“... A Monument to Misguided Enterprise”: The Carp River Bloomery Iron Forge

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The mid-19th-century Carp River Forge was the first iron smelting operation on the Marquette Iron Range, launching the iron industry of Michigan’s Upper Peninsula. At the forge, skilled ironworkers produced iron in bloomery hearths using charcoal, ore, and a water-powered air blast. This paper presents the results of the historical research and three seasons of excavation at the site. Major archaeological discoveries include the dam base, the water wheel gudgeon and crank, parts of the bloomery forges, a blacksmith’s forge base, and the remains of houses for the forge workers. The archaeological remains of the bloomery forges suggest the forge workers employed the latest hot-air blast and firebox design. The spatial distribution of the ore, charcoal, and waste slag, in conjunction with the industrial features, defines the layout and organization of the industrial workings. The Carp River Forge is one of four short-lived bloomeries from the early days of the Marquette Iron Range, and it typifies the difficulties faced by these pioneering enterprises.

Introduction

The story of the Carp River Iron Forge in Michigan’s Upper Peninsula is a tale of misadventure and mismanagement, tempered by sweat and optimism. Established by the Jackson Iron Company in 1847, the forge was the first site of iron production in the Upper Peninsula (UP), proving the value of the district’s rich hematite ores and opening Michigan’s Marquette Iron Range.[1] Over the next 10 years, other iron companies followed the Jackson Company’s lead, constructing bloomery forges at three other locations in the region (Figure 1).[2] All of these forges produced iron using a direct-reduction process to make wrought iron from ore; three of the forges, including the Carp River Forge, used water power to drive machinery. All four of the bloomery ironworks had short lives, going out of operation by the end of the 1850s with an estimated total output of less than 15,000 tons of iron.[3] None of the forges ever returned a profit to investors.

Despite the financial failure of the early bloomery forges, they did stimulate interest in the Marquette Iron Range, which came to be the scene of a thriving iron industry in the late-19th century. Charcoal-fired blast furnaces began making pig iron in the district as early as 1858, and the region became an important area for charcoal pig-iron production throughout the rest of the 19th century. Transportation

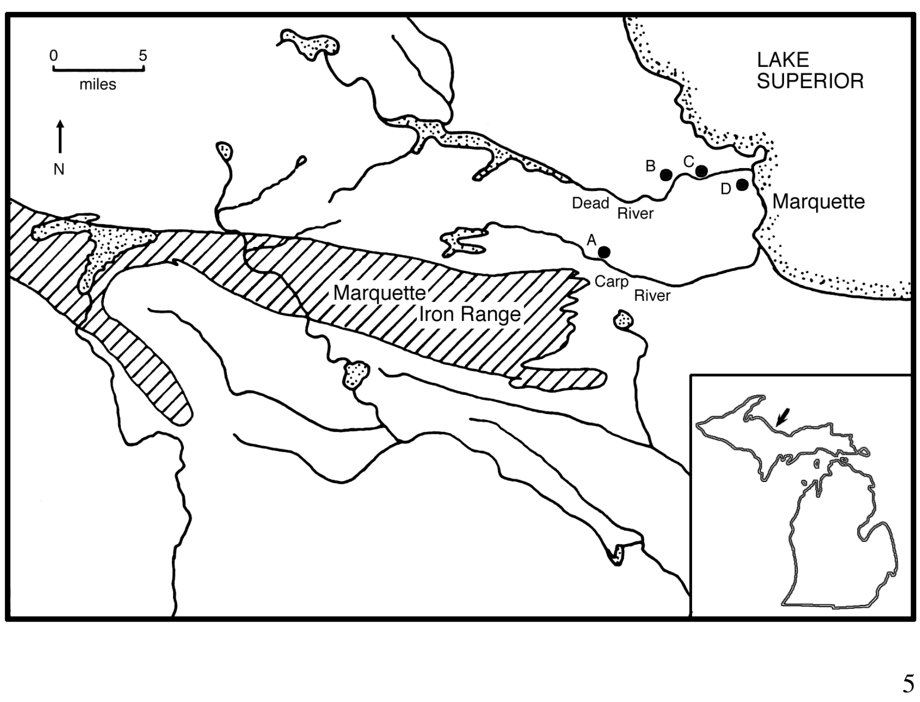

Figure 1. *Map of the Marquette area showing bloomery forges. (A) Carp River Forge; (B) Buckeye/Forest Forge; (C) Collins Forge; (D) Marquette Forge. Inset shows Michigan.* Adapted from Gordon, 1996, Figure 3–22 (note 2).

improvements encouraged the development of the district. The opening of a ship canal at Sault Ste. Marie in 1855 simplified water transport, connecting Lake Superior by water to the cities of the lower Great Lakes. The construction of a railroad from the harbor at Marquette inland to the iron mines in 1857 greatly simplified the hauling of ore. For the district overall, the emphasis shifted from smelting iron to mining and shipping ore. In 1860 alone, ships carried more than 100,000 tons of ore out of Marquette Harbor.[4] The later discovery and opening of additional iron ranges in the UP ultimately gave Michigan a central role in America's iron industry. Michigan was the leading producer of iron ore for part of the late-19th century and was the second leading producer through the 20th century.

The reason the early ironworks on the Marquette Range all chose bloomery technology rather than the more conventional blast furnace technology is not clear. The pioneering nature of these ventures might have made the smaller investment necessary for a bloomery operation seem attractive compared to the larger investment necessary for a blast furnace. Although bloomery iron production was very successful in other regions of the country, the bloomeries in this district were never profitable. In the Marquette region, bloomery techniques of production passed from use after only 10 years, and blast furnaces became the only smelting technology used in the area. It is likely that a combination of technological difficulties, transportation problems, high production costs, and the failure to develop a market willing to pay premium prices for bloomery iron all contributed to the demise of the bloomery ironworks in the UP. The story of the Carp River Forge and the other bloomeries of the region is, thus, a story of small, short-lived enterprises, employing ironmaking technology that never took hold in this district.

As the location of the first iron smelting in the Marquette Range, the Carp River Forge occupies a unique place in the region's history. By 1904, the forge location was already commemorated as a historic site, memorialized by the companies that still mined the district's iron (Figure 2). Today the land adjacent to the forge site is home to the Michigan Iron Industry Museum and serves as a focal point for interpreting the history of the regional iron industry. Nothing survives above ground at the Carp River Forge or any of the area's other bloomery forges, and comparatively little is known about this earliest and shortest-lived phase of iron production on the Marquette Range. Our archaeological and historical study of the site was designed to help improve our understanding of this period by providing an expanded view of the layout, organization, and technology of the forge as well as the lives and work of the region's first ironworkers.[5]

History of the Forge Operation

The copper resources of the Keweenaw Peninsula provided the initial impetus for Euroamerican settlement in Western Upper Michigan, and the discovery of the Marquette Iron Range was an accidental by-product. According to Philo Everett, by 1844, interest in Lake Superior copper had reached a "fever heat," and in the spring of 1845 he decided to visit Lake Superior to see for himself "what all that talk amounted to."[6]

Figure 2. *Monument erected at the site of the Carp River Forge. This piece is made of cast-iron plates put together in the shape of an obelisk.* Photo by Landon.

Everett, at this time, was living downstate in Jackson, Michigan, and he convinced 13 friends to join him in a copper speculation venture. In July 1845, they organized as the Jackson Mining Company, and Everett and several other members of the corporation left for the UP.[7] When the group arrived in Sault Ste. Marie, Everett hired a guide named Louis Nolan to take him to Copper Harbor at the northern tip of the Keweenaw Peninsula. Nolan told Everett that he did not need to go to Copper Harbor because there was "more ore back of Carp River (now Marquette) up at Teal Lake than you can ever get away."[8] With the added help of an Ojibwe guide, Marji Gesick, Everett eventually made it to a mountainous outcrop of specular hematite that became the focus of the Jackson Company's mining operation.

Several tested samples of the ore revealed it to be quite rich, and a mining operation was begun. At this time, any goods shipped from Lake Superior to the lower Great Lakes had to be portaged over an extensive series of rapids at the eastern end of Lake Superior, adding to the cost and difficulty of transportation. In order to reduce transportation costs, the Jackson Company decided to mine and smelt the ore locally, then ship forged iron rather than bulk ore to markets on the lower Great Lakes. In addition to ore, the UP had abundant timber for charcoal and the necessary streams to power forge machinery. The Jackson Company selected a site on the Carp River, between the mine and a shipping port on Lake Superior, for its dam, forge, and sawmill.[9]

Initial construction efforts at the forge site proper were mismanaged and moved slowly. In the words of Everett, McNair, the man hired as master builder, proved to be "one of the most fanciful mechanics for putting up a frame that you ever saw."[10] Ariel Barney, an experienced ironworker, took over from the first master builder and, by mid-winter of 1847–48, Barney had completed two cold-blast bloomeries and an earthen dam.[11] In early February of 1848, Barney and Aaron Olds fired the bloomery, made the first bloom, and pounded it into a bar of wrought iron.

