

The charcoal-fired blast furnaces of Scotland: a review

John H Lewis*

SUMMARY

This paper attempts to up-date W I Macadam's survey, published in 1887, of the early iron industry of Scotland. The majority of the article comprises reports of recent excavations at Red Smiddy, Glenkinglass and Bonawe furnaces but short notes on other sites are also included.

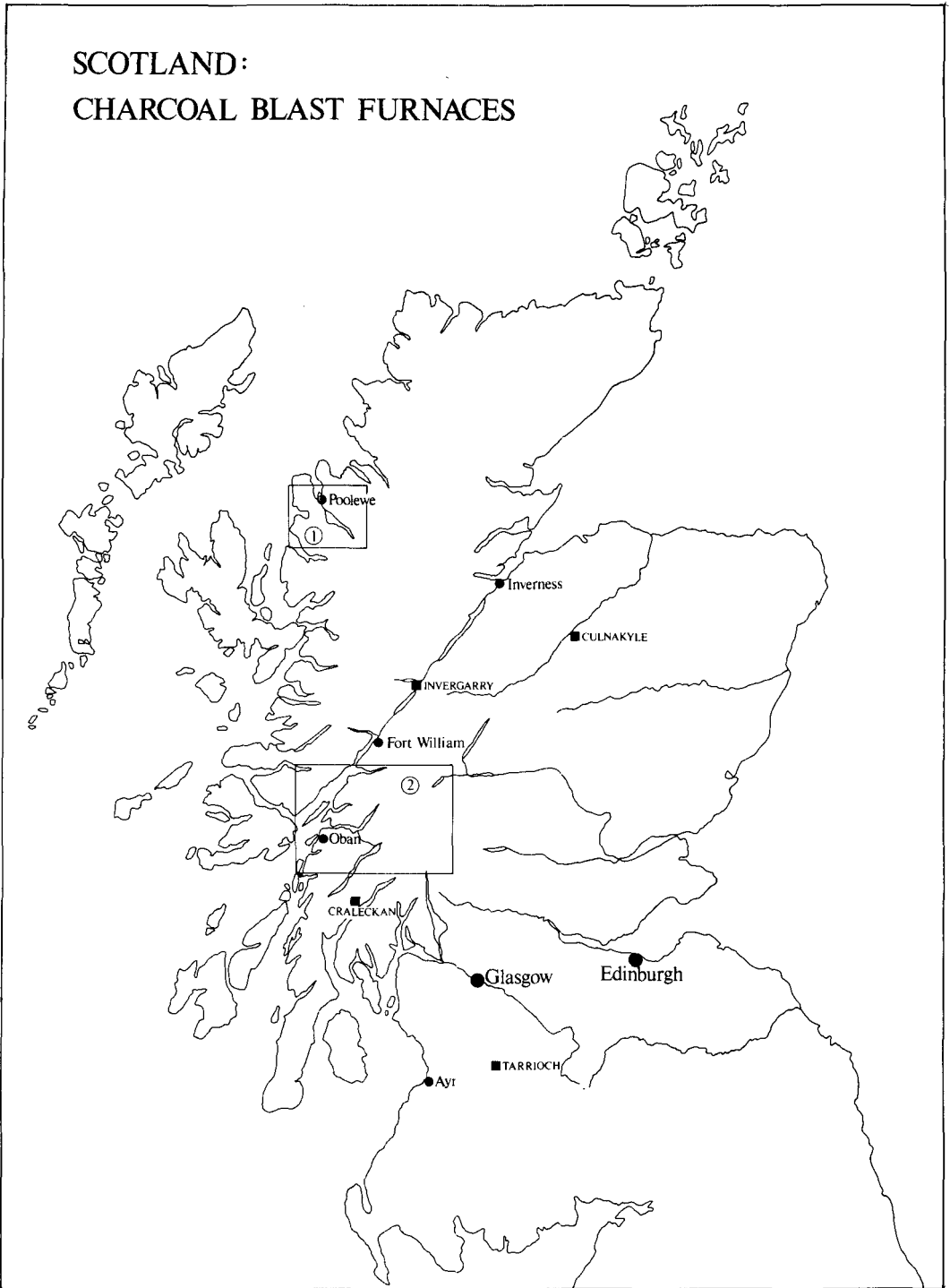
The early 17th-century ironworks of Red Smiddy, in Wester Ross, proved to be a blast furnace but no evidence was found to substantiate the claim that ordnance was cast there. The casting house and furnace at Glenkinglass, dating from 1722, were fully excavated but river action had eroded away the blowing house before work commenced in 1979. The charcoal and ore sheds, to the rear of the furnace, appear to have been timber-built with low non-load-bearing turf walls. At Bonawe the casting house, blowing house, wheel pit, part of the lade and other structures adjacent to the furnace were excavated between 1978 and 1982. The 19th-century reorganization of the mid 18th-century works was particularly evident in the blowing house, where the massive granite blocks used for mounting the blowing engine were still intact.

INTRODUCTION

The first person to attempt a detailed inventory of early Scottish ironworks was an analytical chemist named W Ivison Macadam who described the sites, both known and surmised, of numerous ironworks, most of which appear to have been bloomeries (Macadam 1887). Macadam's work, though informative, included several inaccuracies and some of the dates he attributed to blast furnaces are now known to be incorrect. One of these errors is the date of 1730 he ascribed to the building of Bonawe furnace, which he seems to have confused with that at Glenkinglass. A contemporary of Macadam's, J H Dixon, wrote about iron-working in his native parish of Gairloch in Wester Ross (Dixon 1886), but said little that was not incorporated in Macadam's work. Alfred Fell's account of the Lakeland iron industry (Fell 1908) included the furnaces at Invergarry and Bonawe, both of which were owned by Lakeland companies; other Scottish works, however, he ignored.

These early accounts, while often useful, cannot be relied upon for their accuracy and many later writers have been guilty of perpetuating some of their errors. Recently, however, an investigation of primary source material by J M Lindsay has led to the publication of more accurate accounts of the industry's history in the Highlands. Two papers in particular (Lindsay 1975a; Lindsay 1975b) provide much information relevant to this present work. The account that

*329 Easter Road, Edinburgh EH6 8JG



ILLUS 1 Scotland: charcoal blast furnaces. 1, see illus 2; 2, see illus 7

follows is primarily a report on the excavations at Red Smiddy, Glenkinglass and Bonawe furnaces but, following recent visits to other sites, includes short notes on the furnaces at Fasagh, Letterewe, Culnakyle, Invergarry, Tarrioch and Craleckan. Although much has been published elsewhere, an historical introduction is included so as to provide a framework in which to place the sites.

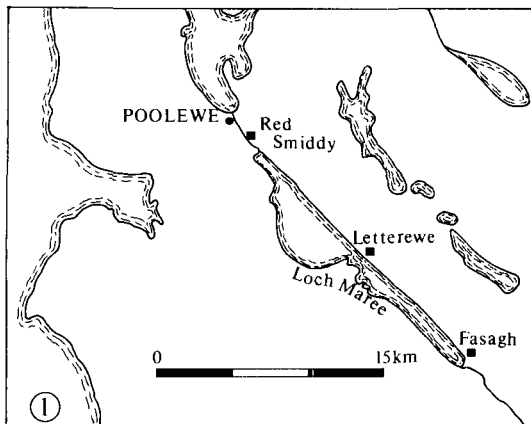
HISTORICAL BACKGROUND (illus 1)

The blast furnace is believed to have been introduced to Scotland shortly after 1600, over a century later than its appearance in the Weald of southern England. Throughout Europe the change from making iron by direct reduction, in a bloomsmithy, to the indirect process used in the blast furnace had been a gradual one and it is quite likely that the earliest Scottish blast furnaces were operating alongside the more primitive bloomeries. A similar situation was to arise again in the Furness area of northern Lancashire (now Cumbria) where iron was manufactured almost exclusively in bloomeries until 1711 when William Rawlinson and John Machell built their blast furnace at Backbarrow.

Prior to the 19th century the demand for iron in the Scottish Highlands was small, most needs being fulfilled by the limited output of local bloomeries. Even when production of the metal was increased in the blast furnaces of the 18th century the majority of the pig iron produced was still exported to England. A major inducement for the continuation of the direct process in the Highlands was the high quality of the iron produced from the poor ores available. Almost the only source of iron N of the Highland Line was bog ore which, containing high concentrations of phosphorus, was usually ignored by blast furnaceman. Further, the cost of building and equipping a blast furnace and the plant needed to convert cast iron into malleable wrought iron must have deterred potential entrepreneurs from departing from local tradition.

The change was initiated, however, in the early 17th century and may have been for the same reasons as in England a century before: many early English blast furnaces concentrated on manufacturing ordnance and the first Scottish works were, perhaps, built with the same intention. There is confusion as to the precise location of Scotland's first blast furnace although it was almost certainly beside Loch Maree, in Wester Ross. Macadam and Dixon listed three possible sites. These were A Cheardach Ruadh (Red Smiddy), near Poolewe; Furnace, near Letterewe; and Fasagh, at the south end of the loch (illus 1 & 2).

Documentary evidence for these early works is scant but the instigator of the industry is thought to have been Sir George Hay, a merchant and industrialist from the eastern lowlands of Scotland who was later to become Chancellor of his country. Along with his partners he was, in 1607, granted lands in the NW of Ross-shire together with estates in the Isle of Lewis (Lindsay 1977, 49). Shortly afterwards, Hay exchanged his island estates for land around Loch Maree sufficient to allow him to concentrate on making iron. In 1609 an Act of Parliament forbade the smelting of iron anywhere in Scotland (*ibid*, 50), forfeiture of the produce being the penalty for transgression. A similar prohibition had been in operation for some time in England where charcoal burning had helped deplete much of the woodland there. Coppicing was still not widespread and there may have been apprehension, on the part of the Scottish Parliament, as to the likely consequences to the forests should the iron industry expand north of the border. In late 1610, however, Hay was granted the right to manufacture iron and the Act of the previous year was, in all likelihood, passed to protect his future enterprises. A further Act, of 1613, prevented the export of iron ores from Scotland (Cochran-Patrick 1878, 8) and, although the reasoning



ILLUS 2 Inset 1: furnaces around Loch Maree

behind this piece of legislation is unclear, it may have served in some way as an added protection for Hay.

Precisely which of the three important Wester Ross locations described by Dixon and Macadam was the site of the first Scottish blast furnace is not clear. Macadam assumed Fasagh to be a bloomery, although Tylecote (1962, 292) suggests it may have been a primitive blast furnace; a recent visit to the site (described below) tends to support Macadam's argument. Documentary sources state that the main product of both Letterewe and Red Smiddy was ordnance (*RMS*, 438) indicating that both were blast furnaces. Subsequent excavation at Red Smiddy has proved the latter point but of the nature of the product there was no evidence. Because of the denuded and overgrown state of Letterewe it is difficult to be positive about its character. However, the possibility that it was a high bloomery later converted to a blast furnace has been put forward as a reasonable hypothesis.

Hay's choice of the rather remote Gairloch parish may have been prompted by his seeing a bloomery operating in the area. Such a bloomery could have been Fasagh which, occupying a position adjacent to the 17th-century road (on the north-east shore of Loch Maree), may have been observed by Hay whilst en route to or from the Isle of Lewis (Poolewe being at that time the principal place of embarkation). Local bog ore may have been used but clayband ores from Fife and haematite from Cumbria were brought by sea to the jetty at Poolewe; thereafter it was a journey of only 1 km to Red Smiddy or a short distance to the waters of Loch Maree where it could be shipped to Letterewe. Accessibility by sea, the nearby hardwood forests and a good water supply combined to provide good locations for these furnaces. Local men were probably employed as unskilled labourers but the skilled men may have come from England (Macadam 1887, 115). No evidence has come to light recently that would help date the closure of Letterewe or Red Smiddy. Knox, writing over 100 years after the event, mentions casting in 1668 (Knox 1787, 222) but the latest reliable date for production in progress is 1621 when Hay was granted a licence to sell iron. Closure was probably some time between these two dates.

Other early works, less successful than Hay's, are described by Lindsay (1977, 53–6). These were at sites in Angus (c 1600); Perthshire (1612); Lochaber (c 1680); and at Achray, near Loch Katrine (c 1720). It is not clear whether all or even any of them were blast furnaces. There are no records, yet discovered, of any iron being exported any distance from these sites and it may be

reasonable to assume that some of them, at least, were producing both cast and wrought iron for local use.

During the 1720s three relatively well-known furnaces were erected in the Highlands, all of them sharing the dubious distinction of being short-lived, added to which two of them were almost always in difficulty. The three were at Glenkinglass, near the shore of Loch Etive in Argyll (illus 7); Invergarry, beside Loch Oich in Inverness-shire; and Culnakyle, in the forest of Abernethy on Speyside (illus 1). None was a locally-inspired enterprise and the partners, particularly those at Invergarry and Culnakyle, paid the price of being strangers in the 18th-century Highlands. The disastrous venture at Invergarry was the result of the recently formed but highly successful Backbarrow Company of Cumbria over-reaching itself by setting up a new company in a region of which it knew little or nothing. As at Gairloch a century earlier, a plentiful supply of coaling wood was the incentive to move northwards, but after negotiating contracts for charcoal with John Macdonell of Invergarry in 1727 the company, under the management of Thomas Rawlinson, found itself in difficulty transporting the ore and pig iron as well as having to endure the hostility of the local populace. After a short and very intermittent life, the furnace was finally blown out in 1736, leaving Rawlinson a broken man.

The irregularity of blowing at Invergarry may also have been linked with a phenomenon beyond Rawlinson's control. The period 1730 to 1733 was a time of considerable drought in England and Wales (Brooks & Glasspoole 1928, 145). Unfortunately, statistics for Scotland in the early 18th century are sparse and for the Highlands non-existent, but if the drought extended over the whole of Britain it could have had a marked effect on iron production. Straker, for example, cites the remarkable dryness of the early 18th century as being a factor in the decline of the Wealden iron industry (Straker 1931, 65). Water power was often reduced in summer months when streams tended to run dry with the result that many furnaces were out of blast from about April to September. If these dry periods continued, however, campaigns would have been decreased even further and production lowered to unacceptable levels.

If the drought did affect Invergarry it may also have upset production at Culnakyle where work ceased in 1734 after only five years' operation (Murray 1883, 64; Macadam 1887, 126). Stoppages were frequent and prolonged; output was poor. Charcoal was local and plentiful and ore was brought from the Lecht mines, near Tomintoul, where both haematite and limonite occur. This short trip of 20 miles was, however, offset by the 60 mile raft journey on the River Spey to Garmouth on the Moray Firth from where the pig iron was exported (Youngson 1973, 30). This long journey to a rather remote harbour must have increased the price of the iron to an uncompetitive level and serves again to underline the lack of thought that was put into such ventures. Culnakyle's main problem, though, was that the parent company – the York Buildings Company, of London – was generally despised in Scotland. This somewhat notorious concern bought up many Highland estates forfeited to the Crown after the abortive Jacobite rebellion of 1715; the dispossessed landowners and tenants were, understandably, resentful. It is hardly surprising that when the company withdrew from the area the local populace was not sorry to write off several debts and to see the backs of the English they despised (Cramond 1897, 227).

After abandonment the site silted up and became overgrown but heavy flooding of the River Spey in 1829 uncovered much of the foundations of the works, including the cellars of the manager's house, and once more revealed the course of the lade and tail race. Since that date it has again been lost to view.

There was a forge at Culnakyle but for castings the York Buildings Company often had to turn to Invergarry and Glenkinglass. This latter furnace, which is well documented by Lindsay (1977, 56–7), was probably founded in 1722 although four partners from the company's early days

– Captain Arthur Galbraith, Roger Murphey, William Kettlewell and Charles Armstrong – who were all Irish, did not come together in business until 1725. The local landowner, Sir Duncan Campbell of Lochnell, had been involved in timber deals with Murphey and Galbraith as early as 1720 (SRO 1730) when the Irishmen must have noticed the potential for industry in such a well wooded and reasonably accessible area (illus 7).

Although Glenkinglass was a long way from a road suitable for freight transport, it was within easy reach of the coast (illus 7). Haematite from Cumbria and bog ore from Jura and Islay were brought by sea and up Loch Etive to the pier at Ardmaddy (Murray 1740, 12). Even the Falls of Lora at Connel could be negotiated by shallow draughted barges at low tide. Charcoal came from as far away as Glenorchy and possibly from Glen Creran where the vestiges of charcoal stances are still visible (RCAMS 1974, 281); again a coastal route was used for some of this traffic. Ironmaking at Glenkinglass does not seem to have continued beyond 1738, the closure of the furnace perhaps being due to several factors. Amongst these may have been the drought of the early 1730s, but the major single cause of failure was probably the economic slump of 1737–8 which resulted in a temporary set back in the iron industry throughout the country but which was particularly felt by those works far removed from the main English markets. Some of the more established concerns were able to weather the storm but Glenkinglass did not survive for long after the depression. Towards the end of its life the company had several new partners from varied backgrounds, some of whom seemed to take little active interest in iron-making. This situation led to discontent, particularly on Galbraith's part, and it must be wondered whether a more sympathetic partnership could not have continued beyond 1738.

As it was, no more iron is thought to have been made in the Highlands until 1753, when the Lorn furnace at Bonawe was built by Richard Ford and Company, a small Cumbrian firm that, as the 'Newland Company', was to become the biggest iron-making concern in the north-west of England. The situation of Bonawe furnace was similar in most respects to that of Glenkinglass, yet the English company managed to continue operating until 1876. It could be argued that the political situation in the Highlands was more stable after the defeat of the Jacobite uprising at Culloden in 1746, but the lands of Glenkinglass were held by the Campbells who had long been loyal to the Hanoverians. It is possible, then, that if the Glenkinglass partnership had been less prone to squabbling it could have survived through the unfavourable economic climate of 1737–8 and continued for many years. As it was, its role was gratefully taken over by the Lorn Furnace Company who negotiated timber contacts with Campbell of Lochnell for the unusually long period of 110 years (Lindsay 1977, 60). As well as the long term agreement with Lochnell, the company undertook shorter contracts with other local landowners, taking in woods some considerable distance from Bonawe. Distance, however, was not a major problem for the heavily indented coastline of Argyll gave shipping easy access to large areas of woodland.

Local trade at Bonawe was overwhelmed by the import of haematite from Cumbria and clayband from central Scotland and the export of pig iron, which, with the exception of cast-iron shot, was the only known commercial product of the furnace, sent to centres in the W of England and Wales (MacGregor *et al* 1920, 4). A new quay was built to cope with this increase in traffic. The furnace, eventually in the hands of Harrison, Ainslie and Company of Ulverston, finally went out of blast in 1876 after several years of intermittent production. Fuller accounts of Bonawe's history have been written elsewhere, the most accurate and informative summary being by Lindsay (1975a, 283–98).

