Feeling the Peat: Investigating peat charcoal as an iron smelting fuel for the Scottish Iron Age

Paul M. Jack

ABSTRACT: The limited woodland resources that have characterised the Northern Isles of Scotland for millennia pose serious questions when attempting to understand how prehistoric communities fuelled their iron smelting endeavours. The archaeological evidence from the Northern Isles and ethnographic studies from the 19–20th centuries tentatively suggests that peat could have been used for such iron smelting activities. This research considers whether peat charcoal is a viable iron smelting fuel via an experimental campaign. Thermal data produced by this campaign, as well as a metallographic and chemical study of the products from the smelts suggest that charcoaled peat may be capable of producing an iron bloom. Important discussions concerning technical, economic, and ideological aspects of Iron Age metalworking can arise from a recognition of peat in the iron smelting process.

Introduction

The way in which metalworking activities consume vast quantities of fuel is well documented, with experimental iron smelts consuming 10–18 kg of charcoal to produce 1 kg of iron (Pleiner 2000, 126). It is also expected that around 8 kg of wood would be consumed in the production of 1 kg of charcoal (Oaks 2018, 48). This means that a total consumption of 63–150 kg of wood may be expected in the production of 1 kg of iron. Therefore, the iron smelting activities occurring during the Iron Age in the Northern Isles of Scotland appears at odds with the marginal woodland resources in the region with just 5–15 % of the pollen recovered from palynological studies being derived from arboreal sources (Edwards *et al.* 2005, 1745; Farrell 2015, 473; Timpany *et al.* 2020, 10). Conversely, peat coverage is extensive in Scotland, particularly in the Northern Isles (Fig. 1), leading Curle (1936, 153) to suggest that peat may have been the iron smelting fuel used at Wiltrow, Shetland. Schubert (1957, 18), Tylecote (1990, 140), Scott (1991, 161), and Dickson (1994, 153) have since joined Curle in suggesting that peat may have been used in various places for iron working activities but Mahler and Jouttijärvi's (2005) report stands as the only published experimental assessment of peat in an iron bloomery furnace.

This research aims to firstly, verify if peat works as an iron smelting fuel in the context of the Northern Isles in the Iron Age. Secondly, it aims to assess whether the use of peat in metallurgical activities leaves a signature that can be detected archaeologically. To achieve these aims, archaeological, ethnographic, and historical records of the Northern Isles will be assessed before presenting the results of an experimental peat charcoaling and iron smelting campaign and exploring the implications for how we understand the period.

The Archaeological Record

There has been little critical reflection on an apparent relationship between metalworking and peat at iron smelting sites in the Northern Isles (Fig. 1). In Orkney, this relationship can be seen at both the recovery of peat

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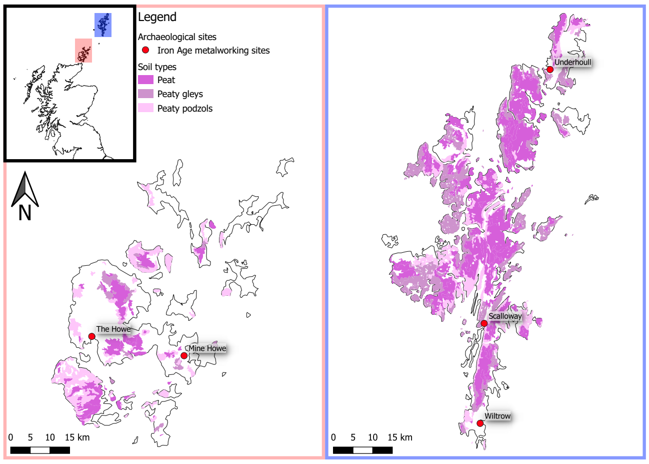

Figure 1: Location of Orkney (left) and Shetland (right) in Scotland showing the distribution of peat and of the location of Iron Age sites discussed (Base map and data sources: OS data © Crown copyright [and database right] 2019; public sector information licensed under the Open Government Licence v3.0; Soil maps of Scotland at a scale of 1:250 000, copyright and database right: The James Hutton Insititute 1981. Used with the permission of The James Hutton Insitute. All rights reserved.)

ash within furnace dump and slag dump contexts at The Howe (Dickson 1994, 131–4) and the carbonised peat recovered in association with furnace deposits, iron slags, and within in hearth rakes at Mine Howe (pers. comm. Nick Card). In Shetland, peat ash covered significant amounts of the iron smelting workshop at Underhoull (Small 1964, 230) while the peat recovered from the smelting site of Scalloway was more humified than that recovered from sites with less evidence for such activities (Campbell 1998, 123; Holden and Boardman 1998,105; Carter *et al.* 1995, 460).

The fact that peat burns so readily to ash also means that its use may be under-represented in the literature when compared to the charcoal present due to the difficulties of recovery during flotation and sieving (Dickson 1994, 134). Peat usage may be further underrepresented due to difficulties in distinguishing between layers of carbonised peat and wood charcoal, such as at The Howe (Smith 1994a, 67). The association of metalworking and peat in the archaeological record may, therefore, be even stronger than has been possible to suggest with the evidence currently available.

The Ethnographic and Historical Record

Oral accounts from the Hebrides attest to the use of peat by blacksmiths in North Uist and the Isle of Jura until the early 20th century (MacDonald 1962; Macleod and Maclean 1971). Blacksmiths would prepare the peat for smithing by burning it in pits 2.4 m long and 0.9 m wide and deep (MacDonald 1962) before smothering the fire to produce a charcoaled peat known as a 'smiddy coal' (MacLeod and Maclean 1971). Similar practices are attested to in the Northern Isles where smaller, circular, pits up to 1.8 m in diameter and 0.36 m deep were employed (Fenton 1997, 237). It appears that '*mòine dhubh*' (MacDonald 1962), Scots Gaelic for 'black peat', referring to more humified peat, was preferred in both the Western and Northern Isles for smiddy coal and could be a tentative explanation for the preference for the more humified peat in use at Scalloway compared to elsewhere.

Figure 2: Example of charcoaled and partially charcoaled peat (source: Jack 2023).

Although these accounts exclusively refer to smithing, there appears to be little mention of smelting in these areas in general. Accounts from the Isle of Harray state that smiddy coal burned like regular coal (Fenton 1997, 213), and 20th century accounts from America state that a peat coke could achieve temperatures up to 2,200°C (Davis 1911, 122) while a declassified CIA report stressed the utility of peat briquettes in 20 m tall blast furnaces (Zlobinsky 1949). Therefore, the focus on smithing may not be a result of an innate unsuitability of the fuel for smelting activities.

In order to test the hypothesis that charcoaled peat is a viable fuel for the production of iron via bloomery furnace, an experimental campaign was conducted to produce peat charcoal and to then use it to smelt iron ore.