Apparently Barney was a better ironworker than millwright. In mid-April of that year, a spring rain on top of melting snow washed away a substantial portion of the earthen dam. The dam could not be repaired until the end of the summer. In November 1848, Everett reported to the company that he had been able to make only 10 tons of iron that fall. Everett's problems, ironically, stemmed from a lack of water to power the equipment. Water levels were high enough that the forge operated through the winter of 1848–49, but it was shut down again in the spring, this time due to a lack of ore.[12] The company also experienced shortages of charcoal. Bloomery forges required some 200–300 bushels of charcoal to produce one ton of iron blooms, and the forge was occasionally forced to close for lack of charcoal.

The Jackson Company's persistent problems led the owners to lease out its forge operation. In fall 1850, the forge passed into the control of Benjamin and Watson Eaton, two ironmaking brothers who leased the forge for a percentage of the iron produced. With new operators came a renewed sense of optimism. As one observer later recalled, when the Eaton brothers came up from Ohio late in 1850 to take control of forge operations, "they commenced operations with a grand flourish of trumpets and high-sounding words that bid fair to eclipse and crush everybody else out of existence in short order."[13]

The Eatons modernized the operation, replacing the two cold-blast forges with four hot-blast forges. Despite producing some iron, the Eatons also failed, and, within a year, the Jackson Company's interests had been purchased by General Joel B. Curtis and the Sharon Iron Company of Sharon, Pennsylvania. Sharon ran the forge sporadically through 1852 and 1853, concentrating more effort on shipping ore back to its Pennsylvania furnaces. When the Sharon Iron Company pulled out of the Marquette Range in 1854, a group of its employees formed the Clinton Iron Company and set out to run the forge. A contemporary newspaper account describes them as "a body of practical men ... who are not possessed of any large amount of means, but who endeavor to make muscle and sinews supply the deficiency."[14] Apparently sinew and sweat were not sufficient. Production costs far outweighed their return on blooms, and the company quickly failed, leaving the forge cold by the end of 1855. Though some people continued to live at the site for the next several years, there is no real evidence anyone ever fired the forge again.

Other Regional Bloomeries

The Carp River Forge was not alone in encountering financial and operational problems, as all three of the other bloomery forges in the district suffered similar difficulties. The history of these companies is closely intertwined with that of the Carp River Forge. The Marquette Iron Co. Forge (1850–53) was established by a company that tried unsuccessfully to take over the Carp River Forge in 1849. It shipped in a steam engine to run forge machinery built by Amos Harlow in a Massachusetts machine shop and established its bloomery on the lakeshore in what became the town of Marquette. Shortages of ore and charcoal plagued the operation, which finally burned down in 1853, having exhausted the investor's capital for very little return.[15] As one later writer estimated, the Marquette Forge was expending $200 to make and ship a ton of blooms that sold for only $80 in Pittsburgh.[16]

Two additional companies began constructing water-powered forges in 1853, perhaps as a result of the destruction of the Marquette Forge. The Buckeye/Forest Iron Co. and the Collins Iron Co. developed sites on the Dead River, north of Marquette, harnessing waterpower to run their forges. Many of the skilled ironworkers from Marquette Forge went on to the Buckeye/Forest Forge, which also employed Richard Barney as a bloomer, presumably a relative of Ariel Barney, the first forgemaster at the Carp River Forge.[17] Richard Graveraet, one of the original organizers of the Marquette Forge, joined with New York investors to launch the Collins Forge. Neither of these forges produced any iron until 1855, and neither operated as a bloomery for more than a few years.

One of our most detailed views of bloomery forge operations in the district comes from a surviving account book of the Buckeye/Forest Iron Co., now in the historical collections at Harvard's Baker Library.[18] This company is likely broadly similar to the others that operated in the district. The account book covers the period from November 1853 through December 1856. It includes a daily list of tasks, a tally of iron production attributed to specific workers, a list of iron shipments from the port at Marquette, contracts for charcoal, and accounts for the company store and boardinghouse. It is one of the most comprehensive original sources on bloomery iron production available for the district.

Throughout this period, the company maintained between 8 and 15 employees, while contracting out for the bulk of its charcoal as well as some hauling. The company spent the better part of its first 18 months cutting timber, raising the dam, hauling in supplies, and building the forge and associated buildings. The pioneering nature of an isolated enterprise is clearly reflected in numerous references to work constructing dwellings and clearing and planting fields of potatoes and rutabagas. Ironworkers "blew" the forge for the first time on March 5, 1855, and made about 600 pounds of bloom by March 7th. Just two days later, the forge blew out "for want of ore."[19]

Difficulties in maintaining the ore supply was only one problem, and the temperamental nature of the forge machinery was apparently another. June 1855 seems to be a typical month. Workers fired the forge on June 5th and ran it until it blew out at 4 PM on June 8th. The bloomers and hammermen spent the next several days repairing the cylinder, blast, and the forge stack. They started the forge again at 8 or 9 AM on June 12th, and it blew out the same night, necessitating several more days of repairs to the blast. The forge was started again on June 19th, blew out on June 22nd, and was apparently out for the rest of the month. Overall, the forge apparently ran for about 9 days in June, with much of the rest of the time spent repairing the forge and preparing supplies. This type of operating record came with what otherwise appears to be an experienced workforce, highlighting the difficulties involved in bloomery iron production in this district.[20]

One of the most striking aspects of the Buckeye/Forest Forge record is the very low level of iron production obtained. In both 1855 and 1856, iron production was a seasonal affair, starting in March or April and running through October. The company made both blooms and bar iron, shipping them out by boat from the port at Marquette. Individual "bloomers" and "hammerman" are listed by name, along with their production of blooms or iron bars. Fourteen different workers appear in this account, many of them working as both bloomers and hammermen and sometimes taking on both of these jobs in the same day. During March and April 1855, the bloomers forged 431 blooms weighing 51,990 pounds. Between the beginning of March and June 13, the hammermen pounded out 18,191 pounds of "flat," "square," and "slab" iron, presumably selecting certain blooms, reheating and consolidating them with additional hammering. Since blooms and hammered iron weights are added together to calculate total output, only a portion of the blooms seem to have been selected for consolidation into bar iron. In 1855, total iron made was only 156,445 pounds; in 1856, the total was 156,360, of which only 7,164 pounds was recorded as bar iron. Seventeen months of construction and two seasons of forging produced just over 156 short tons of iron. The major investment that went into such limited production inevitably exhausted the company's capital.

This type of cost structure doomed the early bloomery operations on the Marquette Iron Range. Despite high hopes and optimistic predictions about the Carp River Forge's prospects, it only operated for seven years, in the process draining the coffers and enthusiasm of four operating companies. Total iron production is difficult to estimate but probably was less than 1,000 short tons.[21] In summer 1855, a New York newspaper article declared that "some efforts have been made at various times to resuscitate it, but in vain, and the old forge, blackened and begrimed, stands as a monument to misguided enterprise."[22] Peter White, an investor in the Buckeye/Forest Forge, was harsher, declaring it "... still more unfortunate that it [the Carp River Forge] did not burn."[23] Mismanagement, transportation difficulties, vagaries of water supply, and the harsh realities of establishing a pioneering operation on a relatively remote iron range all mitigated against the long-term success of the forge.

The Settlement at the Carp River Forge

Except for scattered pieces of slag and ore on the surface, current visitors to the Carp River Forge find few remaining indications that the area was once an ironworks. The Carp River has swept away most of the dam and scoured the adjacent riverbanks. None of the forge buildings remain standing, and the site has been largely reclaimed by forest. Most of the documentary evidence for the forge buildings and attendant architecture is lost. Although the site was the focus of archaeological research in the 1970s, the previous work lacked a real industrial archaeology perspective. During the summers of 1996 through 1998, a cooperative field archaeology project between Michigan Technological University and the Michigan Historical Center's Iron Industry Museum studied the forge site. Over that time, the site was mapped, parts of both industrial buildings and houses were excavated, and a wide range of artifacts were analyzed. Through this work understanding of the routines of daily life for the forgeworkers, and the layout, organization, and technology of the forge proper has increased (Figure 3).

The harsh realities of Upper Michigan's landscape played a primary role in the history of the Carp River Forge and the district's other early bloomeries. Constructing roads and houses, clearing and planting fields, and raising a dam and forge were the starting tasks for each operation. Initial development of these ironworks required skilled artisans, especially for dam and forge construction. Transportation through the rough and swampy terrain was a constant problem. The Jackson Company had to transport raw ore 3 miles from the mine to the forge and then move the iron blooms and bars the additional 12 miles to Lake Superior. Road construction also proceeded slowly because, despite offering generous wages, the company found it difficult to hire workers—they believed they would freeze to death in the cold region.[24] Overland transportation improved little until 1857 (after the forge had already failed) when a railroad finally connected the port at Marquette to the mines.