Shortly after Ford started operations at Bonawe the Duddon Company (again from Cumbria) followed a similar path by building an ironworks near Inverary, on the shore of Loch Fyne, in 1755 (illus 25–27). Situated by the village of Inverlacken (later renamed Furnace) it

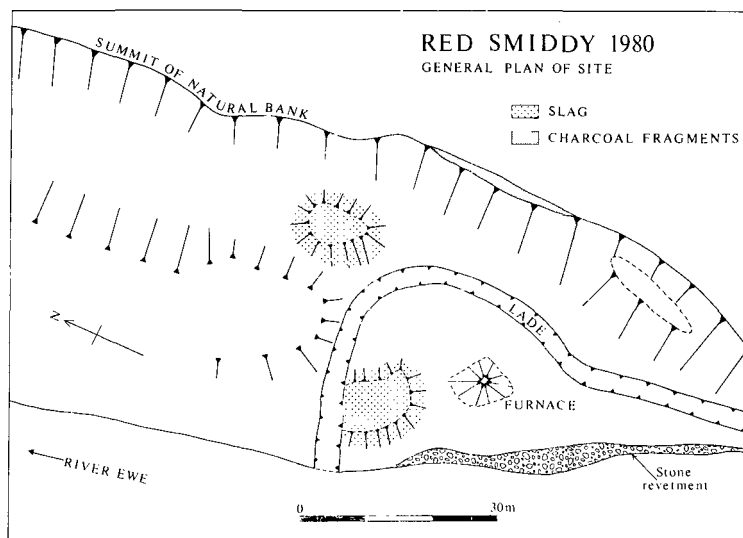
became known variously as Goatfield, Craleckan and Argyle furnace. The parent company's building of Duddon in 1736 was followed almost immediately by the depression of 1737–8 and it was several years before they could expand into Scotland. As at Bonawe, sound contracts for the supply of timber were made with local landowners, including the third duke of Argyll, resident at nearby Inverary Castle. These contracts were not as well recorded as those at Bonawe but it is known that oak, birch, hazel and alder were coppiced in the parish of Strachur (Anderson 1967, 458).

The scant documentary evidence that is available for Craleckan seems to indicate that its life was uneventful and, apparently, successful. Its final blast was not until 1813. Although production figures are scarce the works was broadly comparable in many respects with Bonawe; Anderson states that both furnaces yielded about 700 tons of pig iron in the year 1788 (1967, 457), which is similar to that of contemporary Cumbrian furnaces. Unlike Bonawe, however, Craleckan had a forge and although its precise location is not known, it may have corresponded with the smithy shown in the map of 1871 (illus 26).

All the ironworks mentioned thus far were established by outside speculators trying to capitalize, with varying degrees of success, on the untapped timber resources of the Scottish Highlands. With the exception of Culnakyle, they were built in fairly sheltered locations within easy reach of the west coast and hence the iron mines of north-west England. It must be wondered why this small-scale colonization of the Highlands by the Cumbrian ironmasters was not mirrored by a similar phenomenon in Galloway and Ayrshire where much of the land was still wooded and where harbours were already well established along the Solway coast and on the Clyde estuary. Instead, the English companies saw fit to import charcoal from the south of Scotland without actually setting up any ironworks there. Anderson mentions coppicing in the parish of Minigaff, near Newton Stewart (1967, 459), and the coaling of smaller deciduous trees at Kirmichael-Irongray in Dumfriesshire from where the charcoal was sent to Whitehaven in Cumbria. Kemp listed a furnace at Buittle in Galloway (1887, 295) and said that traces of iron-working were numerous throughout the south of Scotland. Almost certainly most of these works were forges or the remains of earlier bloomeries.

There was, however, one blast furnace operating during the 18th century in the south-west of Scotland; at Tarrloch (or Terrioch) near Muirkirk in southern Ayrshire. Thought to have been built around 1732 by one of the earls of Cathcart (Baird 1910, 44), it used haematite mined at Whitehaugh on the nearby Pennel Burn and refined the pig at its own forge. The furnace was abandoned at an early, but unknown, date when local coaling wood was exhausted and attempts at smelting with peat charcoal proved unsuccessful. According to Baird, ore was carried by pack-horse to Ayr for shipment to Bonawe, the coastal vessels returning with pig iron for refining at the local forge. He does not make it clear whether the mine was closed down after the failure of the Tarrloch furnace and reopened at a later date in order to supply Bonawe or whether the Ayrshire works continued smelting beyond 1753. Another possibility is that Baird, like Macadam (1887, 124), confused Bonawe with Glenkinglass and it is possible that ore was shipped further up Loch Etive than the pier at Bonawe. This problem, however, cannot be resolved at present since the works papers of both Glenkinglass and Tarrloch (if they ever existed) have not been found.

Central Scotland did not contribute to commercial smelting until 1760 when the Carron works, near Falkirk, commenced production. The extensive carboniferous ores of the central belt, being high in phosphorus, were not ideal sources of iron for charcoal blast furnaces, although some clayband ore, mixed with haematite, was used at Red Smiddy and at Bonawe. The first regular use of clayband was at Carron by the partnership of John Roebuck, Samuel Garbett and William Cadell. The building of these coke-fired furnaces is usually taken as the start of the



ILLUS 3 Red Smiddy 1980: general plan of site

modern iron industry in Scotland. It should be noted, however, that the partners, after investigating several potential locations, settled for this situation eventually, partly because of the comparative accessibility to charcoal which came, in fact, from the rather distant woods of Glenmoriston (Anderson 1967, 458; Cadell 1913, 146).

Although its main use at Carron was in the finery, it was also felt that charcoal could be used in the blast furnaces should supplies of coke be held up for any reason.

See appendix for a glossary of technical terms used in this report.

EXCAVATION OF THE FURNACE AT RED SMIDDY (illus 2, 3, 4, 5)

INTRODUCTION

Red Smiddy (Gaelic, *A Cheardach Ruadh*) ironworks (NGR NG 861 798) lies on the east bank of the River Ewe, about 1 km S of Poolewe in the parish of Gairloch, in Wester Ross. The river, which runs only for 3 km, connects Loch Maree, on whose banks are sited the works of Letterewe and Fasagh, with Loch Ewe, itself a sea loch. The position of the furnace was indicated by a bracken covered mound, 10 m across and rising to a maximum height of 1.50 m. Within this mound was a rectangular hole, measuring 900 mm by 720 mm, thought to be the furnace stack.

There were no visible signs of ancillary buildings such as ore and charcoal sheds nor were there structures such as a waterwheel or bellows. However, there did seem to be the course of a lade running to the E of the furnace from which point it continued westwards as a trailrace discharging back into the River Ewe. A raised natural terrace beyond the lade would seem to have been the most likely position for siting the storage sheds, a heavy deposit of charcoal along the slope of the terrace substantiating the idea. A slag heap, measuring about 7 m across, was situated 20 m W of the furnace.

EXCAVATION

The aims of the excavation were: to investigate the character of the furnace (that is, to establish whether it was an early blast furnace); to examine the products (whether ordnance or merely pig iron); and, somewhat dependent on the first two, to place the site in its correct historical context.

Unfortunately, the appallingly wet weather meant that the latter two targets became unattainable. During the period 6–20 September 1980 work was confined to a total of four days and only a small amount of the planned work was carried out, the necessity to backfill the site at the end of the excavation also impinging on the excavators' time. The siting of the lade suggested the blowing arch to be on the east side of the furnace and the tapping arch on the north side. Consequently, in order to make the best use of the time available, only the north-east half of the mound was excavated.

Following the removal of rather tenacious bracken, there was evidence to suggest that this was not the first excavation at Red Smiddy: both within the furnace and outside the tap hole there had been earlier disturbances. Although there are no known written records of an earlier excavation it would not be surprising if work had been carried out by either Macadam or Dixon whilst attempting to examine the site in the 1880s.

Removal of dark brown peaty soil, heavily matted with bracken roots, exposed quantities of rubble comprising water-washed boulders, some faced sandstone blocks and a few brick fragments, some of which bore traces of a lustrous green glaze typical of the slags produced by charcoal blast furnaces. In all probability these bricks would have derived from the lining of the boshes where slag floated on the heavier iron. Below the main body of rubble was a layer of burnt orange clay, up to 500 mm thick, including more rubble which, again, was part of the collapsed furnace stack. Other than the removal of this destruction material and the partial clearance of the area immediately outwith the furnace, very little further excavation was possible.

Within the 5.90 m square furnace the rectangular hearth measured 1.70 m N to S by 1.60 m E to W. Internally it was 900 mm N to S by 740 mm E to W. The casing was of water-washed granite boulders, set in a light grey brown clay, and faced on all sides with squared sandstone blocks, also bonded with clay. There was no evidence anywhere of mortar bonding. The hearth lining was built of

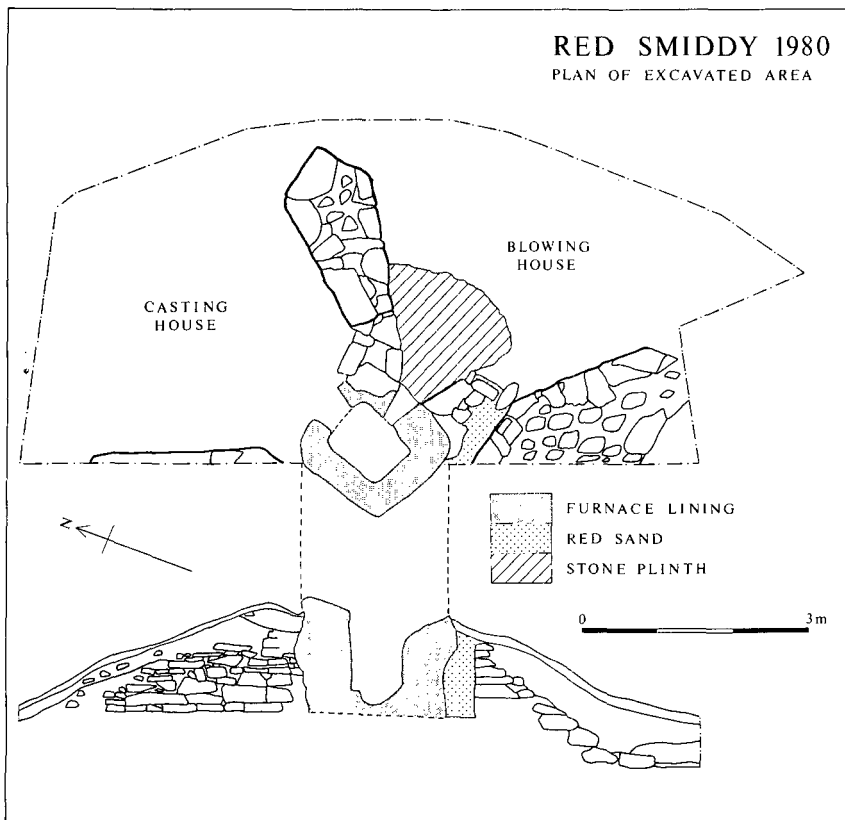


ILLUS 4 Red Smiddy 1980: furnace during excavation, from the N. *Crown copyright*

red sandstone, generally about 350 mm thick but over 500 mm in places. It was more or less intact although heavily vitrified: the vitrification penetrated well into the facing, suggesting that the hearth had been in use for some time after its previous relining. Erosion of the inner casing of the hearth had altered its original rectangular plan into its present subcircular form. Separating the hearth from the outer casing was a cavity, up to 400 mm wide, which had been filled with a clean coarse sand. As well as providing direct insulation against the intense heat of smelting, this sand may have helped counter the forces produced by expansion and contraction of the inner stonework during campaigns (Glenkinglass was found to have a similar arrangement). No evidence has been found so far to suggest that further protection for the furnace building, such as timber bracing, was used.

The blowing and tapping arches, on the east and north sides respectively, were separated by a slender pillar measuring only 600 mm to 1.15 m wide and almost completely robbed out above the foundation level. A risband joint near to the hearth showed the hearth to be a free-standing structure, the stonework between it and the pillar being merely a rubble infill with a distinctly bluish coloured clay as a matrix in contrast to the usual grey brown clay of the main body of the furnace.

To the E of the hearth was the blowing arch wherein survived no visible trace of any part of the blowing mechanism, but the tuyère-hole itself was intact, the tuyère setting being of finely tooled sandstone. Externally the hole measured 300 mm across and tapered to an inner circular aperture of 120 mm diameter. The floor of the blowing house was not fully excavated. The available evidence here did suggest, however, that the furnace had been repaired at least once for the faced stonework of the blow-hole was so obviously a rebuilding, use having been made of odd stones as well as clay bricks bearing traces of glassy slag. These reused bricks must once have formed part of the furnace lining. A plinth of small boulders, bonded with clay, lay immediately outside the tuyère-hole. Time did not



ILLUS 5 Red Smiddy 1980: plan and section of excavated area

permit a proper examination of this plinth but future excavation may show it to be associated with a bellows mounting.

The tapping arch, on the north side of the furnace, had many flat sandstone blocks as well as one well preserved corbel-stone within its rubble fill. Corbelling of the apertures is evident at Bonawe and Craleckan also, but not at Glenkinglass where the apertures were arched. Corbelling may also have featured in the construction of the blowing arch at Red Smiddy but not enough evidence exists to state this with certainty. The tapping arch extended 2.2 m from the tap-hole and partial excavation around the base of the hearth confirmed the existence of heavily burnt floor levels below dense masonry collapse. These floor levels were not removed. The tap-hole was blocked with iron which had not been removed after the end of the final campaign.

As already stated, the excavation had to be curtailed because of atrocious weather and, in consequence, several questions about the site remain unanswered. The works proved, beyond doubt, to be that of an early blast furnace. Whether it was given over entirely to the production of pig iron is not known but the dimensions of the hearth would suggest perhaps that the furnace was too small for casting ordnance. The full height of the furnace cannot be ascertained with any certainty but the slenderness of the masonry pillar would suggest a squat structure, perhaps no more than 5 m high, and this in turn would suggest an early structure, perhaps that built by Hay c 1610. The extent of the vitrification within the hearth lining and the repair to the masonry suggest the possibility of a long life, although the relining of the hearth tended to be a common occurrence in blast furnaces.

There was no time during the excavation to investigate properly the full extent of the slag heaps or, more importantly, the ancillary buildings believed to be on the summit of the terrace to the E of the furnace. No trace of any building was visible there although the dense bracken cover would make identification of low walls very difficult. The storage sheds may have been built of stone but are more likely to have been of turf and/or wood. A wooden gantry may have connected the terrace and the furnace by spanning the gap above the lade. Alternatively, a simpler arrangement such as a ladder may have been sufficient, but if this were the case then it would have been somewhat pointless siting the furnace adjacent to the incline. Further investigation of the site in the near future may yield more information on this and related details.

FINDS

Finds were small in number, as would be expected from the limited scale of the excavation, and all were directly related to the furnace or the smelting process.

Brick

Two fragments of red brick, presumably from the furnace lining, were found during the excavation. One, of an almost complete brick, measured 210 mm long, 100 mm wide and 60 mm deep. The second fragment was similar in width and depth but was only 40 to 70 mm long. Covering part of this smaller fragment was a coating of green glassy slag, typical of that produced in charcoal blast furnaces and often found on furnace linings, particularly in the region of the boshes.

Iron

A fragment of what may have been a tump plate, measuring approximately 300 mm by 180 mm and 20 mm thick, was the only metal artefact found during the excavation.

Ore

Perhaps surprisingly, no haematite was found on the site whereas several nuggets of clayband ore were discovered during the excavation.

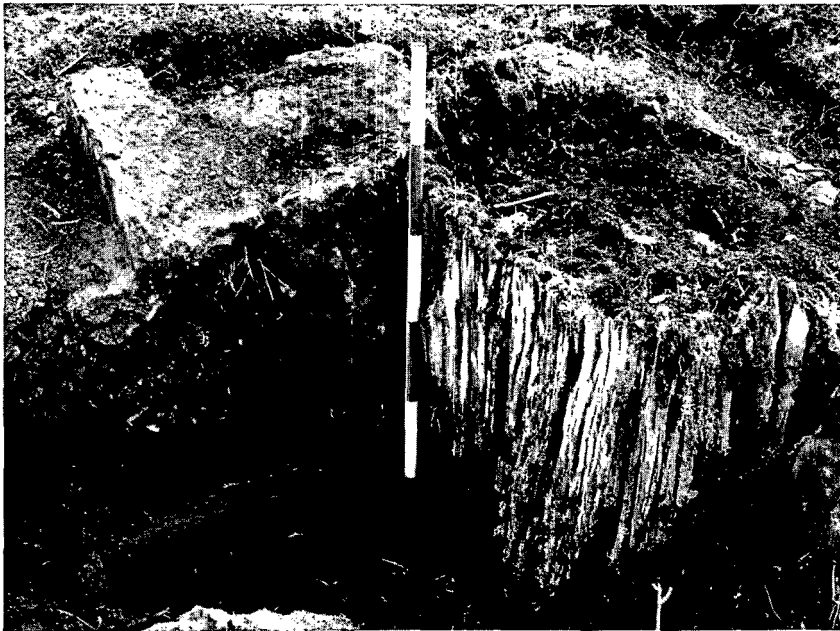
FASAGH (illus 2 & 6)

The former ironworks at Fasagh (NGR NH 011 654) is situated by the Fasagh Burn on the north-east shore of Loch Maree, about 4 km NW of Kinlochewe. The road travelled by Hay to the Isle of Lewis in the early 17th century passed by Fasagh but this route has long since been abandoned in favour of a new road down the west side of the loch.

During a short visit to the site in the spring of 1982 it was hoped to add to the rough plan drawn by Macadam (1887, 107) but limited time and the extensive nature of the site did not allow for a detailed survey. Interpretation of much of the complex was also impaired by the thick plant cover (especially heather) that obscured many features. A limited investigation did, however, reveal several points of interest. It soon became apparent that, during his visit to the site, Macadam attempted some undisciplined excavation (as he may have at Red Smiddy) although the full extent of his work is not known.

From the remains of the structure itself, it was not possible to state with certainty whether the furnace ('I' in Macadam's plan) had been a blast furnace or a bloomery but clues as to its nature were forthcoming from other parts of the site. Slag samples taken from various locations were typical of those produced in bloomeries; no slag of the type normally associated with blast furnaces was encountered. Macadam's analyses tended to support this view. SE of the furnace were the positions of two anvils, comprising tree trunks (illus 6), upon which the iron anvils would have rested. These measured 900 mm and 950 mm in diameter and were set into pits c 1.00 m deep. Surrounding each of them was a level platform of slag and small stones, the slag probably having been viscous when emplaced, giving the material the consistency (and presumably the function) of concrete. Macadam describes 'furnaces' – probably stringhearths – adjacent to these anvils but these were obscured by rubble and vegetation in 1982. There was evidence that a drystone building had enclosed both of these forges.

Slag analysis, the absence of any ore other than bog ore (Macadam 1887, 109) together with the anvils and their associated stringhearths all point to Fasagh having been a bloomery. Its size and sophistication would tend to indicate it being later rather than earlier. There is nothing to suggest a direct connection with either Red Smiddy or Letterewe but the idea that Hay was influenced in his choice of location by a viable works already in existence in the area is an attractive one.



