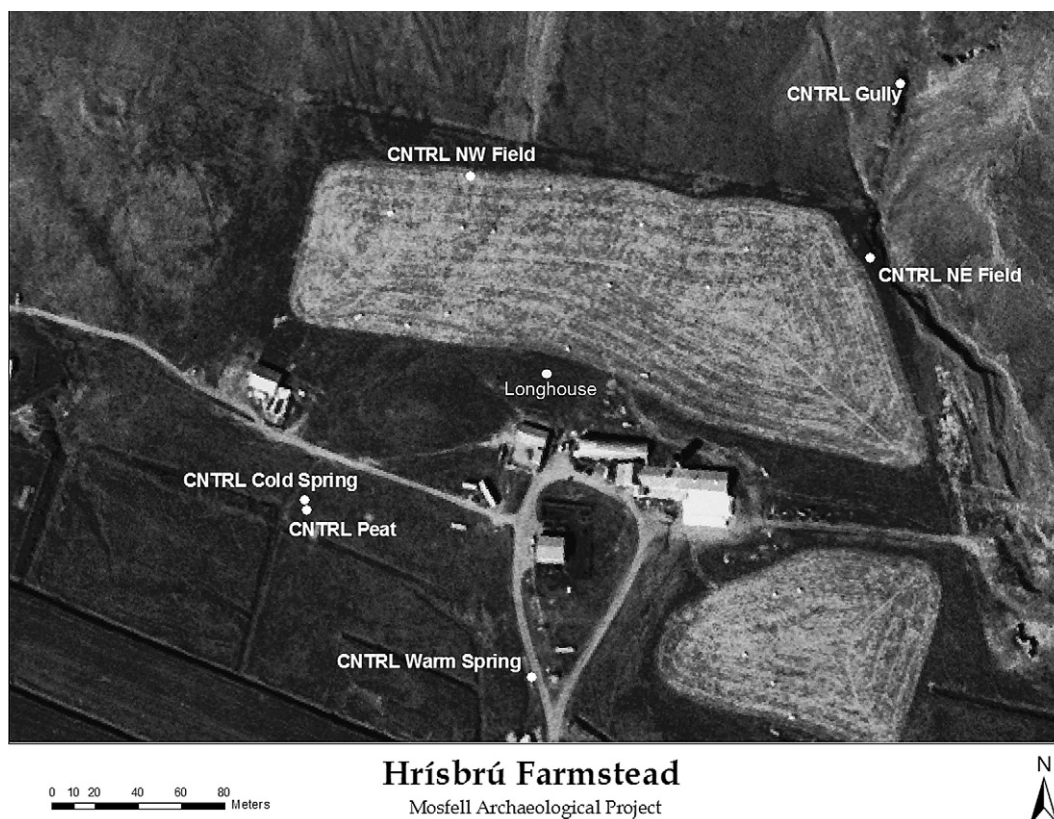


Fig. 2. Topographic map of positive and negative control locations. Positive and negative control samples were taken within a 600 m radius of the excavation site.

Negative control samples were blindly selected from locations at higher elevations than the excavation site, or where diatom growth was expected to be limited due to more arid ecological conditions. The longhouse sits on an elevated slope in the valley, north of which is a hayfield, or *tún*, that stretches to the foot of Mosfell mountain, where the elevation abruptly steepens. Today, this *tún* serves as a hay field that is harvested in the summer after which the resident farmer at Hrísrú lets horses and cows graze in the area. During the Viking Age, a *tún* such as the one at Hrísrú would have functioned as an enclosed home meadow, perhaps enriched with manure but not grazed, as it would have been used for growing hay stored for winter fodder. Rainfall and other waters drain from the *tún* due to the sloping topography, elevation above the water-table and sandy-loam soil. A location for collecting a negative control sample was randomly

chosen in the northwest corner of the *tún*, 127 m from the longhouse at an elevation of 90 MASL. Another location was selected within 110 m of the longhouse at a similar elevation (88 MASL) in the northeast corner. A final sample of sediment was drawn from 94 MASL along the edge of a gravelly gully cutting into the Mosfell mountain 138 m northeast of the longhouse excavation. No standing water was present and no grass was growing in this location, providing meager habitat for diatom colonization.

