The bloomery mounds of the Scottish Highlands. Part 1: the archaeological background

E Photos-Jones, J A Atkinson, A J Hall and I Banks

Abstract

The ubiquitous presence of bloomery mounds in the Scottish Highlands and the speed of their destruction by forestry, agriculture and animal husbandry, combined with the limited understanding of the industry that produced them, has stimulated a one-year pilot investigation aimed at the development of a methodology for their study and means of preservation. Five disciplines (archaeology, history, geology, geophysics and archaeometallurgy) provided the foundations of three separate phases of activity to include (a) the evaluation of documentary sources, (b) the assessment of the mounds and their immediate natural environment by geological, geophysical and archaeological means of prospection, and (c) the scientific examination of potential ore sources and industrial waste. Three phases in bloomery making were revealed: traditional small-scale production, traditional large scale and advanced large-scale (probably making use of water power) at three different locations in the Highlands. Each displayed its own characteristic features, some uniquely Scottish. This paper presents the results of the work so far, and aims to put the Scottish Highland bloomeries back on the archaeometallurgical map. The work has been made possible through the generous support of Historic Scotland. This paper is the first of two parts; the second, to appear in a future issue of *Historical Metallurgy,* will be dedicated to Scottish iron ores and the mechanism of their formation, with particular reference to bog iron.

The Historical Background

Little is known about the early iron industry in the Highlands, the paucity of the documentary record being intensified by the relative scarcity of artefacts. Yet there are numerous folk traditions which must by default fill the existing void of historical information. Legends of smiths and their achievements abound. One such smith, by the name of Andrea Ferrara, was well known at Rannoch Moor for his excellent weaponry (Cunningham 1989, 61), and it is probable that he smelted his own iron. William (the Braveheart) Wallace's two handed and cross-hilted longsword, the claymore, made famous in a recent film epic was probably another product of the same tradition.

Contrary to the documentary record the field evidence in the form of bloomery mounds is substantial. These 'monuments', a ubiquitous feature of the Scottish Highlands, are usually small (about 3m by 5m by 1m) consisting of broken up fragments of dense, black tap slag lying in the proximity of furnace remains (MacAdam 1887; Aitken 1970). For the majority of these mounds the date is yet to be determined.

This form of small-scale activity appears to have been prevalent throughout the Highlands, with concentrations of monuments in areas as widely spread as the Cowal Peninsula, Argyll, Ardnamurchan Peninsula (Lochabar), Loch Maree, Wester Ross and Loch Rannoch, Perthshire (Fig 1).

The numerous bloomery mounds cannot readily be attributed to any particular individual or period. They represent the toil of the 'unknown smith' moving from place to place within a terrain defined by ties of association and kinship, to smelt his ore and most likely make his objects as well. His forced self-reliance may not have been due to the lack of goods and ideas to trade and exchange, but rather to the lack of routes over which trade could pass for a large part of the year. The mounds bear testimony to an industry that was built on self-reliance in a rugged landscape, with remote settlements and extremes of climate, but containing an abundance of natural resources.

There is one area in the Highlands which forms a notable exception to the above rule: Loch Maree, Wester Ross (Fig 1.2). The history of its local iron industry, spread along both shores of the loch, has been well documented by Dixon (1886). A total of six iron working sites and another eleven locations with bog iron have been listed (Dixon 1886) but it is only the three least accessible, along the north shore of the loch, which survive today. These include Poolewe (Red Smiddy), Letterewe and Fasagh (Fig 1.2). The sites are evenly spaced apart, at the upper end, the middle and the lower end of the loch, and all three contain extensive evidence for iron working. Poolewe and Letterewe have been associated with blast furnace and high bloomery (stucköfen) remains, respectively (Lewis 1984; Hume and Tabraham 1980), while Fasagh has been characterised as a bloomery site (Lewis 1984; Hume and Tabraham 1980; J Hume, pers comm).

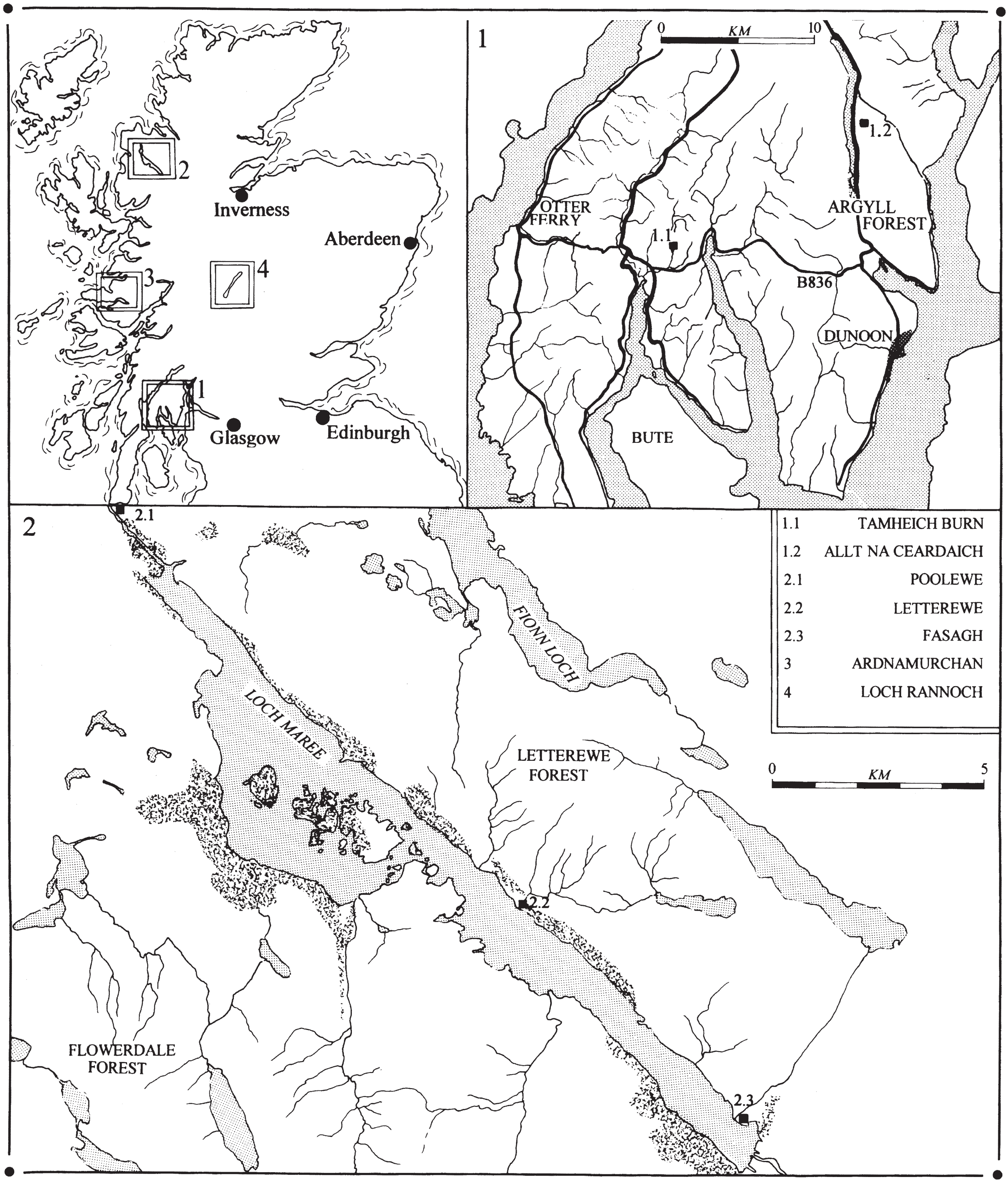


Figure 1: Map of ironworking sites surveyed and excavated in the Scottish Highlands.

Loch Maree, and Letterewe in particular, are closely associated with Sir George Hay, a prominent political figure of the early 17th century, who rose to become Lord Chancellor of Scotland. It seems that Sir George retreated to Loch Maree from Edinburgh in or around 1609 to install 'a company of Englishmen making iron and casting great guns until the wood of it (Letterewe) was spent and the lease of it expired' (Dixon 1886, 79). The workers were apparently mining their own iron ore locally although 'mining' and 'working' may have been used interchangeably by the 17th century source. Sir George Hay was not the only entrepreneur with business interests in the area. Two Englishmen, James Galloway and Nathaniel Udward, in partnership with the Earl of Seaforth, to whom the woods of Letterewe belonged, acquired 'a patent for the manufacture of iron ordnance in Scotland' under Charles I, dated June 1626, with production starting about three years later in 1629 (Lindsay 1984, 51). These later works represented either a 'change in management' or were new ventures altogether. Since Sir George had leased the same woods from the previous Earl of Seaforth, the former seems more likely. Indeed, the Wardlaw MS, dated to *c*1634 refers to 'Letter iu....where the English had a forge and ironworks under Seaforth'.

Given the remains that still survive at Poolewe, Letterewe and Fasagh, it is tempting to ascribe particular works to named individuals. From the archaeological evidence it is quite clear that, at all three sites, considerable capital investment was involved; a sum of upwards of £2,000 is known to have been advanced by the Crown to Galloway and his associates (Lindsay 1984, 51). However, the ironworks may be spaced too far apart to be part of the same cycle of operations, a distance of six to seven miles of very rugged territory separating one from the other. The loch, although navigable, is nevertheless unpredictably affected by the westerly winds, particularly over the winter months. In any case, both phases of activity, the first by Sir George Hay and the second by the three associates, remain to be fully established by the field evidence.

This pilot study aims to juxtapose the local tradition, as represented by the numerous bloomery mounds, with the 'imported' technologically advanced installations seen at Fasagh, and to highlight the differences that have arisen from the study of both so far.

Methodology: an integrated approach

The approach adopted here comprised four separate phases of work: (a) the evaluation of the documentary sources, (b) field assessment (to include bloomery mound recording, industrial waste sampling and geological prospection), (c) field prospection to include geophysical, and archaeological prospection (trial trenching) and (d) materials analysis. A deliberate effort was made to avoid dividing up activities in the conventional manner into archaeology (field based) versus laboratory work (post-excavation). The motive behind such an approach was that these mounds and their associated remains should be continuously examined, not as isolated materials or structures but in the context of the environment that surrounded them and out of which they emerged.

Documentary Source Evaluation

Existing primary sources for references to bloomery sites are concentrated primarily within the National Monuments Record for Scotland (housed by the Royal Commission on the Ancient and Historical Monuments of Scotland) and the volumes of *Discovery and Excavation in Scotland*. To these must be added the secondary sources which include the extensive early surveys by MacAdam (1887) of bloomery mounds in the Highlands and Lowlands of Scotland, of Dixon in the parish of Gairloch, Ross-shire (1886), and the more recent work of Aitken (1970) who surveyed and partly excavated bloomery mounds in Perthshire and Argyllshire. It is from this base that the key concentrations of sites were identified and suitable areas (based on density of sites) were chosen for the field assessment phase of the work.