Methods and Materials

Producing Peat Charcoal

Black peat was sourced from the Aberdeenshire based company PeatHeat which had been extracted using a screw type auger resulting in cylindrical and very slightly compacted peat (pers. comm. PeatHeat) that had an average moisture content of 27.1 %. This was charcoaled in accordance with ethnographic accounts, but on a smaller scale. Circular, steep sided pits of *c.* 76–78 cm in diameter and *c.* 25–26 cm deep were

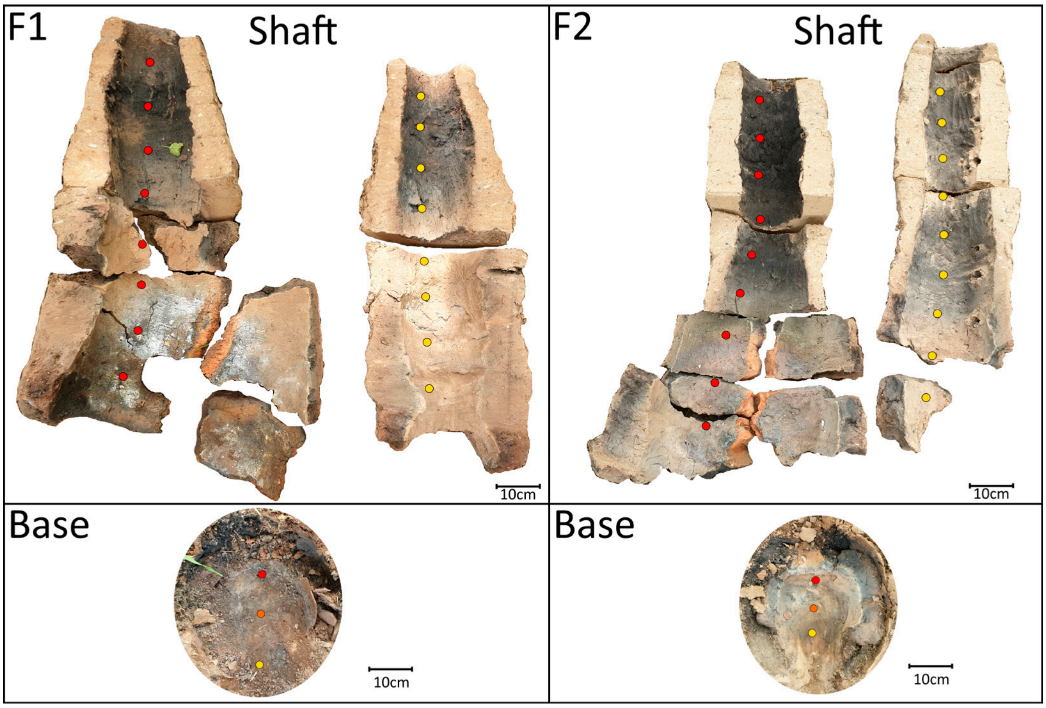

Figure 3: Dissected furnaces. Dots indicate the location of pXRF readings (red denotes tuyère side, yellow door side, orange middle).

dug, and a small fire was lit in the centre using straw wrapped in a light stock cardboard tube and five pieces of wood kindling surrounded by 2.5 kg of peat. The fire was slowly fed peat and was regularly fanned until the whole pit was filled with peat and glowing. Damp turfs were then placed to cover the pit and create an airtight lid (pers. comm. Ditlev Mahler) before retrieving the charcoal (Fig. 2) between 24 and 36 hours later.

Furnace Construction and Operation

Two one metre tall furnaces for iron smelting were constructed from a mixture consisting of 60 % clay, 30 % sand, 2 % straw and 8 % water by volume. Furnace 1 (F1) was to be operated using only hard wood charcoal for the purposes of producing data to compare to that of Furnace 2 (F2) which was to be operated using only peat charcoal. Owing to the limited nature of published dimensional data of Iron Age furnaces from the Northern Isles, a site photograph from The Howe, Orkney was used to establish a 23 cm diameter base and, by employing a pinhole projection formula to the pixel height of the ranging rods located above and within the furnace, with the assumption that the camera was held at a height of ~150 cm above ground, it was possible to calculate a minimum depth of *c.* 8.5 cm (see https://canmore.org.uk/collection/1872106). The thickness of the furnace walls varied from 3 to 10 cm with a tapering internal diameter. F1 tapered to 18.5 cm and 11 cm at 0.5 m and 1 m, respectively, with F2 tapering to 17.5 cm and 12.5 cm at the same intervals. F1 began to topple and required reseating which reduced its overall height to 90 cm. Each furnace featured a door to retrieve the smelt products as well as holes at 20 cm, 40 cm, and 60 cm up the shaft of the furnace for the insertion of type K thermocouples at a depth of *c.* 3 cm to record temperatures at 15 s intervals.

Wood charcoal was placed within a bucket and crushed with a spade to reduce its size before being added to the furnace. Similarly, the peat charcoal was broken by hand during collection. This ensured that the pieces were typically no larger than 5 cm with most being *c.* 2.5 cm. Preheating was commenced using straw and wood kindling before slowly adding the appropriate fuels until the shafts were filled to a height of 90 cm to accommodate the difference in height caused by reseating F1. Bellows of double-lung construction supplied a forced draft which entered the furnace through a clay tuyère with an internal diameter of approximately 3 cm, in accordance with Iron Age tuyères found in Scotland (Tylecote 1990, 142–3). Once the temperatures within the furnaces had reached 850 °C, the first 390 g charge of crushed and roasted refined iron ore pellets (67 % iron content haematite) was added to the furnace. Three more charges of the same size were added at 30-minute intervals with 1.9–2.5 kg of fuel added after the final charge. Slags were retrieved from the furnace once the fuel had dropped to 20 cm within the furnace. In all, smelts ran for *c.* 4 hours which should have been long enough to create the microscopic structures indicative of a successful smelt and chemical data required for this study.