### 3.2. Sampling procedures

Several grams of sediment were collected from each field location in order to allow for changes in weight and sample size that result from drying and to provide an archival sample for future analysis. Sediment samples were left to dry in the field; those that were not completely dry were left to do so once they arrived in the laboratory. From each dried sample, a consistent 1.0 g portion was weighed on a digital scale and processed for analysis.

Sediment pH was tested in order to control for diagenic factors that may affect preservation or explain any observed patterns of evidence distribution. A pH reading was taken from sediment at each sampled location. Sediment samples of 0.5 g were combined with 2.5 ml of distilled water and agitated. Samples were left to soak for 10 min and re-agitated. Sediment pH was measured with a digital meter (QuicKcheK™ Model 106 Pocket Meter by Orion). The probe was calibrated in a 7.0 neutral buffer and was cleaned and recalibrated for each sample.

Dried sediment was disaggregated and organics reconstituted by placing each 1.0 g sample in a 15 ml test tube and capping it with a 0.5% aqueous solution of trisodium phosphate ( $\text{Na}_3\text{PO}_4$ ). Samples were agitated and left to soak for at least 12 h. No effort was made to clean the frustules by removing excess organics from the

Table 1  
Sediment sample locations.

Type of sample	Location	Location from longhouse	Elevation (MASL)
+ Control	Peat exposure	131 m SW	60
	Natural spring	78 m SW	60
	Warm spring		61
– Control	NW corner of <i>tún</i>	127 m	90
	NE corner of <i>tún</i> <sup>a</sup>	110 m	88
	Elevated gully	138 m	94
Archaeological	Wall sample 1	Around longhouse	67
	Wall sample 2	Around longhouse	67
	Roof collapse 1	Inside longhouse	66
	Roof collapse 2	Inside longhouse	66
	Floor 1	Inside longhouse	66
	Floor 2	Inside longhouse	66
	Wall cut	Undisturbed profile	67
	Grave shaft	<10 m S	66

<sup>a</sup> Location of blind test originally selected as a negative control.

samples, as is standard practice in living diatom analysis. Most frustules were already empty and we opted to maintain the microscopic ecosystem in its entirety, including pollen, spores, cysts and other organic ecofacts that might serve as microscopic bio- “indicator groups” (Kenward and Hall, 1997). We were interested in observing what other forms of microscopic evidence were preserved in the samples and how diatoms might relate to such evidence. However, in order to decrease the noise and increase slide clarity, we sorted the heavier components from lighter fractions that could be viewed microscopically by initially sieving the dried samples through a 355  $\mu\text{m}$  mesh (0.35 mm). Aqueous solutions were then concentrated by centrifuge at 3500 rpm for 5 min. A sample of the lightest fraction of sediment was removed by pipette and placed on a glass slide, to which a drop of glycerin was added to improve slide clarity and delay drying time. Slides were examined at 100 $\times$  and 200 $\times$  by transmitted light under a compound microscope. Photographs were taken with a Nikon DXM1200 mounted digital camera at 200 $\times$  and 400 $\times$  magnification under a plan apochromat lens. A total of 5 slides were examined for each of the 15 samples. Identification was determined by consulting Østrup's (1918) freshwater diatom inventory of Iceland, Kelly et al. (2005) and van Dam et al. (1991).

### 3.3. Quantification

As there is a multitude of diagenic, sampling, cultural and natural processes that can affect a diatom assemblage that cannot be adequately controlled, this study does not attempt to calculate true abundance from these collections. The aim is to quantify and spatially compare relative proportions of diatom assemblages. Samples are collected in the same manner and processed by the same methods. Any observed differences in the samples are compared relative to one another. It is not expected that the full range and diversity of genera will be present in a one gram batch sample of sediment, but the most common and abundant genera should be accounted for. Likewise, the number of diatoms present is not a calculation of true abundance, but rather is representative of the taxonomic diversity that can be compared relative to other samples prepared in the same manner.