It is not clear exactly how many structures workers built at the site, but accounts written during different periods of

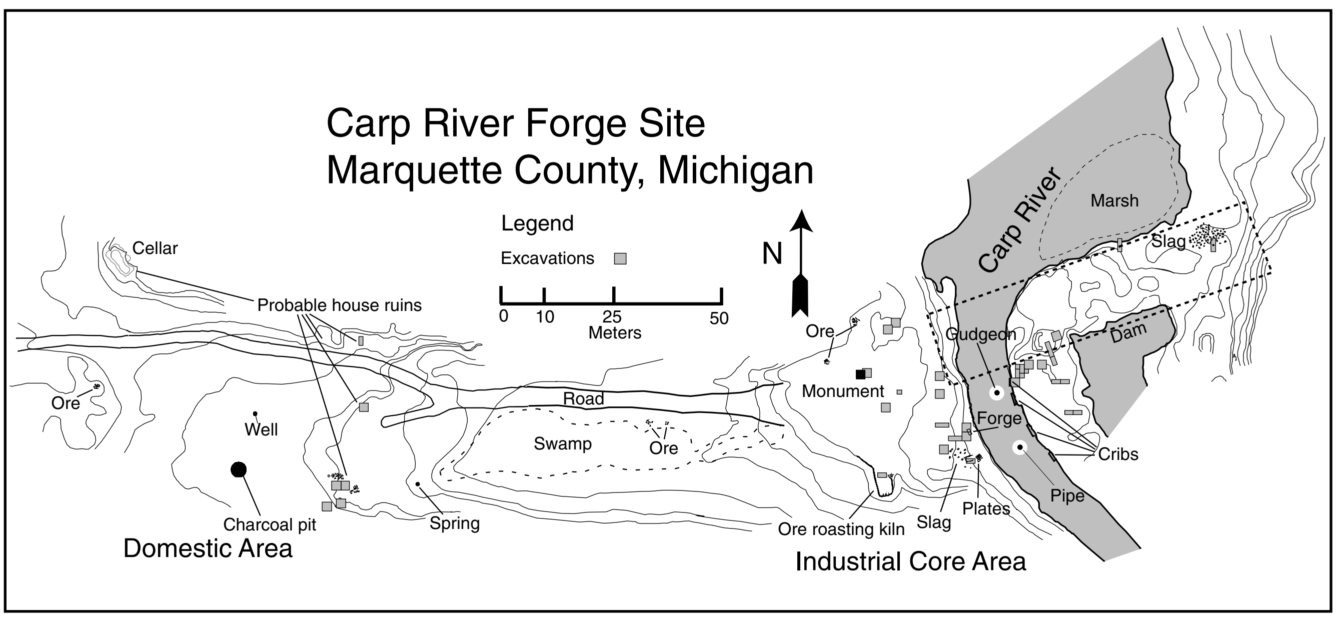

Figure 3. *Map of the Carp River Forge Site, based on archaeological fieldwork.*

forge operation provide clues as to the numbers of workers employed and various buildings at the site.[25] When Peter White arrived at Carp River in 1849, he recalled a forge, a sawmill, store, and blacksmith shop as well as many log houses and a few frame dwellings and barns. In 1851 the Eaton brothers, who were then leasing the operation from the Jackson Company, employed more than 40 men and had 40 horses and two pair of oxen. In 1853, when ownership of the forge had passed to the Sharon Iron Company, its annual report indicated the forge and 20 "dwelling houses" among the improvements on its lands.[26] An 1855 map that includes the site shows about a dozen buildings in the area, many of them spread along the section line to the west of the site (Figure 4). At minimum, we can assume that the site included the forge building, ore-roasting kiln, dam, blacksmith shop, at least one animal barn, and houses for workers. It is likely that the site also included ore stamps, a sawmill, and charcoal storage area, though some of these operations might not have had a separate building.

Based on the archaeological evidence, the small valley west of the main industrial core held a cluster of workers' houses (Figure 3). The artifacts suggest that the last of these buildings was abandoned shortly after 1860, and nothing remains except some minor changes in the surface topography. We located and excavated portions of at least three of the cabins built by the forge workers. These were likely simple log structures with a small number of windows. One structure included a very large stone hearth, perhaps functioning as a communal kitchen or boardinghouse. The artifacts recovered from around these buildings tell little about the composition of the households at the site. Historic documents suggest that this site was a largely male camp during the initial construction but that some families with women and children lived there in the 1850s.

The artifact assemblage from the excavations around the cabins included a variety of household trash as well as nails and window glass from the buildings themselves. The ceramics assemblage included transfer prints, sponge-decorated, edge-decorated, as well as some hand-painted vessels (Figure 5). These are all standard wares of the early to mid-19th century, and many of these vessels are imported, the product of industrial-scale manufactories in Staffordshire, England. Overall, the variety of decorated, imported ceramics provides an interesting contrast to the stereotypical image of isolated, frontier log cabins. Although the housing was rudimentary, the household goods included the common wares of the period, reflecting the site's connections to broad market systems.

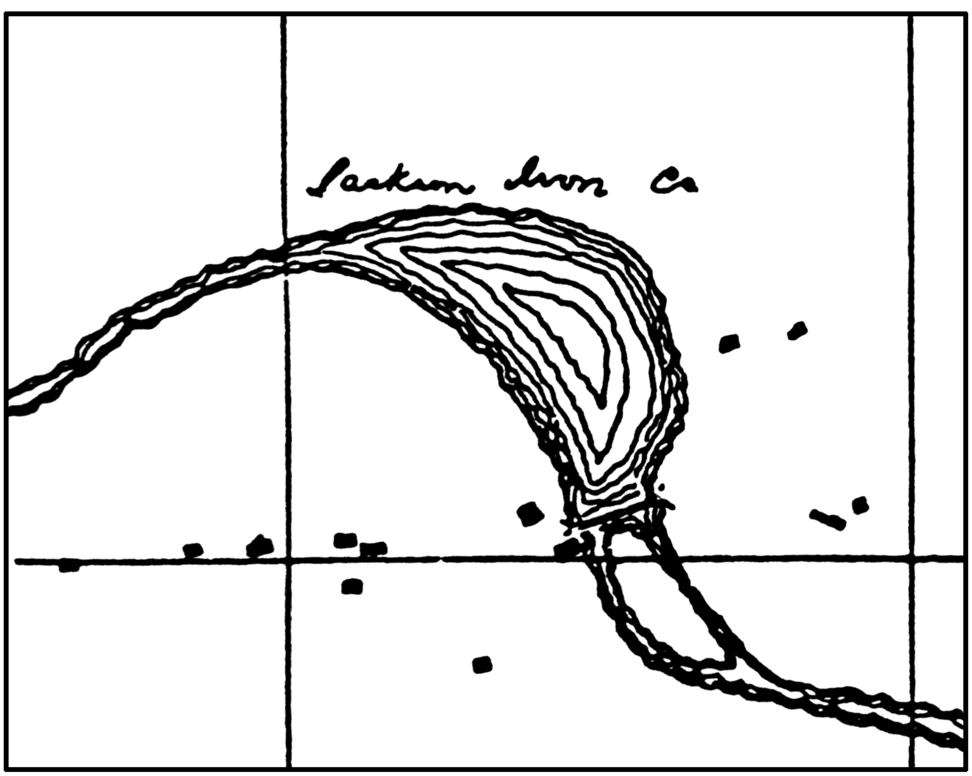

Figure 4. *An 1855 map showing the buildings at the Carp River Forge. Note the remnant island in the river channel, the dam, the impounded pond, and the buildings spread along the section line*. Map courtesy of the Michigan Iron Industry Museum.