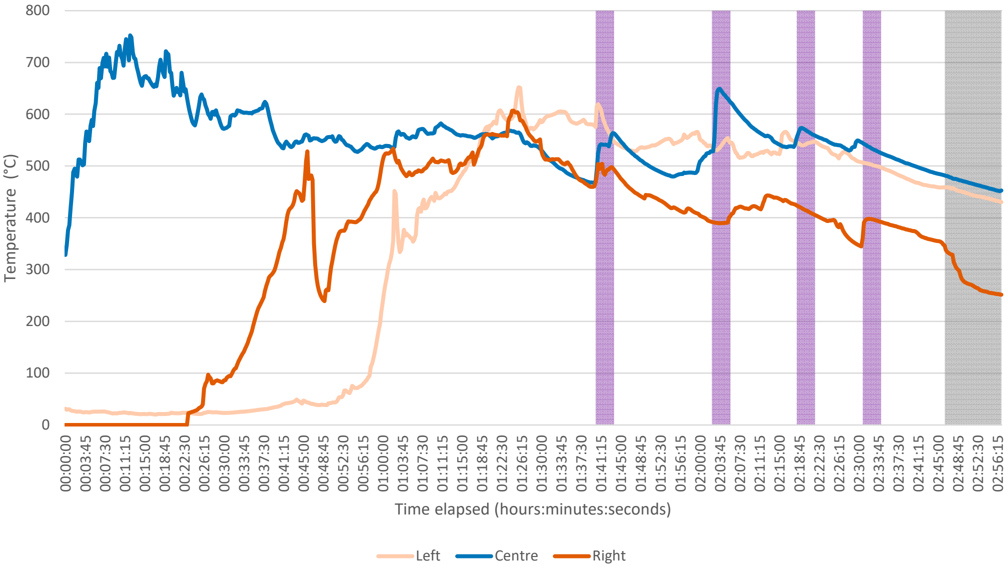

Figure 4: Peat charcoaling temperatures. Increases in temperature associated with fanning highlighted in purple, smothering temperatures highlighted in grey.

Microscopic and Chemical Analysis

The products were classified as ‘iron-rich material’, ‘slag’, and ‘conglomerate’ from each smelt and were dissected and hot mounted in Bakelite, or an epoxy-resin in the case of particularly fragile pieces, before grinding and polishing to a 1 µm finish to prepare them for reflected light microscopy. The identification of iron, wüstite, and fayalite within the samples was used to understand the internal processes and conditions created during both smelts.

Chemical analysis of particularly rich areas of the iron-rich material, more mixed locations and associated slags was conducted to identify elements which may be associated with the use of peat charcoal in an attempt to identify the elements which may signal exposure to peat charcoal. This also allowed for understanding of the risk of introducing excessive quantities of sulphur, which is known to increase the brittleness of iron (Tylecote 1990,144), and phosphorus, which can also alter the mechanical properties of iron (Schmidt and Childs 1995; Tylecote 1990, 156; Vega *et al.* 2003, 344; Hall 2017, 289) and necessitates the development of dephosphorising smithing practices (Vega *et al.* 2003, 344). This was done using the ‘Mining Zu/Cu’ setting of the Niton XL 3t GOLD pXRF which facilitated the identification of sulphur and phosphorus as well as molybdenum, zinc, copper, manganese, calcium, potassium, silicon, chlorine and magnesium which were thought to possibly serve as indicators of having used a peat based fuel owing to their common presence within peat (Rydin and Jeglum 2013, 101). The furnace material was also tested for possible peat charcoal signatures by dissecting both furnaces in two, producing a side with the tuyère hole and a side with the door (Fig. 3). pXRF readings, using the same equipment and settings, were taken at 10 cm intervals down the middle of each half, as well as at each end and centre of the furnace base in order to obtain readings from areas of the furnace exposed to all possible redox environments.

Results

Charcoaling

These experiments produced 26.8 kg of charcoal from 155.6 kg of peat over several charcoaling attempts to attain a maximum yield of 3.7 kg of peat to 1 kg of peat charcoal. The temperatures within the charcoaling pit typically varied by approximately 100 °C at any given time. The thermocouple to the right edge of the pit consistently recorded lower temperatures than that recorded in the centre and the left of the pit (Fig. 4). Therefore, although fanning had a substantial impact on the temperatures recorded, at least 1/3 of the pit failed to maintain temperatures above that required to drive off sulphur, 444.6 °C (Encyclopaedia Britannica n.d.a). See Jack (2023) for a detailed review of the peat charcoaling.

The Smelts

Smelt 1 was conducted in F1 and used hard wood charcoal while Smelt 2 was conducted in F2 and used peat charcoal. The most notable difference between the two fuels were the fact that the peat charcoal fuel rose in temperature more rapidly than the wood charcoal (Fig. 5) which shortened the preheating process for Smelt 2 by approximately 50 minutes and reduced fuel consumption during this stage by 22.1 % (Table 1). However, Smelt 2 also suffered from several blockages. Smelt 2 also failed to produce the distinctive charcoal smell from Smelt 1 which clung to clothes, skin and hair for days but did release a powerful smell of sulphur when the furnace door was opened to retrieve the products.

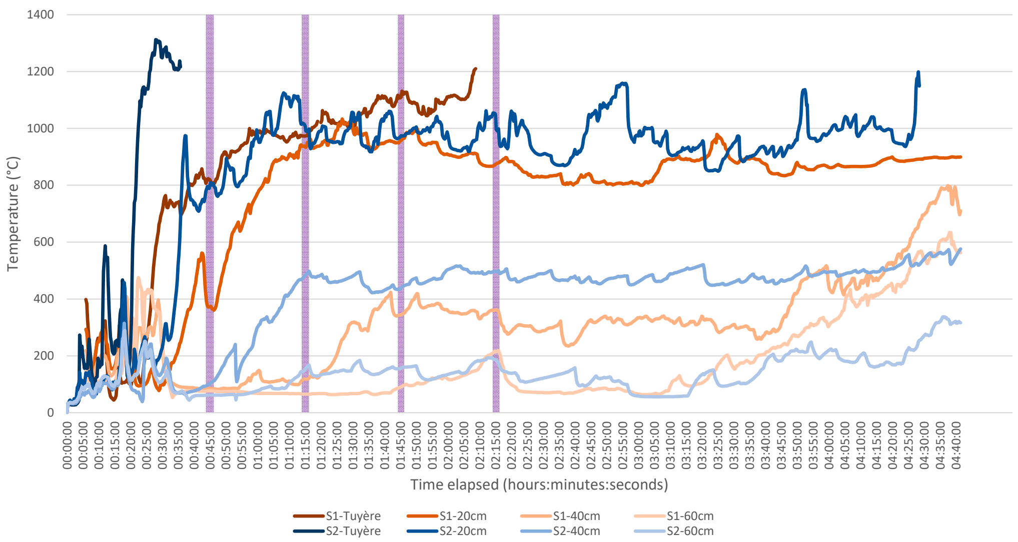

Figure 5: Thermal data for the wood charcoal fuelled Smelt 1 (red) and the peat charcoal fuelled Smelt 2 (blue) from thermocouples positioned at 20 cm, 40 cm, 60 cm, and through the tuyère hole. Vertical purple lines denote the addition of charges of iron ore.