Field and Geological Assessment

Of the 23 sites, three representatives are discussed here. These include Tamheich Burn and Allt na Ceardaich at Loch Eck (Fig 1.1) and Fasagh at Loch Maree (Fig 1.2). Field assessment was designed to allow a better understanding of the relationship between the bloomery sites, the landscapes in which they are found and the natural resources which were utilised for their construction and operation. Bloomery mounds are distinguishable from the rest of the landscape by their bright green covering, which tends to be much greener than the surroundings (this covering arises from sphagnum moss colonisation) and is probably due to drainage. In nearly all cases the mounds were located in the immediate vicinity of usually red-brown stained streams. The sites are mostly undated, although some have been ascribed to the medieval period on the basis of C-14 dating (J Wordsworth, pers comm).

The geological input was an essential part of the field assessment. A prospector's approach was developed, whereby stream beds were panned and the material recovered was analysed and examined in association with metallurgical waste recovered from the furnace (when found) and the slag heaps. By juxtaposing regional and local geology (Hall and Photos-Jones forthcoming), an attempt was made to assess the likely ore deposits whilst avoiding the pitfall of the 'blind' assumption that bog ore was used. Nevertheless, attention was focused on the way that bog iron ores can be prospected for, and used either in isolation or in combination with other sources of ore. The conventional idea that 'peat was lifted and bog ore was retrieved' really begged the question how it was known that ore was there to be found in the first place. The red streams, so common in the Highlands, may have provided a more obvious source, if uncertain in quality, of iron oxy-hydroxides (bog iron ore). The frequent occurrence of the Gaelic word 'méinn' to refer to iron ore associated with red streams has highlighted this connection (R Wentworth, pers comm). All of the above points, together with a general survey of the Scottish iron ores (large and small scale) will be given in Part II, drawing particular attention to the existence and different mechanisms of formation of the oxy-hydroxides as well as bedrock ore, *ie* hematite veins and magnetite.

General slag typology, as could be deduced from surface collection around and from within bloomery mounds, revealed, overall, a small size for what appears to be tap slag, suggesting either breaking of the slag or tapping to form a 'trickle'. A uniform blue-black colour was evident, suggesting a high manganese content. However, at Fasagh, Loch Maree, slag remains were typologically very different. Tap slag was absent and, instead, large blocks of porous, brown-black slag of viscous appearance were concentrated in particular locations around the site. Large round cakes (250-300mm in diameter) of brown-black slag of plano-convex shape were also evident, most occuring in 'pieces of a pie' rather than in complete fragments.

Geophysical Field Prospection

Geophysical prospection consisted of both magnetometer and resistivity surveys. It was followed by trial trenching of the relevant anomalies. A Geoscan fluxgate gradiometer (FM36) and a resistivity meter (RM15) were used. The purpose was to identify the location of the associated hearths/furnaces and other types of working floors. To effect this, a programme of geophysical survey was undertaken, centred on the slag heaps and extending to the surrounding areas.

The fluxgate gradiometer measures alterations in the earth's magnetic field on a micro-scale; it is therefore possible to carry out surveys at 0.25m intervals. Anomalies, with respect to the background, can be geological in origin, but can also be caused by human activities: fires cause a strong increase in the magnetic readings of the soil, while topsoil and subsoil produce different levels of magnetism. Accordingly, negative features containing silts or back-filled topsoil will frequently be apparent geomagnetically, against the background level of the subsoil.

The use of magnetometry on bloomery sites would be expected to give large magnetic anomalies of two types, those associated with thermo-remanent magnetism from the furnace remains and those arising from iron-rich slag. It was postulated that the former would be significantly higher than the latter, thus allowing the location of furnaces to be identified. However, as a result of prospecting at Fasagh, it became apparent that building materials not associated with furnaces, but with the construction of the anvils and their supporting platforms, also produced large magnetic anomalies. This was due to the high iron oxide-metallic iron content of the building materials, the method of production of which is currently the focus of a separate investigation. Only anomalies whose extent was in excess of 2m by 2m were fruitful targets for archaeological trenching, and these were indeed tackled.

Resistivity survey aims to measure the electrical conductivity of the soil; the greater water content of negative features, such as ditches and pits, normally causes them to be readily apparent. Similarly, solid obstructions such as walls and other structural remains will normally be apparent because of their lower conductivity of the charge being passed. The intention of the resistivity survey was to locate water channels and to confirm the magnetic data where structural remains had been indicated. The advantage of the electrical technique is that the presence of large amounts of slag scattered throughout the area would not screen out significant remains, as could happen in the magnetic data.

Analytical Data Acquisition and Methodology

In addition to the library and field-based work, a large programme of analyses was carried out on the metallurgical waste, which consisted of slag, furnace lining and metal (when available) from field surveys as well as from excavated areas. The purpose of this detailed examination was to acquire a representative chemical and mineralogical composition for the Highland bloomery-mound slags. Phase analysis is a useful tool in this connection since it can, in principle, relate slag to ore and artefact. It also provides a possible means of differentiating between slags from different locations, since more than one set of data can characterise the same sample.

Each sample was sectioned, mounted in metallographic resin, ground and polished with 6, 3 and 1 micron diamond pastes. Each was examined optically with the metallographic microscope and then coated for SEM-EDAX analysis.

Because of the large number of samples the following method of analysis was applied: firstly, area analyses (two) were carried out at low magnification (x15-25); secondly, two different representative areas were selected and spot analysis (at x3000, 25keV) was carried out on all crystalline and non-crystalline phases present within each. These phases included wustite (FeO), fayalite (Fe_2SiO_4), titanium or aluminium iron oxides (TiO_2-FeO or Al_2O_3-FeO) and the interstitial glassy matrix which in itself is normally a eutectic of anorthite ($CaAl_2Si_2O_8$) and fayalite. Thus, a set of ten analyses was produced for each sample. Eleven elements were analysed routinely. Table 1 presents the average composition for each phase.

The picture that has emerged from the analysis of Highland bloomery mound slag is that it is surprisingly uniform in chemical composition and mineralogical structure. In the future the aim is to examine the bloomery mound metallurgical waste not in isolation but in combination with metallurgical waste, currently under study, from two medieval urban centres, Perth (Holdsworth 1987) and Inverness (Wordsworth 1982) and indeed other sites as well (Photos-Jones and Atkinson; in press). It was speculated that by analysing medieval and post-medieval material from 'town and country' a possible link might

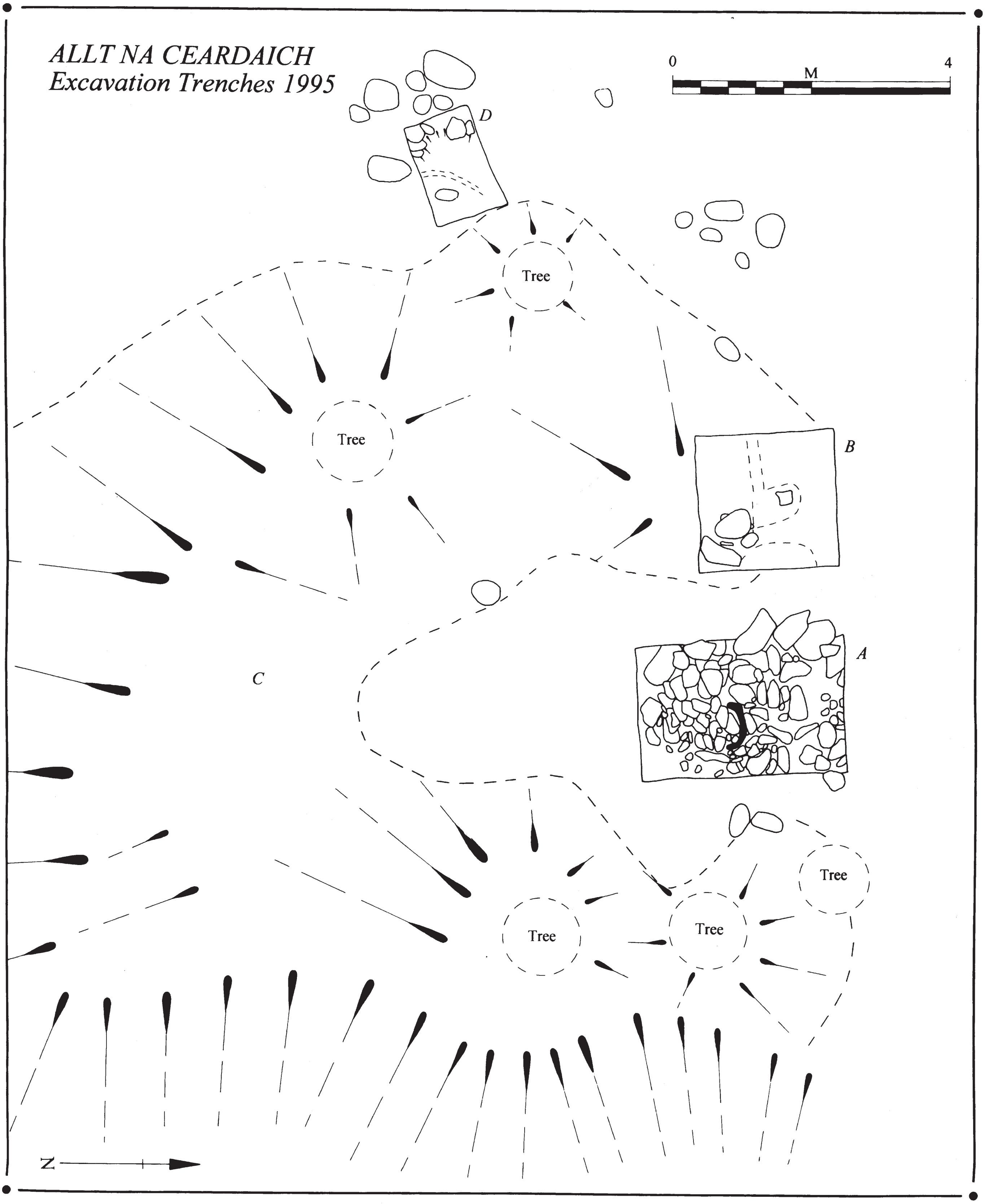


Figure 2: Plan of Allt na Ceardaich, Cowal Peninsula.

eventually arise, connecting urban and rural iron working installations usually associated with smelting (Yeoman 1995). Was smelting carried out in locations in the Highlands which bordered Lowland urban centres or did urban centres like Perth produce their own raw metal?

The Cowal Peninsula Sites

The results of the archaeological work at two locations in the Cowal Peninsula, Tamheich Burn (NS 030 821), the site of two bloomery mounds, and Allt na Ceardaich, Loch Eck (NS 1425 9275) can now be set out in detail. The former is located on a stretch of relatively low-lying ground in a nook of the burn of the same name three miles SE of Clachan of Glendarual on the edge of a Forestry Commission plantation (Fig s 1.1 and 1.2). The site on first assessment consisted of a relatively small slag heap (2m by 2m by 1m) lying in an open area of ground surrounded by scrub and Scots oak on the burn's edge. The slag recovered from the mound was small in size (20-40mm) and appeared as though it had been deliberately broken up.