ILLUS 6 Fasagh: anvil setting

LETTEREWE (illus 2)

Various documentary sources, both primary and secondary, point to the furnace at Letterewe having been Scotland's first blast furnace (Macadam 1887, 109–19) although Red Smiddy must also be considered a likely candidate.

Located about 11 km NW of Kinlochewe on the north-east shore of Loch Maree, the furnace (NGR NG 958 705) is difficult to comprehend because of its very overgrown and collapsed state, but the slags found during a brief visit in 1980 suggest that this was the site of a high bloomery later converted into a blast furnace.

INVERGARRY (illus 1)

The remains of Invergarry blast furnace (NGR NH 313 010), whose history has been described elsewhere (Lindsay 1977, 58; Fell 1908, 343–89) is situated on the south bank of the River Garry about 600 m from the river's debouchment into Loch Oich. The area is now densely covered by trees and undergrowth and, although the furnace and slag heaps are still vaguely recognizable, other structures are difficult to discern.

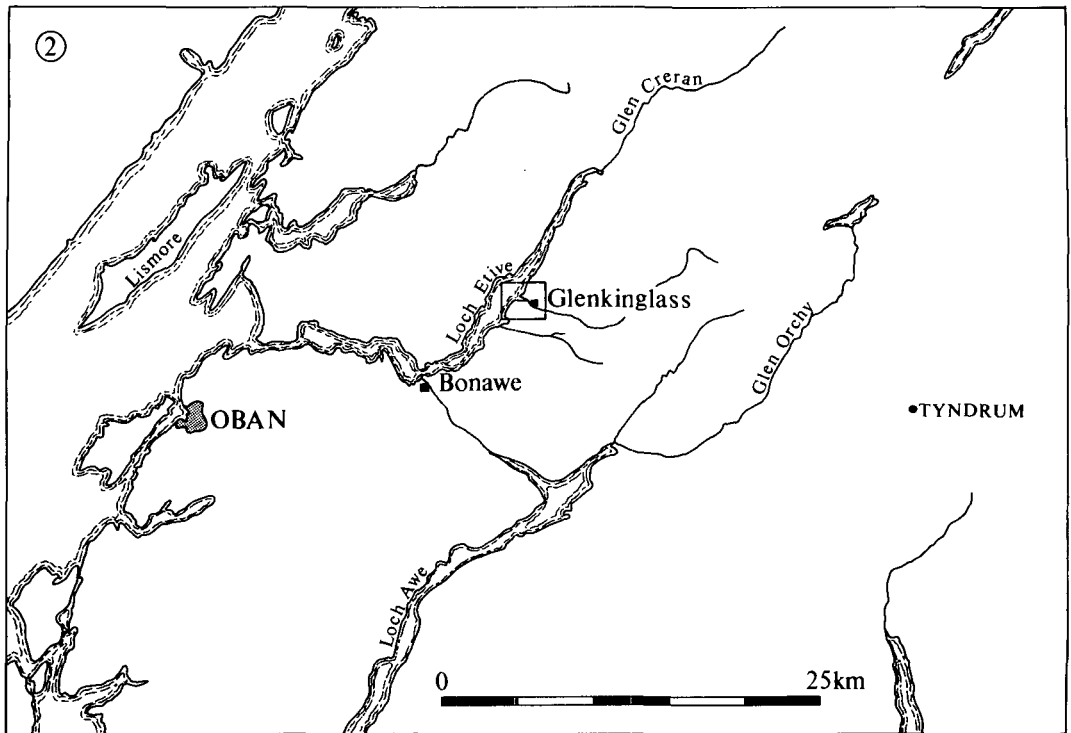
CULNAKYLE (illus 1)

Thought to have been built near the confluence of the River Spey and its tributary the Nethy, in the forest of Abernethy, Culnakyle Furnace was not located on a recent, brief visit to the site. An approximation of its grid reference is thought to be NH 996 217. Charcoal for the furnace was produced locally. Ore came from the Lecht Burn (NGR NJ 238 159), near Tomintoul, where numerous attempts have been made to follow veins of haematite and limonite. None of these attempts was very successful for the veins are narrow and commercially unviable. It is quite likely that this was a contributory cause for the failure of the Culnakyle works as well as other ventures of unknown dates.

EXCAVATIONS AT GLENKINGLASS FURNACE (illus 7–17)

INTRODUCTION

Glenkinglass Ironworks (NGR NN 082 371) is situated 10 km NE of Taynuilt, Argyll, in the parish of Ardchatten and Muckairn, on the north bank of the River Kinglass about 1 km E of its junction with Loch Etive. The country rock of the area is porphyritic Starive granite, an igneous intrusion of Lower Old Red Sandstone age, which is overlain by the products of pronounced glacial activity including, locally, a raised beach deposit of late Pleistocene age situated to the immediate E of the furnace. Oxidation of the upper levels of the glacial till has changed its original colour of blue-grey to brown and over much of the area this has been buried beneath considerable deposits of peat. Even though the parent rock of this part of Scotland is igneous, mineralized zones are uncommon and no metalliferous ores of any commercial value are to be found in the vicinity of the ironworks (MacGregor 1920, 1). The decomposition of these rocks often result in the formation of red-brown deposits and, during the 19th century, this gave rise to the misconception that iron ore had been mined near to the furnace. All of the ores used at Glenkinglass, however, were imported, namely haematite from Furness in Cumbria and bog ore from Islay and Jura.

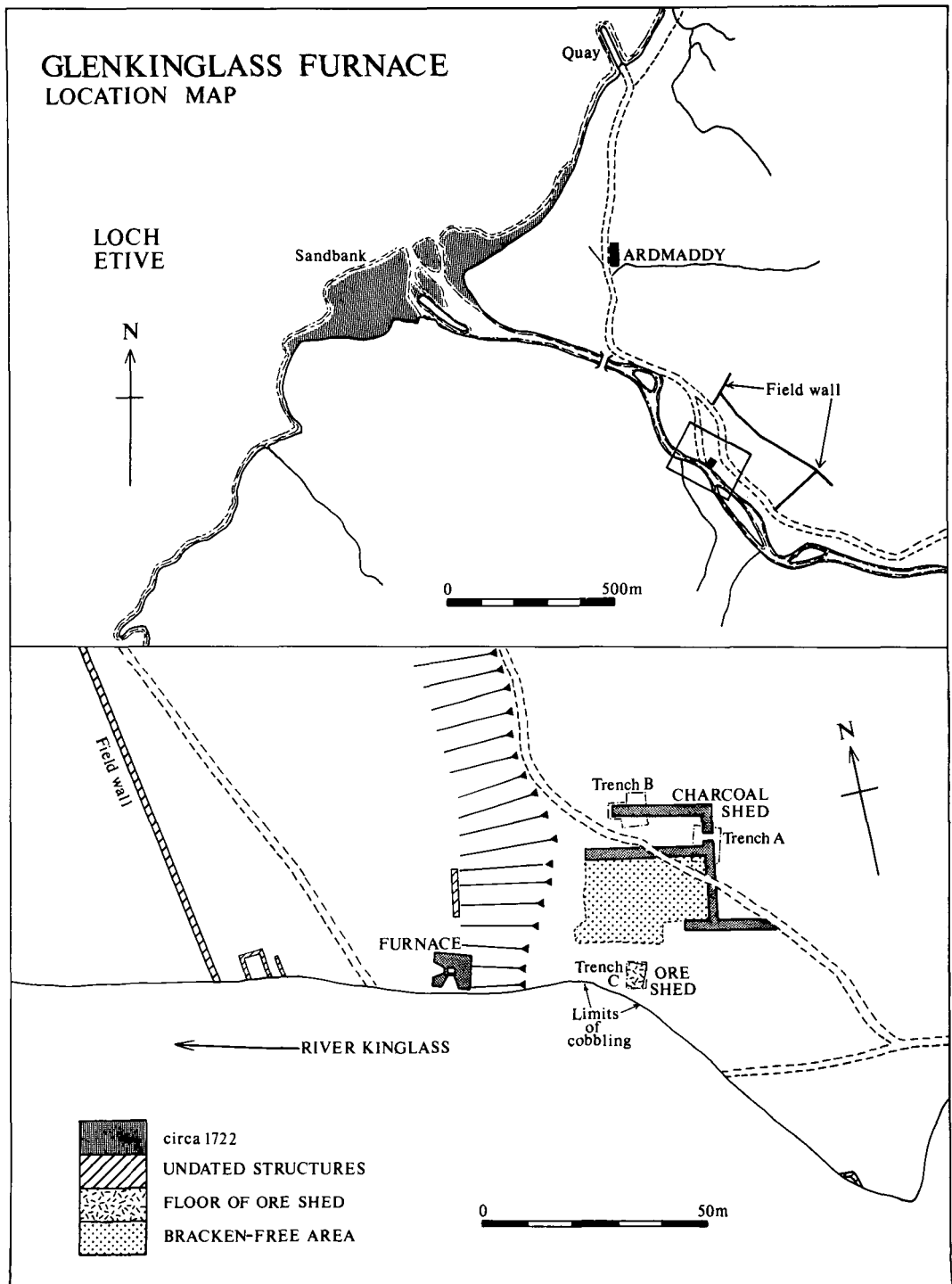


ILLUS 7 Inset 2: locations of Glenkinglass and Bonawe furnaces

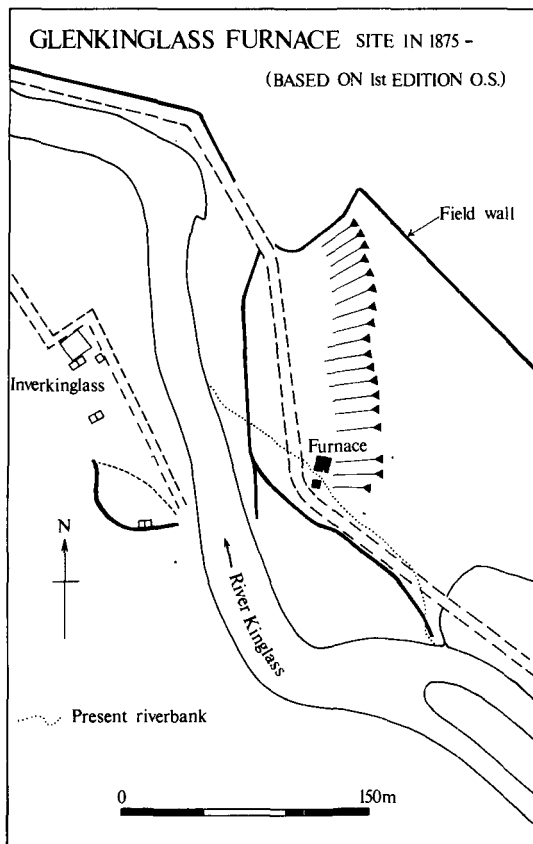
The lower slopes of Monadh Liath, to the NE of the site, are well wooded mainly with oak interspersed with a few birch. A possible charcoal-burning stance midway between the works and Ardmaddy, near Loch Etive, suggests that the company made use of the woods in the immediate neighbourhood of the furnace, although the main sources of charcoal were outside the immediate area. Coastal vessels may have brought in supplies from far away as Glen Creran (RCAMS 1974, 281) while pack-horses or ponies travelled the road from the upper reaches of the glen as well as from Glenorchy. This road may have existed in some form before the furnace was built, but was probably not metalled until the ironworks was in production. Today the road surface comprises granite chippings as well as blast furnace slag which is still present in large quantities close by the furnace.

In the 1960s a 150 m long section of the road was destroyed when, in the course of one night, the swollen River Kinglass swept away a sizeable portion of the land S and E of the furnace. The extent of this and other erosion can be seen by comparing recent editions of Ordnance Survey maps with those of the first edition of 1875 (illus 9). During that century about one hectare of land close to the furnace was lost to the river. Of the whole system of lade, dam, headrace, wheel pit and tailrace, however, there is now no trace; all have been casualties of erosion, much of it possibly in the 1960s. Early Ordnance Survey maps show a rectangular building, of unknown function, immediately S of the furnace but this too has since been destroyed and the rerouted river is now very close to the furnace, placing the structure itself in jeopardy.

The low lying ground, on which the furnace stands, is subject to regular inundations resulting in heavy deposits of riverine sands and gravels having been deposited within the casting



ILLUS 8 Glenkinglass: location maps



ILLUS 9 Glenkinglass: the site in 1875 (based on the 1st ed OS map)

house to the NW of the furnace. If the river was a threat to the casting house during the working life of the furnace then it is reasonable to assume that this threat would have been countered by a wall or artificial levee. The OS 1875 map shows a wall parallel to and W of the road extending along the haugh and continuing past the furnace and up the slope in a SE direction. The bottom course of this unbonded rubble wall still survives, running northward from the river bank about 50 m W of the furnace (illus 8); the remainder of it has, however, been destroyed. Both its original age and function are not certain, but two things point to its having been contemporary with the ironworks. Firstly, on the raised ground, the wall's position adjacent to the road suggests that it served a protective role, possibly keeping traffic away from the section of cliff, already threatened in the 18th century and lost during this century. Secondly, N of the furnace, extensive deposits of slag within, and lack of such material beyond the wall suggest that it was a barrier during the iron company's stay. It is unlikely that this was a farm boundary wall for, on the raised ground, it merely cuts off a very small area of ground from the surrounding rough grazing land and, on the haugh, it simply divides the stony flood plain into two. From these points it would seem reasonable to assume that the wall was part of (if not all of) the works' flood defences. To replace the stretch of road lost by erosion of the cliff, a new section, running well to the E of the original road and completely by-passing the haugh, has been laid in recent years so that the whole glen is still accessible to motor vehicles.



ILLUS 10 Glenkinglass: general view from the W. *Crown copyright*

The gamekeeper's cottage at Ardmaddy is now the only inhabited house in the glen but vestiges of several other buildings, most of them stone built, were found near to the furnace as well as on the opposite side of the river. Without excavating them, however, it was not possible to date the majority of these structures with any certainty; the only ones identified as contemporary with the furnace were the turf-walled storage sheds, described below. Among the other structures were the likely remains of furnace workers' houses. It was the usual practice at such works to hire local men as labourers who would supplement their farming with winter work at the furnace: most of the skilled men would have been brought in from elsewhere. There was evidence of early agriculture just E of the ore shed and possibly just N of the furnace but there is no way of telling whether or not this was contemporary with the ironworks.

Because of the imminent danger to parts of the site, particularly the furnace, an excavation was undertaken by a small team in May 1979. Shortly after the excavation was completed, the stonework of the tuyère setting was removed by the Scottish Development Department (Ancient Monuments) to Bonawe for display. This, in turn, allowed a more detailed study of the hearth which was undertaken during a brief visit to the site, made primarily to complete a survey there, in February 1981.

EXCAVATION

The site was divided into two conveniently separate areas: Area 1, on the haugh, included the

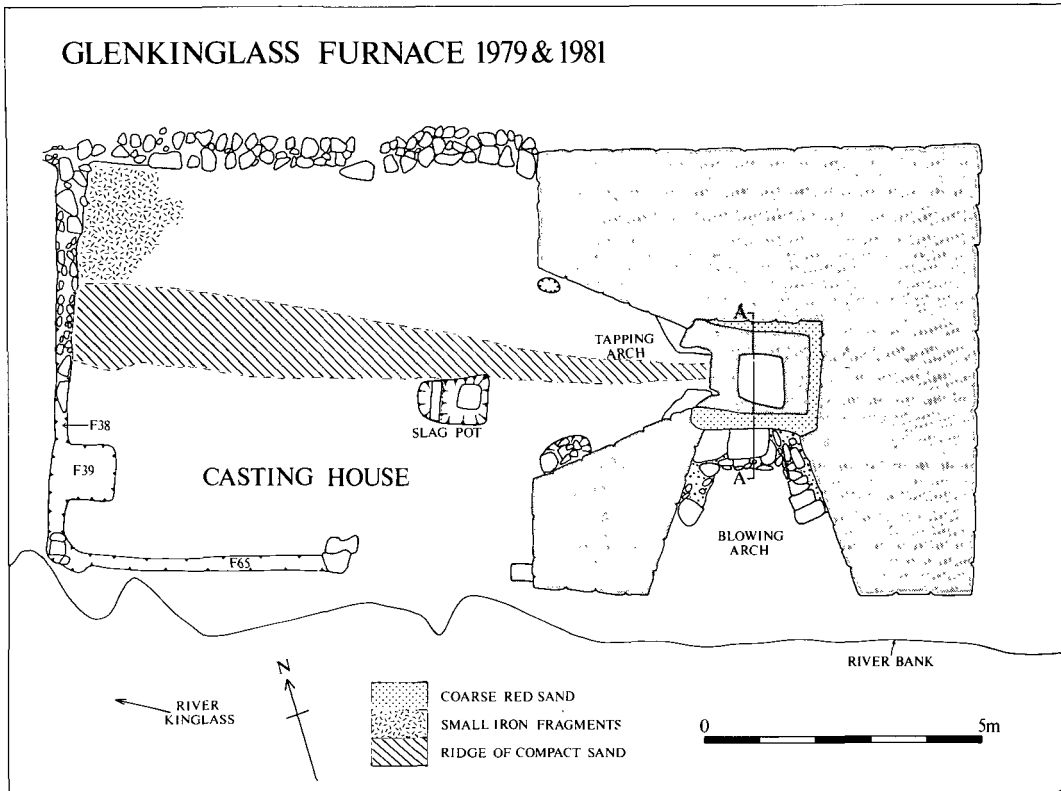


ILLUS 11 Glenkinglass: furnace and casting house from the NW. *Crown copyright*

furnace itself together with the associated casting and blowing areas, the latter almost totally destroyed; and Area 2, atop the plateau of the raised beach and about 10 m above the level of the furnace base. Remains of the turf-walled ore and fuel sheds were discernible in this area. Because of their sizes, no attempt was made to excavate fully these buildings; instead, three trial trenches were opened to determine their general characteristics and a survey of their outlines was also attempted. This latter task proved difficult, particularly during the first phase of excavation when some of the wall lines were obscured by a heavy covering of bracken, but even in the winter of early 1981, when plant cover was at a minimum, the problems of the buildings' dimensions were not all resolved. Excavation was confined to buildings directly associated with the furnace and consequently the stone structures to the W of the furnace and to the N and E of the storage sheds were ignored.