One random 500  $\mu\text{m}$   $\times$  500  $\mu\text{m}$  quadrat was selected on each prepared slide for quantifying richness and diversity. The number of diatoms and the number of taxa present were counted within a quadrat. Five separate slides were prepared for each 1 g sample, with a random quadrat selected for sampling on each slide. The mean number of diatoms and the mean and maximum number of genera were calculated from these five slides, providing an average estimation of density and diversity of diatoms per standardized 1 g batch sediment sample.

## 4. Results

A total of 22 freshwater genera could be confidently identified, most of which prefer cool temperatures and neutral to alkali conditions (Tables 2 and 4). The classification of most diatom evidence was conservatively restricted to the genus level unless distinguishing characteristics could be ascertained in order to avoid errors of over-confidence in differentiating among species. Positive control samples exhibited evidence of 16 different genera in mean densities ranging from 3 to 44 diatoms/500  $\mu\text{m}^2$  (Table 2). Virtually no quantifiable evidence of diatoms was recovered from the negative control samples (0 diatoms/500  $\mu\text{m}^2$ ), save one intriguing exception in the northeast corner of the Hrísbú tún that will be discussed below.

The positive controls and archaeological features shared 16 genera in common (Tables 3 and 5). All genera identified in the

**Table 2**

Relative quantified density of recovered diatoms and sediment pH.

Sample	Mean N diatoms 500 $\mu\text{m}$ $\times$ 500 $\mu\text{m}$	Mean N genera 500 $\mu\text{m}$ $\times$ 500 $\mu\text{m}$	Max. N genera per slide	pH
+ Control: Peat	44	8	17	6.8
+ Control: Cold spring	11	5	8	6.8
+ Control: Warm spring	3	2	6	7.0
– Control: NW field	0	0	0	7.1
– Control: NE field*	2	2	5	7.0
– Control: Gully	0	0	0	7.1
Longhouse wall (1)	65	8	10	7.1
Longhouse wall (2)	107	14	17	7.3
Longhouse roof collapse (1)	3	3	11	7.3
Longhouse roof collapse (2)	8	4	10	7.2
Longhouse floor (1)	82	12	16	7.3
Longhouse floor (2)	24	9	13	7.3
Outside longhouse wall	0	0	0	7.0
Grave shaft in graveyard	0	0	0	7.4

positive control samples were accounted for in the archaeological sediments; however the longhouse features unexpectedly exhibited greater taxonomic diversity ( $n$  22) than the positive control samples ( $n$  16). Of the genera unique to the archaeological features, one was exclusive to floor samples (*Hantzschia*). *Caloneis* and *Stauroneis* were only found in wall and floor sediments. *Diatoma* was exclusive to floor and roof collapse features. And *Mastogloia* and *Nitzschia* were found in all longhouse contexts but were not observed in the any of the 4 modern control samples from the peat-bog.

Within the longhouse archaeological features, a total of 22 genera were identified. As many as 6 additional genera were tentatively identified from archaeological contexts, but were omitted from quantification due to their unrepresentative sample size (identifications were based on single or <5 observations) (Table 3). The longhouse walls, which were likely to have been constructed with a combination of thick blocks and thin strips of turf, demonstrated considerable taxonomic diversity with an average of 11 to a maximum of 17 different genera and a mean density of 86 diatoms/500  $\mu\text{m}^2$ . The floor of the longhouse also demonstrated an average of 11 to a maximum of 16 genera, but considerably less density at a mean of 53 diatoms/500  $\mu\text{m}^2$ . The samples taken from the roof collapse, which was likely primarily comprised of thin turf strips, yielded relatively less evidence of diatoms, with an average of just 3 to a maximum of 11 and a mean of 6 diatoms/500  $\mu\text{m}^2$ . The diversity and especially the relative density of diatomaceous evidence, then, indicate a clear distinction between some archaeological features, differentiating between natural substrates as well as roof collapse from structural wall and habitation floor.