Figure 6 shows that Smelt 2 appears to have achieved and maintained notably higher temperatures than Smelt 1 at 20 cm internal furnace height and below. Of particular note is how the Smelt 2 tuyère thermocouple recorded temperatures exceeding 1200 °C 1.5 hours before Smelt 1 produced similar temperatures. The thermocouples positioned at 20 cm and 40 cm height during Smelt 2 also recorded higher average temperatures than at the same positions in Smelt 1. However, the second noticeable increase in temperatures at 40 cm during Smelt 1 around 3 hours and 48 minutes was not witnessed in Smelt 2, though temperatures were much higher to begin with. A similar, broadly coinciding temperature increase at 60 cm during Smelt 1 appears to have been delayed or interrupted during Smelt 2.

The resulting iron-rich material from Smelt 1 was more substantial in weight, more consolidated and had more visible iron once dissected than that of Smelt 2 (Fig. 6).

Table 1: Summary of smelts.

	Smelt 1 **Wood charcoal**	**Smelt 2** **Peat charcoal**
Smelt Length	246 min	230 min
Ore used	1.56 kg	1.56 kg
Fuel consumed		
Preheating	8.60 kg	6.70 kg
During smelt	3.80 kg	3.20 kg
Total Material Recovered	1.10 kg	1.20 kg

Table 2: Summary of smelt products.

	Iron-rich material	**Conglomerate**	**Slag**	**Ore**
Smelt 1	963.6 g	0 g	129.9 g	14.6 g
Smelt 2	665.3 g	271.6 g	228.0 g	36.6 g

Smelt 2 produced denser slags than that of Smelt 1 as well as more ore that was only partially reacted and more conglomerate (Table 2).

Of note is the fact that although peat often produces large quantities of ash as a result of burning, this did not appear to be an innate characteristic of burning intentionally charcoaled peat.

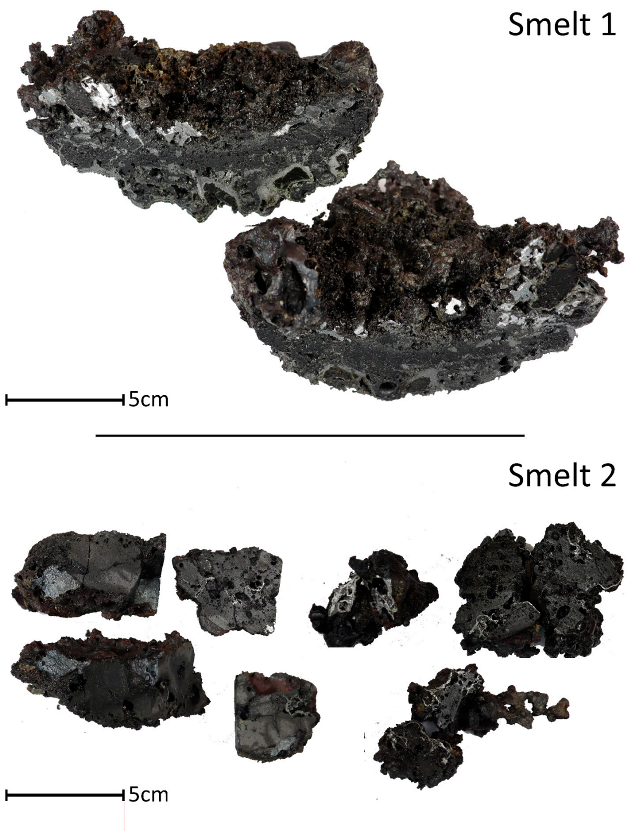

Figure 6: Dissected iron-rich material from Smelt 1 and Smelt 2.

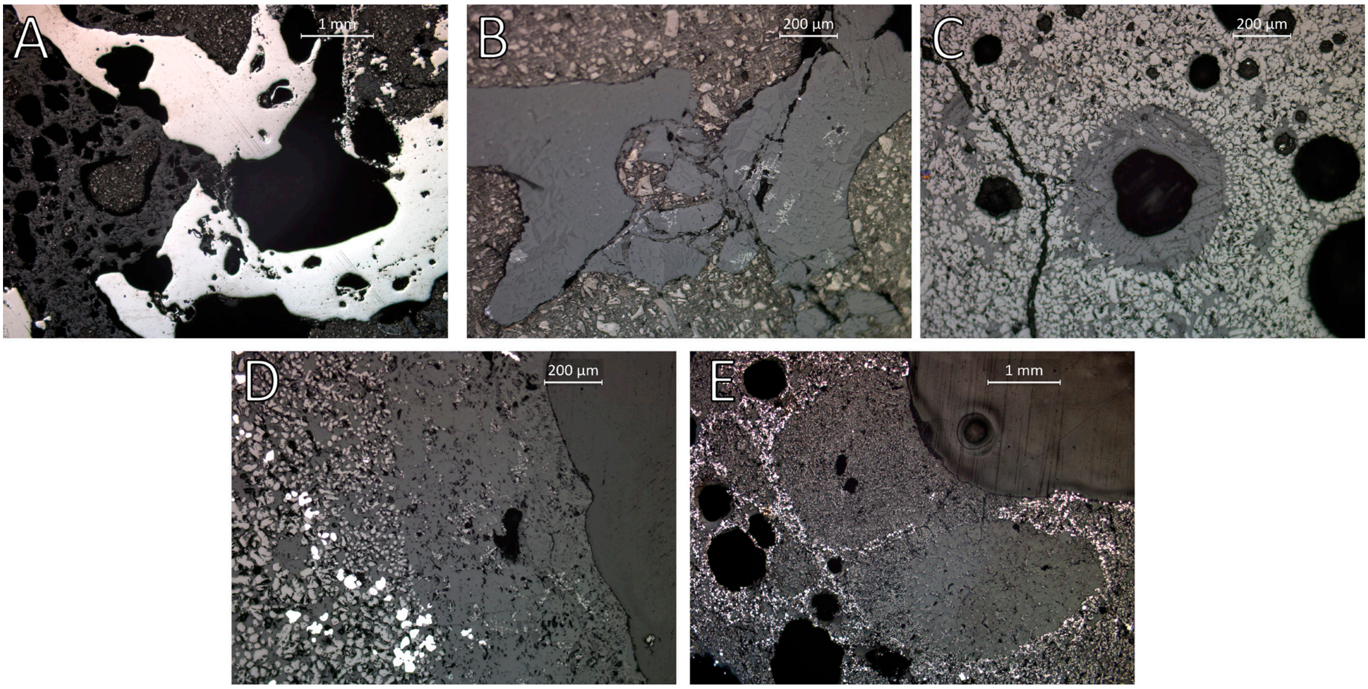

Figure 7: Smelt 1, photomicrographs of (A–B) iron-rich material, (C) more mixed areas of iron-rich material, (D–E) slag.