The furnace

The furnace, standing on the river bank on an approximately NE to SW alignment, measured 7.90 m square at its base and stood to a maximum height of about 4 m. Originally it was probably about 7 to 9 m high but the top half of the building had been destroyed prior to excavation, leaving no clues as to the dimensions of the stack. There was also no way of telling whether or not there had been a charging house. The walls, built of lime-mortared granite rubble, rose vertically for their surviving height and were 3 m thick except in the tapping and blowing arches on the north-west and south-west faces respectively. The interior was filled with collapsed masonry overlain with a thin topsoil which supported some turf, brambles and a few bushes: the task of removing this material was considerable. The spoil was tipped into the river in the hope of affording some protection against future erosion but this proved ineffective: after less than two years the rubble, much of it comprising massive granite



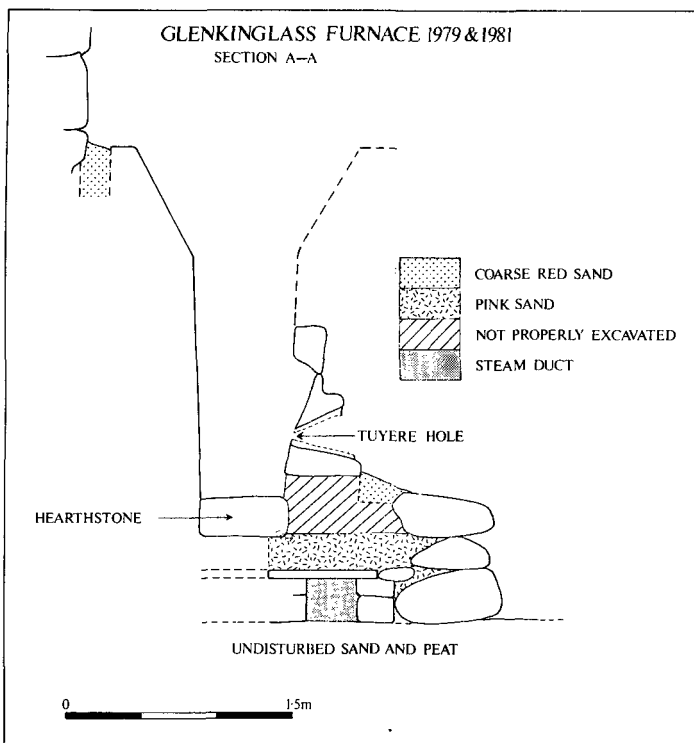
ILLUS 12 Glenkinglass: casting house and furnace, excavated in 1979 and 1981

boulders, had been swept away by the river leaving the furnace still in danger. Among the rubble were found the bones of a few small mammals as well as some butchered bones, debris, perhaps, from some Victorian or Edwardian picnic. Below the main body of the rubble, to the W of the furnace was a thin layer of ash and mortar containing several sherds of mid-19th-century pottery, dating the main collapse of the furnace to at least a century after the works' closure. The hearth was filled with coarse purple sand and sandstone fragments, resulting from the decay of the furnace lining, and there was little meaningful stratification among this material, or in the rubble within and outwith the furnace building.

Although the upper part of the building was badly damaged there was still evidence of springers within both the tapping and blowing apertures. This suggested that these openings had been arched, unlike the corresponding structures at the later Bonawe and Cralekan furnaces, where they are lintelled. At Duddon, in Cumbria, both the tapping and blowing apertures were originally arched but the collapse of the blowing arch resulted in its being replaced by a lintelled arrangement. The tapping arch remained barrel vaulted. Lintelled openings did not necessarily replace earlier arched ones, as the tap-arch apertures at the early 17th-century site of Red Smiddy has shown.

Between the outer casing and the inner core of the furnace, around the whole circumference of the inner structure, was a 200 mm gap filled with coarse red sand. Similar material was found at Red Smiddy and similar functions of insulation against heat and protection against stress are assumed.

The hearth measured 700 mm square at its base, widening slightly to 800 mm at the junction with the boshes 1.60 m above the hearthstone. Unlike the hearth the boshes were circular in cross section (circular boshes generally replaced square ones in the mid-17th century), widening out, like a truncated and inverted cone, to an estimated maximum diameter of 2.20 m. Estimation was necessary here because of the severe damage suffered by this part of the furnace. The east corner of the boshes was intact and from this point upwards the furnace tunnel continued for a further three or four courses;

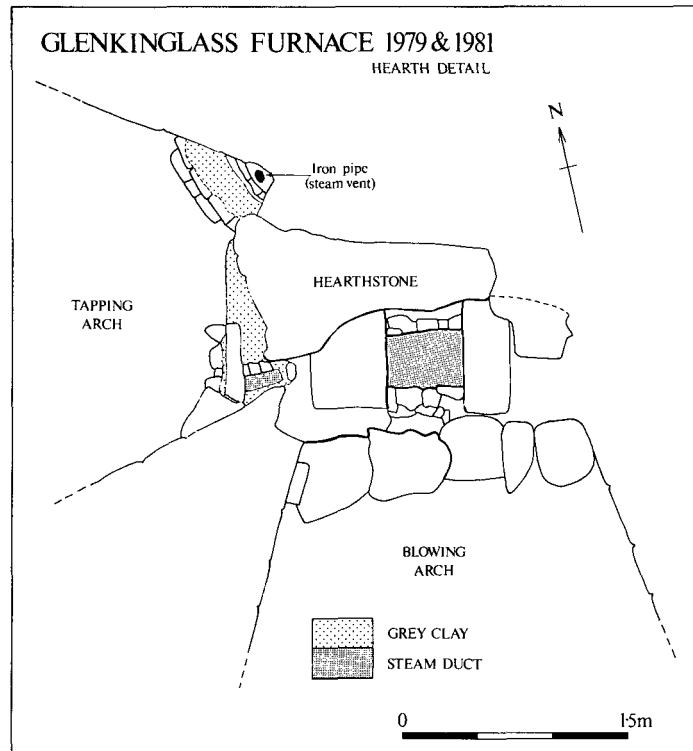


ILLUS 13 Glenkinglass: section A-A through the furnace

thereafter the remainder of the stack had been entirely destroyed. The angle against the vertical of these few surviving courses suggested the conventional slight upward narrowing of the tunnel. Contact metamorphism had altered the gross structure of the quartz crystals in the sandstone of the boshes and where the slag covering was absent this was apparent, the stones resembling the granite of the outer casing of the building.

The removal of the stonework of the tuyère setting, shortly after the 1979 excavation, involved the partial demolition of the furnace interior allowing a fairly detailed examination of the hearth and the drainage system it overlay. The hearthstone was a single block of sandstone, 1.62 m long and varying in width from 400 mm at the back of the furnace to a maximum of 850 mm near the taphole. Pronounced banding was exhibited throughout the 200 to 250 mm of the stone's thickness. The colours of these bands ranged from deep red, where the stone had been in contact with the molten iron, to its natural yellow where it rested on coarse riverine sands. This sand extended into the blowing arch and by removing some of it there it was possible to investigate below the hearthstone without actually dislodging it. In the area excavated the 200 mm deep bed of sand overlay a series of cast-iron plates, each measuring 650 mm by 450 mm and 50 mm thick, and a single granite slab of similar dimensions set towards the furnace rear. One of the iron plates was removed revealing a channel 340 mm wide and 270 mm deep defined by two lines of sandstone fragments running parallel with the long axis of the hearthstone (illus 14). These stone supports were built on natural sand and peat.

Early blast furnaces were usually built at the foot of slopes and close to a source of water, as at Glenkinglass. Water seeping below the hearth would be vaporized by the heat of the furnace and could, if allowed to accumulate within a confined space, cause an explosion. To combat this threat a drainage channel was often cut around the outside of the furnace (Schubert 1957, 197), as may have been the case at Bonawe, but this measure was not necessarily enough and other safety measures, such as escape passages for water vapour, were introduced. Such was the system built into the furnace at Glenkinglass, the channel found below the iron plates being a steam duct. Although it was not possible



ILLUS 14 Glenkinglass: hearth after the removal of the tuyère setting

to excavate the area to the back of the hearth or below the hearthstone itself, it is assumed that at least one more duct ran below the furnace base. Steam was vented to the open air by means of pipes set on either side of the taphole, but only one of these pipes still survived, this being adjacent to the north face of the tapping arch (illus 15).

The surviving pipe had been fashioned from a single sheet of wrought iron and shaped into a 500 mm long truncated cone, 200 mm in diameter at its base, narrowing to 50 mm at its apex. It was positioned 300 mm above a small rectangular aperture, 180 mm by 150 mm, and held in place by a cladding of thick grey clay. This clay extended as far as the opening in the form of a hollow channel, thus functioning as a continuation of the pipe and allowing free passage of the vapour from below the furnace to the open air. The whole feature was protected by a stone wall, 700 mm high, curving slightly between the hearth and the north face of the tapping arch. Similar stonework was found on the opposite side of the hearth but the pipe itself had already been removed prior to excavation. Removal of this stonework revealed another small aperture, 200 mm by 40 mm, which was found to be a continuation of the steam duct running below the iron plates and which originally would have carried vapour to another pipe for venting. The Irish company must have considered the steam ducts sufficient to cope with water seeping beneath the hearth for there was nothing to indicate that any channels had been dug to divert water draining down the slope behind the furnace.

In some early blast furnaces a timber bracing was built around the outside of the building to provide protection for its masonry. Such a framework may have been present at Glenkinglass but the only surviving trace was a horizontal groove, 250 mm wide and recessed 70 mm, situated 3.20 m above the base of the north-east wall of the furnace building. At this height the other three walls of the building were either badly damaged or destroyed altogether, so it was not possible to tell whether the grooving originally extended around the entire building. Further protection may have been provided by the layer of sand around the inner layer of stonework which would have lessened the strain on the furnace casing.



ILLUS 15 Glenkinglass: hearth after the removal of the tuyère setting. *Crown copyright*

Overall, the safety measures at Glenkinglass would seem to have been sufficient to prevent a major disaster. There was no evidence of a catastrophe having occurred during the working life of the furnace. Its end seems to have been a peaceful one, since 19th-century pottery below the bulk of the furnace collapse indicates that the building was still standing some considerable time after it was blown out.

The tapping procedure of early blast furnaces is described in some detail by Schubert (1957, 238-43) and a few aspects of particular relevance to Glenkinglass are described below in the section on the casting house. Structural details of the area of the taphole, however, were few since much of this part of the furnace had been badly damaged, leaving a gap (which would have been partially covered by the damstone) 700 mm across by 800 mm high, in the north-west face of the furnace hearth. To prevent any molten metal or slag percolating down through the casting floor sands and running below the hearth, a large deposit of grey clay was positioned against the hearth base (illus 14, 15).

Charging the furnace

Prior to excavation there was no obvious evidence of a charging house at Glenkinglass, the topmost half of the furnace being completely destroyed; nor was there any indication of a bridge between the furnace top and the bank upon which the storage sheds had been built. The raw materials could have been transferred via a ramp or ladder but the furnace was in a well-appointed position, its top probably level with the bank opposite and it would seem inevitable that a bridge once spanned the gap between these two points.

A trench extending from the river bank to a line 1 m beyond the north-west wall of the furnace and continuing up the slope from the back of the building failed to reveal any sign of posts that could have supported such a bridge. Likewise there were no niches within the back wall of the furnace to indicate that any timber had been set therein, although the existing height of only 3.5 m of this wall was not enough to state that none had ever existed. Extending this trench may have revealed postholes but this was not possible in the time available.

This trench did, however, reveal considerable quantities of charcoal as well as ore dust intermixed with lenses of sand, gravel, peat and buried turf, resulting from bank slippage. The predominance of pink staining, associated with haematite, over the light brown staining characteristic of bog ore may simply have been because dust from bog ore is not obvious when mixed with sands and soils of similar hues. Alternatively, the ironmasters may have had a preference for the richer

haematite, being very low in phosphorus. Very few nuggets of either type of ore were found in this area, whereas charcoal was plentiful here, possibly having spilled from overloaded baskets whilst in transit across the bridge (boggy ground in the vicinity of the storage sheds would probably have ruled out barrows). The ores, being denser materials, probably would not have filled the baskets and hence not have spilled.

Blowing house

The only surviving features associated with the blowing mechanism were found within the blowing arch itself: all traces of water courses leading to and from the wheelpit, as well as the pit itself, have eroded away. The lade is not shown in the first edition of the OS map of 1875 but it may have already silted up by then. To reach the furnace either the lade or the headrace must have crossed the road and the tailrace would have run off via a culvert beneath the road and probably also beneath the flood wall.

Near to the furnace the gradient of the river is quite gentle and it seems unlikely that the lade could have been elevated enough to have turned anything other than an undershot wheel. After the abandonment of the furnace the wheel may have been reused elsewhere. Although no other blast furnace was to operate in the area for 15 years it could have been used in another local industry, such as the mill that was operating in the glen at the time (Paton 1922, 3).

The only surviving remains of the blowing apparatus, found within the blowing arch, were the tuyère setting and part of the support for the front of the bellows. This support was a rather crudely built structure of mortar-bonded granite rubble, three courses high, butting against both splays of the arch (illus 16). It was built on a series of sands and gravels, 300 mm to 400 mm deep and heavily contaminated with ash and charcoal which, in turn, overlay undisturbed fluvial sands. This indicates that the support was not a primary feature but had, at some time, replaced an earlier structure. 370 mm above the level of the hearthstone was the tuyère hole, externally 500 mm and internally 110 mm in diameter, its setting being of well tooled sandstone. Within the blowing arch, intermixed with contaminated sands, were deposits of grey clay, probably that used to seal the gap between the blow



ILLUS 16 Glenkinglass: blowing arch. *Crown copyright*

hole and the tuyères when in blast. Similar material was also found in the tapping arch where its uses were many.

There was no evidence of a formal floor to the blowing house and nothing to indicate that there had ever been one. Likewise no roofing materials were found but this tends to suggest that the building was roofed with turf or bracken rather than being open-topped.

Casting house

Several problems concerning the casting house have proved difficult to resolve but the overriding impression is of a rather insubstantial structure far removed from those associated with later furnaces and more akin to the earlier, rather flimsy, constructions portrayed in the 16th-century paintings of Van Valkenborch and Blè (Schubert 1957, 182, 198). Both examples used by Schubert show the casting areas roofed with thatch and only partially walled, the walls themselves looking somewhat fragile. That thatch would have been used to roof a furnace and casting house at a works as late as Glenkinglass is somewhat surprising, but the complete absence of slates, tiles or any other inorganic roofing material within the debris in and around the furnace would suggest that thatch was the material used to safeguard against rain and snow. The availability of heather (and perhaps bracken) must have outweighed the advantages of using more permanent roofing materials even though slate had been quarried at Ballachulish, a distance of about 40 miles by boat, for over 30 years prior to the founding of the ironworks at Glenkinglass.

Although crudely built, the casting house was certainly larger than those depicted in early paintings and greater in area than that at Bonawe (illus 12). At Glenkinglass it was housed within an area 8.40 m by 7.10 m, defined on the NE by a 600 mm wide wall of unbonded granite rubble, only one course of which survived, and with no obvious bedding trench. A return wall seemed to run SW for the north corner of the building but its stonework extended only for 4.50 m before petering out within a trench that narrowed from 600 to 200 mm and deepened to a maximum of 250 mm. From here the trench (F38) continued for a further 500 mm before widening out into a rectangular pit (F39), 1.30 m by 1.10 m and 400 mm deep, after which the trench extended for a further 600 mm to the W corner of the building. This corner was marked by a post-pit, 350 mm in diameter and 320 mm deep overall, within which were two vertical packing stones either side of a flat basal stone. From this point another narrow trench (F65), 220 to 280 mm wide, continued in a south easterly direction for 4.50 m before terminating at a possible entrance – a 2.70 m wide gap between F65 and the south-west face of the furnace pillar. On either side of this entrance were flat stones, settings perhaps for door posts. Although the north wall seemed to continue into F38 its narrowing and deepening suggest that it was not a bedding trench for another stone wall. F38 and F65 may, however, have housed sleeper beams but no evidence of such timbers was found; if they had been positioned in these trenches they would probably have been removed when the furnace was abandoned. Sleeper beams, though, would not account for the deepening or the narrowing of F38 as it approached F39; nor would they account for F39 itself.

Turf, furnace collapse and 100 to 250 mm of topsoil (mostly river washed sands, redeposited during flooding) were removed from within the casting house and tapping arch. Below this the entire floor surface was of coarse fluvial sands but divided into three distinct areas. A slightly elevated ridge of hard packed yellow sand extended along the entire length of the building, widening from 300 mm in the tapping arch to a maximum of 1.40 m adjacent to F38.

The most likely explanation for the existence of this ridge of heat-affected sand is that it was the course along which the molten iron ran, becoming raised when contaminated sands to either side of it were periodically removed. To the NE of this low ridge there was heavy iron staining and in the north corner an irregular patch of small iron fragments possibly resulting from molten metal splashing on to a damp sand during casting. On the other side of the ridge was a 20 to 50 mm deep layer of charcoal, ash and slag which had stained the topsoil overlying it. The burnt material extended over a large area but did not go beyond F38, F39 or F65. This division of the casting house suggests that iron was cast toward the north-east half of the building while the remaining area was given over to the disposal of furnace waste.

The casting floor sand would have been removed frequently and replaced by clean material but there seems to have been no attempt to use anything other than the sand found in the nearby river beds, unlike the hypothetical situation presented by Schubert where the founder carefully selected the sand and supervised its transport to the furnace (1957, 241).

During smelting slag would have been tapped periodically and solidified near to or within the tapping arch, the process being effected in a 'slag pot' where the molten slag would solidify before being further removed. At Bonawe furnace the slag pot was situated outside one of the splays of the tapping arch and at first it was thought a similar location had been utilized at Glenkinglass. However, the particular feature in question proved to be a large post-pit. The slag pot may have been the rectangular pit just outside the confines of the tapping arch, measuring approximately 1.20 m by 800 mm and cut into the casting house floor and natural sands to a depth of 520 mm. Above the bottom fill of small slag fragments were set a 400 mm square flat stone and a small section of an iron pig. Overlying these was a series of redeposited sands, 170 mm deep, this material being a continuation of the topsoil. Rather than being the slag pot itself, this hole may well have housed a movable iron pot, set upon the flat stone and capable of being emptied elsewhere.

Evidently, not all Glenkinglass iron was made into pigs, for the head of a small iron ladle (illus 17), covered with cast iron, was found in the debris of the casting house. The ladle would have been used to transfer the molten metal to prepared moulds and perhaps used in the manufacture of domestic wares for local consumption. Burt, however, states that iron was not used extensively in the 18th-century Highlands (1815, 122–3). One object almost definitely cast at Glenkinglass is a fire-back from Achnaba farmhouse (found locally and now exhibited at Bonawe) bearing the inscription D.C. (? Duncan Campbell) and the year 1732 (RCAMS 1974, 243–4).

Two post-pits adjacent to the arch splays still remain unexplained. The large pit, adjacent to the furnace pillar, 1.07 m by 530 mm and 400 mm deep, could have housed a post of c 260 mm in diameter which, when secured by the series of vertically placed packing stones, could have either provided support for an iron duct or acted as an upright to which a movable ladle was attached. The other post-pit, or posthole, being much smaller and having no stone packing may have had a secondary supportive function but precisely what it was is not known.

Interpretation of features within the casting house floor proved difficult mainly because of the damage caused by frequent flooding. In the period of less than two years between the two phases of excavation the casting area had been inundated by the river on several occasions, leaving fresh deposits of sand up to 250 mm deep. The corollary of this is that much of the sand of the casting house floor may have been removed from the site since 1738, resulting in some of the original features being obliterated. The situation was further complicated by numerous voids, caused by boulders from the collapse of the furnace and those washed in by the river being deposited in the sand to be removed again during flooding at a later date. It proved very difficult at times to distinguish between some of these voids and the true postholes.