The denser, more varied samples in this study were collected from the longhouse walls and floor. We attribute the relatively dense evidence from the floor to result from the mechanical compaction of turf, dung and peat ash sediments trampled into the surface over time.

The central hall of the longhouse had been dug out and into the natural paleosol. To assess whether or not there were diatoms in the paleosol the longhouse was cut into, a sample was taken from an undisturbed section of the excavation profile. Another negative archaeological sample was collected from a grave shaft in the Viking Age graveyard less than 10 m south of the longhouse. It was expected that this sample would also test negative for diatoms, as turf was not a component of grave construction. Both samples were negative of diatom evidence.

**Table 3**  
Diatom taxa distribution by feature (presence/absence).

Genera	Peat-bog	Cold spring	Warm spring	Longhouse wall	Longhouse floor	Longhouse roof collapse	Northeast exposure
<i>Achnanthes</i>	x	x		x	x		
<i>Amphora</i>	x				x		x
<i>Caloneis</i>				x	x		
<i>Cocconeis</i>						a	
<i>Cyclotella</i>				a			
<i>Cymbella</i>	x	x		x		x	x
<i>Denticula</i>	x			x	x		
<i>Diatoma</i>					x	x	
<i>Diploneis</i>			x	x	x		
<i>Encyonema</i>						a	
<i>Epithemia</i>	x	x	x	x	x	x	x
<i>Eunotia</i>	x					x	x
<i>Fragilaria</i>				a			
<i>Frustulia</i>			x			x	
<i>Gomphonema</i>	x			x	x	x	
<i>Hantzschia</i>					x		
<i>Mastogloia</i>				x	x	x	
<i>Melosira</i>	x	x	x	x	x	x	
<i>Meridion</i>						a	
<i>Navicula</i>	x	x		x	x		
<i>Nitzschia</i>				x	x	x	
<i>Pinnularia</i>	x	x	x	x	x	x	x
<i>Rhopalodia</i>	x	x		x	x		
<i>Stauroneis</i>				x	x		
<i>Staurosira</i>	x			x			
<i>Surirella</i>						a	
<i>Synedra</i>	x	x		x	x	x	
<i>Tabellaria</i>	x	x		x	x	x	

<sup>a</sup> Rare or tentative identification based on <5 total observations.

## 5. Discussion

Dense and diverse concentrations of diatoms were consistently found in locations where turf was utilized in construction along the longhouse walls, roof and floor. Even marginal samples of just one gram of sediment yielded quantifiable evidence to distinguish anthropogenic activity from the natural substrates.

### 5.1. Diatom preservation

The preservation of diatoms recovered from archaeological sediments was very good, although some contexts exhibited more evidence of crushing and breakage than others. The denser, more varied samples of diatoms were collected from the longhouse walls and floor. Most damaged diatoms were also found in the longhouse floor sediments. We attribute the relatively dense and damaged evidence from the floor to result from the mechanical compaction of turf sediments trampled into the surface over time. And it is likely that turf was not the only contributing source of diatoms found in the floor. Peat was regularly dried and burned for fuel (McGovern et al., 2007: 39), as was dung and turf (Simpson et al., 2003). Peat sediments would also have contained diatoms and burning is likely to have damaged frustules or rendered them more fragile. Animal dung tracked into the house may also have contained phytoplankton obtained from fodder and/or water, mechanically damaged during mastication or trampling (Brochier et al., 1992; Macphail et al., 1998:639). Mud on shoes and other forms of traffic could contaminate the floor surfaces, as could rain and spilled or intentionally sprayed water which might be used to keep dust down during dry weather conditions or to compact a floor during cleaning events (Milek, 2006). Charcoal, bone and fungal spores were also common microscopic artifacts in floor sediments. Heavily damaged diatoms, then, found in association with other microartifacts including large concentrations of charcoal and bone may be considered bioindicator groups indicative of a floor context.