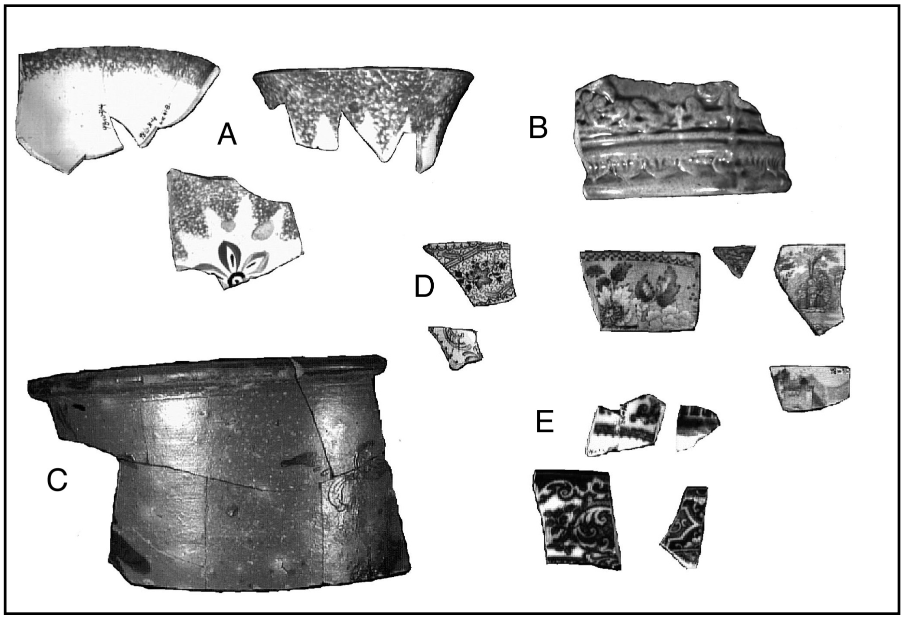

Figure 5. *A sample of ceramics from the workers' housing. (A) red and green sponge decoration on white earthenware; (B) lead glazed redware with molded design; (C) gray salt-glazed stoneware crock with cobalt decorations; (D) red and light blue transfer-printed designs on white earthenwares; (E) "flow blue" transfer-print design on white earthenware.*

Fuel, Ore, and Processing

The small valley where the housing was located also functioned as the primary route for transporting ore from the Jackson mine, several miles to the west. Raw ore is scattered throughout the area, often in small stockpiles. Colliers also produced charcoal in the forests surrounding the cabins. Although many of the later blast furnaces in this district had permanent charcoal kilns, we have not identified the remains of any permanent kilns in the area around the site. The Carp River Forge apparently relied on temporary kilns, either surface piles or pits, for charcoal production. We only identified one of these remnant charcoal burning spots, visible as a slight round rise in the ground surface, which, when cored, revealed a thick layer of solid charcoal (Figure 3).

The collier and his assistants cut timber, piled it into pits, covered the piles, coaled the wood in a controlled burn, and hauled the charcoal to the forge. This was a time consuming but crucial task. In a hot-blast bloomery, a ton of blooms required some 300 bushels of charcoal.[27] Assuming 40 bushels per cord and 35–40 cords per acre of cut timber, each acre provided enough charcoal for about 5 tons of blooms.[28] At a small-scale operation like the Carp River Forge, 5 tons of blooms likely represented two good days output, running all four hearths. Burning wood to heat houses and to roast ore added to the fuel consumed. The consumption of several acres of timber per week cleared the forest around the site rapidly and quickly moved most of the charcoal production out of the immediate vicinity of the forge.

Charcoal production records for the Buckeye/Forest Forge add several details to this picture.[29] One record lists "wood measured in pits" with four pits listed at 23, 38, 36, and 30 cords. This presumably reflects the size of individual burns in charcoal pits. Three other records detail large charcoal purchases for 1853–54, 1855, and 1856, totaling 681, 670¼, and 946¾ cords. Wood appears to have been cut, coaled, and delivered by subcontractors who hired their own crews, then estimated or counted by one of the forge workers. The charcoal listed in the account would have consumed more than 60 acres of timber and provided enough fuel to make more than 300 tons of blooms.

Immediately adjacent to the west side of the Carp River is a large flat terrace that served as the primary stockpiling area for charcoal, probably in an enclosed building or roofed shed (Figure 3). This terrace was also the processing area for ore. Forge workers roasted the ore in a kiln to drive off moisture and make it more friable, thus easier to crush. An 1870s-era calcining kiln at the Au Sable Forks Forge in New York was "26 feet long, 24 feet deep, and 12 feet high at the back, and 5 feet at the front, built of rough stones laid up with clay" and could hold 300 tons of ore.[30] The ore kiln at Carp River is smaller and more rectangular, being roughly 15 feet deep and 10 feet wide, with a back wall height of approximately 10½ feet. This kiln is only partially built with dry-stone masonry, one wall is formed by the natural bedrock (Figure 6). The kiln also features a loading ramp, which peaks at the natural wall of the kiln.

Figure 6. *Interior view of the ore kiln, facing west.*

Inside an ore-roasting kiln, workers arranged rows of wood in layers, forming a lattice pattern. The stacked wood came to about 3 feet high. Partially calcined ore from previous firings was placed on the wood first, followed by ore in descending order according to size. The kiln was then fired, taking about three to six days to complete the calcining.[31] If we conservatively estimate the Carp River Forge kiln at about 120–150 tons capacity, no more than two or three burns per year were likely necessary.

After the calcining process, the ore needed to be broken down into pieces of appropriate size. We have very little information about how this was done at the Carp River Forge, though this was typically done with ore stamps. We have not found any detailed description of the ore stamps or recovered any parts of stamping machinery in our excavations, but it is likely they were simple gravity stamps. Our excavation recovered about ¾ of a ton of ore, in fist-sized pieces and larger, in one small area on the eastern side of the current path of the Carp River. The raw ore is metallic-gray specular heamatite, but the pieces of this ore in this concentration are mostly reddish in color, apparently as a result of being roasted. This roasted-ore concentration likely represents a stockpile of material for the stamps, suggesting the stamps were on the east side of the industrial workings. A specific size for ore does not seem to have been recorded, but crushed ore specimens recovered from Carp River seem to average around ¼-inch in diameter. Accounts from newspapers of the period state that the ore was crushed to a "fine size," and, in some places, it is described as being crushed to the size of sand.[32] Once the ore had been calcined and stamped to the desired size, it was ready to be smelted into iron.

The forge operation was centered on the river, using waterpower to run the air blast and the helve hammer. The original dam crossed the river at the upstream end of an existing island in the river, using the island and many wheelbarrows of rock and sand fill to help anchor the timber cribbing of the dam base. The dam itself stood about 18 feet tall, according to the 1873 Geological Survey of Michigan.[33] One of the only historic photos of the site is a rather poor quality shot of the dam, showing that the main superstructure of this dam was made from unhewn logs, faced with planking on the upstream side (Figure 7). Today the dam is breached at the western end, the superstructure is entirely gone, and only the buried portions of the eastern cribbing and massive amounts of fill survive.

The headrace appears to be made from square-hewn logs. All evidence points to a single headrace on the western end of the dam, using the western branch of the river as the tailrace. Power for the site was supplied by one or more waterwheels located just behind the dam. The headrace did not extend very far out from the dam, suggesting the main waterwheel was located closely underneath. During a river bottom survey, a cast-iron gudgeon with a bearing and attached crank arm was located and pulled from the bottom of the river, very close to where the headrace would have been (Figure 8). The gudgeon would have formed one end of the central axis of a waterwheel with the crank possibly powering the air blast. Given the variety of machinery employed at the site, multiple waterwheels would have been useful. There is no second headrace visible in the photo and no indication that the operation ever had a steam engine in operation. If a single waterwheel powered all the machinery, it is likely that the machinery was all clustered in a small area adjacent to the wheel. If the headrace fed multiple wheels, the machinery was probably arranged in a linear fashion on either side of a flume. It is also possible that belt drives ran power to more distant machines. The breach of the dam in this location and the loss of the wooden frame make it unclear exactly how power was used to run the helve hammer, the air blast machinery, or any other machinery in use at the site.

Bloomery Forge Technology

During the Jackson Company's initial occupation of the site, two cold-blast forges made the iron. Details of these forges remain sketchy. We have found only one intact forge base on the site, a square structure made of rough-cut, dry laid, locally quarried schist (Figure 9). Most of the slag recovered from around this forge has a very low iron

Figure 7. *The Carp River Forge, looking east (c. 1900), one of the few historic photos showing the site. The wooden timbers visible among the trees in the center of the picture are the upper parts of the dam. Note the tree growth upstream of the dam to the left. The ore kiln is just outside the edge of the picture to the right. The bright area behind the dam is an exposed face of schist, somewhat more overgrown but still visible today.* Courtesy of Michigan Iron Industry Museum.