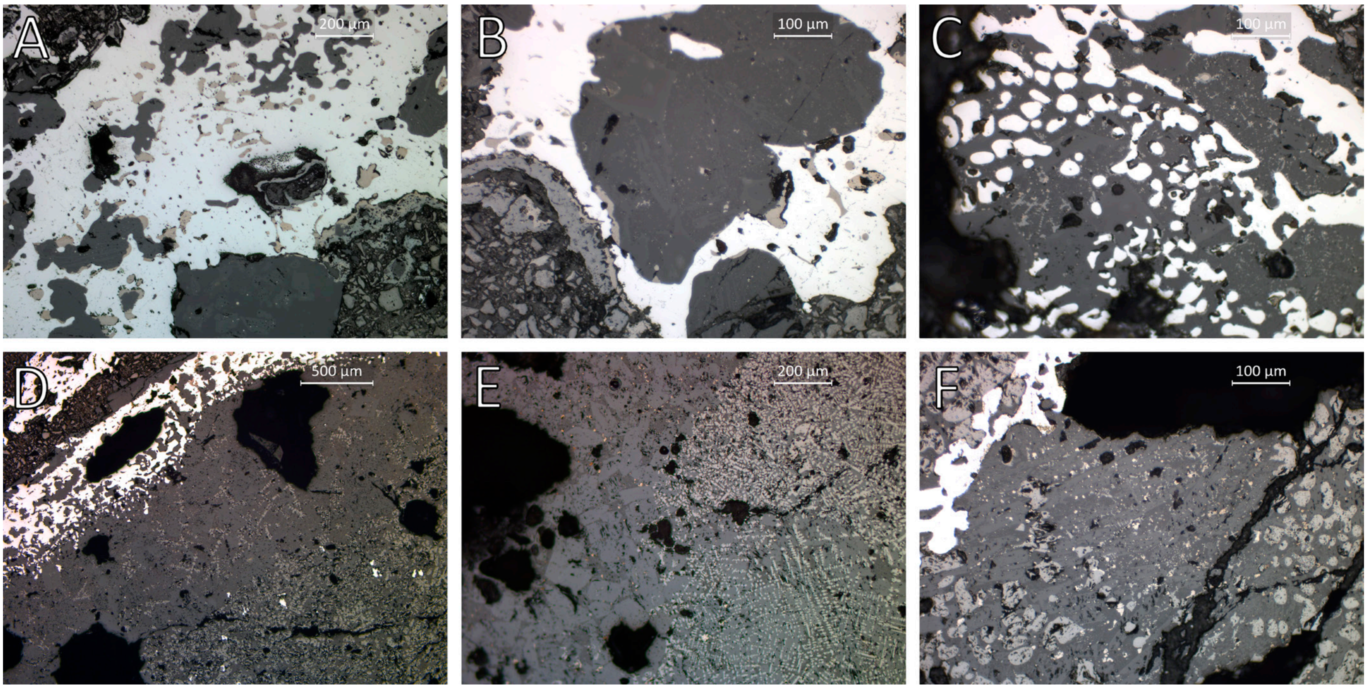

Figure 8: Smelt 2, photomicrographs of (A–C) iron-rich material, (D) more mixed areas of iron-rich material, (E) slag, and (F) conglomerate.

Microscopy

Smelt 1 (wood charcoal)

The iron-rich material, in select areas, was 60–70 % iron excluding voids (around 60% of the total surface) (Fig. 7A). The eutectic contained both a glassy fayalite lath matrix, and small quantities of dendritic wüstite towards the edge of the sample, away from the iron formation (Fig. 7B). Other less iron rich areas were dominated by globular wüstite and small quantities of fayalite laths which were most apparent near voids (Fig. 7C).

The slag from this smelt consisted almost entirely of wüstite, mainly globular in nature but with some dendrites and very limited fayalite lath formation (Fig. 7D). Iron crusts occasionally formed, typically in sub-circular patterns (Fig. 7E).

Smelt 2 (peat charcoal)

Iron formation was typically less dense in the iron-rich material produced by Smelt 2 when compared with that of Smelt 1 (Fig. 8A) but with voids making up a much lower proportion of the sample. The occasional yellowish/creamy features found in association with the iron (Fig. 8A) may be sulphur-related due to the way that it has affixed to the iron, as well as its slight resemblance to pyrrhotite (Mathieu 2019,14) and chalcopyrite (Shirazi *et al.* 2018, 126) found in ores. The eutectic contained dendritic wüstite and fayalite laths (Fig. 8B) with more crystalline structures also present in notable quantities (Fig. 8B–C). Less iron rich areas primarily contained dendritic wüstite towards its edge with iron formation largely restricted to a thin crust around the edge of the sample and globular wüstite elsewhere (Fig. 8D).

The slag from this smelt consisted almost entirely of dendritic wüstite in areas of lower and higher density. Fayalite formation was limited but was most obvious near the edge of the sample and was often crystalline in nature (Fig. 8E).

The conglomerate was characterised by a dense globular wüstite-ore mix which became less dense towards the iron crust that formed in parts. Some of this iron crust features the possible sulphur-related content witnessed in the iron-rich samples (Fig. 8F). The sparse fayalite formation has taken a mostly crystalline form (Fig. 8F).

Chemical analysis

The pXRF analysis of the smelt products (Table 3, Fig. 9, 10) revealed that the titanium content of the Smelt 2 products along with aluminium and sulphur, both of which are present within peat, were greatly elevated compared to the Smelt 1 products. Magnesium, also present in peat, was wholly unique to the products of Smelt 2. Conversely, silicon and chlorine, despite being present in peat, were present in the products of Smelt 2 in quantities that were 27.8 % and 69.4 % lower on average, respectively, than those of Smelt 1. The quantities of other elements expected to be contained within peat were present in negligible quantities in the products of both smelts.

The sulphur and phosphorus content of Smelt 2 were on average 320.2 % and 23.2 % higher than that of Smelt 1, respectively. However, the entire range of phosphorus readings from the Smelt 2 products are within the same range as those from Smelt 1 (Fig. 9) and as such, it is

Table 3: Average pXRF results of smelting products in ppm. '' denotes elements likely to be present in peat. Differences were calculated between average smelt 2 readings and average smelt 1 readings.*