Allt na Ceardaich, the largest site visited in the Cowal Peninsula, is in fact the largest of all those examined in the Highlands (Atkinson and Photos-Jones 1995), with the exception of Fasagh. The site is located on the E shore of Loch Eck (Fig 1.2). Lying immediately W of the burn of the same name some 30m above the old line of the loch-side road, it was evident within a clearing amidst forestry plantation. The site covered an area of 12m by 10m and stood to a height of 1m. The mound of slag was formed into a horse-shoe shape with gaps in the N and W edges. At two locations, and in the immediate vicinity of the burn within the horse-shoe, mature trees were growing over the top of the heaps (Fig 2). Place-name evidence indicates that the site had been used for iron working (literally translated as 'the river of the smith').

Geophysical survey and excavation at Tamheich Burn

Tamheich Burn I, a small mound standing on the W bank in a loop of the burn, was surveyed with the fluxgate gradiometer as a single 20m grid at 1m intervals, although the available area for survey was only 15m by 15m. The mound stood out clearly, while there were indications of at least one high anomaly outwith the mound, suggesting the presence of a furnace, Figure 3, above. A resistivity survey was also undertaken but the results were poor in comparison.

A rapid scan was conducted over the ground between the small mound of Tamheich Burn I and the marginally larger mound of Tamheich Burn II. During this scan, two points were noted where high magnetic readings were apparent, which might have revealed the location of either piles of slag or small furnaces. The second bloomery mound, Tamheich Burn II, was somewhat higher than the first, although roughly in the same area. Trial trenching revealed a severely disturbed structure, so no further work was carried out.

At Tamheich Burn I, after de-turfing and initial cleaning, an area of stonework consisting of large flat slabs which varied in size from 0.20-0.30m by 0.10-0.20m, was revealed; this stonework was formed in such a way that it established a small mound of overlapping slabs with a flatter area on the top. Removal of the first layer of stonework revealed the outline of a centrally positioned clay-built and clay-lined furnace in-filled with a combination of upper stonework and charcoal-rich silt. The furnace bowl appeared square with rounded corners, measuring 0.30m E-W by 0.32m N-S. A vitrified clay lining was intact along three sides and still standing to a height of 0.30m on the W side. The E side was missing; likewise the supporting stone structure on this side had also been severely disturbed. An alteration to the bowl was also evident on its S edge (Fig 3, below). Two stone slabs partially covered the base of the furnace, however there was no evidence that these slabs had been heated to a high temperature and consequently they are interpreted as

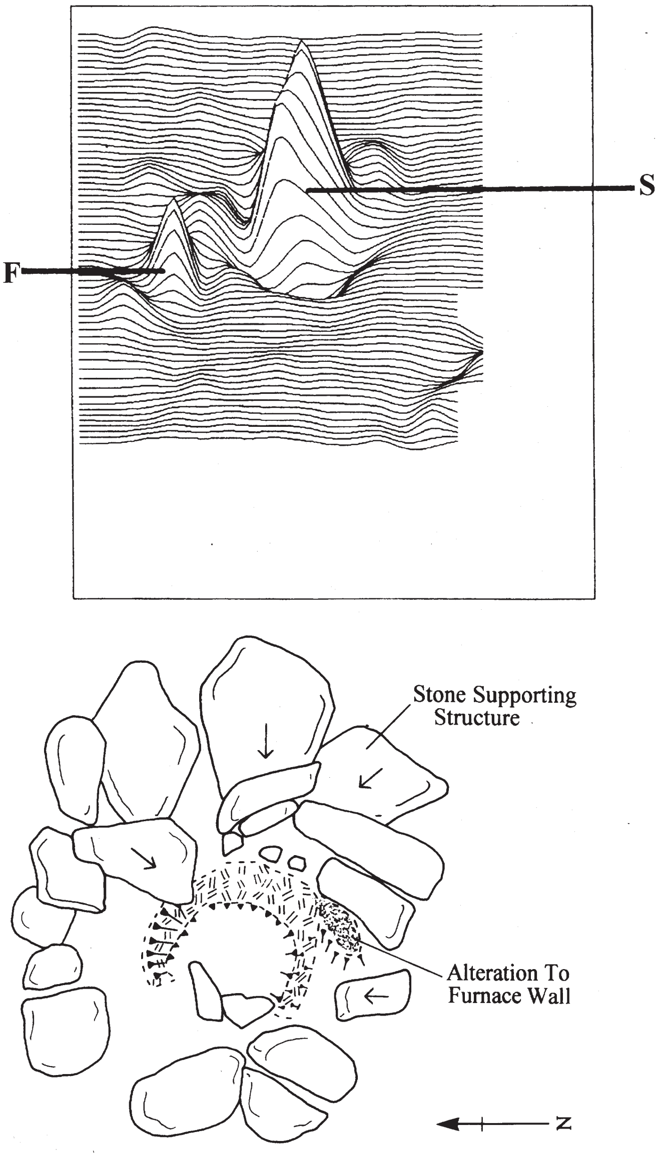


Figure 3: Tamheich Burn I, Argyll. Above: geophysical survey, 1:369, F=furnace, S=slag heap. Below: plan of furnace, 1:20

tumble after the final cleaning out of the furnace. The tuyère must have been positioned on the W side, given the higher degree of vitrification along that wall.

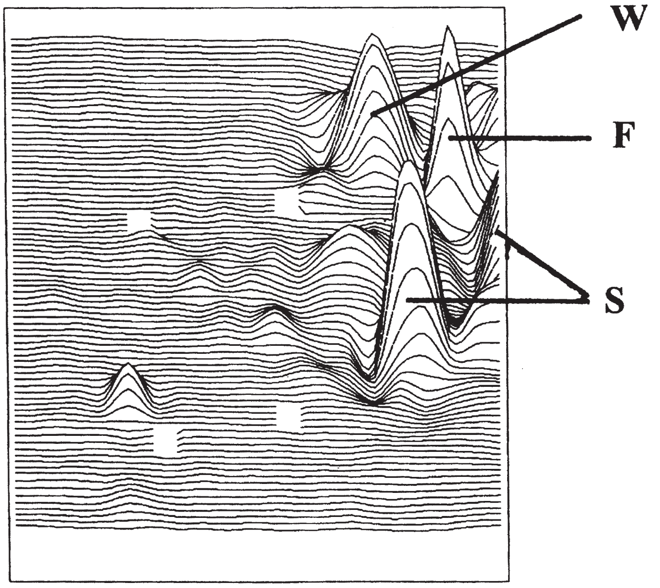
Geophysical survey and excavation at Allt na Ceardaich

This survey was undertaken solely with the fluxgate gradiometer. It had been the intention to use resistivity as well at this site, but, because the bloomery mound stands in the middle of forestry and the location is thick with fallen trees and branches, it would have been difficult to obtain good electrical contact between the probes and the soil.

The survey consisted of a single 20m grid. The plot (Fig 4 above) shows the extent of the mound, and also apparent are two patches of high magnetic readings, one in direct relation to the mound and the other some 5m to the SW. Both are less magnetic than the slag of the mound and as a result stand out within the data set. The mound itself appears as a series of separate dumps of slag which have built up into the current horse-shoe shape. Area A had been visually identified as slag heaps. Excavation revealed B as a working floor and C as a furnace. The plot in Figure 4 can be compared with the plan of the site (Fig 2). A third trench was also introduced to assess whether the area surrounding the mound was in fact a water channel; substantial stone blocks along the edges of this area suggested this as a possibility.

The geophysical survey at Allt na Ceardaich successfully located the furnace and thereby allowed the excavation trench to be positioned directly over it. After primary cleaning it was evident that the furnace was not quite as simple as the one at Tamheich Burn. The construction of the supporting stone structure used medium-sized stone slabs (approximately 0.2-0.3m long by 0.1-0.2m broad) built up to form a mound (Fig 4, below). This did not however appear to be the case on the E side where a large upright slab appeared to delineate the edge of the structure. The furnace bowl of squarish section had become filled with a mixture of silt with occasional charcoal flecks. Further excavation of the interior of the bowl revealed a tumbled stone slab layer which sealed the primary deposit of charcoal-rich silt in the base of the furnace. The charcoal layer, comprising birch (*Betula*), hazel (*Salix*) and willow (*Corylus*), was sampled and radiocarbon dated (at the Scottish Universities Research and Reactor Centre) to cal AD 1450-1660 at 2 sigma (95% confidence) (GU-4415).

The only existing furnace wall stood 0.35m high on the north side with the tuyère positioned only 100mm from the base. The materials for the furnace walls varied considerably from the vitrified lining material on the N, to merely stone slab in the S and partly to the W and tapped slag overlaid with a stone upright in the E side. Tapping of the slag at right angles to the tuyère is perhaps not as common as tapping from directly opposite. On the other hand the positioning of the tuyère is critical to the shape and mechanism of formation of the bloom. At Allt na Ceardaich the tuyère hole is rather low, not allowing, in principle, enough room for the bloom to grow and separate from the slag.