### 5.2. Positive and negative control samples

Minimal evidence of diatoms was recovered from the natural substrates of the elevated portion of the valley. Sediment collected from the northwest corner of the *tún* and the gravel gully was quantifiably bereft of diatoms. Likewise, the natural sediment from the paleosol profile of the longhouse and the *Kirkjuhóll* grave shaft contained no quantifiable evidence of diatoms. These results were expected, as diatom growth is limited where moisture is constrained, as it is in these locations. The isolated, unquantifiable diatoms that were occasionally observed in these samples were likely the result of aeolian and/or mechanical transportation (i.e. horse/cow hooves/foot tracking/dung) or fill contamination, and are considered intrusive and/or uncommon in the natural substrate.

Positive control samples from the peat-bog were dense and varied in diatom diversity and other microscopic flora and fauna. These samples, taken from agricultural drainage ruts made in recent years, reflect the modern ecology of the Hrisbrú peat-bog. Samples taken from sediment close to natural springs reflect similar taxa to those found in the peat, although they do not occur in as much abundance. Two genera were recovered from warm spring sediments that were not observed in other positive control samples, although they were present in archaeological samples: *Diploneis* and *Frustulia*.

### 5.3. Ecological indicators

Archaeological and control samples shared 16 genera in common (Table 5). Ecological reconstruction based on the parameters of these recovered taxa indicates diatoms from Hrisbrú sediments were formed in a wet to moist, alkaline, freshwater basin. The predominantly benthic and epipellic preferences of most recovered diatoms (Plate 1) favor shallow water conditions, with the exception of a few planktonic genera that require water deep enough for suspension. This ecological profile

**Table 4**  
Summary of the most important habitat and ecological preferences of recovered diatoms.

Genera	Fresh water ecology
<i>Achnanthes</i>	Circumneutral – alkaliphilous; epiphytic; phytosynthetic; wide range
<i>Amphora</i>	Circumneutral – alkaliphilous; epipellic to sub-aerial (i.e. dripping surfaces, mosses); pollution tolerant
<i>Caloneis</i>	Alkaliphilous; motile to epipellic, standing water (not common in rivers); pollution sensitive
<i>Cocconeis</i>	Circumneutral – alkaliphilous; benthic; periphytic; fast moving rivers; common in summer; pollution tolerant
<i>Cyclotella</i>	Planktonic; estuarine; phytosynthetic; widespread
<i>Cymbella</i>	Alkaliphilous; eutrophic; epiphytic; pollution tolerant
<i>Denticula</i>	Alkaliphilous; motile; epiphytic/epilithic, submerged plants/mosses; pollution tolerant – sensitive
<i>Diatoma</i>	Alkaliphilous; planktonic; pollution tolerant – sensitive
<i>Diploneis</i>	Alkaliphilous; littoral sediments; epipellic, standing waters; pollution tolerant – sensitive
<i>Encyonema</i>	Eutrophic; streams and rivers (widespread but not abundant); pollution tolerant
<i>Epithemia</i>	Alkalibiontic; epiphytic/epilithic (seasonal flooding)
<i>Eunotia</i>	Circumneutral – acidophilous; epiphytic; pollution tolerant – sensitive
<i>Fragilaria</i>	Alkaliphilous; pollution tolerant – sensitive; wide range
<i>Frustulia</i>	Alkaliphilous; can occur on damp surfaces; pollution tolerant
<i>Gomphonema</i>	Circumneutral – alkaliphilous; eutrophic; epiphytic; pollution tolerant – sensitive; wide range
<i>Hantzschia</i>	Circumneutral; planktonic or epipellic/terrestrial (soils); aerophilic; pollution tolerant
<i>Mastogloia</i>	Alkaliphilous; epipellic in high conductivity; pollution sensitive
<i>Melosira</i>	Planktonic; eutrophic; phytosynthetic; widespread
<i>Meridion</i>	Circumneutral – alkaliphilous; planktonic to epiphytic/epilithic; pollution sensitive; abundant early spring
<i>Navicula</i>	Alkaliphilous; benthic to epipellic; aerophilic; often with wet mosses; pollution tolerant – sensitive; wide range
<i>Nitzschia</i>	Alkaliphilous; motile or epiphytic/epilithic; pollution tolerant
<i>Pinnularia</i>	Circumneutral – acidophilous; epipellic (humic terrestrial shade); aerophilic; pollution tolerant – sensitive; wide range
<i>Rhopalodia</i>	Alkaliphilous – alkalibiontic; benthic to epiphytic to periphytic; low light; pollution tolerant – sensitive
<i>Stauroneis</i>	Circumneutral; epipellic; polytrophic; pollution tolerant – sensitive
<i>Staurosira</i>	Alkaliphilous; pollution tolerant
<i>Surirella</i>	Alkaliphilous; planktonic or epipellic; pollution tolerant
<i>Synedra</i>	Alkaliphilous; epiphytic/epilithic; widespread; pollution tolerant
<i>Tabellaria</i>	Circumneutral – acidophilous; planktonic or epiphytic/epilithic; pollution sensitive