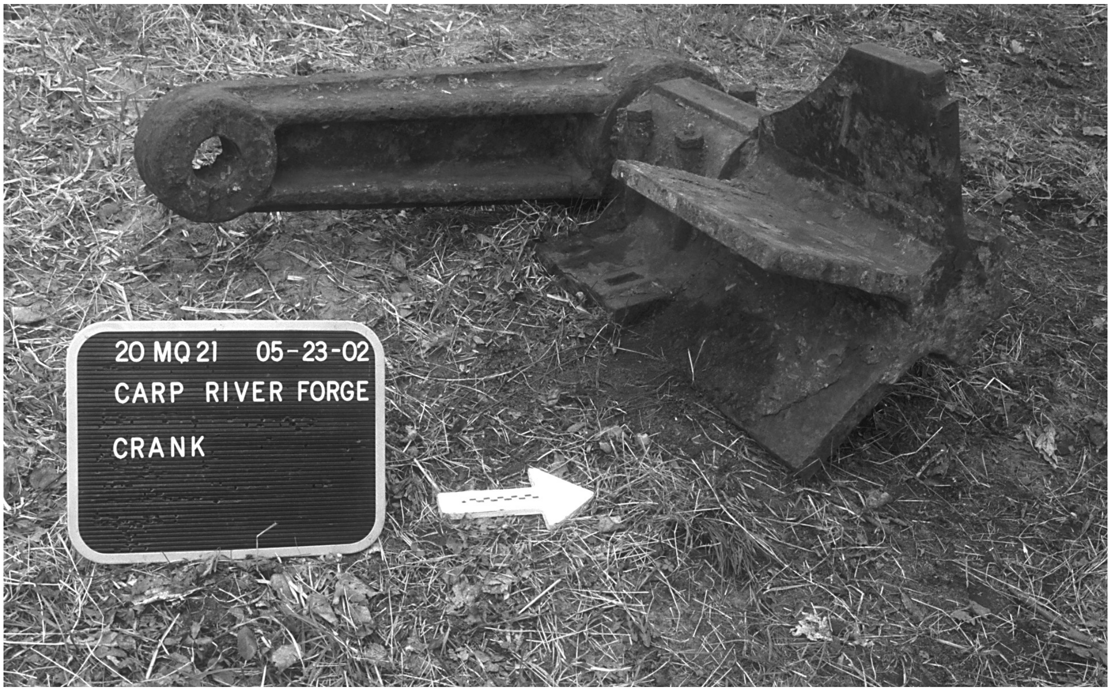

Figure 8. *Water wheel gudgeon from the Carp River. The cast-iron flanges on the right would have fit into the end of the water wheel axis timber. The bearing in the center of the gudgeon is held together by four large bolts.*

Figure 9. *Forge base, looking east. The Carp River is just visible in the upper right-hand corner of the photo. This excavation unit encountered thick deposits of charcoal, sand, and slag, which included blacksmithing artifacts like wrought nails, oxen shoes, and iron scrap.*

content and looks like blacksmithing slag, not bloomery slag. Further, many of the artifacts from around the forge base also suggest blacksmithing, including oxen shoes, wrought-iron nails, and iron scrap. However, the crop end of an iron bar was also found here, the only one found in the excavations. When the Eaton brothers took control of the forge in 1851, they built four hot blast forges to replace the earlier cold blast ones. It is possible that the stone forge base is the remains of one of the original cold blast forges at the site, converted to use as a blacksmith forge, though this interpretation remains speculative.

The Eatons' construction of hot blast bloomeries marked a major step forward in the forge's technology. The blast air was preheated by running through iron pipes in the exhaust stack, capturing heat from the forge fire. Hot-air blast reduced the consumption of charcoal in the forge fire and improved the efficiency of the process. A contemporary account describes Carp River's forges as follows:

> The furnaces are something like a blacksmith's fire, on a large scale, being open in front and back, enclosed at the sides and tops with heavy cast iron plates, receiving the hot-blast at either side. The application of hot instead of cold air to fan the flame is one of the greatest improvements of the age. ... The air is heated by passing it up and down in heavy iron pipes, placed in the center of the stack or chimney, and exposed to all the intense heat of the surrounding fires.[34]

This account suggests that the hearths were open at both the front and back, with tuyeres on both sides of the forge firebox. This design seems atypical, as most bloomery forges were apparently only open on the front with a single tuyere.[35] It is not clear if the Carp River forges really did differ in design or whether this particular account is more impressionistic than precise.

Figure 10. *T-shaped air blast pipe pulled from the bottom of the Carp River. The Eatons used cast-iron pipes like this in the stack of the forges, heating the air for the blast*. Photo by Martin.

The physical evidence for the hot-air blast forge configuration at Carp River includes sections of cast-iron air blast pipes and eight cast-iron firebox plates. The air pipes include a flanged pipe and a T-shaped pipe with a now inoperable mechanism to open and close the pipe, presumably controlling airflow into the forge (Figure 10). The firebox components include two cinder plates, two tuyere plates, two merritt plates, and two broken, unidentified plates (Figure 11). These metal plates would have formed the lining of the forge firebox and been surrounded by a masonry structure. None of the plates were in their original location, though they were found clustered in the area just downstream from the forge base discussed above. All told, parts of the firebox and air pipes for two of the four hot blast forges were recovered.

The bloomery forge stack was usually constructed of firebrick. Only a small number of unmarked firebricks were found in the excavation, suggesting the bricks might have been salvaged after the forge closed, perhaps used to help line one of the district's later blast furnaces. Several pieces of slagged schist that appear to be from forges were found, suggesting some use of local stone in place of nonlocal

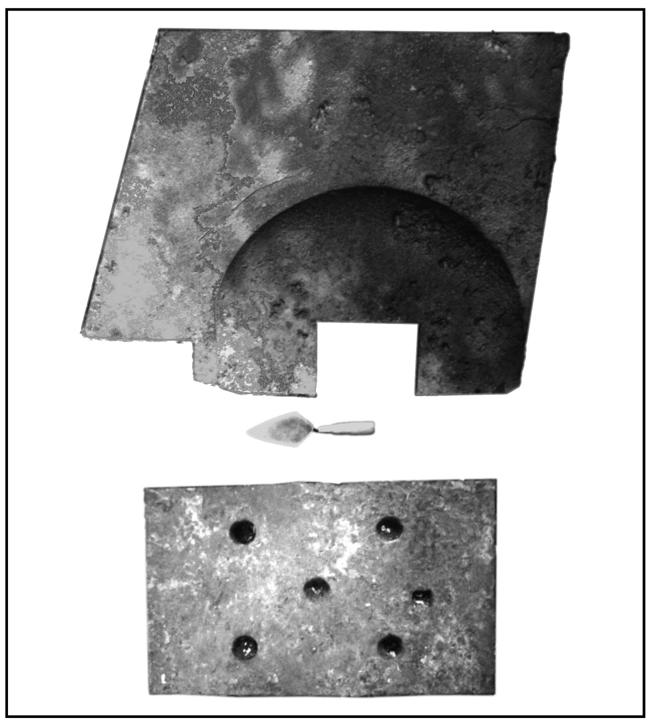

Figure 11. *Two cast-iron firebox plates. (Top) merritt plate; (bottom) cinder plate. The square notch at the bottom of the merritt plate held the tuyere in the forge. Forge workers reamed the holes in the cinder plates to tap liquid slag during the formation of the bloom. The 9-inch long trowel is for scale*.

firebrick. This would have obvious advantages when building a forge in such a remote location.

An interesting aspect of the firebox plates is that they closely parallel plates illustrated in an 1880 description of the bloomery process in Upstate New York, especially the tuyere, cinder, and merritt plates (Figure 12).[36] Differences are minor rather than major. The merritt plates are identical in shape to those from New York, but instead of having a hollow water jacket, the area around the tuyere hole is thickened to protect the tuyere nozzle. Gordon and Killick suggest that ironworkers had made the most important technological developments in bloomery design by 1850 and that the process changed relatively little after that point.[37] The apparent similarity between the 1850 Carp River firebox design and the 1880 New York design seems to support this contention, suggesting that firebox components for bloomery forges changed little from 1850 to 1880.

The Eaton brothers' use of a hot-air blast and the design of their firebox plates show that some aspects of the bloomery technology in use at the Carp River Forge were, for 1850, fully up to date. This physical evidence is somewhat at odds with the historical description of the forge technology (detailed above), which suggests an atypical design. This disparity makes it difficult to fully describe the technology in use at the Carp River Forge and to assess what role, if any, technological failure might have played in the operation's demise. While the forge firebox plates appear to be a standard design, the rest of bloomery forge might have been a nonstandard design that included local materials in the construction. It is also unclear how important water-jacketing of the plates and tuyeres was to successful operation; obviously if these melt, the forge must be shut down for repairs. Although firebox design remained relatively unchanged after 1850, changes such as the development of better tuyere cooling procedures or alterations in the air blast might have improved the reliability and efficiency of American bloomeries.