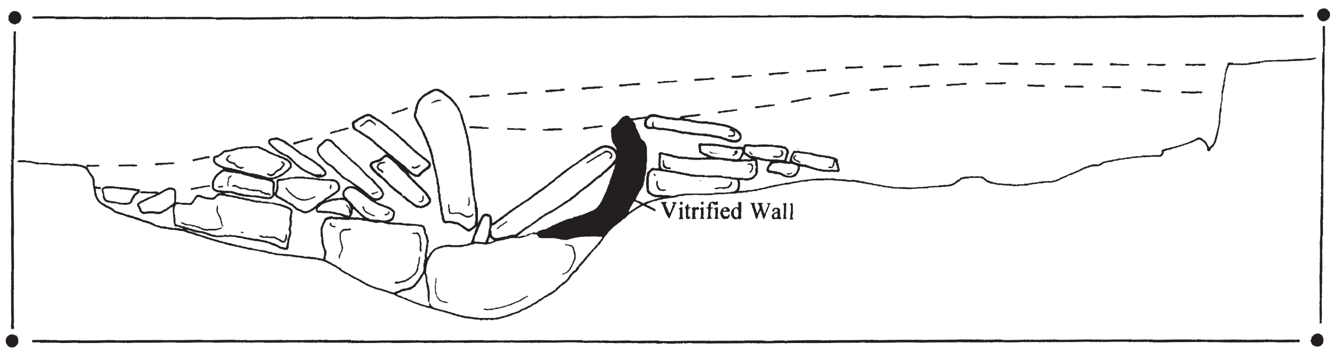


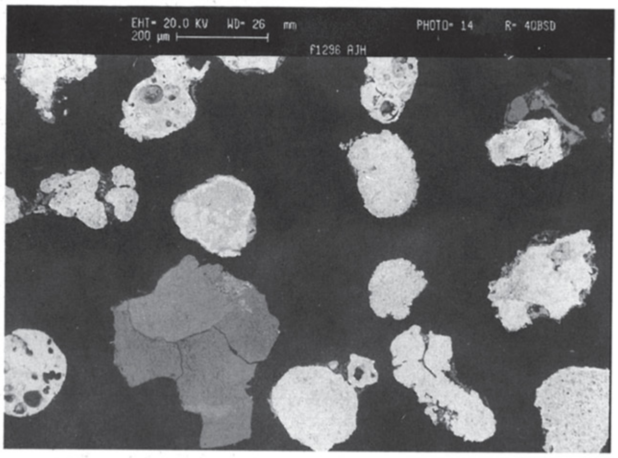
Figure 4: Allt na Ceardaich, Argyll. Above: geophysical survey, 1:369, F=furnace, S=slag heap, W=working area. Below: East-facing section of furnace, 1:20

Analysis of Allt na Ceardaich 'ore'

At Allt na Ceardaich a panned concentrate was obtained from the soil around the hearth. This was subjected to X-ray diffraction analysis (XRD) and polished thin-section petrography. XRD analyses confirmed major magnetite and hematite with quartz and possible wustite. Polished thin section petrography confirmed coarse grained magnetite with some hematite and this should be considered as a potential source of ore. The grains proved in thin section to display a large range in textures mainly indicative of variably processed iron ore suggesting all stages from partial reduction to metallic iron (Fig 5a). Figure 5b presents the qualitative analysis of each individual grain of a sample of panned concentrate shown in Figure 5a. Apart from quartz and K-feldspars, iron-rich grains contained minor and trace amounts of manganese and aluminium. The various stages of reduction of an individual iron-rich pellet are shown in Figures 5c and 5d. Manganese appears to increase towards the rim of the grain suggesting that perhaps the element was absorbed into the iron grain from small manganese nodules like that shown in Figure 5e. The origin of the latter may be in

Figure 5: Panned concentrate from the vicinity of the hearth at Allt na Ceardaich. SEM BS images of a) grains in polished section, c) iron-rich grain and e) manganese nodule. SEM-EDAX qualitative analyses: b) most grains are iron-rich, d) iron-rich grain showing areas of manganese enrichment.

a



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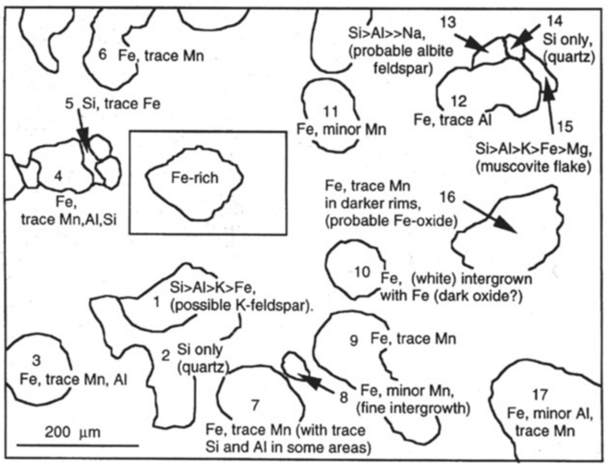

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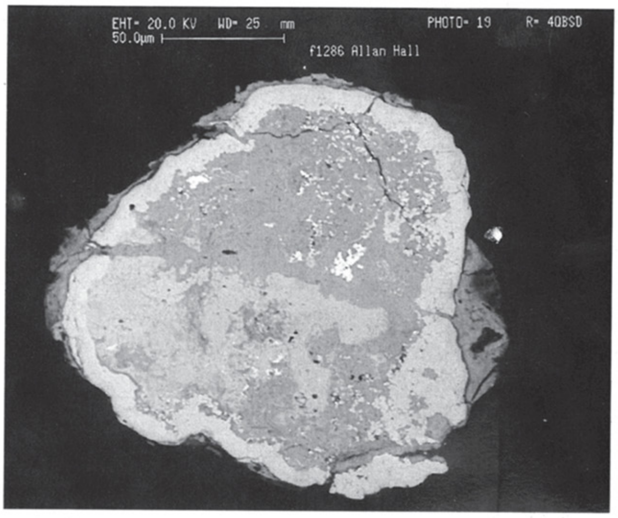

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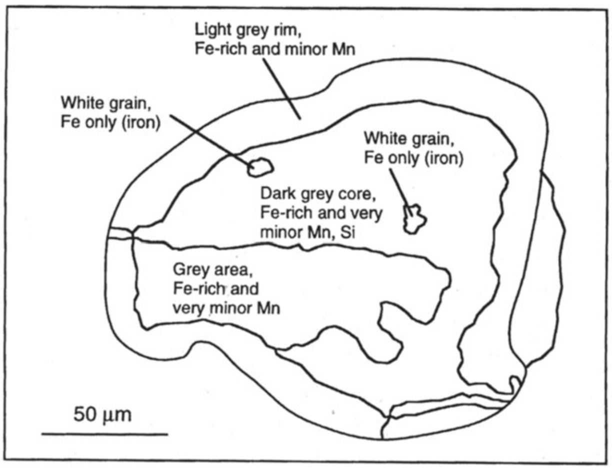

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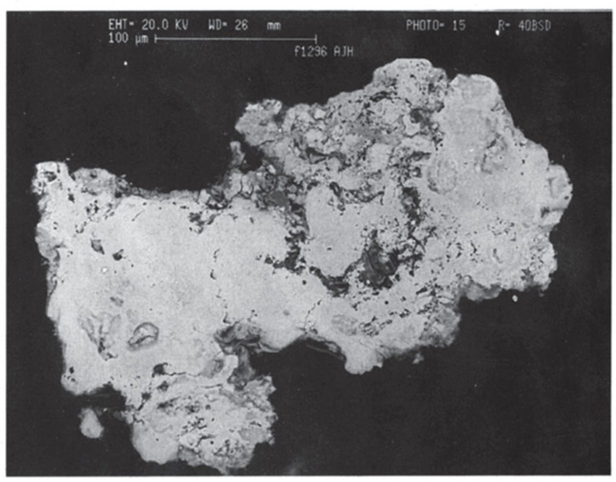

local manganiferous bog iron ore although the nodules may have also been a constituent of local peat.

The metallurgical waste at Tamheich Burn, Allt na Ceardaich and other sites in the Highlands

The analysis of the metallurgical waste from various areas in the Cowal peninsula from both surface finds and excavated material suggests bloomery iron smelting and possibly iron smithing as well, at least at Allt na Ceardaich. Bloomery slags were primarily small in size (less than 50-60mm) and had been tapped. Tapping must have been continuous, but in small amounts, equivalent to a 'trickle', as deduced from the multiple solidification fronts (Fig 6a). Large pieces, or slag cakes, were retrieved from Allt na Ceardaich only. Slags were blue-black in colour, dense and heavy with little sign of rusting and porosity.

XRD analyses of three samples from Allt na Ceardaich (BCP 10, 13 and 14, Table 1) revealed wustite and fayalite as well as hercynite (XSB3). Hercynite is an Al_2O_3-FeO phase which can incorporate small quantities of silica, calcium and manganese. Magnetite has been identified in one sample on the basis of grain morphology (it is angular as opposed to wustite which is round) suggesting local oxidising conditions. Magnetite can be accurately differentiated from wustite on the basis of hardness testing or petrographic examination of a polished thin section (Killick and Gordon 1987) but no such testing was undertaken here.

A select number of bloomery slag analyses from the Cowal and other parts of the Highlands (including Fasagh) are shown in Table 1. Cowal slags are characterized by a high iron content ranging between 60-70% FeO in area (3mm by 4mm) analysis with the SEM-EDAX. Most of the iron appears to be in the oxide and silicate phases with little evidence of metallic prills. The main phases include fayalite (long needles), wustite (dendrites fine and coarse) and a silicate-rich interstitial glass which is finely crystalline at high magnification. Excess aluminium (*c*10% on area analysis) often leads to the formation of angular grains of hercynite, with the relative amounts of each component ranging from 20% Al_2O_3-70%FeO to 40% Al_2O_3 - 45%FeO (Fig 6b). The formation of hercynite can probably be attributed to the presence of small amounts of aluminium in the ore.

The presence of manganese is ubiquitous from almost all sites sampled around the Highlands. In some cases it is as high as 30% (on large area analysis). On the other hand, phosphorus is generally low, but it would not be expected to be present in the slag, partitioning instead within the metal. Calcium, potassium and magnesium are also rather low (less than 2-3%) with some trace levels of sodium present as well. The presence of barium was also noted in the slags' glassy phase. Barite with or without calcite can often accompany hematite. Manganese and aluminium appear to 'fingerprint', albeit in a coarse manner, the composition of Highland bloomery slags and will be used for future comparison with bloomery slag from other locations in Scotland.

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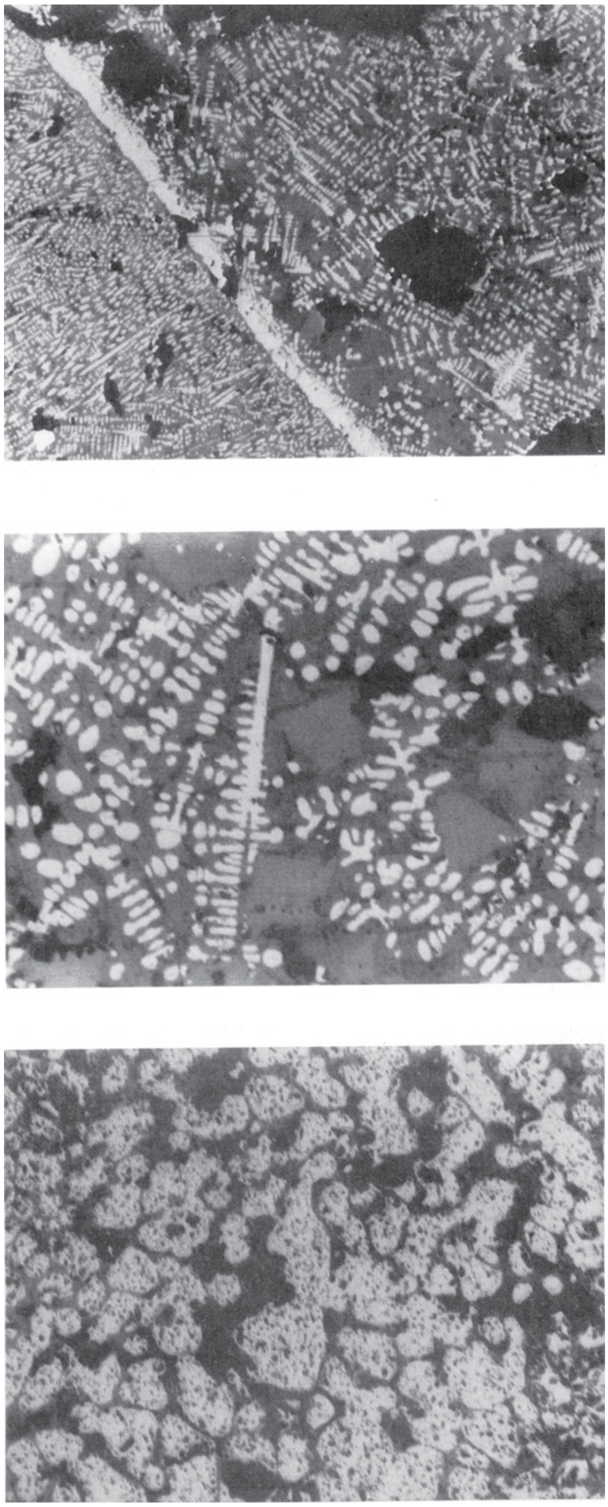

Figure 6: Optical images of slag samples a) solidification fronts, x 45, b) mineralogical phases include wustite, fayalite, hercynite and glassy interstitial material, (x350), both from Allt na Ceardaich, c) massive wustite (x350), from Fasagh.