Sources: Denys and Verbruggen (1989), Dickman et al. (1993), Kelly et al. (2005), van Dam et al. (1991).

**Table 5**  
Context of recovered diatoms.

Genera	Both control & archaeological	Archaeological only	Rare archaeological
<i>Achnanthes</i>		<i>Caloneis</i>	<i>Cocconeis</i>
<i>Amphora</i>		<i>Diatoma</i>	<i>Cyclotella</i>
<i>Cymbella</i>		<i>Hantzschia</i>	<i>Encyonema</i>
<i>Denticula tenuis</i>		<i>Mastogloia</i>	<i>Fragilaria</i>
<i>Diploneis</i>		<i>Nitzschia</i>	<i>Meridion</i>
<i>Epithemia</i>		<i>Stauroneis</i>	<i>Surirella</i>
<i>Eunotia</i>			
<i>Frustulia</i>			
<i>Gomphonema</i>			
<i>Melosira</i>			
<i>Navicula</i>			
<i>Pinnularia</i>			
<i>Rhopalodia</i>			
<i>Staurosira</i>			
<i>Synedra</i>			
<i>Tabellaria</i>			

is in keeping with the geological history of the Mosfell Valley as an alkali glacial melt-water lagoon. Genera such as *Achnanthes*, *Cymbella*, *Eunotia* and *Pinnularia* are commonly found in peat-bogs, fens and similar terrestrial environments (Pouličková et al., 2004; Ryu et al., 2008). The three most abundant diatom taxa recovered from both control and archaeological samples were *Epithemia*, *Melosira* and *Pinnularia*. All are widespread genera found across a diversity of habitats and ecosystems. The similarity in the ecological parameters between modern control samples and archaeological samples suggests that the turf used to construct the longhouse walls and roof was likely harvested from the local neutral-alkali peat-bog. The ecological profile of the diatoms found in the compacted floor sediments are consistent with those found in the walls and roof; the exceptions being *Amphora*, a genus also recovered in the modern peat samples, and *Hantzschia*, discussed in more detail below. All of the genera present in the control samples were also observed in the archaeological samples.

