

CHAPTER 7: SLAG ANALYSIS AND IRONMAKING

INTRODUCTION

Historical documentation shows that there were at least two forges that once operated at Middleford Mills. While the precise location of the forges is not known, there are two known slag piles that may correspond to the original locations. Slag is a by-product of iron production and includes silicon, phosphorus, sulfur, aluminum, ash, and unrefined ore. Samples of slag were taken from one of these piles, as well as from iron ore and slag found scattered in the vicinity of Bridge 238, to determine whether these artifacts have any research potential related to the history of iron making in Middleford.

HISTORY OF IRONMAKING

Two main types of forges, bloomery forges and blast furnaces, produced iron in Colonial America. A bloomery forge, such as the one present at Middleford, was named after the initial product of the forge, an approximately 100-pound bar called a bloom (Rolando 1992:17). Bloomery smelting reduces iron ore “directly to solid metal with charcoal to make wrought iron” (Gordon and Killick 1993:244). A bloomery forge at Middleford would have used bog ore, or limonite, to produce wrought iron. This was fashioned with relatively little effort into horseshoes, wheel rims, or plows, or drawn into rods to make nails. Burning charcoal produces carbon monoxide, which reduces iron ore to metallic iron at temperatures as low as 800° C. The melting point of slag is about 1,200° C. This was therefore the lowest temperature at which a bloomery forge could operate, well below that of a blast furnace. A blast furnace, named for the large blast of air that was needed to maintain high temperatures within the furnace stack, produced cast iron, or pig iron, containing large amounts of carbon. An advantage of a bloomery forge was that at its comparatively low temperature, most of the impurities in the ore stayed in the slag, producing a very pure iron (Gordon and Killick 1993:246).

The bloomery forge process of iron production was a very inefficient one in the sense that much usable iron remained in the slag; however, the process remained popular because it required a much smaller initial investment of money and labor than a blast furnace (Rolando 1992:20). The average furnace required 4 tons of ore and 300 bushels of charcoal to produce a single ton of iron, which required furnace companies to purchase thousands of acres of land just for wood fuel (Rolando 1992:20). A bloomery forge consumed less fuel and required less time to achieve the desired temperature compared to the large blast furnace, which took days to slowly bring up to operating temperature. While the blast furnace had to remain in continual operation both day-and-night for months, the bloomery cycle ended with the removal of the bloom from the hearth. This meant that a bloomery forge could respond easily to fluctuations in the supply of ore and fuel, as well as the demands of the market. Since the domestic needs of blacksmiths forging horseshoes and door hinges could be better met by the direct ore-reduction process of the bloomery, these small ironworks across the Delmarva region became more significant contributors to the market needs of colonial Delaware than did the blast furnace.

Many people viewed American iron as a convenient alternative to Swedish or Russian iron, while others considered it an inferior product at least for making steel, but nevertheless a source of potential competition with the British iron industry (Mulholland 1981:106). The Iron

Act of 1750 allowed for the export of pig and bar iron from the colonies but did not allow the colonies to construct rolling mills, plating forges, or steel furnaces. Bar iron exports from America rose only slightly just after the Iron Act and exports from the Chesapeake Bay region remained stable at 2,500 tons per year (Mulholland 1981:107). Exports from the New York and Pennsylvania regions increased from 200 to 1,000 tons per annum as a result of the building of new furnaces. By the mid-18th century, colonial industries were utilizing the expanding domestic market by producing utensils, tools, and implements. By 1775, the colonies had built more than 80 furnaces, and possessed at least 175 forges, exceeding the number of similar facilities in England and Wales (Mulholland 1981:108, 116). With exports sufficient to rank the colonial iron industry third in the world, behind only Russia and Sweden, the American colonies, with a much smaller population, were out producing both England and Wales.

PIXE ANALYSIS

Parsons conducted a pilot chemical analysis several samples of slag in order to explore the information potential of this type of artifact. Parsons sent (13) samples to Charles Swann of the University of Delaware for PIXE analysis. Particle induced x-ray emission (PIXE) is an elemental analysis technique that was developed by Sven Johansson, a nuclear physicist at the Lund Institute of Technology in Sweden, in 1970. In this technique, a sample is irradiated with a proton beam produced from pure hydrogen by a linear accelerator. The protons interact with the electrons in the inner shells of the sample atoms, which creates inner shell vacancies. X-rays, with energies that are unique to the individual elements of the periodic table, are emitted when electrons from the outer shells refill the vacancies. The number of these specific x-rays emitted is proportional to the relative amount of that element within the sample. Therefore, an element-specific analysis of a sample is provided through the PIXE technique. With Trace element detection, sensitivity can reach a few parts per million. In addition to its applications in fields such as nuclear physics, biomedicine, and atmospheric science, the PIXE technique now is being used in archaeological studies to characterize artifact materials, including metals, ceramics, lithics, and bone. The PIXE analysis technique offers advantages over other material characterization techniques, most notably its non-destructive nature, high sensitivity, and multi-element capability (Materials Research Science and Engineering Center 2001; Johansson et al. 1995).

Table 7 provides an overview of the PIXE analysis results. Detailed results are provided in Appendix B.

Sample No./ Bag No.	Artifact No.	Test	Stratum	Material	Function	Notes
42	1	STP J-4	D	Furnace Byproduct		
43	4	Unit 1	A	Slag		
44	2	Unit 1	B	Slag		
51	3	Unit 4	B-2	Bog Iron		
54	1		Surface	Furnace Byproduct		From mill race north of Bridge 238, prob. tap slag (with sand and pebbles)

Sample No./ Bag No.	Artifact No.	Test	Stratum	Material	Function	Notes
						adhered)
55	1		Surface	Slag		From vicinity of Point H in Figure 38
57	1	Feature 2		Ferrous alloy	Cut nail	From east side of construction
58	2	Feature 4		Ferrous alloy	Cut nail	From east side of feature
59	3	Feature 8		Ferrous alloy	Cut nail	From east side of construction
62	5	Feature 24		Slag		From fill
63	4	Feature 24		Slag		From west side
64	1	Feature 24		Charcoal		Charcoal/clinker/slag

- 1) Sample 42 was initially thought to be bog iron, and Sample 54 was thought to be slag. However, these are not slags but rather products of the interaction of hot slag with the bottom (earth) of the bloomery furnace.
- 2) Samples 51 and 63 are slags on one surface and the byproduct of hot slag interacting with the bottom of the bloomery furnace.
- 3) Samples 43, 44, 55 and 62 are all slags but may not be from the same bloomery or perhaps the same bloomery but at a different time.
- 4) Sample 64 is charcoal and likely the type of fuel used in the bloomery.
- 5) Samples 57, 58 and 59 are cut nails that have been cut from a sheet of iron from which the slag has been forced out and the carbon reduced by firing.

The results of the study appear to confirm the identification of the Middleford forge as a bloomery forge. The operators likely would have used bog iron as their source of ore (available locally) along with limestone as a flux, and charcoal as the fuel (Swann personal communication Feb. 13, 2002). Because the compositions of the slag samples were found not to be uniform, the results suggest that chemical analysis of the iron samples and slag has the potential to illuminate the techniques used in manufacture, and to distinguish between material from the different forges. To carry the study further, a source of possible bog ore and the limestone used would be needed.