Sample type	**Bal**	**Sb**	**Sn**	**Mo***	**Nb**	**Zr**	**Sr**	**Rb**	**Bi**	**As**	**Au**	**Pb**	**W**
Smelt 1													
Average Iron-rich	466526.9	0	0	3.7	10.6	63.6	2844.3	10.8	0	7.8	7.9	0	0
Average Mixed iron content slag	365326.6	0	0	0	6.2	29.1	345.9	10.8	0	0	0	0	67.2
Average Slag	376458.6	0	0	0	2.3	31.4	1069.6	17.2	0	8.4	0	0	77.3
Average All	402770.7	0	0	1.2	6.3	41.4	1419.9	12.9	0	5.4	2.6	0	48.2
Smelt 2													
Average Iron-rich	357499.7	0	0	0	5.2	57.5	332	18.9	12.3	0	0	0	0
Average Mixed iron content slag	467945.6	19.9	20.6	0	2.6	44.8	205.2	10.3	0	16.1	0	0	67.6
Average Slag	338012.9	0	0	0	4.4	67.9	148.1	34.8	0	0	0	0	0
Average All	387819.4	6.6	6.9	0	4.1	56.7	228.4	21.3	4.1	5.4	0	0	22.5
Absolute difference	-14951.3	6.6	6.9	-1.2	-2.3	15.4	-1191.5	8.4	4.1	0	-2.6	0	-25.6
Relative difference in %	-3.7	0	0	0	-36.1	37.2	-83.9	64.9	0	-0.5	0	0	-53.2

(continued)

Sample type	**Zn**	**Cu***	**Ni**	**Fe**	**Mn***	**Ti**	**Al**	**P***	**Si***	**Cl***	**S***	**Mg***
Smelt 1												
Average Iron-rich	22.6	46	53.1	261655.2	353.4	296.6	27517.6	1786	223530.1	185	2286.5	0
Average Mixed iron content slag	0	69.6	117.2	536038.8	0	0	19349.1	535	75283.1	492.4	1750.2	0
Average Slag	0	78.8	105.2	447531.4	154.5	316.5	30253.7	1351.4	136492	4797.9	283.8	0
Average All	7.5	64.8	91.8	415075.1	169.3	204.4	25706.8	1224.1	145101.7	1825.1	1440.1	0
Smelt 2												
Average Iron-rich	0	94.7	91.7	429167.8	299.7	914.1	38898.2	1897.3	92373.6	351.1	9054.1	68542.5
Average Mixed iron content slag	6.7	39.3	111.5	375684	225.3	806.9	31958.7	1435.3	84923.0	403.0	6013.9	19844.3
Average Slag	13.6	0	85.4	425292.2	263.9	766.8	50262.6	1192.5	137008.4	922.3	3084.8	42214.3
Average All	6.8	44.7	96.2	410048	263	829.3	40373.2	1508.4	104768.3	558.8	6051	43533.7
Absolute difference	-0.8	-20.1	4.4	-5027.1	93.7	624.9	14666.4	284.3	-40333.4	-1266.3	4610.8	43533.7
Relative difference in %	-10.3	-31.1	4.7	-1.2	55.3	305.7	57.1	23.2	-27.8	-69.4	320.2	0

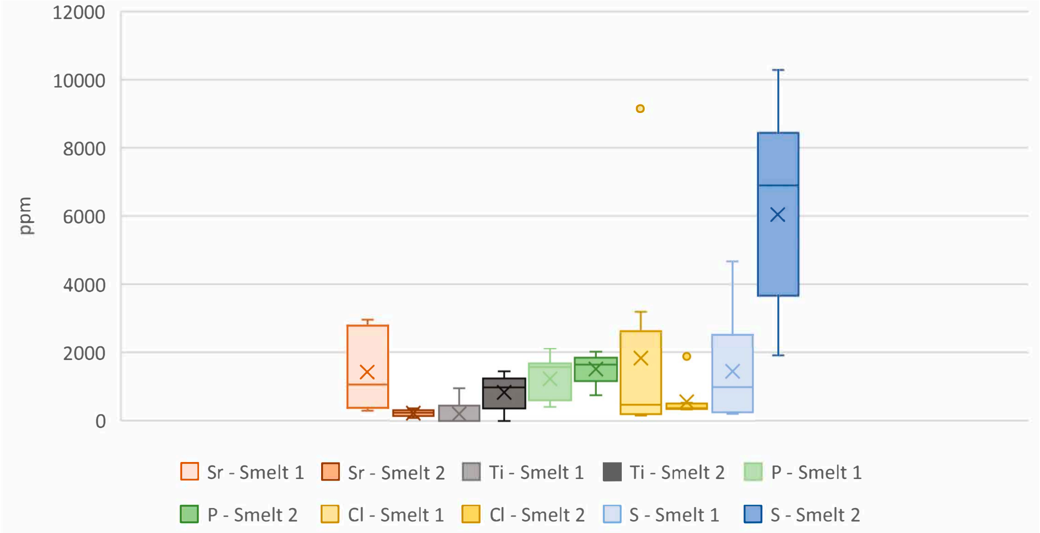

Figure 9: Box and whisker chart showing select results of pXRF analysis of smelt products (< 12000 ppm).

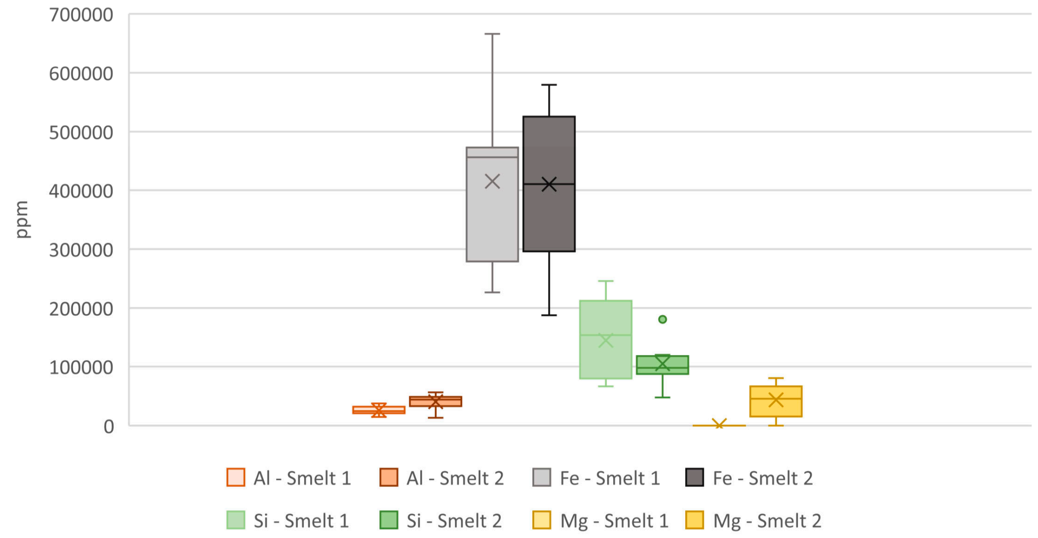

Figure 10: Box and whisker chart showing select results of pXRF analysis of smelt products (> 12000 ppm).

not believed that the use of peat charcoal introduced any significant quantities of phosphorus to the smelt.