Charcoal was found in abundance at Allt na Ceardaich and from within the furnace itself, suggesting that it was the only fuel used. Birch, hazel and willow were all recovered, so the use of peat as a source of fuel is rather unlikely.

Furnace construction at Allt na Ceardaich

From the lower illustration in Figure 4 and the variety of materials associated with construction, it is apparent that the Allt na Ceardaich furnace is not of conventional shaft furnace design. In reality a closer parallel exists with a hearth. An early description of a bloomery hearth in Britain appears in a series of letters written in 1674-5 by a Mr John Sturdie of Lancashire concerning the conversion of iron ore (and more particularly of hematites), into wrought iron at Milthorpe Forge in that county. The letters were published in the *Philosophical Transactions* of 1694, describing the hearth and process at Milthorpe Forge and were communicated by Dr Martin Lister FRS (Fell 1908, 204): '... it (the hearth) is very like a Blacksmith's, *viz* a plain open hearth or bottom without any enclosing walls, only where the nose of the bellows comes in through a wall there is a hollow place (which they call the Furnace) ... This hollow place they fill and up-heap with Charcoal, and lay the Oar (broken small) all round about the charcoal upon the flat Hearth to bake it as it were ... The glassie Scoriae run very thin, but the Metal is never in a perfect Fusion, but settles as it were in a Clod, that they take it out with Tongs and turn it under great Hammers, which at the same time beat off (especially at first taking out of the Furnace) a deal of coarser Scoriae and form it after several Heats into Bars' (Letter dated 25th September 1675).

The smiths at Allt na Ceardaich appear to have run a quite inefficient process with much iron being lost in the slag. Very few metallic prills (inclusions) have been noted within the slag, an observation implying that most of the iron formed and consolidated nearer the tuyère, or in any case far away from where the slag was tapped. On the positive side, the presence of such high levels of iron and manganese must have made the slag run quite freely, or, to quote Mr Sturdie's account, 'very thin'. Should Allt na Ceardaich smiths have been operating a bloom hearth rather than a furnace, this may have been their intention all along. A programme of analysis of the metallurgical waste from Allt na Ceardaich will follow a season of excavation of the entire site. The interpretation of the furnace and its products will be deferred until then.

Fasagh, Loch Maree

Survey and excavation at Fasagh

The site of Fasagh, Loch Maree (NH 011 654) sits on a tongue of land created by glacial melt waters at the foot of Slioch, at the confluence of the Albhuinn an Fhasaigh (Fasagh Burn) and Loch Maree itself (Fig 1, 2.3). The site covers a substantial area, but is most clearly seen in the elongated horse-shoe-shaped area defined by slag and upcast heaps, evidence of filled-in water leats and tailraces. It stretches for some 70m in length and is *c*20m broad at its widest. This is clearly the site of a large-scale industrial establishment with the possibility of further activity outside the horse-shoe, particularly to the N, where two substantial bloomery slag heaps are evident (Fig 7).

The site of Fasagh consisted of substantial banks and structures, leading to a rise and fall in heights accentuating inherent difficulties in the geophysical survey. Accordingly, grid transects followed slope rather than horizontal distances, ensuring complete coverage of the ground. Reading intervals were again 1m across 20m grids. The survey was impeded by tall bracken and heather. The extent of the area surveyed is indicated in the data, activity appearing to cease some 70m from the top of the horse-shoe (Fig 7). Two major anomalies were apparent, the readings from which were extremely high, indicating either very intense heating or the presence of substantial amounts of iron-rich material such as slag. Also apparent in the data were an area of high readings on the higher ground on the N side of the site, high readings at the E end of the site and high readings at the top of the horse-shoe. The geophysical results indicate a complex site with considerable activity within the working area and the possibility of further activity/industrial remains around the edges, particularly on the N edge of the area.

Two major geophysical anomalies were apparent within the central working area, each coinciding with the two structures previously interpreted as anvil blocks (Lewis 1984, 444). The anomalies reflect the building material encasing the two massive tree trunks (A and B, Fig 8). Similar high readings were recorded on the high ground to the N side, suggesting either similar types of building material or a large accumulation of slag.

Although substantial amounts of slag were identified and recovered from two large slag heaps to the N of the main working area, there was no evidence of what has been classed as a furnace in the plan provided by MacAdam of the Fasagh ironworks (1887, 107). Therefore trial trenching was targeted directly on structures A (NW anvil block) and structure B (SE anvil block) for the purpose of ascertaining their function as anvil blocks and establishing the precise cause of the high magnetic readings.

Structure A, Fasagh

The work focused on the cleaning of the feature and its adjacent channels (Fig 9); it was not the intention here to excavate in section. After cleaning it became clear that this had quite rightly been identified as an anvil block. The casing had been 'cast' to secure and protect a substantial

Table 1: SEM EDAX analyses of bloomery slags

Sample	Phase	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO
Tamheich Burn												
BCP16	W	0.00	0.00	0.64	1.01	0.00	0.24	0.00	0.12	0.36	7.27	90.4
	F	0.00	0.00	0.00	26.90	0.30	1.10	0.00	1.23	0.11	17.70	52.7
	I	2.85	0.00	17.08	34.70	0.61	0.86	6.28	8.16	1.89	5.48	22.1
BCP22	A	1.11	0.00	9.68	21.50	0.00	0.66	0.99	1.23	0.33	1.73	62.8
	I	0.00	0.00	36.16	3.27	0.00	0.37	0.06	0.09	0.59	1.22	57.8
Allt na Ceardaich, Cowal												
BCP10	A	1.84	0.27	7.82	19.8 0	0.41	0.63	1.49	2.11	0.39	8.75	56.5
	W	0.43	0.00	0.42	0.99	0.00	0.23	0.07	0.06	0.38	6.56	90.9
	F	2.23	0.60	9.06	29.00	0.19	0.27	2.14	2.98	0.26	10.90	42.0
	I	0.54	0.18	10.49	31.50	0.00	0.00	2.15	3.41	0.32	10.90	40.1
	H	0.00	0.00	28.41	3.13	0.00	0.00	0.20	0.24	1.15	6.40	60.5
BCP13	A	1.69	0.63	5.14	21.80	0.41	0.81	0.68	1.21	0.41	7.12	60.1
	W	1.12	0.63	0.86	1.06	0.62	0.46	0.00	0.00	0.91	3.15	90.9
	F	0.71	0.79	0.00	24.40	0.00	0.87	0.06	0.32	0.00	10.20	62.6
	I	2.31	0.00	16.85	35.30	0.81	0.91	4.88	4.40	1.14	2.35	27.0
BCP14	A	1.01	0.00	7.18	20.10	0.65	0.63	1.17	0.73	0.00	4.72	63.8
	W	1.64	0.41	1.06	2.01	0.00	0.59	0.06	0.05	0.63	2.65	90.8
	F	1.30	0.59	1.76	21.00	0.08	0.47	0.25	0.30	0.20	6.16	67.9
	I	3.88	0.00	15.42	37.80	1.72	1.00	5.99	4.29	1.47	2.09	26.4
XSB1	A	0.00	0.36	9.22	32.10	0.39	0.53	2.43	2.12	0.90	15.60	36.3
	F	0.00	0.57	0.33	27.30	0.00	0.00	0.00	1.28	0.07	23.60	47.8
	I	0.00	0.00	21.03	51.30	0.00	0.00	15.50	0.86	0.16	0.79	3.3
	I	0.00	0.00	24.33	21.90	0.40	0.00	4.60	2.68	5.71	6.05	33.0
XSB2	A	0.50	0.00	6.17	21.60	0.29	0.37	0.92	0.91	0.22	6.19	62.9
	W	0.00	0.00	0.55	0.61	0.00	0.00	0.05	0.00	0.61	2.32	95.9
	F	0.00	0.25	0.00	26.60	0.41	0.22	0.03	0.40	0.00	8.97	63.2
	I	3.14	0.14	14.68	35.20	1.71	1.27	6.03	4.16	0.63	2.64	30.4
XSB3	A	0.89	0.00	7.48	19.60	0.00	0.57	0.45	0.76	0.41	5.69	64.1
	W	1.17	0.27	0.71	1.35	0.32	0.21	0.03	0.03	0.67	2.39	92.9
	H	0.00	0.60	40.69	5.27	0.00	0.00	1.39	0.88	0.58	2.92	47.5
Cowal												
BCP1	A	1.46	0.28	3.97	14.80	0.71	0.87	0.48	1.63	0.68	11.40	63.8
	W	1.10	0.19	1.15	1.24	0.00	0.47	0.00	0.05	0.28	7.02	88.5
	F	0.75	0.33	4.54	21.50	0.19	0.48	0.24	2.19	1.51	14.00	54.3
	I	1.78	0.00	12.02	29.10	1.23	0.79	2.57	5.56	1.44	10.50	35.1
Sunfield, Cowal												
BCP4	A	1.14	0.97	5.37	21.10	0.45	0.55	0.84	4.88	0.65	30.30	33.8
	W	0.00	0.00	0.58	1.85	0.00	0.00	0.04	0.64	0.00	27.30	68.6
BCP5	A	0.00	0.00	4.70	13.80	0.55	0.00	0.79	2.94	0.40	11.40	65.5
	W	0.00	0.00	0.37	0.78	0.00	0.00	0.06	0.18	0.00	9.65	89.0
	F	1.13	0.21	7.85	26.00	0.99	0.43	1.55	5.70	0.78	14.60	40.8
Cowal												
BCP6	A	0.64	0.61	7.53	21.80	0.57	0.00	1.56	2.22	0.08	19.00	45.5
	F	0.00	0.00	1.26	5.99	0.00	0.00	0.17	0.50	0.36	15.00	76.7
	I	0.48	0.96	1.69	27.50	0.00	0.00	0.50	1.54	0.11	27.20	40.0
BCP7	A	1.10	0.00	6.15	15.80	0.21	0.44	0.66	1.43	0.00	13.50	60.6
	W	0.58	0.19	0.88	1.21	0.22	0.18	0.10	0.13	0.14	9.66	86.7
	F	1.27	0.67	1.42	26.40	0.11	0.18	0.20	1.91	0.07	21.30	46.4
	I	1.73	0.00	17.87	35.80	1.33	1.41	4.14	5.17	0.00	5.77	24.8
Sunfield, Cowal												
BCP8	A	1.34	0.00	4.69	13.40	0.00	0.30	1.31	1.84	0.44	6.13	70.5
	W	1.08	0.37	0.68	1.06	0.16	0.65	0.00	0.00	0.12	5.48	90.4
	I	0.86	0.12	9.51	30.60	1.25	1.06	3.42	4.96	1.07	7.82	39.4