The lack of positively identifiable postholes rendered the interpretation of the overall structure of the building very difficult. The only posthole which was reasonably placed to accommodate a roof support was found in the west corner of the building. The roof could have been tied in to the main structure of the furnace but, as flimsy as it probably was, it would still have required more than one post to support its weight. A depression, 230 mm in diameter and 220 mm deep in the north corner of the casting house floor and equidistant from both the north-east and north-west 'walls', resembled a posthole but the small iron fragments found in this area sealed its fill of iron-free grey sand, implying that the hole was merely a void.

The almost complete absence of recognizable postholes around the perimeter of the casting house must mean that they had been obliterated rather than never having existed. There seems little chance that the weight of the roof could have been borne by the walls of the building, and the absence of walls on two sides would rule out this being a cruck-framed building. A reasonable hypothesis concerning the roof might include a thatched surface, perhaps continuous with the furnace top, sloping away from the main building, its pitch carrying rainwater into the trenches on the north-west and perhaps the south-west sides. These trenches – F38 and F65 – would, then, have to be interpreted as drainage ditches rather than bedding trenches and the problem of the stonework extending from the north-east wall into F38 is no nearer resolution. It is possible that the original intention had been to continue the stone wall around the entire perimeter of the house and for some reason this work was never completed. This would suggest that either the building was never used – and this is patently not the case – or that a different style of construction was employed part way through its fabrication; this seems unlikely.

The only positively identifiable wall was on the NE, but its poor construction probably meant that it had no supporting role. If there had been a sloping roof to the casting house this wall might have

been quite low towards the north corner of the building which, in turn, would have reduced the corner to a rather inconvenient place in which to work, perhaps confining casting operations to a very small area. The iron splashes, then, may simply have been raked into the corner prior to the renewal of the floor and out of the way of fresh castings. Judging by the poor construction of the wall, it is unlikely that it included a window and to ensure adequate lighting one or more sides of the building may have been left open. It could be argued that this would have obviated the need for a formal entrance but the movement of heavy materials across F38 and F65 would have posed problems of carriage.

Like so many other features within the casting house, the rectangular pit, F39, cannot be interpreted easily. It could be seen as a temporary repository for ash pulled into this part of the building from casting in the NE of the shed. More likely is a role associated with the drainage of rainwater along F38 and possibly F65. There was a gentle, but definite, slope along these trenches towards the west corner of the building and water may have been channelled into F39 which acted either as a soak-away or, conversely, as a water collection point. If the latter was the case then F39, at least, must have been lined with clay, wood or some other impervious material. The post that presumably stood in the west corner would surely have obstructed the flow of water from F65 towards F39 and so the hypothesis of a roof sloping downwards to the NW and carrying rainwater in F38 alone seems the most fitting.

The full extent of this building may have been lost because of erosion. It is possible that, as at Bonawe, the casting and blowing houses came to be included within a single large building, the re-entrant angle again, perhaps, being used as a store. No evidence of a building could be seen between the casting house and the present river bank but, given the small area of land still remaining, it is difficult to be certain that no such structure ever existed.

Charcoal shed

Prior to excavation, this appeared to be a fairly simple rectangular building, defined by low turf walls or banks on three sides only and measuring 25 m E to W by 7 m N to S. The west wall, however, was not obvious. Two trenches, A and B, were opened at the presumed south-east and north-west corners of the building (illus 8). Trench A, 8 m N to S by 6 m E to W, was thought to include an entrance; Trench B, approximately 12 m W of A, incorporated the apparent termination of the north wall. This second trench originally measured 6 m N to S by 5 m E to W but was later extended a further 3 m westwards to include the whole of this wall.

In both trenches, below the turf and 200 to 500 mm of black peaty topsoil, a charcoal spread, 150 to 200 mm deep, lay on all sides of the walls. These walls, standing only 700 mm high, were built of turf blocks, each 300 mm long and 150 mm square in section, their outlines well preserved in the acid soil. The north wall did not terminate within the original area of Trench B, as was first thought, but petered out in the trench extension, without exhibiting any obvious sign of collapse or trace of a return wall running either to the N or S. The absence of a west wall, together with the spread of charcoal on all sides, suggested that the walls so far encountered were internal partitions. The lack of any obviously related features N of these trenches, however, renders this theory inconclusive. The east wall was breached by a 2 m wide entrance; a spread of small granite chips at this point served, perhaps, as a threshold.

Removal of the charcoal spread in Trench A revealed a 2 m wide pit adjacent to and running parallel with the south wall and extending beyond the west edge of the trench. The pit was cut into the natural peat to a depth of 500 mm and was filled with charcoal fragments up to 80 mm in diameter. The remainder of the area inside the shed walls comprised a floor surface of small turf blocks, set mainly on the natural peat. However, below the floor, adjacent to the north wall and continuing into the west edge of the trench, was another linear charcoal-filled pit, 1 m wide and 400 mm deep. There may have been any number of these narrow pits within the building but limited excavation was unable to determine either their frequency or the full extent of the two already revealed. None, however, was found in Trench B. The abandonment of the earlier pit, revealed in Trench A, may have been due to flooding and laying a floor may have helped alleviate this problem. A more extensive examination of the pits may give a better indication of their function. It is thought, however, that much of the charcoal was stored in them to counter the lack of available height within the building.

To keep the charcoal dry, drainage ditches may have been dug around the outside of the building, for it was noticeable during the excavation that water drained through the peat for some considerable time after the cessation of rain. There was no obvious indication of drainage channels but

it is easy to imagine their silting up over two centuries. It was standard practice to ensure that all materials charged into the furnace were as dry as possible for, if water were present, it would have been necessary to increase the quantity of charcoal in the charge to counteract the loss of fuel caused by the ensuing water-gas reaction. If insufficient fuel was available, the smelting process would not be completed properly and iron would be lost to the slag.

The possibility of the north wall being internal was echoed by a similar situation concerning the south wall, which again may have been an internal partition within a very large building. From Trench A the E wall extended a further 14 m southwards from which point walls extended at right angles to both the E and the W. Here the picture became unclear for neither of these walls continued very far; the 'wall' running eastwards was perhaps only a waste dump (from road building?) and that running westwards petered out after only 6.5 m. From here the line of this wall continued to be defined only by differential plant growth: a thick cover of bracken to the S of this line contrasted markedly with the complete absence of the plant to its immediate N (illus 8). If this line, which continued northwards to meet the south turf wall, is taken as an outer limit of the building then, internally, the shed must have measured a minimum of 27 m by 18 m, making it a very large store. A small (1 m square) trench was cut within the area between the bracken and the south turf wall. Below the stunted heather was a spread of charcoal fragments together with a few nuggets of bog ore (but no haematite) which directly overlay the natural peat with no evidence of a floor surface between. This small trench, then, did not provide enough information to answer the question of whether or not this area was within the building: the charcoal and ore would suggest the inside of a shed, but the lack of a proper floor surface would argue against it.

No roofing materials were found either in Trench A or Trench B. It is reasonable to suppose that the shed roof would have been thatched since slates or tiles would have added to the company's costs and thatch was probably used to cover the casting house. However, it had been hoped that some timber roof supports would have been found, but although conditions were ideal for their preservation (a fairly waterlogged soil and a low pH) no timbers, worked or otherwise, of any appreciable size were found in either trench. Also absent were recognizable postholes either in the floor levels or within the walls of the building. The latter suggests that this was not a cruck-framed building, but the height of the walls, the lack of postholes within the floor and the traditions of Scottish vernacular architecture prevailing in the 18th-century Highlands would all point to the opposite.

Ore shed

Both bog ore and haematite were found in large quantities at the base of the cliff, to the S of the charcoal shed. It was thought likely this was the result of erosion removing part of an ore shed. Consequently a trench, C, was opened near to the cliff edge in the vicinity of this erosion, to establish whether or not there had been a shed there. The trench measured 6 m N to S by 4 m E to W and incorporated two possible walls which, on excavation, resembled banks of redeposited topsoil rather than the turf walls of the charcoal shed.

Below the turf and 150 mm of black, peaty topsoil were several lenses of soils with high clay contents. These soils exhibited pronounced staining, by both haematite and bog ore, as well as including nuggets of the ores themselves. Below these clays, at a total depth of 300 to 350 mm, most of the trench was covered with a 20 mm deep spread of charcoal, lying on a floor of granite boulders set directly on the natural peat. This floor covered the entire trench apart from the lines of the presumed walls where some peat blocks, resembling a somewhat insubstantial foundation course, were placed at a level slightly below that of the floor.

Erosion between 1979 and 1981 exposed a line of boulders in the cliff face which could be seen from the opposite bank of the river but could not be examined closely because of a dangerous overhang. If the line of the east wall of the ore shed was projected southwards it would meet the cliff at the east extremity of the cobbling there. It would therefore be reasonable to assume that the cobbling within the trench and that showing in the cliff face belonged to the floor of the same building (illus 8). On this evidence, the ore shed would have measured approximately 18 m E to W but its N to S dimension could not be determined because part of the building had already been lost. All that can be said is that its width (or length) was at least 8 m.

A stone floor within the ore shed may have been necessary to counteract the weight of the minerals, especially the very dense haematite which would have sunk easily into a peat floor. This type of situation would not have arisen in the charcoal shed because the fuel was very light. However, a

stone floor would have provided a better work surface and a generally drier environment there. Perhaps this is an indication of the somewhat temporary nature attributed by the company to these storage sheds.

The primary function of this shed must have been storing ore: the quantities of the minerals at the base of the cliff testify to this. Judging by the spread of charcoal on the shed floor, however, the building must also have been used to store fuel at some time, possibly during summer months when furnaces were often out of blast because of water shortages. The practice of combining different ores in a single charge was probably followed here for haematite and bog ore were found more or less intermingled within various levels of the building. Bog ore may have offset the price of the more expensive haematite while the latter would have enriched the charge.

Limestone was (and still is) a common fluxing agent. This was quarried on nearby Lismore and at Appin and was to be used later at Bonawe but none was found in the storage area at Glenkinglass. However, several blocks of the mineral had been used in the construction (or repair) of the bellows support. It is unlikely that these stones were glacial erratics and their appearance at the site would suggest that limestone was imported, being used primarily as a flux.

During the 18th century, calcination of ore was usually carried out at the furnace site. There was no evidence of a calcining kiln at Glenkinglass and it is probable that roasting was carried out in the open air at this particular works.

Storage shed construction

As previously stated, it was impossible to determine the original size of the ore shed because of extensive erosion. For different reasons, a proper interpretation of the charcoal shed also proved difficult. To determine its overall dimensions a large-scale area excavation would probably be necessary but this was not possible during either phase of excavation already undertaken. In fact, opening Trenches A and B posed more problems than were solved. It had been expected to find a wall returning from the west end of the north wall, within Trench B, but no such feature was discovered. This led to the idea that the north wall was an internal partition; and the discovery, in February 1981, of the rectangular area, defined in part by bracken growth, suggested a similar role for the south turf wall. If they were internal walls, then the outer limits of the building still await discovery.

The west wall may have been deliberately dismantled but no reasonable explanation for such an action can be offered. If this wall had not even been built then the interior of the open-ended building would have been at the mercy of the prevailing westerly (and often wet) winds. More likely is that the wall was destroyed during erosion of the slope that marks the north-west limit of the raised beach.

The absence of postholes within the floor and the low, but consistent heights of the charcoal shed walls point to this having been a cruck-framed building. More advanced building techniques were probably confined to the construction of the furnace by masons and other tradesmen brought in from England and perhaps Ireland; ancillary structures would have been left for local men to build.

The predominant style of early 18th-century Highland vernacular architecture was undoubtedly the cruck-frame where the roof was supported by a series of pairs of substantial timbers – or crucks – set at intervals along the side walls. The bases of the crucks rested within the walls; if the walls were of turf then they would be placed upon stone plates to minimize decay (Fenton & Walker 1981, 45). No such stone features were found within the excavated walls at Glenkinglass but this may simply demonstrate the lack of building skills among the local populace. Also absent were the crucks themselves, although it was the usual practice to remove structural timbers from a building rendered derelict. Ownership of such timbers varied with the location; sometimes they belonged to the tenant, sometimes to the landlord. The likelihood of Galbraith or Lochnell departing from the site with structural components rescued from the works is small and in all probability the wood was used in the construction of farms such as Ardmaddy where the original tack, dated 1739, was given out shortly after the demise of the furnace (Paton 1922, 61–2).

One of the advantages of cruck-framed buildings was that the wall, not being load-bearing, could be built of almost any available material such as peat, which was plentiful at Glenkinglass. Low walls would allow for a steeply pitched roof, a common feature of architecture in Argyll where rainfall is high. This style of cruck-frame, known as Dalriadic, was common in the western Highlands and the inner isles and contrasted with the Hebridean style of the outer isles where the characteristic gently sloping roofs and hipped end walls allowed for conditions of low rainfall and high winds. The Glenkinglass charcoal shed may have been a hybrid of these two styles for the typically Dalriadic gable

end seems to have been absent there. All of the turf walls were very low, showing no obvious signs of collapse around them, and were never likely to have been tall enough to reach the roof ridge.

If the charcoal shed occupied the ground bounded by the north and east turf walls together with the lines marked by the limit of the bracken, then the overall internal surface area of the building would have been approximately 600 m². This figure is roughly the same as that of the total floor surface of the charcoal sheds at Bonawe in 1753. The large area of the Glenkinglass store and its linear storage pits, together with its steeply pitched roof, may have compensated (in terms of charcoal storage) for the lack of height of the walls. If, however, the area of this building was only the 175 m² (25 m by 7 m) originally thought, then the storage space available must have been very small and the possibility of there having been another charcoal shed must be considered. There was certainly evidence of charcoal staining at various points along the river bank but this is not enough evidence in itself to postulate a fuel shed having been a victim of cliff erosion. Dross would have been removed periodically from the shed(s) and deposited locally; this material is quite possibly now showing in the cliff face. Added to this is the lack of evidence of any further wall lines that may have suggested another building.

An argument against a large building, with two or more bays, is that if the roof of the building was steeply pitched (should one assume that local styles were followed) then either the roof would have been extremely tall or it would have comprised two or more sections, with guttering between, to allow rainwater to be removed before it penetrated the interior of the shed.

In short it must be admitted that the structure of the charcoal shed is not fully understood. The whereabouts of the west wall is not known; the building's full dimensions are far from clear; and its being cruck-framed is assumed more than it is proven. Even less information was forthcoming on the construction of the ore shed for time did not permit a very extensive examination of it. The walls appear to have been robbed out almost to the natural peat, to a level below that of the stone floor. The wisdom of robbing turf walls is questionable and it is possible that sleeper beams were set on the turf blocks so that this shed had load-bearing walls. However, it seems unlikely that a style completely different from that used in the charcoal shed was used here; it is, then cautiously suggested that this was another cruck-framed building.

FINDS

Pottery

The majority of material was found within the furnace rubble and was of mid to late 19th-century date, probably associated with Victorian or Edwardian visitors. Only three sherds of pottery that could predate the closure of the furnace were found on the entire site, all within the contaminated sands of the casting house floors. None is illustrated.

One body sherd of red earthenware, fairly gritty, with a good lead glaze coloured dark brown by iron pigment on the inner face only and with a series of indented parallel lines as the only decoration. Probably early 18th century.

Two body sherds of Delftware, with a smooth creamy fabric. Hand painted blue stripes on a white glaze, the glaze being on both sides of these two small sherds. Possibly 18th century or earlier; origin unknown.

Glass

A number of fragments of green glass, generally poor in quality and often well bubbled, were found throughout the site. Apart from one neck and three basal fragments, all were small body fragments and these latter were considered of insufficient importance to list here.

Neck fragment of green glass bottle, 18 mm diameter at mouth, found at the base of the slope to the rear of the furnace. Early 18th century.

Three basal fragments of green glass belonging to at least two separate bottles, all of about the same maximum diameter (140 mm), the bases being inverted 30 to 40 mm. All were 9 mm thick and all were found within the contaminated sands of the backwash in the casting house.

The reasonable abundance of glass on the site may be related to the custom, prevalent at early furnaces, of inaugurating a campaign by supplying quantities of alcoholic drinks to the workforce.

Animal remains

All such remains found at Glenkinglass post-dated the collapse of the furnace. The few bones

found among the rubble belonged to small mammals, perhaps voles or mice, as well as domestic herbivores resulting perhaps from later visits to the site.

Clay tobacco pipes

Only two fragments of pipes were found, both in the blowing arch within grey clay that was probably used to seal the tuyère hole.

One bowl fragment, bearing no stamp, but typically early 18th century.

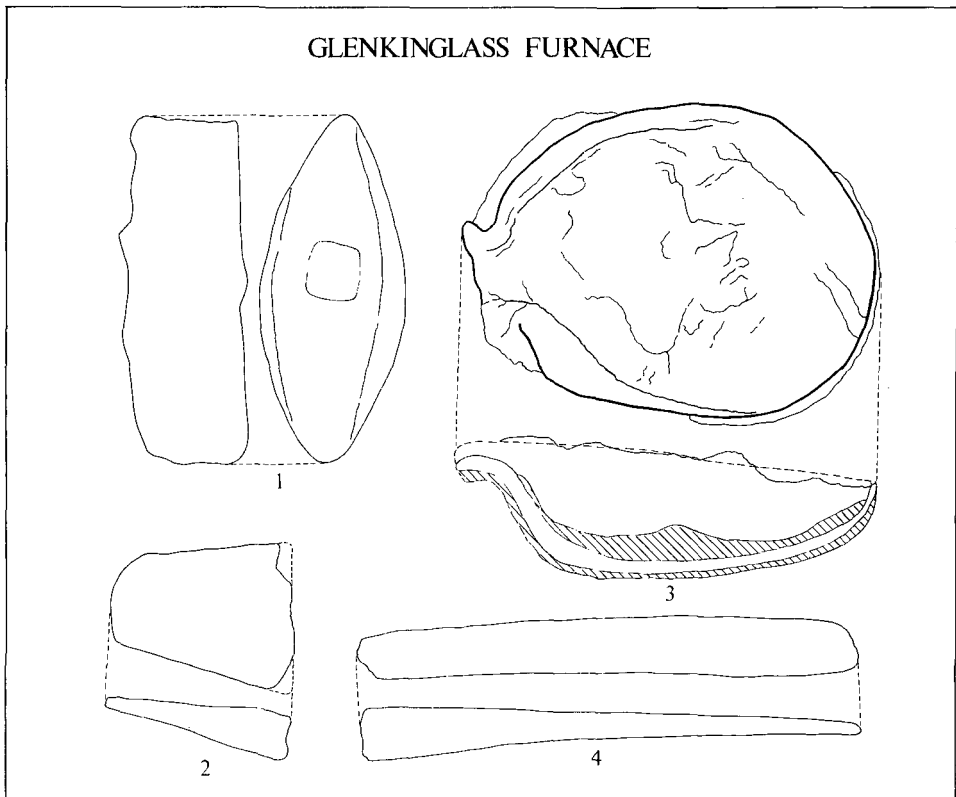
One stem fragment, the bore typically 18th century.