Similar to the smelting products exposed to a peat based fuel, the furnace material of F2 produced much higher sulphur and magnesium readings than that of F1, an increase of 193.5 % and 164.5 %, respectively (see Table 4), as well as a trend for elevated phosphorous, aluminium and chlorine, though with substantial overlap in the range of values recorded (Fig. 10, 11). Potassium and calcium were also present in quantities above 1000 ppm but, despite being expected to have been elevated due to their presence in peat, were present in F2 58.6 % and 22.3 % less, on average, than in F1.

Discussion

The smelt and its products

Although Smelt 2 produced less iron, the findings of the experimental smelts are optimistic about the feasibility of peat charcoal as an iron smelting fuel for the Scottish Iron Age. This is because Smelt 2 produced some iron alongside wüstite and fayalite and therefore attained a suitably hot and reducing environment for the smelting of iron. The discrepancy in the quantity of iron produced likely lies in the disruption of the fayalite-magnetite-quartz buffer equilibrium, as evidenced by the more crystalline fayalite structures (Bourgarit 2019, 213). By more thoroughly crushing the peat charcoal than the wood charcoal, it is believed that the blockages, the primary culprit, can be resolved. Repetition of these experiments must be undertaken to test the impact of this on the quantity of iron produced and the temperature readings, which the blockages may have inflated through the additional draught along the furnace walls.

The identification of a key chemical signature of peat charcoal in the smelt products or the furnace material is not simple. Although magnesium was unique to the products of Smelt 2 and was substantially more

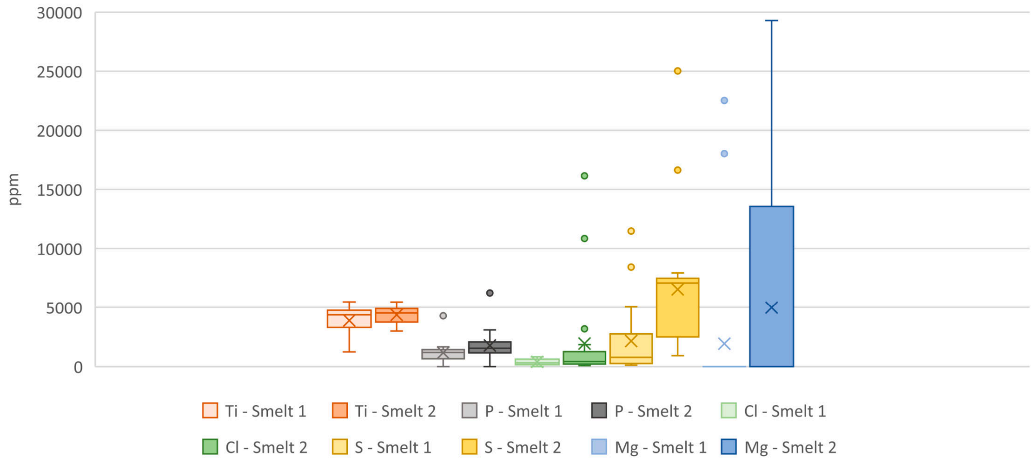

Figure 11: Box and whisker chart showing select results of pXRF analysis of furnace material (< 30000 ppm)

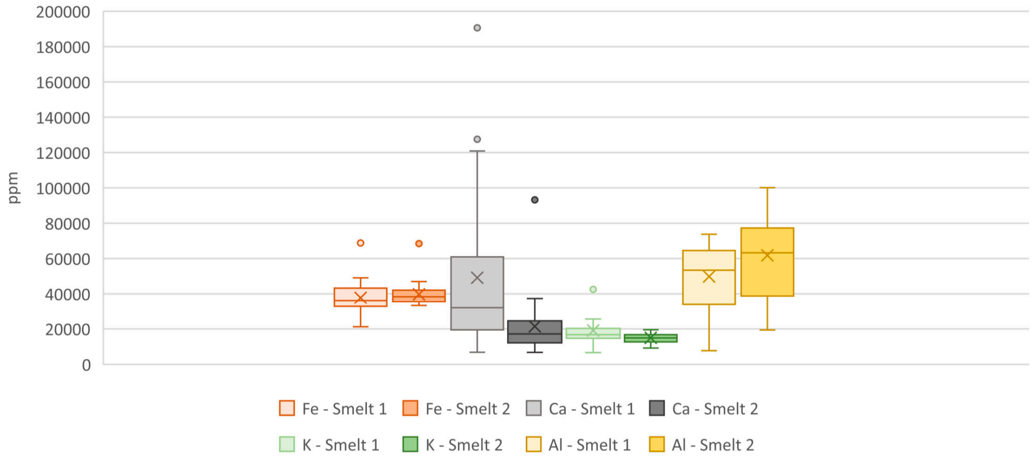

Figure 12: Box and whisker chart showing select results of pXRF analysis of furnace material(> 30000 ppm)

prevalent in the furnace material of F2 compared to F1, this is likely to be obscured through the use of bog ore, common in Northern Scotland (Bayley *et al.* 2008, 4). Similarly, although the chlorine content of F2 was, on average, 356% greater than F1, the distribution of the readings overlap substantially (Fig. 10), suggesting that high chlorine levels may be indicative of peat charcoal but is not innately diagnostic.

Although the sulphur content of both the smelt products and furnace material may help identify the use of peat charcoal, it is likely so high as to be problematic for the mechanical properties of any iron produced from its use. Future experiments should seek to reduce this by improving the even spread of heat during the peat charcoaling process which struggled to maintain temperatures above the boiling point of sulphur throughout the charcoaling pit. It is believed that with further experience, and the natural draught of the Northern Isles' wind, more even temperatures could be attained and the sulphur content reduced.

Assuming a better quality peat charcoal was employed than was used here, peat charcoal does not introduce

Table 4: Average pXRF results of furnace material in ppm. '' denotes elements likely to be present in peat.*

Furnace no.	Bal	Mo*	Nb	Zr	Sr	Rb	Bi	As	Pb	Zn*	Cu*	Fe
F1	664404.3	0.4	10.0	129.3	227.1	63.1	0	6.5	30.5	113.4	10.4	37754
F2	644162.9	0.2	11.8	137.1	76.6	70.9	6.2	17.6	73.9	222.7	7.6	39624.3
Absolute difference	-20241.4	-0.3	1.8	7.9	-150.4	7.9	6.2	11.1	43.5	109.3	-2.8	1870.3
Relative difference in%	-3.0	-59.4	18.1	6.1	-66.2	12.5	0	171.2	142.6	96.4	-26.7	5.0

(continued)

Furnace no.	Mn*	Cr	V	Ti	Ca*	K*	Al	P*	Si*	Cl*	S*	Mg*
F1	209.5	65.9	92.3	3879.3	49117.1	19101.1	49805.8	1169.3	168427.6	392.7	2150.5	1931.5
F2	444.0	82.3	96.7	4347.3	20335.5	14838.3	61852.9	1714.8	197031.7	1790.6	6311.6	5109.3
Absolute difference	234.4	16.4	4.4	468.0	-28781.6	-4262.9	12047.1	545.5	28604.0	1397.9	4161.2	3177.8
Relative difference in%	111.9	24.9	4.7	12.1	-58.6	-22.3	24.2	46.7	17.0	356.0	193.5	164.5

new hurdles in smelting iron other than the requirement for smaller pieces to be introduced to the furnace. This is because the phosphorus content of the products from Smelt 1 and 2 are broadly comparable, suggesting that the use of peat charcoal does not result in the introduction of additional phosphorus to the smelt, negating the need to develop new dephosphorising smithing techniques (Vega *et al.* 2003, 344). Similarly, the fact that the charcoaled peat did not produce a significant amount of ash, like uncharcoaled peat, means that the typically small furnaces of the Scottish Iron Age, as replicated here, would not require alteration to accommodate peat charcoal.