Phases: A = area analysis, F = fayalite, H = hercynite, I = interstitial glassy matrix, W = wustite

Sample	Phase	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO
Whistle Field Road, Cowal												
BCP17	A	0.72	0.17	4.99	13.30	0.12	0.20	0.61	0.56	0.41	5.20	46.6
	F	0.00	0.00	7.29	20.70	0.00	0.00	1.18	1.81	1.11	9.14	58.7
	I	6.66	0.00	11.33	30.40	1.62	0.00	4.57	4.55	1.31	2.41	37.2
	H	0.00	0.00	20.74	3.71	2.34	0.00	0.00	0.00	1.18	5.47	66.6
BCP18	A	0.56	0.20	5.95	22.70	0.36	0.89	0.86	1.40	0.45	4.47	62.3
	W	1.21	0.00	2.51	5.35	0.28	0.43	0.53	0.53	1.25	1.67	86.3
	F	0.00	0.21	0.00	23.00	0.71	0.65	0.00	0.41	0.13	5.82	69.0
	I	1.98	0.00	13.31	34.20	0.65	1.46	4.21	5.44	0.79	2.57	35.4
	H	0.00	0.00	39.49	0.49	0.00	0.00	0.03	0.00	0.64	2.77	56.3
High Hall, Cowal												
BCP19	A	0.75	0.54	1.98	8.24	0.58	0.32	0.20	0.58	0.00	5.29	81.5
	W	1.03	0.38	0.63	1.03	0.00	0.23	0.08	0.00	0.04	3.47	93.1
	F	0.39	0.00	0.00	26.60	0.00	0.00	0.08	2.44	0.00	10.60	59.9
	I	1.17	0.00	4.18	25.50	0.40	0.00	2.98	5.17	0.00	7.22	51.7
Strone Road End, Cowal												
BCP23	A	0.00	0.00	2.65	15.10	0.00	0.25	0.64	0.88	0.17	4.02	76.3
	W	1.28	0.21	1.12	1.03	0.00	0.41	0.03	2.11	0.00	0.00	93.5
	F	0.00	0.39	0.00	25.00	0.00	0.53	0.00	0.38	0.28	7.07	66.4
	I	2.87	0.00	17.62	36.70	1.89	1.59	6.35	6.21	0.42	1.88	24.5
BCP24	A	2.21	0.41	4.51	20.60	0.24	0.27	1.03	1.79	0.17	3.13	65.7
	W	0.81	0.00	0.49	1.31	0.00	0.89	0.04	0.04	0.23	1.53	94.6
	F	1.11	0.53	0.00	25.80	0.88	0.94	0.00	0.62	0.00	4.61	65.6
	I	2.56	0.00	12.08	32.80	3.14	1.49	3.87	6.36	0.35	1.82	35.6
Allt Beiche, Arran												
BAR3	A	1.00	0.46	6.16	21.90	0.28	0.32	0.57	0.88	0.21	5.78	62.5
	F	1.91	1.04	1.24	26.00	0.00	0.16	0.07	0.53	0.31	8.38	60.4
	I	0.65	0.00	12.83	47.70	0.82	0.62	1.02	1.15	0.47	3.51	31.3
BAR4	A	0.00	0.00	3.97	19.50	0.20	0.00	0.64	1.65	0.12	5.14	68.8
	W	0.00	0.48	0.90	1.37	0.32	0.34	0.03	0.30	0.40	2.03	93.9
	F	0.00	0.79	0.13	24.10	0.20	0.54	0.00	0.70	0.08	7.17	66.3
	I	2.69	0.00	14.27	35.00	1.77	1.42	6.15	8.51	0.00	1.85	27.9
Dun Antrek, Isle of Skye												
BAR5	A	0.00	0.00	2.40	8.72	0.00	0.42	0.00	1.23	0.00	1.63	85.6
	W	0.00	0.23	0.17	1.12	0.00	0.03	0.23	0.11	0.62	1.38	96.4
	F	0.00	1.46	0.40	28.90	0.00	0.03	0.48	4.03	0.32	4.26	59.9
	I	2.05	0.22	11.69	33.10	0.55	1.58	3.68	13.20	0.68	1.77	31.6
Colliemore, Arran												
BAR6	F	0.34	0.22	4.76	19.00	0.37	0.00	0.38	1.35	0.12	4.60	66.7
BAR8	W	0.00	0.00	0.22	1.13	0.16	0.00	0.08	0.00	0.34	2.41	95.2
	F	1.80	1.02	0.00	27.50	0.00	0.00	0.00	0.81	0.03	7.67	61.2
	I	0.00	0.00	13.64	38.49	1.33	0.31	4.21	7.23	0.43	2.10	31.9
BAR9	W	0.00	0.27	5.15	9.58	0.29	0.00	1.11	0.00	1.34	0.23	81.8
	H	0.00	0.00	22.68	41.10	0.00	0.00	6.96	0.07	0.40	0.00	29.1
Aulich, Perth												
BRM1	A	0.69	0.20	4.53	17.40	0.00	0.00	0.69	1.30	0.18	0.74	74.3
	W	1.52	0.83	1.40	1.40	0.00	0.00	0.02	0.00	0.16	0.59	93.9
	F	0.53	0.70	0.15	27.30	0.00	0.00	0.09	0.91	0.09	1.41	68.3
	I	2.26	0.00	17.33	38.40	0.20	0.00	4.30	8.00	0.48	0.57	28.5
BRM2	A	0.98	0.00	4.84	11.10	0.60	0.40	0.14	0.69	0.07	5.04	75.7
	F	1.16	0.55	0.88	26.50	0.26	0.00	0.17	1.11	0.00	12.30	56.4
BRM3	W	0.49	0.00	1.53	2.70	0.16	0.00	0.37	0.55	0.30	5.10	88.7
	I	2.59	0.00	14.87	27.70	0.85	0.29	2.97	5.84	0.00	5.05	37.0
Fasagh, Loch Maree												
FA 101A	A	0.54	0.55	2.32	15.63	0.75	1.80	0.73	1.94	0.00	0.52	75.2
FA 101B	A	0.00	0.22	0.98	11.93	0.62	1.97	0.10	0.14	0.00	0.60	83.1
FA 102	A	0.07	0.64	1.47	9.66	0.49	1.38	0.39	0.85	0.00	0.36	84.7
FA 103	A	0.00	1.42	1.45	16.51	0.73	3.15	0.00	1.47	0.10	1.96	73.1

Phases: A = area analysis, F = fayalite, H = hercynite, I = interstitial glassy matrix, W = wustite