Coin

A badly corroded copper coin was found in the casting house, within a layer of redeposited sands. It measured 24 mm in diameter and weighed 43.2 grains. On the obverse side the only discernible inscription was . . . ET . . . MARIA.D and, in fact, nothing else whatsoever was to be seen on the coin, it being so badly corroded. By its size and weight it must be a bodle and would appear to be of the reign of William and Mary and, if minted in Scotland, then belonging to the period 1691–4. This would pre-date the site by 30 years but, because of the heavy corrosion, there was no way of telling the degree of wear on the coin prior to its deposition.

Iron objects (illus 17)

Several pieces of pig and other formless fragments of cast iron were found within the furnace rubble and in the disturbed sands of the casting house floor. These will not be described or illustrated



ILLUS 17 Glenkinglass: iron objects (scale 1:4)

here. All objects described below were found in the casting house unless otherwise stated. No metal finds were discovered in the vicinity of the storage sheds.

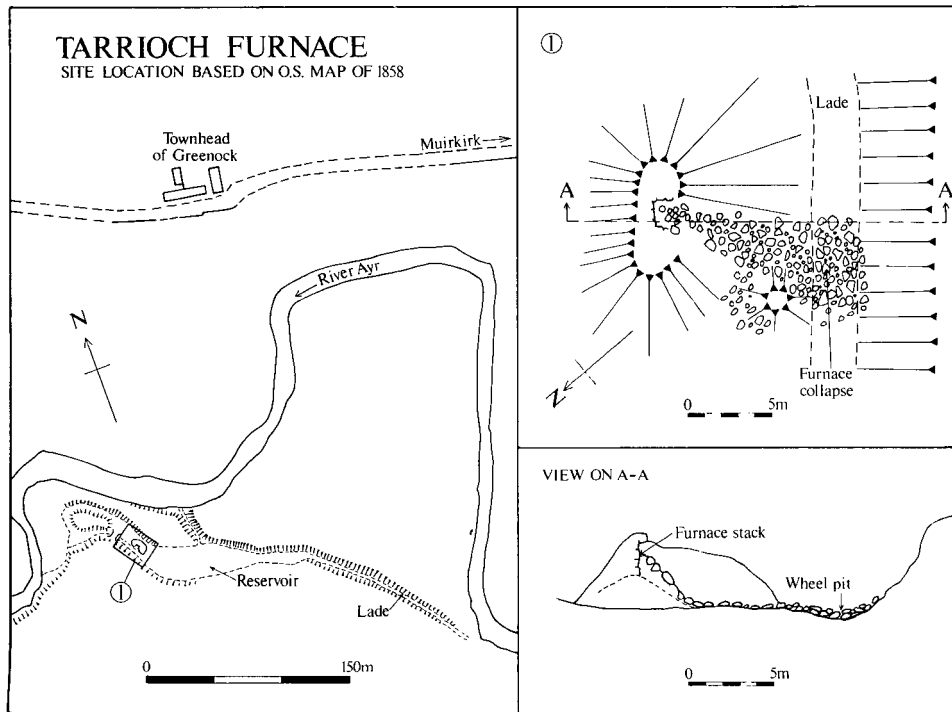
- 1 Double-edged axe head; 180 mm long, 73 mm wide at the central socket and 62 mm deep.
- 2 Small single-edged axe head; 95 mm long, 75 mm wide, tapering to 45 mm at the cutting edge. Badly corroded, showing no obvious point of attachment for a shaft.
- 3 Ladle head; 220 mm by 160 mm, 55 mm deep and 8 mm thick. Cast iron fused on to all surfaces to a maximum thickness of 17 mm on its interior.
- 4 Slightly curved iron chisel or wedge (?); broken length 260 mm with the top end damaged where it measured 26 mm square in section.
- 5 Iron plate, irregularly shaped, measuring approximately 340 mm by 140 mm and 10 mm thick (not illustrated).
- 6 A number of nails of various sizes, mostly broad-headed (20 mm diameter) and varying in length from 65 to 112 mm (not illustrated).
- 7 Within the blowing arch: 24 flat-headed nails, maximum length 80 mm, within the grey clay found near the tuyère hole. Possibly associated with repairs to the wooden structure of the bellows (not illustrated).
- 8 Iron pig 1.60 m long, 120 mm wide; approximately semi-circular in section, radius 30 to 35 mm, weight 40 kg (not illustrated).

Pig iron sample

A sample of pig iron, when analysed, produced the following percentages of trace elements:

Si	P	S	Mn	C
0.59	0.05	0.003	0.26	3.60

The sample taken was of a remarkably good iron, being quite low in silicon and very low in phosphorus and sulphur. There is very little iron produced today with a phosphorus content as low as 0.05% or a



ILLUS 18 Tarrloch: site location maps

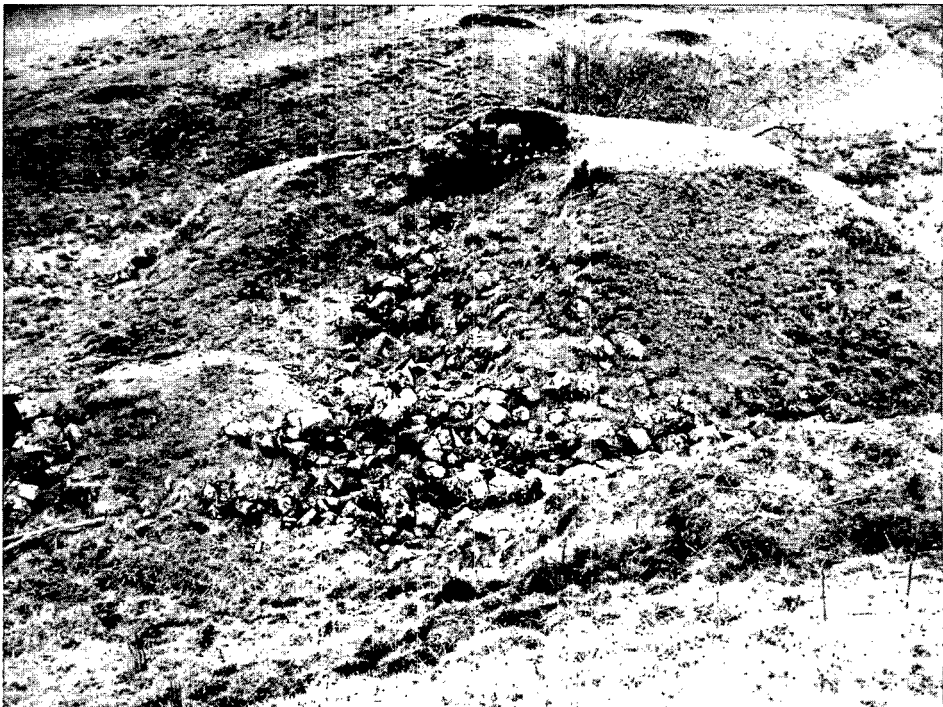
sulphur content less than 0.04%. These figures suggest that, being high in both phosphorus and sulphur, bog ore was used only as a small proportion of the total ore content, at least in this particular charge. In all, it can be said that if this iron was typical of that produced at Glenkinglass then the works maintained high standards of quality.

TARRIOCH FURNACE (illus 18 & 19)

Thought to have been the site of the only charcoal-fired blast furnace in the south of Scotland, Tarrioch (now spelt Terrioch) (NGR NS 642 269) lies on the south bank of the River Ayr, near the B743 Muirkirk to Sorn road, 5.5 km W of Muirkirk in Ayrshire. Neither the date nor the original owner have been positively confirmed. Undoubtedly one of the earls of Cathcart was responsible for the building of the furnace, but confusion has arisen as to precisely which earl it was. Baird, writing in 1910, mentions 1705 as the date of construction given to it by some local people but he assumed the furnace to date from 1732 (Baird 1910, 44). This would place the original ownership with the third earl, a local landowner.

The site is extensive and use seems to have been made of natural features. The furnace remains are within an irregular 3 m high mound, approximately 14 m N to S by 9 m E to W, which is now completely grassed over apart from the top four visible courses of the furnace interior. This measures 1.40 m N to S and is presumably square at this point, although this cannot be proved without excavation.

The present river meanders just E of the furnace and, leading from one of the bends of the river (250 m SE of the furnace), a natural water course seems to have been adapted as a lade.



ILLUS 19 Tarrioch: furnace mound from the SW

Halfway along its length it broadens into a 25 m wide reservoir before narrowing again into a headrace close to the furnace. A channel, possibly an overflow or even a lade for a forge, leads back into the river from a point midway along the length of the reservoir.

The extensive tract of elevated ground to the W of the furnace was evidently the site of the charcoal and ore sheds, where traces of structures can be seen. Charging would have been via a bridge spanning the wheel pit between the furnace and the storage area. The pit is now filled with rubble from the collapse of the furnace. It follows, from the position of the water wheel, that the blowing house was on the west and casting house on the north sides of the furnace. Access between the lower furnace level and the storage area was over a small arched bridge across the tailrace to the NW of the furnace.

Siting the works on the south bank of the river would have presented problems when importing and exporting materials. There are signs of an old road leading southwards across the moor to the present Muirkirk to Cumnock (A70) road, but if this was used by the iron company considerable expenditure must have been incurred to ensure it was good enough to carry heavy freight across 1.5 km of undulating marshy ground. More likely is that the river was crossed, probably by fording (no evidence of a bridge survives) and use made of the road on its far bank.

According to Baird pig iron from Tarrloch, as well as some from Bonawe, was refined at a local forge. The location of this forge is unknown and there is no obvious sign of such a building near to the furnace, although it may have utilized the reservoir at the back of the furnace and perhaps used the channel leading back into the river as a lade.



ILLUS 20 Bonawe: general view of furnace from the W. *Crown copyright*

EXCAVATIONS AT BONAWE FURNACE (illus 20, 21, 22, 23, 24)

INTRODUCTION

The extensive remains of the ironworks at Bonawe (NGR NN 009 318), on the south bank of Loch Etive near the village of Taynuilt, Argyll were taken into the care of the Secretary of State for Scotland in 1973 and much of the work of consolidation of the upstanding masonry structures (ie the furnace stack with its charging house, the iron ore shed and two massive charcoal sheds) was completed by 1977. In 1978 archaeological investigation of the ruined blowing and casting houses immediately adjacent to, and integral with, the furnace stack was carried out. This initial investigation was completed in 1979; the foundations of walls and other features revealed have subsequently been consolidated and are now on display. Further work, carried out in 1982, concentrated mainly on clearing the wheelpit and part of the lade.

EXCAVATION

The furnace and its adjoining charging house, in common with the remainder of the upstanding masonry structures, have been comprehensively described elsewhere (RCAMS 1974, 281-92) and will be referred to hereafter only when they have a direct bearing on the archaeological evidence. Prior to excavation, it was possible to trace the grass covered outline of structures built against the north and west elevations of the furnace stack. The structure set against the north elevation proved to be the blowing house and that against the west elevation the casting house. The function of the building in the angle formed by these two structures was not apparent at the outset. Cadell, following his visit to the site early this century, advanced no theories although he noted a small rectangular room in its north-west corner which he referred to as the 'pay office' (Cadell 1913, 149). This was not apparent prior to excavation in 1978, whereas a rectangular structure set against the outside face of the north wall, termed a 'smithy' by Cadell, was clearly visible. Both the smithy and an adjacent lean-to shed are, however, shown standing with their roofs intact in a drawing by Alfred Fell, dated 1908 (Fell 1908, 400). Oral sources claim that these two small rooms were used as farm outbuildings, but of the lean-to shed there was no sign either before or during the excavations. Fell's sketch shows that the roofs over the blowing house, the casting house and the intermediate building had collapsed leaving the gables and wall-tops bare.

Excavation comprised mainly the removal of large quantities of rubble which covered much of the site but which was particularly deep around the collapsed walls and within the blowing house. Amongst this debris were artefacts of late 19th- and 20th-century dates, indicative of the site's use as a dumping ground, although some of these finds may have been associated with the smithy which continued operating into the present century.

Because of the lack of suitable documentary evidence and the absence of meaningful stratigraphy over most of the site, no attempt has been made to give absolute dates to most of the features excavated although it is thought that a wholesale reorganization of the casting and blowing houses may have been carried out at the same time as the furnace stack was raised, during the second quarter of the 19th century (RCAMS 1974, 284).

Blowing house

The blowing house measured 6.80 m from N to S by 4.70 m E to W, within granite rubble walls 700 mm thick. The east wall, dividing the blowing apparatus from the waterwheel, still stood to a height of 3.50 m. A wholesale reorganization of the internal layout at a later date had resulted in the removal of much of the original detail but sufficient survived to indicate the entrance had been originally at the south end of the west wall. The N wall extended 2.30 m westward beyond the W wall, evidence perhaps that the west wall with its entrance, was further protected from the elements by a lean-to roof forming a verandah similar to that which survives along the north face of the ore shed.

Midway along the east wall of the blowing house was a brick arched opening through which the drive shaft connected the waterwheel to the blowing mechanism. The excavation provided no clue as to the nature of the blowing apparatus during the early period but it may have comprised either wooden box bellows or the more primitive leather bellows of the type believed to have been used at Glenkinglass.



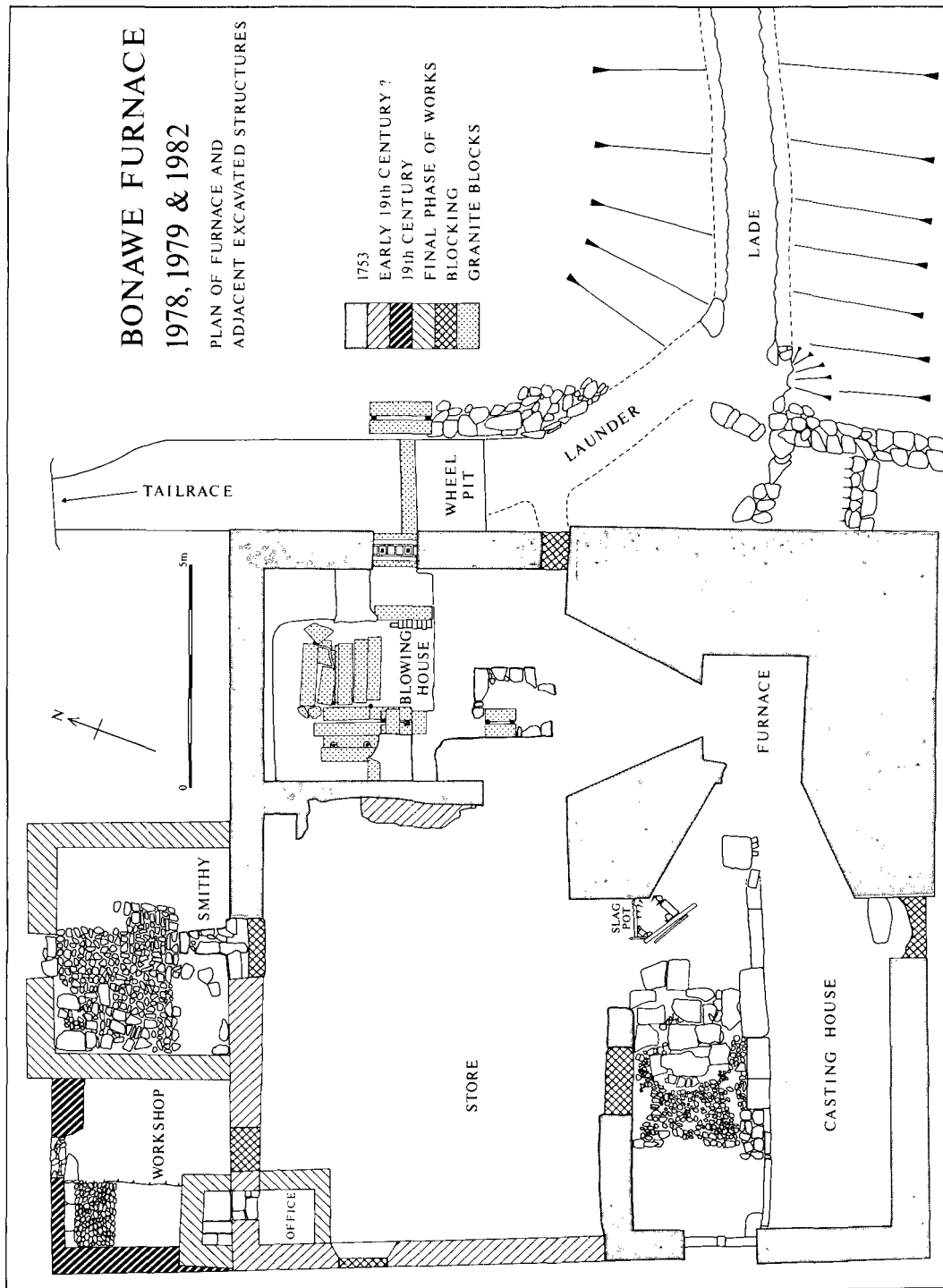
ILLUS 21 Bonawe: blowing house showing the granite mounting blocks. *Crown copyright*

Whatever its nature may have been, the original blowing apparatus was later stripped out to accommodate a new blowing mechanism. A 3 m wide opening through the north wall (since blocked) may have been forced through to admit the new machinery. In 1876, when the furnace was finally out of blast, the blowing apparatus was removed to the parent company's operations at Newland, Cumbria and only the granite blocks, each measuring 1.40 m long and 250 mm square in section, upon which the blowing apparatus was mounted, remained (illus 21). These were insufficient in themselves to reveal the identity of the apparatus they supported but it is likely that cast-iron blowing cylinders were used throughout much of the 19th century.

At the south end of the east wall, adjacent to the furnace stack, were two openings, one above the other. The upper opening, 460 mm wide at its base and 560 mm wide at its present maximum height of 1.96 m, had been blocked with rubble at a later stage but it is not clear whether or not this was a primary feature of the blowing house design. The lower of the two, 650 mm wide and lintelled over, was partially revealed by excavation in 1978. In 1982 removal of some of the debris within the opening exposed a lead pipe leading from the blowing house to the outside of the east wall, about 1 m below the lintel. The size of the opening – 1.35 m by 650 mm – indicated that accommodating a water pipe of only 25 mm in diameter was not its original function. It has been suggested that either, or both, of these openings was associated in some way with the mechanical arrangements for regulating the flow of water from the launder on to the wheel.