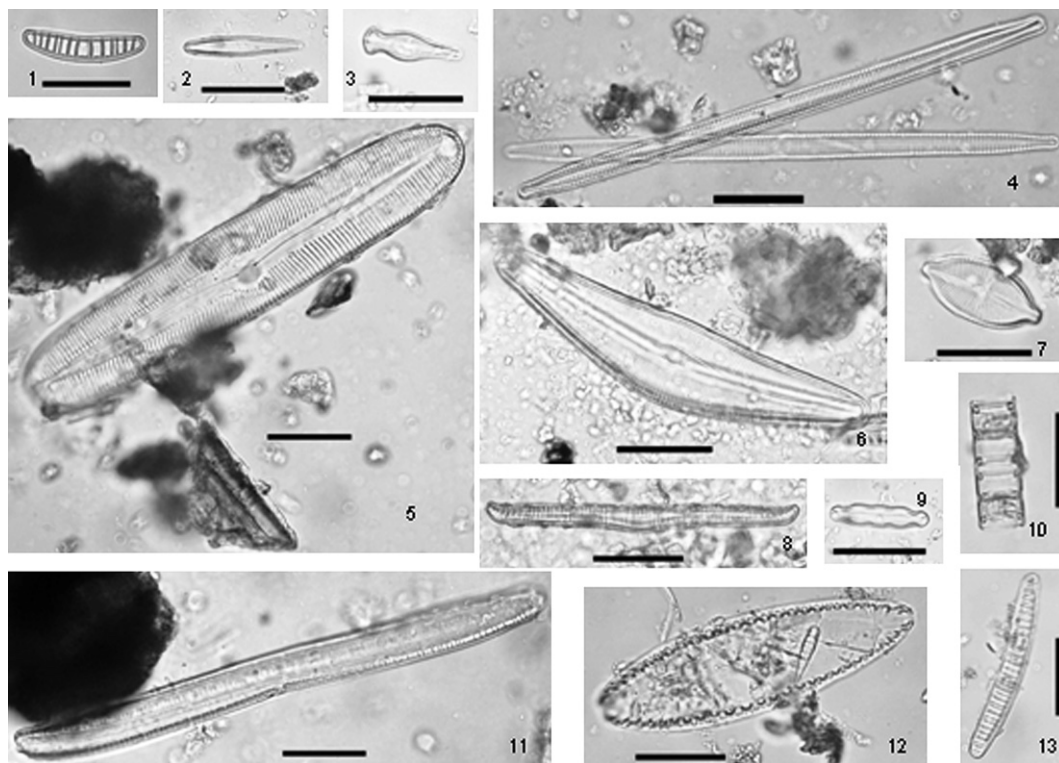
There were six genera noted in the archaeological features that were not present in control samples, a discrepancy indicative of a loss of biodiversity over time. We attribute this oligotrophy to the drainage of the peat-bog for arable land, as diatom growth and proliferation is negatively impacted by reduced moisture (Pouličková et al., 2004) and depressed by a resulting reduction in nitrogen and phosphorous availability (van Dam et al., 1991). Of these genera, *Hantzschia amphioxys* was observed solely in the longhouse floor samples. *Hantzschia* is commonly found on damp soils, requires open oxygen for growth (aerophilic) and is tolerant of organic pollution. It has also been encountered in domestic animal dung (Macphail et al., 1998) and may therefore be a result of tracked and trampled sediments brought into the longhouse or ash from dung fuel burned in the hearth. However, *Hantzschia* was not encountered in any of the modern control sediments from the farm where livestock are currently kept; we suggest the longhouse floor likely represents the natural living habitat of this diatom at Hrísrú.

Two genera were unique to all archaeological contexts but were not observed in any control samples: *Mastogloia* and *Nitzschia*. Both are commonly observed in the archaeological samples. While both are alkaliphilous and epipellic, *Nitzschia* prefers more organically rich conditions, whereas *Mastogloia* is more sensitive to organic pollutants (Kelly et al., 2005). It is possible that the source for these diatoms differed, and that *Nitzschia* thrived in the ecology of the longhouse whereas *Mastogloia* was introduced through transported turf.