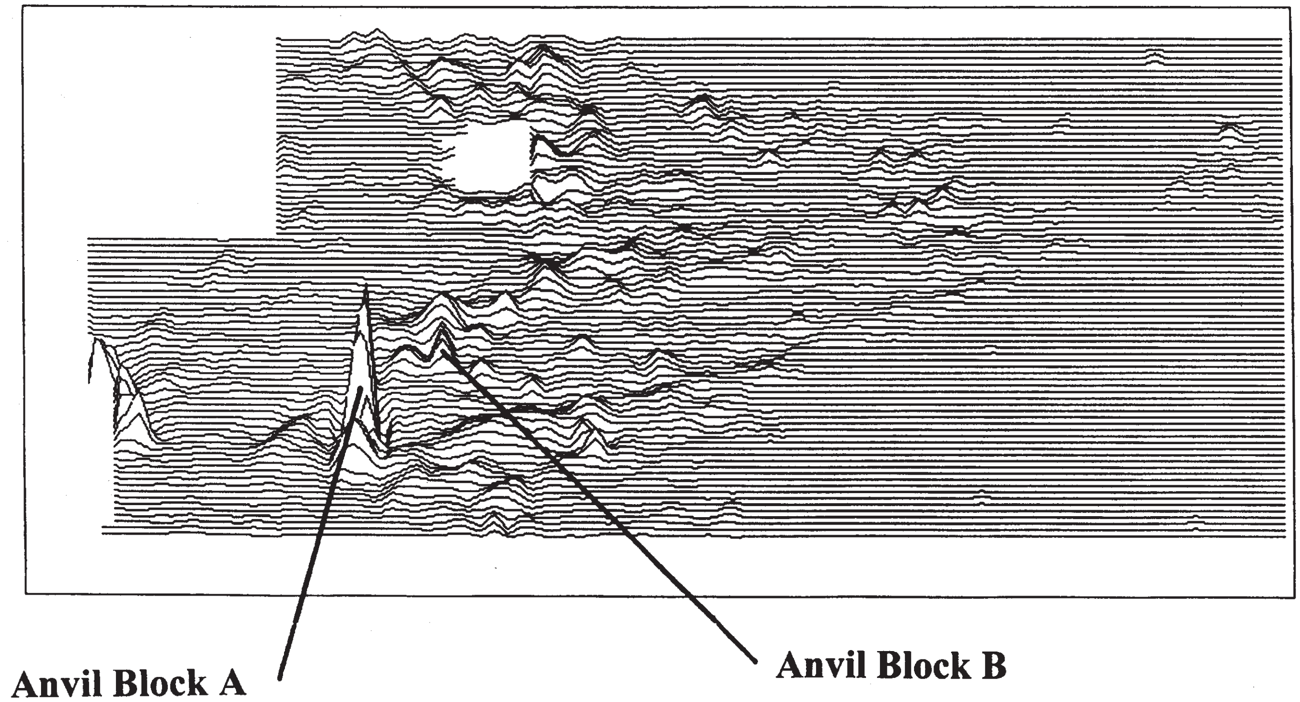

Figure 7: Geophysical trace plot of Fasagh iron works, view to NE, 1:738

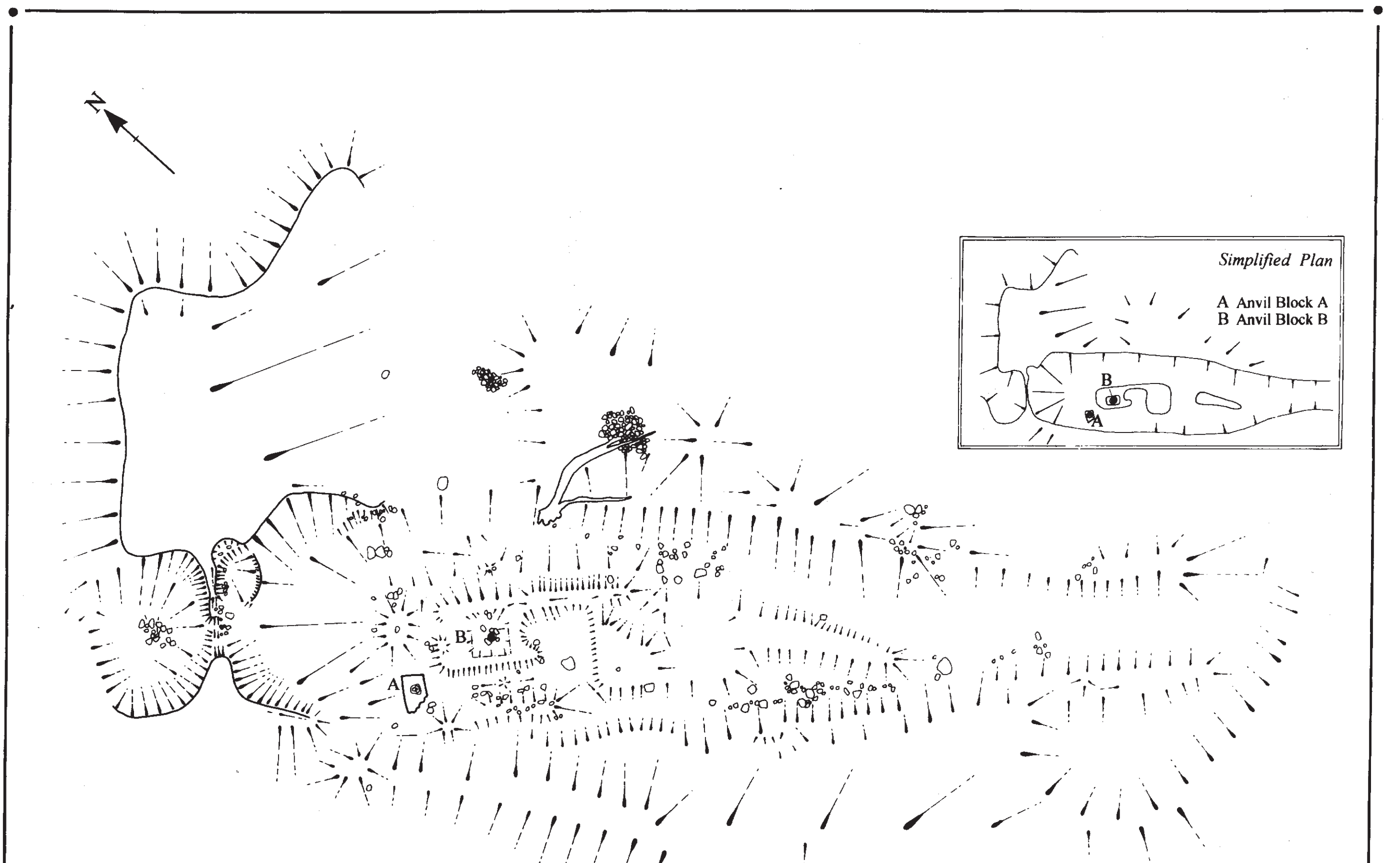

Figure 8: Plan of Fasagh iron works

timber in the centre (tree trunk), which in turn had the remains of an iron collar still in place, in the centre of the timber, for positioning the anvil proper. The design of the casing was elaborate with large notches carved out of all four sides and extending to the channels running along the NE and SW sides of the feature. On close inspection it became apparent that these channels had projecting lips along their upper portions suggesting that perhaps they were not originally open to the elements. Within the notch to the NE of the feature a large structural timber was discovered linking or perhaps keeping securely apart the SE and SW ends of the casing. The casing, an artificially produced conglomerate, consisted of a ferruginous mass acting as a mortar holding together aggregate made up of quartz pebbles and other materials.

Lying to the SW of the anvil casing was a level platform, once again of the same vitrified conglomerate. This feature had two slots associated with it, each with locating keys cast into them. It seems likely that this was a base for machinery, and given the size of the anvil block it is postulated that this may have served as a base for a water-powered hammer.

Excavation of structure B, Fasagh
Structure B was excavated in section (NW to SE) to reveal an anvil block, though the sophistication of the below-surface construction was unexpected. A series of substantial wooden beams laid within channels 'cast' of ferruginous mortar and aggregate were evident on the SE and NW sides of the anvil block casing. In the SE side of the section a second channel was visible running perpendicular to the main beam channel. This was much smaller in size, only 0.1m in breadth. There was also evidence of another structural timber which was lying in NE to SW alignment and appeared to end at the anvil casing; there was no channel evident for this timber and it was positioned spatially above the other timbers already discussed. The casing itself was also made of the same materials as the channels and had been cast to allow the positioning of a substantial timber (tree trunk) within it. There were also areas within the casing where a reduction of the wall thickness had occurred, and series of notches had been introduced; they may have been utilised for locating timbers within. To the NW of the section lying on top of the adjacent bank a series of features were evident, however the decision was taken not to excavate these, though their position and extent were recorded.

Analyses of slag from Fasagh
Unstratified slag samples were collected from two locations outside the horseshoe along the E end of the N flank and at the NW end of the N flank. The slag consisted of primarily large amorphous blocks (about 200-300mm along the long axis), brown-black in colour with fragments of charcoal embedded in them. Of considerable interest

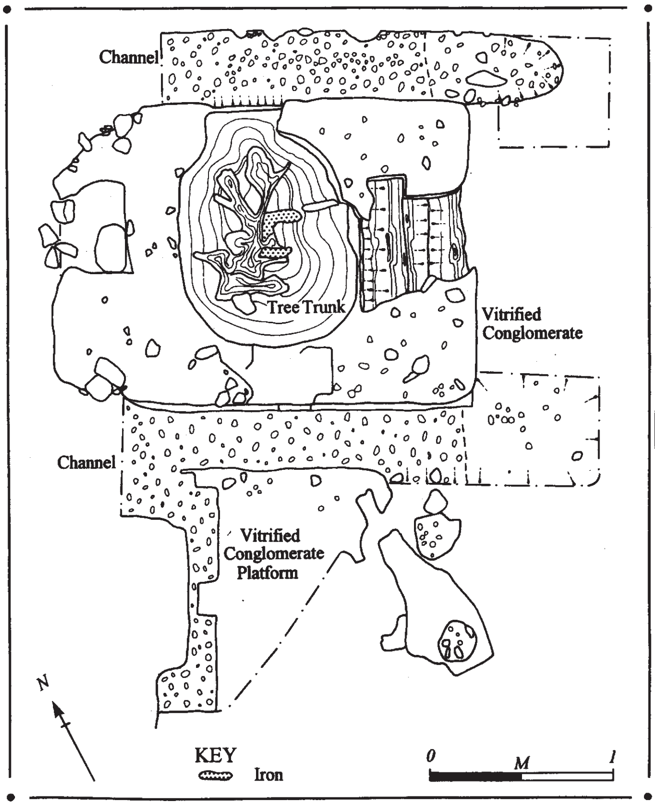

Figure 9: Plan of NW anvil block (A) and casing, Fasagh iron works.

were some fragments which formed part of large flat-based shallow cakes. A third typologically distinct group consisted of amorphous, porous, light brown and at places orange-tinted and extensively-weathered slag, the difference in colouration arising perhaps from prolonged burial. There was no evidence for tap slag of the type encountered at Allt na Ceardaich.

Chemical and mineralogical analysis (see Table 1) has revealed the presence of large amounts of 'massive' wustite (lack of dendrites of wustite) in a matrix consisting of a eutectic of two phases (Fig 6c). One of the two is fayalite incorporating a considerable amount of sulphur while the other phase consists of a calcium potassium alumino-silicate with varying amounts of phosphorus and sulphur. The extent to which these compositions are representative of the stratified slags on the site will have to be determined by further analyses. In any case, from the small number of samples analysed so far, slag mineralogy does not point to the bloomery type encountered at other sites. Indeed, Poolewe, Letterewe and Fasagh metallurgical waste each displays different characteristics corresponding to blast furnace, bloomery and smithing or fining slag respectively.

Discussion

The bloomeries encountered in the Cowal Peninsula at Tamheich Burn and at Allt na Ceardaich may represent two types of establishment, which appear to differ not so much in the material but rather in the quantity which they produced. Both contain furnaces which are similar in the shape and dimensions of their hearth. Both have produced manganese-rich slag which has been tapped, the size of the tap slag cakes at Allt na Ceardaich being quite substantial. Nevertheless, two levels of social organisation of the industry are implied. While the Tamheich site may reflect the activities of one or more people making iron for their own use, Allt na Ceardaich most probably represents the combined efforts of a number of individuals, making iron in order to meet the needs of a larger community. Associated activities, like charcoal making, should be evident at Allt na Ceardaich, with perhaps evidence for settlement sites. The site would have been chosen on the basis of accessibility or seclusion, as well as relative proximity to raw materials.

At Fasagh, however, both the scale and range of activities testify to an advanced level of social organisation of the iron industry based on probably imported technological know-how. The construction of the site is reflected by the variety of materials used. Both local techniques (the production of the concrete-like casing material) and imported materials (fragments of bricks), combined with the sophistication in the design of the system of beams and channels, suggests investment in both capital and expertise.

Thus, even at this stage of the investigation there is an opportunity to examine the archaeological evidence from the point of view of the development of the metallurgical process itself, and as a means of reflecting on aspects of social organisation in the region, in the medieval and post-medieval periods. Bloomery activity must have been evident in Loch Maree before Sir George Hay arrived in the area, as can be deduced from Dixon (1886). However, some or all of the three sites on the N shore must reflect, at least on technological grounds, the late phase of the bloomery as well as the introduction of the blast furnace.

In the late-medieval and post-medieval periods two major technological innovations in iron making are evident: firstly, the introduction of water power in bloomeries, and secondly the introduction of the blast furnace and the indirect method of making wrought iron by the decarburization of pig iron. In many respects the innovations associated with the former went largely unnoticed, contrasting with the scale of developments introduced with the operation of the blast furnace. Charcoal was the fuel used in both cases (at least in Scotland). The introduction of water power became important as a means of mechanising the iron industry in the aftermath of the Black Death (1348) in south-eastern England. 'By the appalling mortality it caused [the Black Death] became one of the greatest catastrophes in the economic and social history of England [with] far reaching results in the history of every branch of industrial activity including iron making' (Schubert 1957, 12).