Casting house

This measured 7.50 E to W by 5.74 m N to S, within granite rubble walls 750 mm thick. Like the blowing house, this structure had also undergone subsequent modification but sufficient archaeological evidence was forthcoming for a reasonable picture of its original appearance to be drawn. Three entrances had been used at various periods, one through the west gable wall and two through the north



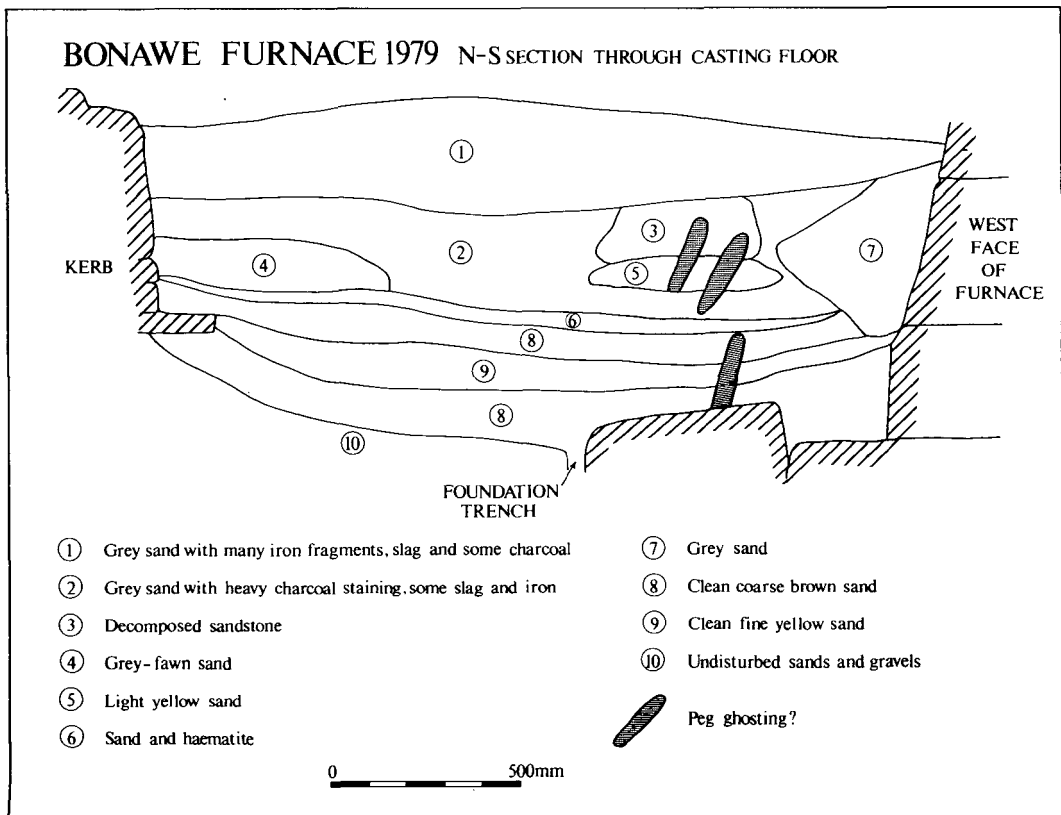
ILLUS 22 Bonawe: plan of furnace and adjacent structures excavated in 1978, 1979 and 1982

wall separated by a rectangular pier, 900 mm by 700 mm. If the granite block, projecting from the west face of the furnace pillar at this point, is taken as the remnant of a door lintel then the height of the entrance here would have been about 3.50 m. There were indications in the lowest course of the west wall to suggest that here, too, the north face of the casting house, with its double entrance, had been further protected by a lean-to roof forming a verandah similar to that postulated for the blowing house.

At some stage (probably in the 19th century) the more westerly of the two openings through the north wall was blocked with rubble and the raising of the floor level resulted in the replacement of an early crude threshold in the west wall with a more elaborate arrangement of sandstone blocks. These were socketed so as to allow the use of a two-leafed door, 1.64 m wide overall.

Beneath the slates of the collapsed roof was the latest floor level, more or less intact and divided into almost equal halves, perhaps echoing the original arrangement. The northern half was a working surface comprising a combination of bricks, stone slabs and iron plates; a granite kerb separated it from the southern half which consisted of fine sandy deposits of the casting floor. A section through this floor revealed the ghostings of two timber(?) pegs (illus 23) possibly associated with the moulds used in small-scale foundry work. There was nothing else, however, to elucidate the nature of the finished product; we can only assume that it was mainly pig iron.

The decision to leave the well preserved later floor intact allowed only the briefest glimpse of the early floor levels in the section cut through the casting sand. The original floor consisted of assorted fine sands in which was traced the ghosting of another timber(?) peg, 250 mm long and 40 mm in diameter. The fragments of worn sandstone beneath the granite kerb of the later floor suggests that the casting house had always been divided into two halves – the working surface on the N, the casting floor on the S.



ILLUS 23 Bonawe: N-S section through the casting floor

At the point where the south wall meets the furnace building there had been originally an opening, 1.37 m wide, 1.75 m high and lintelled over with the socket housing the lintel still visible in the west face of the furnace. The position of this opening, facing the bank at the furnace rear, would seem to rule out its being a door or a window; instead it may have been associated in some way with the original drainage scheme, perhaps in conjunction with the drainage channel running along the base of the south face of the furnace (located in an earlier clearance exercise). At some point the opening was partially blocked with an assortment of stone and firebrick, the remaining space being filled by a massive granite slab, measuring 1.04 m E to W by 400 mm N to S and set at floor level. It has been suggested that the slab had once supported a water tub the contents of which may have been used to moisten the casting floor sand prior to tapping and into which the furnaceman could have doused their hand-tools. A small aperture within the upper courses of the blocking may have provided access for a water pipe to this tub and a stretch of lead pipe was found within a stone-lined culvert set into the earth and rubble fill S of the furnace. The lead pipe is evidently a late insertion and excavation failed to discover its course further W.

The forehearth and its environs revealed two features of specific interest. The first of these, sited immediately outside the left-hand splay of the tapping arch can best be interpreted as a slag pot (sometimes referred to as a slag dam, or retainer) into which the liquid slag was run. The pot, crudely formed from broken firebricks and cast-iron bars, was roughly circular with a diameter of c 640 mm internally, though this has been reduced in size subsequently. Quantities of slag were found in its fill. As at Glenkinglass, there was no evidence of a channel by which the slag ran from the furnace to the pot.

The second feature, centrally situated within the jaws of the tapping arch and resting on the stone levels, was a rectangular plinth, 600 mm N to S by 700 mm E to W, composed of a stone core partially surrounded by clay bricks, three of which survived. This feature had been liberally splashed with iron and can be interpreted as a platform on which a container was placed for receiving the molten metal before it was channelled either into pig beds or ladled into moulds. Alternatively, the plinth could have been a platform upon which a founder stood whilst controlling the tapping of the iron. It is likely that this plinth, together with the reduced slag pot, were both fabricated towards the end of the ironworks' life.

Store

At some stage the re-entrant angle formed by the blowing and casting houses, originally an open yard, was built over. The lean-to roofs protecting the entrances into the two houses were demolished and replaced by a rectangular structure, 7.80 m N to S by 7.60 m E to W, whose granite rubble walls, only 600 mm wide, had been bonded in a pink mortar markedly different from the yellow mortar of the original buildings. Besides a dump of grey clay in the south-west corner – used perhaps to seal the tuyère hole and the tympan prior to blasting – nothing more was found to identify the function of this building more closely, and it may have served simply as a store and a place in which to weigh the pigs. Vestiges of what may have been a small cupboard were located in the north-east corner of the store but this area had been so badly affected by tree roots that a more positive identification was not possible.

Admission to the store was from either the casting house or blowing house but, at one time, there had also been two openings through the north wall, subsequently blocked up. These openings had allowed access to two structures built against the north wall of the store; the more westerly was, at first, thought to be the small square building shown to be still roofed and adjacent to the smithy in Fell's sketch (Fell 1908, 400), but excavation in 1982 proved this assumption to be false.

Smithy

The more easterly opening from the store led into a stone-built structure, noted by Cadell as the smithy. Excavation here was not completed but sufficient evidence was found to indicate that the smithy had continued in use as such after the blowing out of a furnace in 1876. The date of its construction is not known but a floor level 300 to 500 mm above that of the adjacent store would suggest a separate build. Ceramics recovered from beneath the metallised floor would suggest that this was towards the end of the furnace's life. Further excavation may shed light on this building's internal organization, such as the position of the hearth and setting for the anvil.

Office

The office, described by Cadell as the the 'Pay Office', was situated in the NW corner of the store and measured only 1.30 m square. The walls, which stood to a height of 700 mm above a well made floor of large slates, were rendered and finished with a smooth cream plaster. A cupboard had been placed against the south wall. The office had been added at a later date for the only entrance into it had been forced through the north wall of the store. Access was gained by means of three steps comprising reused stones and firebricks enclosed by low, poorly built walls. Although Cadell referred to the building as the pay office, this is unlikely to have been its true function (the pay office, at least latterly, was situated in the range of workers' housing to the NE of the furnace); rather it is seen as a small office used for tallying the produce leaving the works. Its position, near to the casting house door (the only logical exit for the iron), supports this notion.

Shed

A small shed, shown by Fell as adjacent to the smithy, is said to have been used as a wood store well into the present century and its construction may have post-dated the demise of the furnace. During excavation the only indication of this shed were three shallow postholes adjacent to the north wall of the store, presumably to house the roof supports of the small lean-to building. Fell shows no entrance but it seems unlikely that access was gained via the store since its west doorway is believed to have been blocked at a relatively early date. An error on the part of the artist cannot be dismissed here.

Workshop

Excavation below the shed (described above) revealed a structure predating both the smithy and the entrance steps of the office; this building is referred to as the workshop, for want of a more specific description. The 4.00 m long and 600 mm wide west wall of the workshop was a continuation of the west wall of the store although the two were of separate builds; that of the workshop butting on to the north-west corner of the store/office. Midway along this wall was a bricked recess, 700 mm long and 200 mm deep, the function of which is not understood. Being partly overlain by the smithy (itself not completely excavated), the full E to W dimension of the building could not be determined. The length of the north wall uncovered was 4.43 m but if the 900 mm wide entrance in this wall is taken as being central to the structure then the building would measure 5.30 m externally, E to W. To the E of the entrance the north wall was 680 mm wide, to its W only 280 mm wide, although at some stage an attempt had been made to increase this width to 500 mm.

Internally the workshop was divided into two distinct areas. In the W of the room and overlain, in part, by the office steps was a working area, itself divided into two sections: one of cobbles and one of mortar and sand compacted into a hard floor surface. Upon this surface was a 170 mm thick deposit of grey sand with small slag and iron fragments, resembling used casting floor sand. This room, then, may have been a foundry although the distance from the tapping hole would tend to detract from this theory.

The remaining area of the room was filled with rubble to a total depth of 500 to 650 mm. The upper deposits of this material comprised the collapse of the store and smithy walls and post-dated the construction of the lean-to shed. Below this material the debris included some granite fragments and mortar but was mainly of firebrick and sandstone fragments, perhaps being the waste from hearth relinings. Upon the sandy floor below the rubble was evidence of a walkway leading from the entrance in the north wall of the workshop to the now blocked entrance in the north wall of the store.

A large drain was cut into the natural gravel below the floor. It originated in or beyond the store, running below the workshop and smithy and debouching, perhaps, into the tailrace. A fuller investigation of this feature was not possible. Similarly, the western half of the building was not fully excavated, several problems remaining unresolved. A rectangular posthole, 250 mm by 220 mm and 650 mm deep was sealed by the compact mortar. It may have been the setting for an early roof support but no other such features were visible at this level. Presumably, a posthole similarly situated in the E of the room would be obscured by the smithy.

The function of the workshop is not clear from the evidence so far available. The contaminated sands suggest foundry work but the distance from the source of molten iron would argue against this. A more likely role is seen as a predecessor to the smithy, perhaps becoming redundant when the working area became too small.

Lade

Prior to excavation, the masonry of the lade was not visible although the line of the watercourse leading to the wheelpit was obvious. Between the turf and the lade top some 500 mm to 1.00 m of overburden was removed and within the lade further bank slippage overlay about 600 mm of silts and gravels, being wash from the River Awe. In the construction of the lade a scoop, 6 to 7 m wide, had been taken out of the natural bank against which the furnace was built, leaving slopes angled at about 30° from the horizontal on either side of the watercourse.

The drystone rubble walls, partly coursed, were 1.00 to 1.30 m high. They were generally well built although repairs had been effected in places, particularly on the north side but, unlike the original stonework, these repairs were not of a standard consistent with the work of skilled masons. Here, and at several other points on the site, it was evident that major building work had been done by skilled craftsmen (presumably from Cumbria) while minor works and repairs had been carried out by unskilled, probably local, labourers.

About 4.50 m E of the furnace the lade changed direction. Traces of wooden planking between this point and the wheelpit suggest a wooden launder, although several transverse lines of iron nails attaching these planks to the ground suggest a fixed structure rather than a movable chute. Within the debris near the beginning of the launder was found an iron leaf-trap. Roughly comb-shaped, it was 2.00 m wide with 25 'teeth', each c 1.00 m long and 25 mm in diameter. Although somewhat corroded it was still upright and probably near its original position spanning the width of the lade/laundry.

A widened lade and a 1.30 m long section of cross wall suggested that a small dam had collected a head of water before it was allowed to flow at a regulated rate along the launder and thence on to the wheel. Unfortunately collapse of the bank, its retaining wall and part of the lade itself made interpretation of this area difficult.

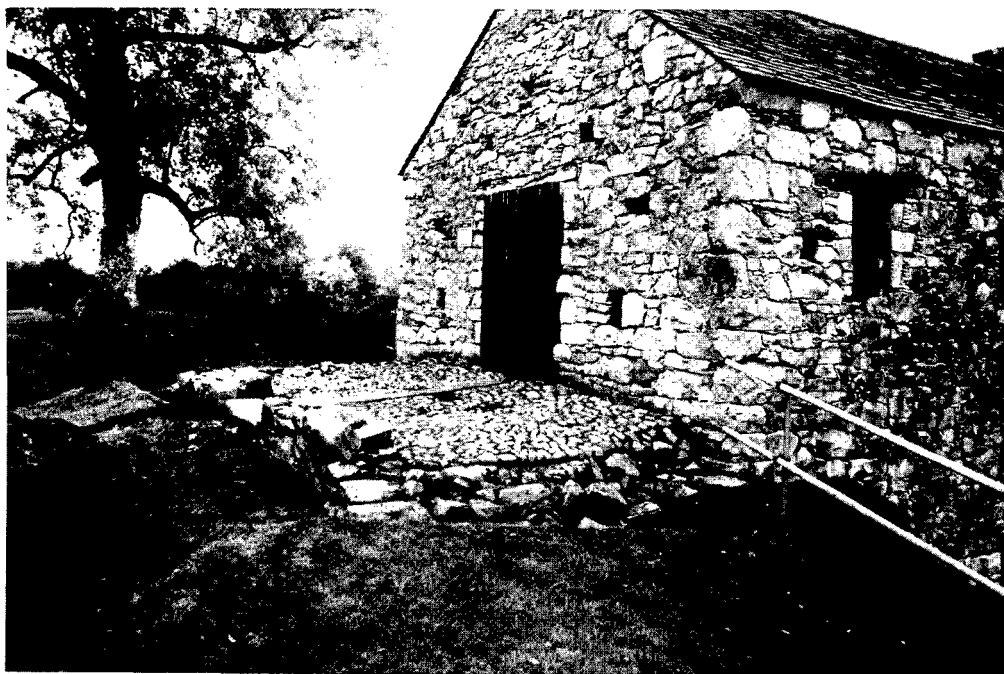
Limited excavation did not reveal an outlet for the drain at the furnace rear, although its course may run below the levels investigated. Likewise, a 700 mm wide rubble wall, parallel to the east wall of the furnace and extending up the slope, was only partially uncovered. Neither its full length nor function is certain although it may have been associated in some way with the entrance to the furnace master's chamber situated in the east face of the furnace complex between the charging house and furnace stack.

Wheelpit

The wheelpit was 1.95 m wide after which the channel narrowed into the tailrace. From the end of the launder, the pit, lined with firebricks, sloped downwards in a pronounced curve (presumably echoing that of the wheel), terminating at a granite slab 330 mm wide and spanning the entire width of the pit. From this slab the wheelpit, no longer lined, dropped a further 200 mm on to natural gravel.

The drive-shaft, supported on cast-iron mountings set in granite blocks, communicated motion to the blowing mechanism through the brick-arched opening in the east wall of the blowing house. When photographed in 1972 the opening was partially blocked, leaving a wood-lintelled aperture, estimated at c 1 m high, to accommodate the drive shaft. Since that date the whole of this blocking (obviously a secondary feature) has been removed. Whether the wheel's axle tree and the drive-shaft were one and the same is open to doubt. If the axle tree was central to the mountings within the blowing house wall the wheel would have had a maximum diameter of 3.95 m. More likely is that the drive-shaft through this opening was connected to a fly wheel, in which case the waterwheel's axle may have been mounted midway along the granite blocks, E of the pit, allowing a maximum diameter of 3.80 m for the wheel. That section of the launder near to the wheelpit has suffered considerable damage and it was not possible to tell at what precise level the water ran on to the wheel. Available evidence indicates, however, that this level may have been about midway between that of the wheelpit base and that of the axle tree; the wheel then must have been a low breastshot type.

Originally, the wheel may have been narrow, allowing water to be diverted to its side when the blowing mechanism had to be stopped. The cast-iron wheel removed for its scrap value during World War II, however, is known to have spanned the whole width of the pit and a different by-pass arrangement must have been in operation. It has been suggested that the lower of the openings in the blowing house wall, adjacent to the furnace, was at some time associated with the mechanism for regulating this flow of water (possibly after the lead pipe had become redundant). A slot in the opposite face of the launder may also have had such associations, perhaps by housing a beam



ILLUS 24 Bonawe: charging house and annexe floor, from the E. *Crown copyright*

connected to a water-regulating barrier. The ensuing build-up of water in the lade would have been diverted into the overflow channel some 80 m E of the furnace.

Charging house

Excavation adjacent to the charging house revealed a structure 7.80 m E to W by 3.20 m N to S, its mortared rubble walls almost completely robbed out. The cobbled floor of the charging house is a late feature (RCAMS 1974, 286) and so, therefore, must be the floor of the annexe, being its extension.

Entry to this annexe was over a 1.65 m wide threshold comprising a large slate slab and a smaller piece of limestone, socketed to allow a small two-leafed door, similar to the arrangement for the equally-sized charging house entrance (illus 24). Positioned between the two doorways were two iron plates and there were indications that similar plates once extended through the charging house floor, presumably to allow barrowing of raw materials. It was decided not to remove the late floor but limited excavation outside the threshold revealed, below 350 mm of make-up, a series of large slates which proved to be part of an early pathway.

The remains of four paths, 700 to 950 mm wide, all of flat slate slabs and each one leading to one of the ore shed's bays were found immediately outside the latter's verandah. The alignments of these paths indicated that they may meet approximately 10 m SE of the charging house entrance.