The skill of the forgemaster was equally important to the success of the bloomery. At the forge, a bloomer added the finely crushed ore and charcoal to the firebox. The melting of the slag and the reduction of the ore formed a spongy mass of iron in the center of the firebox. As the operation progressed, the size of the bloom grew. Excess molten slag was tapped out through holes in the cinder plate. When the forgemaster judged the iron bloom complete, after several hours, it was forcibly hoisted from the forge and taken to a mechanical helve hammer.[38] The bloomer or hammerman pounded the bloom, expelling additional slag and consolidating the

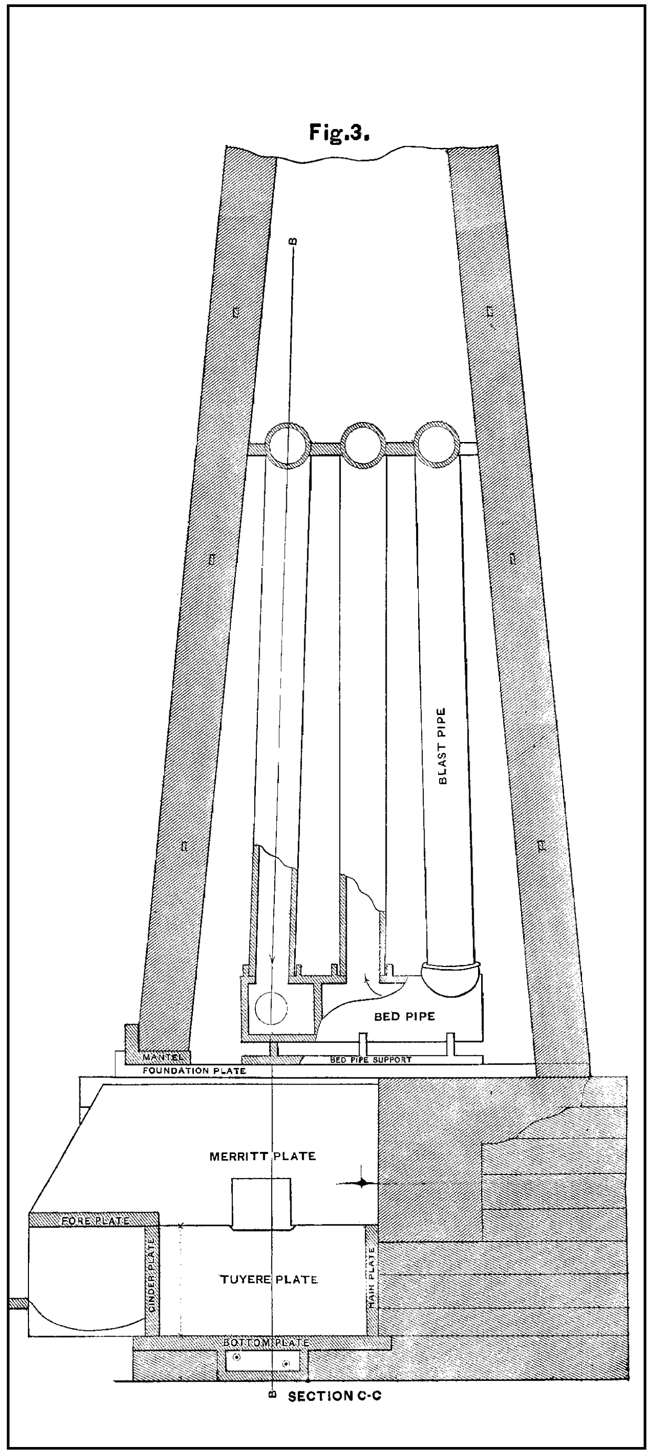

Figure 12. *Illustration of a late-1870s era hot-air bloomery forge from New York. The shape of the merritt plate is very similar to that from the Carp River Forge. Note the location of the cinder plate at the front of the firebox and the cast-iron pipes built into the stack to heat the blast.* From T. Egleston, "The American Bloomary Process for Making Iron Direct from the Ore," 1880 (note 29).

bloom into one or more rough bars. In the Marquette bloomeries, forgeworkers apparently selected some of the blooms and hammered them further, pounding them into bars of wrought iron. Records relating to both the Carp River Forge and the Buckeye/Forest Forge differentiate between blooms and bar iron as products. For example, in July 1849 the *Lake Superior News and Mining Journal* reported a shipment from the Carp River Forge of 213 blooms totaling 13 tons and 120 bars of iron totaling 2½ tons.[39]

Process Residues

The most abundant artifact recovered from the forge area is slag, the waste product of the iron production at the forge. The slags were studied to try to better understand the forge operation; slag samples were collected from across the surface of the site and in all the excavations.[40] Beginning with the second season, magnets were routinely used to collect small magnetic residues in the excavation areas and in the screens where the excavated sediments were seived. Sediment cores were collected on a grid pattern on the eastern side of the current river channel; magnets were run through all of the sediments in the cores to try to find small magnetic residues. It was hoped this last sampling scheme would help identify the location of the helve hammer by pinpointing a concentration of highly magnetic hammer scale, a byproduct of pounding the bloom under a helve hammer.[41]

In the lab, macroscopic characteristics of the ironworking residues such as color, density, morphology, vesicle size, and inclusions were used to create a classification typology for the site (Table 1). The basic composition of several of the samples were determined (Table 2), some of the larger pieces were sectioned to look at internal structure (Figures 13 and 14), and a sample of tap slag was thin-sectioned to look at its microstructure (Figure 15).[42]

Table 1. Ironworking Residues from the Carp River Forge Site

Bloomery Forge Residues

Type	Description	N	Weight lbs. (kg)
Tap slag	Dense, opaque, and often smooth slag, sometimes with a few large vesicles; often has a ropy or flowing texture from being in liquid form at tapping; dark gray to brown color.	1858	404.96 (184.04)
Sponge slag	Porous, rough, "spongy" slag with many small vesicles and often with small charcoal inclusions; light brown to rust color.	1942	35.25 (16.02)
Mixed tap/sponge	Specimens mixing morphology of tap and sponge slags, often with one very porous side and one dense side; same color range as tap and sponge slags.	2552	216.37 (98.35)
Bloomery forge bottoms	Rough surfaced, with convex bottom and flat to slightly concave top; top is often more porous with larger vesicles; oval or round in plan; often has charcoal and iron inclusions; dark brown to dark gray color.	38	150.00 (68.19)
Blooms (rejects)	Rough surfaced and heterogeneous mixture of slag, charcoal, and iron; similar in shape to bloomery forge bottom, but larger; mottled rusty brown color.	4	330.42 (150.19)

Other Ironworking Residues

Type	Description	N	Weight lbs. (kg)
Blacksmith slag	Rough, glassy slag with vesicles of different sizes; lighter, less dense, and lower iron content than bloomery slag; wide color range from drab gray to black, bluish, and greenish.	4276	250.11 (113.69)
Blacksmith hearth bottom	Similar in appearance to other blacksmith slag, but in a larger cake with a convex bottom and slightly flatter but convex top.	1	1.74 (0.79)
Slaggy conglomerate	Mixture of slag, charcoal, and local schist, either from material melted together at the edge of the forge or when tapped slag fused to material on the ground.	261	16.98 (7.72)
Cinder	Extremely porous and lightweight with tiny vesicles; resembles pumice; dark gray or dark brown to black color.	122	1.01 (2.33)
Other/Miscellaneous	Slags with unusual surface characteristics from contact with brick, local schist, or other material, plus specimens too small to assign to a category.	113	10.24 (4.65)

Table 2. Elemental Composition of Ore and Slag Samples from Carp River Forge.[a]

Element[b]	Tap slag	Tap slag	Sponge slag	Sponge slag	Forge bottom	Smith slag	Ore
Aluminum	4.10	5.20	3.16	4.40	4.30	3.99	3.53
Barium	0.07	0.08	0.08	0.08	0.14	0.14	—
Calcium	4.09	3.71	4.60	3.14	4.05	5.50	—
Chlorine	—	—	0.16	0.15	—	—	—
Iron	78.50	76.00	76.40	76.90	75.40	65.60	92.80
Magnesium	0.40	0.39	0.42	0.23	0.31	0.75	—
Manganese	0.23	0.34	0.25	0.35	0.52	0.54	—
Phosphorus	0.29	0.36	0.33	0.33	0.39	0.24	0.12
Potassium	1.70	2.09	1.85	1.60	2.44	3.71	—
Silicon	9.70	10.70	11.90	11.90	11.60	18.50	3.17
Sodium	0.14	0.22	0.16	0.12	0.14	0.45	—
Strontium	0.09	0.15	0.09	0.10	0.10	—	0.05
Sulfur	0.06	—	—	—	—	—	—
Titanium	0.27	0.33	0.20	0.31	0.26	0.30	0.09

[a] All figures are elemental percentages, calculated from XRF Spectrometry analysis run by Ed Laitila.
[b] No elements are listed that are less than 0.1% in all samples.

Figure 13. *Photograph of the central section of a slag bloomery forge bottom. The light colored areas are iron, and the flat black areas are charcoal. The large chunks of iron in the slag represent iron lost by the bloomer*. Photograph by Landon.

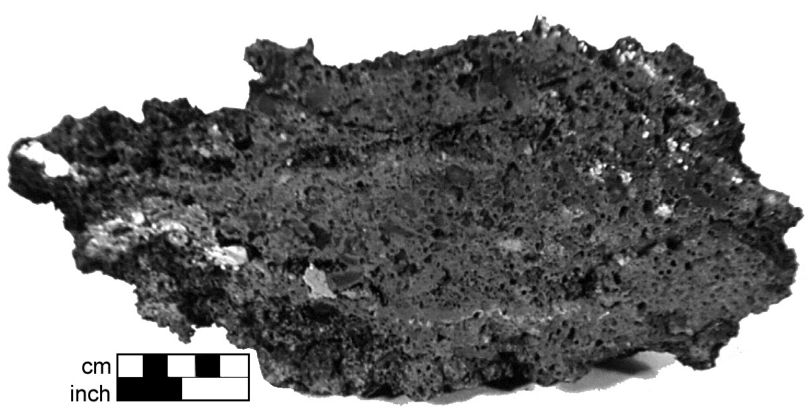

Figure 14. *Photograph of the central section of a "reject bloom" recovered from the site. The light colored areas are iron. Note the band of iron at the left side and the drops of iron scattered throughout the upper right of the section*. Photograph by Landon.