Compared with earlier bloomeries, the evidence for those using water power is sparse. There are three well-known examples, Rockley Smithies, Yorkshire (Crossley and Ashurst 1968), Muncaster Head, Cumbria (Tylecote and Cherry 1970) and Stoney Hazel Forge, Cumbria (Crossley 1990, 154), but as Crossley observes: 'all ... pose problems of interpretation' (1994, 15). Information about a number of other water-powered bloomery sites is emerging, but details are still incomplete. These include a late medieval bloomery at the head of Bishopdale, N Yorkshire (Moorhouse 1995) and perhaps two in NW Wales dating to late in the 16th century (Crew and Crew 1995).

Water power may have been applied to both the traditional bloomery furnace and the high bloomery or stucköfen, an intermediate stage between the traditional bloomery and the blast furnace. According to Percy (1886, 326), conditions in the high bloomery 'are so favourable to the formation of cast iron that the metallic lump is occasionally carburised to such a degree that it must be subjected to a decarburising process before it can be worked under the hammer'. High bloomeries may be evident in Loch Maree on account of the distinctive type of slag associated with the process. High bloomery slag tends to be less rich in iron compared with traditional bloomeries. Letterewe furnace has already been identified as a stucköfen (J Hume, pers comm) on account of the size of the furnace combined with the type of slag produced.

Some parallels can be drawn between the two anvils at Fasagh and the anvil and hammer illustrated by Percy (1886, Fig 121), associated with the Swedish Lancashire hearth. The description given is as follows: 'Motion is communicated by an overshot water wheel. The anvil is a solid block of white cast iron. It rests upon a wooden block of the anvil, square in section with the angles rounded off. It is composed of four equal and similar pieces of timber well fitted together with the fibre vertical and firmly bound with wrought iron hoops. The anvil block is supported on wooden foundation constituting of pieces of timber laid horizontally thus forming an elastic bed and acting as a spring without which the iron would break on being hammered into bars. The anvil block is surrounded by framework of wood partly filled with cinder from the finery stamped solidly down'. Many similarities are evident with the hammer installations at Fasagh, namely the large wooden block on which the anvil would have rested and the extensive beam system underneath the anvil, which would have supported it; equally important was the framework of wood, partly filled with cinder, which may have served the same purpose as the material encasing each of the anvil blocks at Fasagh. Parallels are also evident with the forge installations at Chingley, Kent (Crossley 1975) and at Ardingly (Crossley 1990, 167).

Dixon (1886, appendix G) reports that Sir George Hay arrived in Loch Maree with the express aim of making cannon. In 1621, nearly 15 years after his arrival, he obtained a licence to transport his iron to any port or harbour of the Free Royal Burghs of Scotland and perhaps England as well. The type of cannon he undertook to make is not clear, in the sense that we do not know whether they were cast or wrought. Wrought iron cannon, bombards, were quite common throughout Europe (Smith and Brown 1989) but perhaps not as late as the 17th century. The 'barrels were made up of long forged bars welded together and then held by fitting great hoops of hot iron which, when cool, contracted and gripped the bars tightly...These great guns (were) the most massive forgings of the medieval world and their production must have required equally impressive facilities to manipulate, heat and forge these prodigious quantities of iron' (Craddock 1995, 268). It is likely that the Fasagh installations, with the one or more large anvil blocks attached to hammer heads, were set up for that purpose.

If, on the other hand, cannon were cast, characteristic casting-pits and mould material would be expected during future excavations. At present, it is only at Poolewe that there are remains of a blast furnace, accompanied by blast-furnace slag, but no casting pits have been reported (Hume and Tabraham 1980).

It is not yet clear whether Sir George Hay centred his activities on Poolewe. Should he have made cast cannon, he would have chosen this site on account of easy access to a port (the river Ewe, which connects Poolewe with Loch Maree is not navigable at its southern end on account of rapids). However, Poolewe is a good ten miles north of Letterewe House, where it is believed he resided, the road veering inland rather than along the coast (Dixon 1886, map of Gairloch Parish). On the other hand, the extant remains at Letterewe do not provide enough space for iron making in a bloomery furnace, as well as for processing, particularly for the hammers and forges needed for bombard making.

Conclusions

In the course of this pilot study an integrated methodology was adopted in the examination of the bloomery mounds and the environment surrounding these monuments. Three key points have emerged.

Bloomery mounds

These mounds still abound throughout the Highlands, even after extensive forestry ploughing, agricultural improvement and other related activities, and they warrant study and protection. Given the small-scale of smelting, and probably smithing activity, which gave rise to the mounds, geophysical survey can locate the furnace or associated working floors. This can serve as a useful tool for field exploration should there be a need for rescue work to be undertaken. In general, the combination of geophysical and limited archaeological prospection can provide almost complete characterisation of the working areas associated with the mounds.

Natural resources, furnace design and the waste associated with bloomery mounds

If bog ore were the smiths' preferred raw material, the source was not obvious in the immediate vicinity of the sites surveyed and excavated, despite efforts at location. Additional ore sources may have been sought, in combination with bog iron ore, at least from what can be deduced in Allt na Ceardaich (Hall and Photos-Jones forthcoming).

Bloomery-mound slags can be characterized by their high iron and manganese contents. Occasionally hercynite (alumina-rich) phases are present. The substantial quantity of iron lost in the slag suggests that primarily oxidizing conditions were prevalent in the furnace. Yet all this iron (and manganese) would have made the slag very fluid, which may have been the smiths' intention all along.

The data related to furnace construction is still limited given that only two were excavated. Tamheich Burn furnace consists of a sub-circular shaft. In Allt na Ceardaich only one side of the furnace wall, that supporting the tuyère, was evident.

Social organisation of the Highland bloomery iron industry and implications for archaeometallurgical studies

Tamheich Burn, Allt na Ceardaich and Fasagh may reflect three stages in the social organization of a traditional iron industry. Technological innovations like the introduction of water power or the mixing of ore sources (imported and local) may have been brought in as a means of enhancing both productivity and yields. The increase in investment in both human effort and capital is also clear. While bloomery mounds like that at Tamheich Burn may represent the activity of a farmer-smith, at Allt na Ceardaich 'professional' smiths may have made iron to meet demand for this metal by one or more clans.

At Fasagh are seen the foundations of an iron industry previously unmatched elsewhere in Scotland with foreigners or Englishmen being brought in to add their expertise to that of the local work-force. Not only is Fasagh a complex industrial processing site, but the foundations of a settlement as well as burial grounds are also evident. The 26 or so graves clustering around the Lochan, where the Sassenachs (literally translated as English-speaking foreigners) threw away their tools at the end of the operations, suggest that the iron-working community lived and worked on its own and did not share the same consecrated burial ground (on the Isle Maree) as the local inhabitants.

In most research into archaeometallurgical sites the human element has not been particularly obvious, coming in only with ethnographic studies. It is true that much pioneering archaeometallurgical work, dealing as it did with prehistoric industrial activities, could not hope to reveal unequivocally the inherent human element, but we question this attitude. We argue that apart from documentary sources, the only real link between the present and the past lies in the landscape, both natural and man made. To identify the nature and level of organisation of the industry at a particular site calls for a balance between evidence from the landscape and from the processes themselves.

References

Aitken G 1970, 'Excavations of bloomeries in Rannoch, Perthshire, and elsewhere', *Proceedings Society of Antiquaries of Scotland* 100, 188-203.

Atkinson J A and Photos-Jones E 1995, Medieval metallurgical waste and the preservation of bloomery sites: a feasibility study. Internal interim SAS/GUARD report to Historic Scotland.

Craddock P T 1995, *Early Metal Mining and Production* (Edinburgh).

Crewe P and S 1995, 'Medieval bloomeries in Coed y Brenin: magnetic susceptibility surveys as a management tool', in *Iron for Archaeologists Workshop: Abstracts*, Snowdonia National Park Study Centre, 70.

Crossley D 1975, *The Bewl Valley Ironworks, Kent c 1300-1730*, (Royal Archaeological Institute Monograph, London).

Crossley D 1990, *Post-Medieval Archaeology in Britain* (Leicester).

Crossley D and Ashurst D 1968, 'Excavations at Rockley Smithies, a water-powered bloomery of the 16th and 17th centuries', *Post-Medieval Archaeology* 2, 10-54.

Cunningham A D 1989, *A History of Rannoch* (Inverness).

Dixon J H 1886, *Gairloch in North-West Ross-Shire: Its Records, Traditions, Inhabitants, and Natural History with a Guide to Gairloch and Loch Maree*. 4th Reprint. (Fort William 1984).

Fell A 1980, *The Early Iron Industry of Furness and District* (Ulverston).

Hall A J and Photos-Jones E forthcoming, 'The bloomery mounds of the Scottish Highlands. Part II: a review of iron mineralisation in relation to the investigation of bloomery iron making in the Scottish Highlands', *Historical Metallurgy.*

Holdsworth P (ed.) 1987, *Excavations in the Medieval Burgh of Perth 1979-1981*, Society of Antiquaries of Scotland Monograph Series No 5 (Edinburgh).

Hume J and Tabraham C J 1980, Excavation at a Cheardach Ruadh iron works in Ross and Cromarty. Unpublished report.

Killick D J and Gordon R B 1987, 'Microstructures of puddling slags from Fontley Roxbury, Connecticut, USA', *Historical Metallurgy* 21(1), 28-36.

Lewis J 1984, 'The charcoal fired blast furnaces of Scotland: a review', *Proceedings Society of Antiquaries of Scotland* 114, 433-479.

Lindsay J M 1984, 'The iron industry in the Highlands', *Scottish Historical Review*, 63, 49-63.

MacAdam W I 1887, 'Notes on the ancient iron industry of Scotland'. *Proceedings Society of Antiquaries of Scotland* 21, 89-131.

Moorhouse S 1995, 'A late Medieval water-powered ironworking complex at the head of Bishopdale, North Yorkshire', in *Iron for Archaeologists Workshop: Abstracts*, Snowdonia National Park Study Centre, 28-31.

Percy J 1886, *Iron and Steel*, Vols I and II (London).

Photos-Jones E and Atkinson J A, in press, 'Ironworking in medieval Perth, a case of town and country', *Proceedings Society of Antiquaries of Scotland*

Schubert H R 1957, *History of the British iron and steel industry* (London).

Smith R D and Brown R R 1989, *Bombards*, Royal Armouries Monograph 1 (London).

Tylecote R F and Cherry J 1970, 'The 17th century bloomery at Muncaster Head', *Transactions Cumberland and Westmorland Antiquarian and Archaeological Society,* ns 70, 69-109.

Yeoman P 1995 *Medieval Scotland* (Edinburgh).

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The Authors

E Photos-Jones is at Scottish Analytical Services for Art and Archaeology, Glasgow and the Department of Archaeology, University of Glasgow. J A Atkinson and I Banks are with GUARD, Department of Archaeology, University of Glasgow, A J Hall is at the Department of Geology and Applied Geology, University of Glasgow.