Methodology Review

The pXRF analysis utilised here facilitates a rapid, inexpensive, and non-destructive methodology for identifying different fuel uses within the archaeological record with relative ease. Provided with an adequate dataset for statistical analysis, it may be able to distinguish material exposed to peat charcoal and wood charcoal via chlorine content. However, SEM-EDS and LA-ICP-MS would offer more detailed readings and provide a more nuanced understanding of the chemical composition of these materials. Ultimately, a larger dataset, from multiple smelts, should be used to substantiate the observations produced here and would facilitate the creation of a statistical model to explore the question of fuel use. This would lead to a better understanding of whether metallurgical activities are a legitimate explanation for the contextual relationships between peat and iron working witnessed in the archaeological record of the Northern Isles.

Fuel as a choice

The a priori assumption must be that past communities were capable of conceptually inventing (Roux 2010, 220–223) the peat charcoaling process and its use for metalworking. The similarity between the peat charcoaling process with that of charcoaling wood (Oaks 2018, 48), the extensive domestic use of peat (Dickson 1994, 127–130), and the length of contact communities had with the fuel (Richards 1996, 203) make the conceptual invention of peat charcoal likely through the extensive familiarity they had with the fuel and charcoaling process. Additionally, peat would have had numerous perceived inherent relationships (see content and context biases in Henrich and McElreath 2003, 129). Given the spatial relationship peat had with the bog ore common in the Northern Isles (Bayley *et al.* 2008, 4) a conceptual relationship between iron and peat also seems possible. Additionally, the practice of depositing metalwork in watery contexts (Armit 2016, 105; Manning 1977; Piggot *et al.* 1995, 5), and the well-like structure at the centre of the metalworking site Mine Howe (Card and Downes 2003, 17), may have served to further strengthen such a conceptual relationship between metalwork and watery places, such as peat bogs.

With this assumption, there are several significant implications for how we understand the economy, and possibly the society, of the Scottish Northern Isles during the Iron Age depending on whether or not its invention moved beyond the conceptual stage and its use can be identified archaeologically.

If peat charcoal was used for iron smelting, as this study suggests is possible, it may imply that past communities had concerns over the ability of woodland management strategies to support iron smelting activities. Although potentially easing pressures on coppicing cycles, the need for peat domestically means that the over-cutting of peat could be as disastrous for a community as the overharvesting of wood. Historically, the depletion of peat led to the abandonment of settlements, such as on Unst and Papa Stour, Shetland (Fenton 1978, 223) while over cutting peatlands can cause extensive damage to otherwise suitable grazing ground (Fenton 1978, 209). Archaeological evidence for peat shortages may be attested to in the later stages of the occupation of The Howe, when the community resorted to using heather for fuel (Smith 1994b, 124).

If peat charcoal never made it to or beyond a conceptual invention, an explanation must be sought. One such explanation lies in the fact that different fuel types (peat, wood, and coal) have historically been tied to status in the Northern Isles, with peat associated with the poorest and most rural members of society (Fenton 1997, 213). Given the relative scarcity of woodland resources, its use for iron smelting may be viewed as a form of conspicuous consumption perhaps necessary to reflect/reinforce the status of the metalworker, the person or community they were working for, or the metalwork itself. The unique smell of the wood-based fuel, that clings to the skin, hair, and clothes, unlikely to be encountered in domestic life, may also provide an olfactory ‘otherness’ to the metalworker and their craft. In such a scenario, the marginality of woodland resources may be the precise reason why it was chosen.

By mixing peat and wood charcoal, which may be identified archaeologically, it becomes possible to mix the benefits of both fuels. Through the management of both woodland and peatland resources, it may be possible to invoke the potential status of woodland resources while limiting the impact on the resource and maintaining conceptual links between the fuel, the ore and, possibly, watery places. Alternatively it may be that these fuels are used at distinct times when one resource may be under particular stress. This may be considered an explanation for the occurrence of both charred peat and wood charcoal in metalworking contexts in Orkney (Dickson 1994, 131, 13–14; Smith 1994a, 67; pers. comm. Nick Card) and Shetland (Small 1964, 230; Curle 1936, 153, 164; Campbell 1998, 123).

Conclusion

This experimental campaign has shown that peat charcoal has potential as an iron smelting fuel within the context of the Iron Age in the Scottish Northern Isles. The metallographic structures identified in the products from the peat charcoal fuelled smelts suggest a suitably hot and reducing atmosphere was achieved. The blockages that occurred during the use of peat charcoal appear to have hindered the progress of a successful smelt but may be easily avoidable. Chemical analysis of the resulting smelt products and furnace material suggests that peat charcoal impacts their chemical composition and through a larger data set, can lead to models which can be applied to archaeological material. Examining fuel choice will lead to substantial gains in our understanding of metalworking as a technical craft as well as past economies, ideologies, and identities.

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The Author

Paul M Jack graduated from the Archaeology Institute at the University of the Highlands and Islands (Oilthigh na Gàidhealtachd agus nan Eilean) based in Orkney with a 1:1 in 2020 where he dedicated the last two years of his study to exploring iron working practices in the Northern Isles during the Iron Age. In 2019, he won a scholarship from the Carnegie Institute to conduct a 4-week experimental campaign into furnace design and the different thermal shock resistance properties of ceramics based on different tempers. In 2021 he graduated from the University of Sheffield with a distinction in Archaeological Science (Archaeomaterials) having completed a dissertation which explored the possible use of peat as an iron smelting fuel. Currently, Paul Jack is employed as a Historic Environment Consultant in Scotland.

Address where the research was conducted: Department of Archaeology, University of Sheffield, Minalloy House, 10-16 Regent Street, Sheffield S1 3NJ.
Current address; 6 (1f1), Queen's Park Avenue, Edinburgh EH8 7EE, United Kingdom
e-mail: p-jack@outlook.com