Three additional genera were unique to the longhouse floor and one other archaeological feature. *Caloneis* and *Stauroneis* were only found in floor and wall samples, whereas *Diatoma* (*Diatoma hiemale*) was only encountered in floor and roof collapse samples. *Diatoma* is a planktonic genera and therefore likely a component of turf translocated in strips cut from the peat-bog for the longhouse roof or the result of tracking/dung transference from a standing body of water. Both *Caloneis* and *Stauroneis* are potentially epipellic, found in moist soils or shallow standing water (Kelly et al., 2005; Mann and Droop, 1996:23). Considering they are not present in either the positive or negative control samples, where moist soils are also encountered, they likely represent genera that were more conducive to the ecology of the longhouse. Together with *Hantzschia* and *Nitzschia*, *Caloneis* and *Stauroneis* show potential as a bioindicator group typical of archaeological floor sediments.

## 6. Blind test case

The selection for negative control samples was made blindly by RB in order to avoid selection bias. One of the samples was taken from a natural exposure of sediment located in the northeast corner



**Plate 1.** Photomicrograph samples of recovered diatoms. 1. *Eipthemia* sp. (floor). 2. *Gomphonema gracile* (roof). 3. *Gomphonema truncatum* (floor). 4. *Synedra ulna* (roof). 5. *Pinnularia* sp. and tephra shard (roof). 6. *Cymbella* sp. (peat-bog). 7. *Navicula decussis* (floor). 8. *Rhopalodia* sp. (peat-bog). 9. *Pinnularia mesolepta* (cold spring). 10. *Melosira varians* (wall). 11. *Nitzschia* sp. (wall). 12. *Surirella* sp. and *Meridion* sp. (inset) (roof). 13. *Epithemia arcus* (floor).

of the farmer's field. It was expected that the natural exposure was a paleosol and that no diatom evidence would be evident. Unexpectedly, the sample yielded nominal quantifiable evidence of diatoms (an average of 2 genera and 2 diatoms per 500  $\mu\text{m}^2$  grid). Follow-up consultation revealed that the site of the exposure was indeed an archaeological feature of unknown age that had been recorded by the Mosfell Archaeological Project in 2002 (Byock et al., 2003). This blind sample inadvertently confirmed that even marginally quantifiable diatom evidence is capable of identifying anthropogenic activity on natural substrates.

## 7. Conclusions

We have found diatoms to be useful in southwestern Iceland as an indicator of ancient turf features. These microfossils were formed in a peatland ecosystem, where they were incorporated into turf as it grew over peat and was subsequently cut and transported to a location where diatoms do not naturally accumulate in large numbers. Diatoms were more common in the archaeological features where turf was utilized in the construction of the Hrisbrú longhouse than they were in the natural pre-settlement sediments that the house overlaid. Broken and damaged diatoms were more common in floor sediments than they were in wall or roof samples, suggesting the condition of diatoms may be useful in differentiating between archaeological features or strata. Additionally, we found that epipellic diatoms *Nitzschia*, *Hantzschia*, *Caloneis* and *Stauroneis* were exclusive to archaeological sediments and may reflect an ecosystem unique to the longhouse that is distinct from other sediments including those of the natural peat-bog. Future comparisons with other habitation features will allow us to test this hypothesis.

This new method of identifying turf structures offers more clarity and differentiation than field assessment alone and limits the damage otherwise caused by shovel-testing or excavation. Due to

the small quantity of sediment necessary to quantifiably confirm the presence and relative abundance of diatoms (1.0 g), analysis can be conducted with minimal cost and effort. In the future, we plan to incorporate this microscopic methodology to lend more clarity to a systematic core survey of the Mosfell Valley. The utility of this method is limited to locations where turf was used as a building material and where buildings were constructed in a location distinct from a peatland ecosystem. In peatland environments, this method would not be able to differentiate natural diatom assemblages from archaeological evidence. Known cultural areas where turf architecture was used and where we envision this technique would be useful include most of the Norse North Atlantic from Newfoundland through to Norway, Denmark, and the northern British Isles.

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