The only other North American bloomery slag typology comes from Gordon and Killick's work on bloomery slags from the Adirondacks.[43] This study differs in several ways. It is based on a large collection from a single site and includes a significant amount of excavated material as well as surface-collected samples. Robert Gordon and David Killick describe tap slag, plate slag, flat bottoms, fragments, and skulls. This study includes both their tap slag and plate slag types in a tap slag category, as both these types result when molten slag is run out of the forge. Also, nothing was found in this work that was really analogous to their flat bottom or skull types. In the Adirondack forges, flat-bottomed slag formed when molten slag solidified against the iron bottom plate of a furnace when it was taken out of blast and cooled. The absence of these in the Carp River Forge assemblage presumably reflects some difference in forge design between the Carp River and the Adirondack forges, possibly showing that the Carp River bloomery forges lacked a bottom plate to the firebox. If this is the case, it highlights the potential value of slag to provide insight into aspects of forge design.

Nothing was found to match with Gordon and Killick's skull slag type. In Adirondack bloomeries of the 1870s and 1880s, skilled ironworkers formed the iron into a circular basin by manipulating it with an iron rod. The slag that formed in the basin helped prevent reoxidation of the iron. The basin also trapped any iron formed while excess slag slipped over the side to be tapped off. Gordon and Killick interpret skulls as the solidified remnant of this pool of slag that formed above the bloom, broken off the bloom after it is removed from the fire.[44]

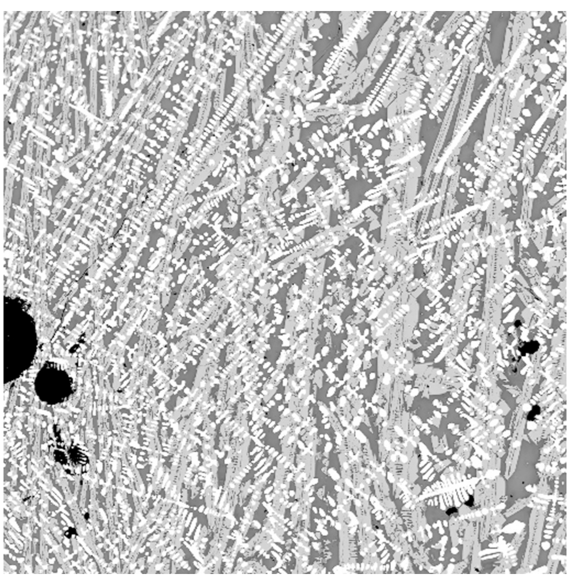

Figure 15. *Reflected light micrograph of a polished thin section of tap slag from the site. The width of the section is 1 mm. White = wustite; light gray = fayalite; dark gray = glass with approximate composition of anorthite; and black = void spaces. The presence of wustite in the tap slag represents iron lost by the bloomer. But trying to recover more iron from the slag by attaining more reducing conditions would have risked making steel blooms rather than wrought iron*. Micrograph by Karl Peterson.

This study found slags that share some gross morphological characteristics with Gordon and Killick's skull slags, but they are refered to as bloomery forge bottoms, with the belief that in the Carp River forges, these slags formed below the bloom rather than above it. The convex bottom of these pieces of slag shows no sign of a breakpoint where it was separated from the bloom, but it is uniformly rough and dimpled. It is believed this surface morphology comes from sitting on other material such as fine charcoal or sand in the forge base. In addition, a variety of blacksmithing and bloomery forge types producess similarly shaped pieces, plano-convex in section and round to oval in plan. These are routinely identified as hearth bottoms, reflecting slag and metal that dripped into bottom of the hearth and consolidated there.[45] It is believed that the similar shape of these pieces in the collection from the Carp River Forge is not coincidental but reflects similar formation processes. If this interpretation is correct, it suggests that the techniques of the bloomers might have varied considerably between the Carp River Forge and the later bloomeries of the Adirondacks. Further work to experimentally replicate historic bloomery processes must be coupled with additional laboratory analyses of historic ironworking slags in order to improve understanding and interpretation of archaeological slags.[46]

This study of the slags was geared towards identifying the different processes used at the site and reconstructing their spatial layout. Based on the slags, two major processes at the site were successfully distinguished, bloomery smelting and smithing, identifying a surviving stone forge base as a blacksmith forge. The blacksmithing slags are distinguishable from the bloomery slags because they are less dense, have a lower iron content (Table 2), are more glassy, and exhibit a different color range. All of the slags contain calcium, potassium, and sodium from charcoal ash (Table 2). Similarly, the silicon-to-aluminum ratio in all of the slags is higher than that in the ore and is highest in the smith slag. This shows that sand was added in the smelting charge to form slag and that additional sand was used in the blacksmith forge. Historical documents suggest that some reheating and consolidation of blooms took place after the manufacture of the initial bloom, but it is not clear if the bloom was always reheated in the bloomery hearth or if that could be done in another type of forge. It is possible, in fact, that some reheating and consolidation took place at the forge identified as a blacksmith forge. Slags from this type of operation might, in fact, look much like blacksmith slags. However, with the exception of a single crop end of an iron bar, the artifacts associated with the slag in the archaeological deposits suggest this was a blacksmith forge.

While the blacksmith slags cluster around the forge base, bloomery slags are spread across the industrial core of the site on both the west and east banks of the present channel of the Carp River (Figure 3). The largest concentration of surface slags is located at the eastern edge of the site, atop the dam base. This deposit is entirely bloomery slag, waste that was collected from inside the forge building and hauled outside to be dumped. Bloomery slag is common, scattered across the surface of the dam and is part of the upper layers of dam fill in some areas, showing the use of forge wastes to help anchor the dam during operation of the site. There are no aspects to the spatial distribution of the bloomery slags, either across the surface or in the excavation areas, that allowed us to differentiate slags from the cold blast versus hot blast forges.

On the western side of the site, slightly upslope from the likely location of the main forge building, four large lumps of mixed slag, charcoal, and iron were found that were interpreted as failed blooms. These range from 75 to 125 lbs. (34–57 kg) in weight. Their internal structure is quite heterogeneous, with large chunks of iron, charcoal, and open vesicles in a slag matrix (Figure 14). There are many reasons the bloomery process could fail, including a fire that was too hot or too cold, inattentiveness on the part of the bloomer, inadequate ore, or a failure of the air blast. A successful bloom is, by definition, a piece of almost continuous iron. These large pieces have a relatively low iron content and are primarily slag. They appear to represent a failure where a significant portion of the bloomery forge charge cooled and fused into a large mass. In all likelihood, the bloomers simply dumped them outside of the building, waiting for the right opportunity to break them up and add them to another forge fire. Apparently this opportunity never came, and the rejected blooms were abandoned along with the forge.

No concentration of residue at the site was found that could be convincingly related to the operation of the helve hammer. Bloom consolidation with a helve hammer expels slag and forces off highly magnetic iron fragments known as hammerscale.[47] T. Egleston reports that this material was collected and reused in the forges, but very small fragments of similar residue have been recovered at some ironworking sites.[48] An earlier field project at the Carp River Forge (in preparation for the Bicentennial) reported finding hammerscale in one area of the site and suggested that a frame for the hammer had been built on the current ground surface in that area.[49] The tests in this area recovered no hammer scale but recovered lots of ore and slag. In an expanded coring operation, magnets were used to test sediments from across the eastern half of the industrial core of the site, looking for small magnetic residues that might be linked to the helve hammer. No such residues were found. Forgeworkers always built a solid foundation for an anvil base so it could absorb the relentless pounding of the hammer, but the remains of the substructure for the hammer was not found in any of the excavations.[50] While it is likely that the hammerhead and anvil were salvaged from the site, the wooden supports for the anvil base appear to have been destroyed by the winter ice and spring floods of the Carp River.