FINDS

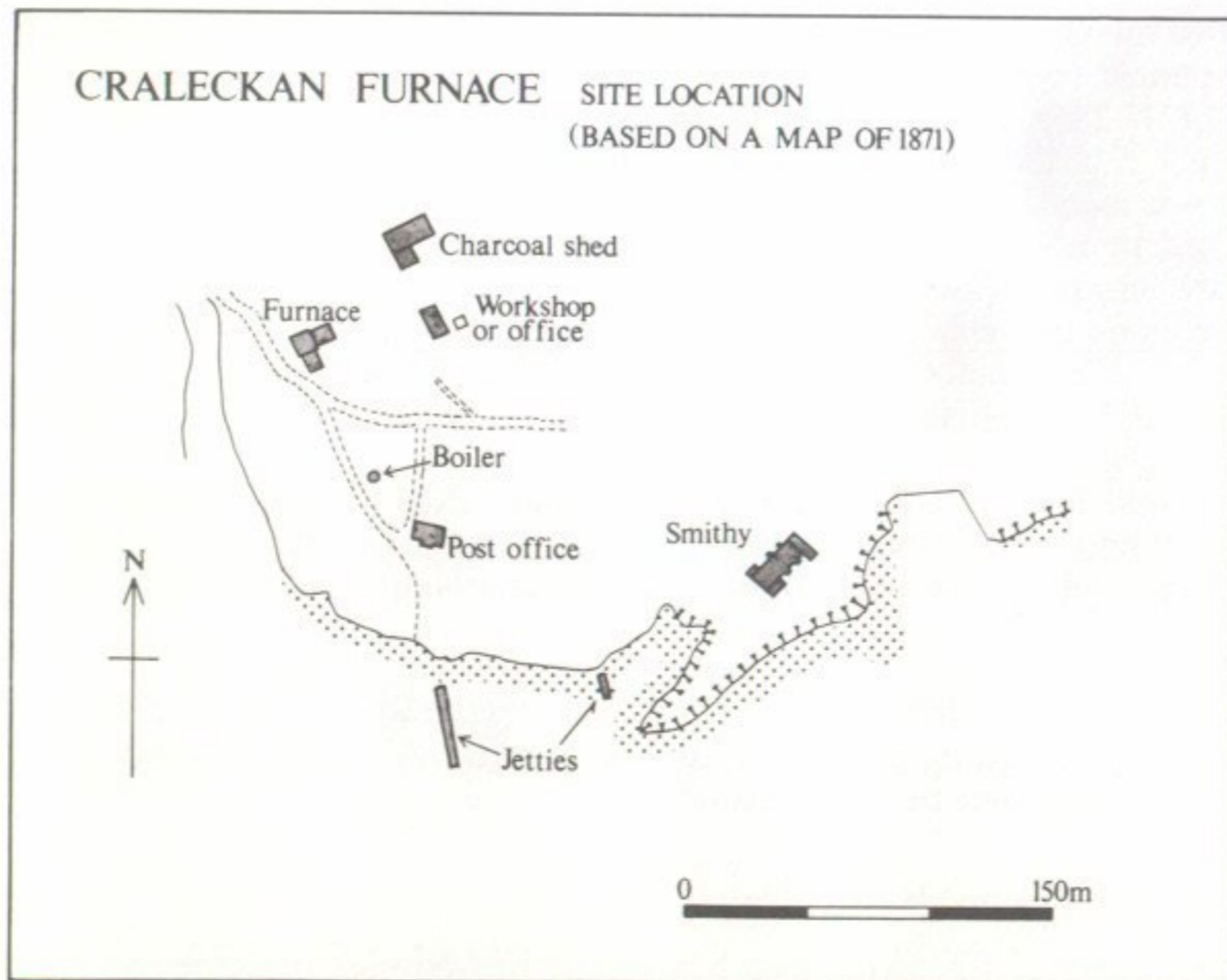
All of the finds discovered during three seasons of excavation were within late contexts, mostly in levels associated with activities post-dating the closure of the furnace. All of the pottery was of late 19th- and 20th-century dates and will not be discussed here.

CRALECKAN FURNACE (illus 25, 26, 27)

Craleckan furnace (NGR NN 027 001) was built near the hamlet of Inverlacken on the north shore of Loch Fyne, 12 km SW of Inveraray, Argyll in 1755 (not 1775 as is often quoted).



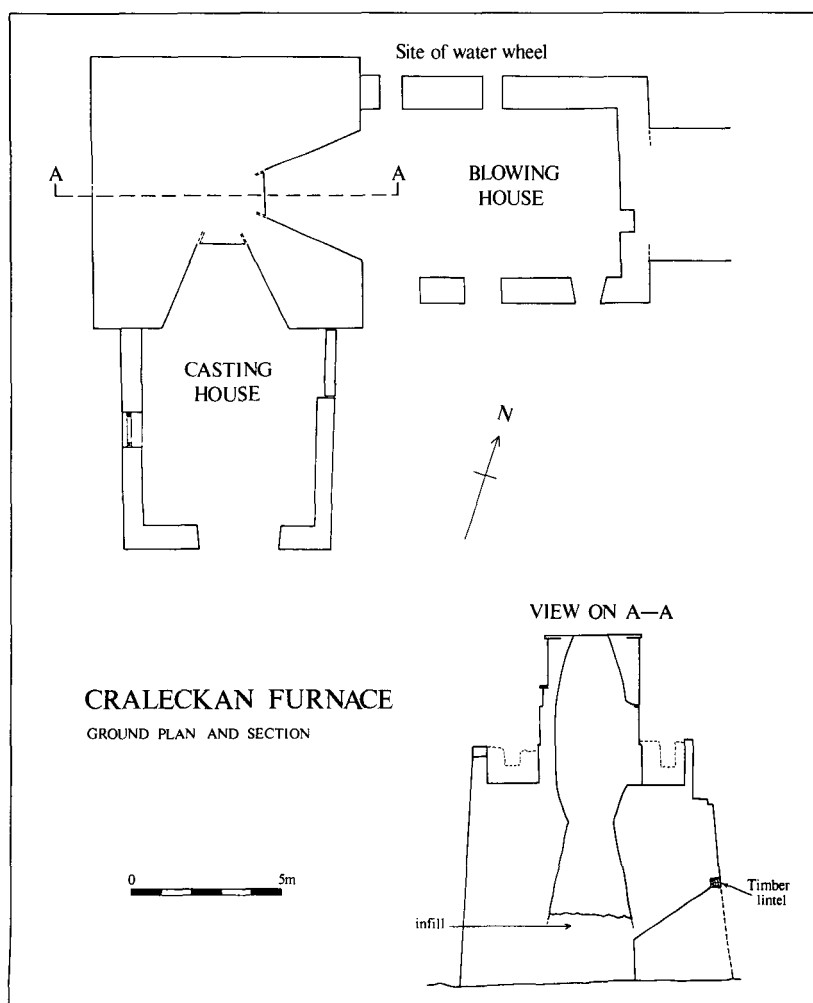
ILLUS 25 Craleckan: furnace, from the S. Crown copyright



ILLUS 26 Craleckan: site location – based on a map of 1871

'Craleckan' is probably an Anglicization of a name occurring as Craleacain farm (1 km N of the furnace) which lies at the foot of Dun Leacainn. Within this hill a quarry was opened in 1841 which, as well as supplying granite to Glasgow, provided some of the building materials for a local gunpowder works, named after the nearby Goatfield Farm. This name has also been applied, erroneously, to the furnace. A further complication arose when the village of Inverlacken was renamed 'Furnace'.

Extant buildings comprise the furnace, with casting and blowing houses, and a rubble-built charcoal shed, situated some 40 m to the NE. The storage shed measures 17.7 m by 7.6 m with an adjoining annexe (possibly a later addition) measuring 8.8 m by 7.5 m. As was customary, use was made of a natural slope; the one remaining storage shed was uphill from the furnace, providing easy access to the furnace top for charging. No other storage sheds still stand, nor have they for some time according to the map of 1871 (illus 26). Other structures, probably related to



ILLUS 27 Craleckan: ground plan and section

the works and shown on the early map include the smithy (which may have been the original forge), the 'workshop or office' and the jetties.

Externally, the rubble-built furnace measures 8.90 m square at its base, tapering to 7.80 m square at a height of 8 m: from this point the chimney rises a further 3.70 m. Internally, the stone-lined furnace seems to be remarkably intact and filled, to a depth of c 2 m, with debris from the final blast and decayed furnace lining. The dimensions of the (presumably) square hearth are not known because of the infill, but the circular boshes splay to a maximum diameter of 2.80 m; the stack then narrows to 1.50 m. Thereafter the tunnel widens to 2.35 m in diameter and narrows to its minimum diameter of 1.45 m at the furnace top (illus 27). Access to the hearth via the tapping arch is restricted because the casting house is now used as a private garage. This single-storeyed rectangular structure, built of unmortared granite rubble and now roofed with corrugated iron, measured 6.50 m by 5.70 m. However, the blowing house once occupied the ground floor of a two storey building which is now partly ruined. The upper floor was the charging house but this second level is now virtually demolished and its roof is missing. The blowing house is slightly larger than the casting house, measuring 8.60 m by 5.50 m and, again, is constructed of drystone rubble (Hume 1977, 151).

It is not known what type of blowing mechanism was used here but being of mid 18th-century construction either leather bellows or wooden box bellows may have been used at first. At the parent company's works at Duddon iron blowing cylinders were installed before the end of the 18th century (Fell 1908, 228) but whether such apparatus was installed at Cralecken before it finally went out of blast in 1813 is open to doubt.

APPENDIX

GLOSSARY OF TERMS

Blast furnace

Plant where molten cast iron is produced by the reduction of ore using carbon (as charcoal, peat or coke) with or without a flux. A temperature of 1400°C to 1500°C is reached, this being high enough to dissolve some of the carbon as well as traces of other elements; some desirable, some not.

Bloomsmithy or Bloomery

An early type of furnace where wrought iron was produced by direct reduction of the oxide. Lower temperatures were attained than those in a blast furnace, the iron did not melt and, consequently, only minimal amounts of unwanted elements dissolved into the metal. Quite pure iron was produced but output was low.

Blowing arch

An aperture in the furnace, integral with the blowing house, which housed the bellows front and its support together with the opening for the tuyère.

Bog ore

A recently formed ore, yellow to brown in colour, produced by the surface oxidation of carbonates and occurring in many parts of Scotland. Consisting mainly of limonite, it was widely used in bloomeries but its usually high phosphorus content made it unpopular in blast furnaces.

Boshes

The carburization of the metal took place in the boshes, being that part of the furnace immediately above the hearth and resembling an inverted and truncated cone or pyramid. The upper portion of the boshes was the widest part of the furnace allowing for the expansion of materials.

Campaign

The period of blowing in a blast furnace during which iron was regularly tapped. This period could last for several months particularly during the winter.

Cast iron

An alloy of iron and carbon (2–5%) usually trace elements – some desirable, such as manganese (in steel-making) and others detrimental, such as phosphorus and sulphur. It is the product of a blast furnace where the temperature is well above the melting point of the alloy. It is strong in compression (ie it withstands heavy loads) but is weak in tension; it is too brittle to be worked.

Clayband ore

A Carboniferous ore, commonly occurring in the central belt of Scotland. Comprises ferrous carbonate – Fe_2CO_3 – plus shale or clay and, being fossiliferous, it includes high proportions of phosphorus. Not widely used before the advent of coke smelting.

Flux

A raw material sometimes added to a charge to aid the removal of gangue and hence promote slag production. Fluxes are commonly basic oxides, such as limestone which is added independently; or they may occur in association with ores eg aluminium oxide in the company of limonite.

Forge

The plant where cast iron is decarburized to produce wrought iron. This refinement involves the introduction of oxygen and the removal of carbon.

Foundry

A works where cast iron is poured (or ladled) into prepared moulds for the manufacture of specific goods.

Gangue

The rock in which ores are embedded. Its composition varies with the ore, eg Carboniferous ores have gangue with a high proportion of clay or shale whilst Cumbrian haematite has gangue with a high silicon content. Fluxes are necessary to remove this material except when it already comprises a high proportion of basic oxides.

Haematite

A rich, dense ore comprising mainly ferric oxide – Fe_2O_3 – not common in Scotland but formerly imported from Cumbria. A siliceous ore, it has several forms, including specular ore with tabular crystals and the botryoidal reniform (kidney) ore which varies in colour from red to black.

Hearth

The base of the furnace where molten iron collects. This term is often used to describe the hearthstone and the area between it and the boshes, although this should really be termed the crucible.

Lade

An artificial watercourse leading from a river to a reservoir or dam, and thence to a waterwheel or, sometimes, directly to the wheel itself.

Launder

A wooden chute taking water from the dam to the waterwheel.

Limonite

An iron ore consisting mainly of cryptocrystalline goethite. Its formula is usually given as $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ or $\text{FeOH} \cdot 3\text{H}_2\text{O}$ as well as other variations. It occurs as a rock ore eg in the Lecht mines near Tomintoul where it was extracted by the proprietors of the Culnakyle furnace, as well as being the main constituent of bog ore. It is often associated with hydrated aluminium oxide which can act as a self-fluxing agent.

Pig beds

That part of the casting house floor in which the molten iron is run into narrow moulds to form pig iron.

Pig iron

The main product of the blast furnace; the iron being cast as long narrow ingots or 'pigs' in sand moulds known as pig beds.

Pillar

The stone pier between the tapping and blowing arches of early furnaces.

Slag

The main waste product of the iron industry. In a blast furnace it is produced in a molten state and periodically tapped from the hearth.

Slag pot

Usually outside the tapping arch, this was a pit or a container within a pit into which slag was run from the furnace and kept there until cool.

Tailrace

A channel conducting spent water from the furnace wheel back to the river.

Tapping arch

The splayed aperture in a blast furnace from where the molten iron and slag are tapped.

Tuyère

A conical tube, usually of clay in early furnaces, connecting the bellows nozzle and the tuyère hole of the furnace.

Wrought iron

Almost pure iron. The product of the bloomery, where it was reduced directly from the ore, and of the forge, where cast iron is decarburized.

ACKNOWLEDGEMENTS

The Glenkinglass and Bonawe excavations were funded by the Scottish Development Department (Ancient Monuments) and a grant from the Society of Antiquaries of Scotland helped finance work at Red Smiddy. Work at Bonawe in 1978 and 1979 and at Red Smiddy in 1980 was directed by C J Tabraham and that at Glenkinglass in 1979 and 1981 and at Bonawe in 1982 by the author. The considerable results achieved at these excavations were due to the excellent work carried out by the staff, who frequently had to endure some of the heaviest rain the West Highlands could throw at us. These brave souls were: David Carmichael-Stewart, Eoin Cox, Gordon Ewart, George Haggarty, Reginald Hughes, John Hume, Colin Miller and Allan Shedlock. In addition I thank Fred and Gladys Bettes, Graham Douglas and Guy Gueritz for their site survey work and the handful of volunteers who gave valuable assistance on several of the digs. The surveys at Tarrioch and Craleckan furnaces were carried out by Graham Douglas, of the Scottish Industrial Archaeology Survey, University of Strathclyde.

The excavations at Red Smiddy and Glenkinglass and the surveys at Letterewe and Fasagh were made possible only by the permission of the various owners, readily given – Mr MacDonald Buchanan, Mr R Fleming, Colonel Whitbread and Mr Whitbread. A warm 'thank you' is extended to Kay Matheson of Inverasdale, Poolewe who generously provided three of us with accommodation, food and amber fluid while we were battling with the elements at Red Smiddy and Fasagh; and to Tim Healy, gamekeeper at Glenkinglass, for his welcome to that particularly beautiful part of Scotland.

I have been fortunate on many occasions to have had the help of John Hume of the Department of History, the University of Strathclyde. He read two drafts of this paper, thus preventing several errors coming to print and has imparted much to me from his vast knowledge of Scotland's industrial history. During the assemblage of this paper my wife – Lorna – has managed to instil into me some knowledge of the workings of the English language; for this I am eternally grateful.

Lastly, I must thank Chris Tabraham (SDD AM) for his support during the excavations and for his help, encouragement and patience while awaiting the completion of this paper.

REFERENCES

- Anderson, M 1967 *A history of Scottish forestry*, 1. Edinburgh.
- Baird, J G A 1910 *Muirkirk in bygone days*. Muirkirk.
- Brooks, C E P & Glasspoole, J 1928 *British floods and droughts*. London.
- Burt, E 1815 *Letters from a Gentleman in the North of Scotland to his Friend in London*, 2. London.
- Cadell, H M 1913 *The story of the Forth*. Glasgow.
- Cochran-Patrick, R W 1878 *Early records relating to mining in Scotland*. Edinburgh.
- Cramond, W 1897 'Notes on the casting from Abernethy works, now presented to the Museum', *Proc Soc Antiq Scot*, 31 (1896–7), 224–7.
- Dixon, J H 1886 *Gairloch in North-West Ross-shire*. Edinburgh.
- Fell, A 1908 *The early iron industry of Furness and District*. Ulverston.
- Fenton, A & Walker, B 1981 *The rural architecture of Scotland*. Edinburgh.
- Hume, J 1977 *The industrial archaeology of Scotland, 2: the Highlands and Islands*. London.
- Kemp, D W 1887 'Early iron smelting in Sutherland', *Trans Roy Soc Arts*, 11 (1887), 286–303.
- Knox, J 1787 *A tour through the Highlands of Scotland and the Hebride Islands in 1786*. London.
- Lindsay, J M 1975a 'Charcoal iron smelting and its fuel supply; the example of Lorn furnace, Argyllshire, 1753–1876', *J Hist Geogr*, 1,3 (1975), 283–98.
- Lindsay, J M 1975b 'Some aspects of the timber supply in the Highlands, 1700–1850', *Scot Stud*, 19 (1975), 39–53.
- Lindsay, J M 1977 'The iron industry in the Highlands: Charcoal blast furnaces', *Scot Hist Rev*, 56,1 (1977), 49–63.
- Macadam, W I 1887 'Notes on the ancient iron industry of Scotland', *Proc Soc Antiq Scot*, 21 (1886–7), 89–131.
- MacGregor, M *et al* 1920 *The iron ores of Scotland: Special reports on the mineral resources of Great Britain*, 11. Edinburgh.
- Murray, A 1740 *The true interest of Great Britain, Ireland and our plantations*. London.
- Murray, D 1883 *The York Buildings Company: a chapter in Scottish history*. Glasgow.
- Paton, H M (ed) 1922 *The Clan Campbell: Abstracts of Entries relating to Campbells in the Sheriff Court Books of Argyll at Inverary (1913–22)*. Edinburgh.
- RCAMS 1974 Royal Commission on the Ancient and Historical Monuments of Scotland, Argyll, *an inventory of the ancient monuments*, vol 2, *Lorn*. Edinburgh.
- RMS *Registrum Magni Sigillii Regum Scotorum*, J M Thomson *et al* (eds), 8. Edinburgh.
- Schubert, H R 1957 *History of the British iron and steel industry from c 450BC to AD1775* London.
- SRO 1730 Scottish Record Office, *Breadalbane Muniments*, GD/112/16/11/1–16.
- Straker, E 1931 *Wealdon Iron. A monograph on the former ironworks in the counties of Sussex, Surrey and Kent*. London.
- Tylecote, R F 1962 *Metallurgy in archaeology*. London.
- Youngson, A J 1973 *After the '45: the economic impact on the Scottish Highlands*. Edinburgh.

This paper is published with the aid of a grant from the Scottish Development Department (Ancient Monuments)