Conclusion

While the archaeological research proved frustrating at times, the sweat expended in this study seems to have paid off better than that of the original forgeworkers. A great deal was discovered about the layout and organization of the forge and the living conditions of the forge workers. Ultimately this information serves a direct purpose in assisting the Michigan Iron Industry Museum in its interpretation of the site. This information also enhances understanding of the earliest phase of mining on the Marquette Range. Although early bloomery operations like the Carp River forge were very much pioneering ventures, they worked hard to connect to larger markets, shipping out iron to distant foundries and bringing in a variety of tools, equipment, and household goods for the forgeworkers. Poor overland roads and limited shipping options made this a long and expensive task. The Eatons' rebuilding of the forge in 1850 modernized the operation, using a hot-air blast and cast-iron component firebox design that appears to have changed relatively little for the rest of the 19th century. On the Marquette Range, the bloomeries' production costs far exceeded the sale price for their iron, and they lasted less than a decade. As Peter White, one of the successful developers of the Marquette Range later wrote, the early development "... was all a work of faith and perseverance..." while "... man after man and company after company cast all they had into the gulf which only time could fill."[51] White and others later made their fortunes on the Marquette Range but not by making bloomery iron.

Notes

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1. For general overviews of the history of the district, see Burton H. Boyum, *The Saga of Iron Mining in Michigan's Upper Peninsula* (Marquette: Marquette Co. Historical Soc., 1977); and Kenneth D. Lafayette, *Flaming Brands: Fifty Years of Iron Making in the Upper Peninsula of Michigan, 1848–1898* (Marquette: North Michigan Univ. Press, 1977).
2. Robert B. Gordon, *American Iron, 1607–1900* (Baltimore: Johns Hopkins Univ. Press, 1996).
3. George A. Newitt, "The Early History of the Marquette Iron Ore Range," *Lake Superior Mining Institute Proceedings* 19 (1914): 303, estimates that the total ore consumed by the bloomeries was 25,000 tons, setting an upper limit of about 15,000 tons of iron produced. Production figures for the early bloomeries are very sketchy, and many seem to be over-inflated, especially by the promoters of the early works, so a conservative estimate seems warranted.
4. James Moore Swank, *History of the Manufacture of Iron in All Ages, and Particularly in the United States from Colonial Times to 1891* (Philadelphia: American Iron and Steel Assoc., 1892), 327.
5. A more detailed view of our work is presented in Andrew Sewell, "Cultural Continuity and Technological Change at the Carp River Iron Forge" (master's thesis, Michigan Technological Univ., 1999); Jason Menard, "Final Report of the 1997 Carp River Forge Project" (master's thesis, Michigan Technological Univ., 1998); Timothy A. Tumberg, "Industrial Archaeology of the Carp River Forge" (master's thesis, Michigan Technological Univ., 1997).
6. Philo Everett, "Recollections of the Early Exploration and Discovery of Iron Ore on Lake Superior," *Michigan Pioneer and Historical Society Historical Collections* 11 (1888): 161. For a full account of Everett's life, see Frank B. Stone, *Philo Marshall Everett: Father of Michigan's Iron Industry and Founder of the City of Marquette* (Baltimore: Gateway Press, 1997).
7. Boyum, *Saga of Iron Mining*, 6 (see n. 1).
8. Everett, "Recollections," 163 (see n. 6).
9. Thomas G. Friggens, *An Historical Survey of the Michigan Iron Industry* (Lansing: Michigan Department of State, Bureau of History, 1986), 20.
10. Michigan History Division, *Carp River Forge: A Report* (Lansing: Michigan History Division, Dept. of State, 1975), 8.
11. Ibid., 8.
12. Ibid., 9.
13. Ibid., 15.
14. *Lake Superior Journal*, 31 May 1855.
15. Peter White, "The Iron Region of Lake Superior," *Michigan Pioneer and Historical Collections* 2d. ed. (1907) VIII: 151.
16. Newitt, "Marquette Iron," 302 (see n. 3).
17. Several workers listed as "bloomers" in the Marquette census of 1850 show up in the account records of the Buckeye/Forest Forge.
18. Forest Iron Works Records, 1853–1865, manuscript in Baker Library collection, Harvard Univ.
19. Ibid.
20. It is difficult to gauge the experience of the workforce, but several of the bloomers apparently had previous work at the Marquette Forge (see n. 17), and ages and family names listed in the census suggest two are probably second-generation bloomers.
21. Michigan History Div., *Carp River Forge*, 20 (see n. 10).
22. *New York Daily Tribune*, 28 June 1855.
23. White, "Iron Region," 151 (see n. 15).
24. Everett, "Recollections," 168 (see n. 6).
25. Michigan History Div., *Carp River Forge*, 17 (see n. 10).
26. Friggens, *Michigan Iron Industry*, 28 (see n. 9).
27. Robert B. Gordon and David J. Killick, "The Metallurgy of the American Bloomery Process," *Archaeomaterials* 6 (1992): 163.
28. William G. Mather, "Charcoal Iron Industry of the Upper Peninsula of Michigan," *Lake Superior Mining Institute Proceedings* 9 (1903): 66–67.
29. Forest Iron Works Records (see n. 18).
30. T. Egleston, "The American Bloomary Process for Making Iron Direct from the Ore," *Transactions of the American Institute of Mining Engineers* 8 (1880): 517.
31. Ibid., 517.
32. *Lake Superior Journal*, 25 June 1851; Gordon and Killick, "American Bloomery Process," 145 (see n. 27).
33. Thomas B. Brooks, *Geological Survey of Michigan: Upper Peninsula 1869–73. Vol. 1, Part 1, Iron Bearing Rocks (Economic)* (New York: Julius Bien, 1873).
34. *Lake Superior Journal*, 25 June 1851.
35. See for example, Frederick Overman, *Treatise on Metallurgy* (New York: D. Appleton and Co., 1852), 541.
36. Egleston, "Bloomary Process," plate b (see n. 30).
37. Gordon and Killick, "American Bloomery Process," 164 (see n. 27).
38. Many of the accounts of the early Marquette Range suggest 6 hours in the fire to make a bloom, but these accounts appear to draw only from each other. By contrast, Egleston, "Bloomary Process," 534 (see n. 30), documents 3 hours to make a bloom.
39. *Lake Superior News and Mining Journal*, 16 July 1849.
40. For examples of the value of slags for archaeometallurgical research, see David Killick and Robert B. Gordon, "Microstructures of Puddling Slags from Fontley, England, and Roxbury, Connecticut, USA," *Journal of the Historical Metallurgy Society* 21, 1 (1987): 28–36; Robert B. Gordon, "Material Evidence of Ironmaking Techniques," *IA: Journal of the Society for Industrial Archeology* 21, 2 (1995); and Robert B. Gordon, "Process Deduced from Ironmaking Wastes and Artefacts," *Journal of Archaeological Science* 24 (1997): 9–18; Henry Unglik, "Observations on the Structures and Formation of Microscopic Smithing Residues from Bixby Blacksmith Shop at Barre Four Corners, Massachusetts, 1824–55," *Journal of the Historical Metallurgy Society* 25, 2 (1991): 92–8; Henry Unglik, "Ironworking at an Early-19th-Century Blacksmith Shop, Fort St. Joseph, Ontario: An Examination of Slag and Iron," in John D. Light and Henry Unglik, *A Frontier Fur Trade Blacksmith Shop, 1796–1812* (Ottawa: Parks

Canada, 1987), 93–130; and John R. White, "Historic Blast Furnace Slags: Archaeological and Metallurgical Analysis," *Journal of the Historical Metallurgy Society* 14, 2 (1980): 55–64.
41. David Starley, "Hammerscale," *Historical Metallurgy Society: Archaeology Datasheet* 10 (1995).
42. The identification of the phases in the tap slag microstructure was done by Karl Peterson at Michigan Technological Univ.
43. Gordon and Killick, "American Bloomery Process," 147–54 (see n. 27); and Ross F. Allen et al., "An Archeological Survey of Bloomery Forges in the Adirondacks," *IA: Journal of the Society for Industrial Archeology* 16, 1 (1990): 8–11.
44. Ibid., Figure 5. Although this appears in a multiauthored piece, most of the slag characterization in this article on the Adirondacks appears to have been done by Gordon and Killick.
45. Gerry McDonnell, "Tap Slags and Hearth Bottoms, or How to Identify Slags," *Current Archaeology* 86 (1983): 81–3; and Peter Crew, "Bloomery Iron Smelting Slags and Other Residues," *Historical Metallurgy Society: Archaeological Datasheet* 5 (1995).
46. Early examples of American bloomery forges have been replicated, but not a 19th-century forge. David Harvey, "Reconstructing the American Bloomery Process," *Historic Trades* 1 (1988): 1–38.
47. Starley, "Hammerscale" (see n. 41).
48. Egleston, "Bloomary Process," 539 (see n. 30).
49. Michigan History Division, *Carp River Forge*, 30 (see n. 10).
50. Researchers found remnants of hammerbases at both the Saint-Maurice Ironworks and Valley Forge. Pierre Beaudet, "The Saint-Maurice Ironworks, Canada," *Journal of the Historical Metallurgy Society* 17,1 (1983): 41; and Helen Schenck, "The Upper Forge at Valley Forge," *IA: Journal of the Society for Industrial Archeology* 18, 1 & 2 (1992): 25–8.
51. White, "Iron Region," 151 (see n. 15).