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ANALYSES AND EVALUATION OF THE RAW MATERIALS USED IN THE EATON (HOPEWELL) FURNACE[1]

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ABSTRACT. Analyses of samples of the raw materials locally available for use in the Eaton (Hopewell) Furnace indicate that the iron ore and bituminous coal were of good smelting quality while the limestone (flux) was not. The limestone had a much higher then desirable silica content and a low calcium content. The limestone was insufficient to the task of removing impurities introduced through the fuel combination of charcoal and raw coal and contributed to the early demise of the furnace operation only 6 years after its start.

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INTRODUCTION

During the summers of 1975, 1976 and 1977 archaeological excavations were carried out at the Eaton (Hopewell) Furnace site near Youngstown, Ohio (White 1980). Erected in 1802 against the steep gorgeside of Yellow Creek, the Eaton (originally spelled Heaton) was blown-in in 1803 and lasted until about 1808. After a failure of the inwall lining and the subsequent spillage of the entire cast onto the casting floor as a large multi-lobed salamander, the furnace owners decided not to repair and relight.

Until the archaeological work was undertaken there was very little known about this modest smelting operation. According to historical information, it was the earliest blast furnace west of the Allegheny Mountains and the earliest industry of any kind in the Western Reserve. Outside of this observation, little else was known about the day-by-day operation of the furnace itself, its efficiency (or lack thereof), the production economics, or the quality of the raw materials employed. These were some of the reasons why the

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archaeological work and subsequent chemical and metallurgical analyses were carried out.

The archaeological field work itself lasted approximately 20 weeks and led to the recovery of thousands of artifacts and units of data as well as several significant structural features. Among the more ubiquitous remains, along with slag, were numerous fragments of iron ore and coal. While we fully expected to find ore in abundance, especially in the tipple or charging zone on the slope above and behind the furnace, the finding of such large amounts of coal came as a surprise and, when substantiated by the chemical and metallurgical findings, led to the inescapable conclusion that the Eaton Furnace was using coal in combination with charcoal as a fuel. The use of this fuel combination is the earliest known in the New World (White 1978) and occurred more than 30 years earlier than at the Pioneer Furnace (1839) in Pottsville, Pennsylvania, the site previously credited as being the first (Warren 1973, Hogan 1971).

Analyses of the furnace raw materials, products and by-products provided valuable insights into the Eaton smelting process and indicated the level of operation efficiency. This report deals with the lithic raw materials iron ore, coal and limestone and discusses their specific role in the successes and failures at the furnace.

METHODS AND MATERIALS

Through its operation, the Eaton Furnace utilized a reniform or kidney ore, a concretionary ore consisting of masses of impure carbonate of iron in a discoidal or ellipsoidal form and invariably bounded by curved surfaces. (The renal shape and deep red-brown color is responsible for its name.) As with other kidney ores, the Eaton materical was generally composed of concentric layers or shells made distinct by exfoliation and weathering. Quite close-grained and heavy, the specimens observed at the site ranged in size from 2.5 cm to more than 45 cm in length. In the Yellow Creek gorge where the furnace was located, the ore is found abundantly weathered as float material and in beds of shale where they are often in close conjunction with the coal measure strata. The 6 ore samples, along with 8 pieces of coal and 4 specimens of limestone, were taken from various stratigraphic levels and areas of the site and tested by a combination of spectrochemical and wet chemical procedures.

RESULTS

The Fe_2O_3 content of the ores varied between 44.0% and 58.6%, with an average of 51.3%; the Fe by itself ranged between 34.1% and 46.7%, with a mean of 39.8%. The SiO_2 content, the principle gangue material, varied between 5.1% and

TABLE 1
Analysis of Eaton iron ores, %*

Constituents	Specimen Number						Mean
	1	2	3	4	5	6	
Fe_2O_3	53.2**	57.8	46.5	44.0	58.6	47.9	51.3
SiO_2	5.1	6.9	15.9	11.7	6.8	17.0	10.6
Al_2O_3	2.5	1.6	3.3	3.8	2.7	5.2	3.2
CaO	1.7	0.5	2.0	2.3	1.0	1.4	1.5
MgO	1.0	0.3	3.5	2.2	0.9	2.0	1.7
MnO	2.0	1.6	1.2	1.4	5.0	1.2	2.1
Cr_2O_3	0.1	0.1	0.1	0.1	0.2	0.4	0.2
TiO_2	0.2	0.2	0.3	0.2	0.1	0.1	0.2
Na_2O	0.1	0.1	0.2	0.1	.35	.60	0.2
Loss on Ignition	32.5	29.5	28.0	29.1	25.4	25.0	28.3
Fe	41.4	44.9	36.0	34.1	46.7	35.6	39.8

*By Frank Galletta, Research and Development Laboratory, Youngstown Sheet and Tube Company.
**Rounded to nearest tenth. Figures are percentages by weight.

17.0% with an average of 10.6%. Loss on ignition ranged between 25.0% and 32.5%, the mean being 28.3%. Full constituent percentages are shown in table 1.

An analysis of the 8 coal specimens taken from the site indicates a high quality bituminous coal of the Block variety; typical of other Mahoning Valley coals, it is relatively low in ash and sulfur content.

Proximate analysis of the Eaton Coal specimens yielded the results shown in table 2. The ash content varied between 1.66% and 4.06%, with a mean of 2.88%. Volatile matter, including moisture, lost on burning ranged between 36.0% and 39.28%, averaging 37.43%. Fixed carbon varied between 57.25% and 60.91%, with a mean of 59.05%. A low sulfur coal, the specimens contained between 0.52% and 0.79%, with a mean of 0.64%.

Premium blast furnace fluxes are usually selected for a low silica–high calcium (lime) ratio (McGannon 1964). The mean silica content for 4 Eaton specimens was 33.8% (the high was 35.2%). For the calcium, the mean was 27.5%.

DISCUSSION

The Eaton ironmakers utilized a high quality reniform iron ore with an average of 39.8% iron (Fe). This high iron–low silica ore compared favorably with contemporary ores in use and, in fact, would be good by today's standards. It was gathered locally as float material or from beds of shale.

As a point of comparison, records show that in 1883 the iron ore used at the Pennsylvania Hopewell, the Berks County furnace thought to be the namesake of the Eaton, contained an average of 37.85% metallic iron (Walker 1966). An analysis of kidney ores utilized by furnaces in the mid-19th century and coming from the Mahoning Valley district (in which the Eaton is located) averaged 45.0% (Lord 1884a).

As compared to coals from nearby deposits analyzed in 1884 by Professor N. W. Lord, chemist of the Ohio Geological Survey (table 3), the Eaton coals were not atypical. They were high quality coals with a low ash and sulfur content; they had on the average less ash than all but 4 of those analyzed by Lord and less sulfur than any. However, the low temperatures maintained by the furnace and the poor desulfurizing capacity of the slag were not sufficient to allow its successful use even with these fine properties.

Unfortunately, "high quality" is a relative condition — what might constitute high quality in the furnaces of the late 19th century and today might not have been sufficient for the technologically primitive blast furnace of the early 1800s. The Eaton slags analyzed (White 1977) in-

TABLE 2
Proximate analysis of Eaton coals, %*

Constituents	Specimen No.								Mean
	1	2	3	4	5	6	7	8	
Volatile Matter**	36.0†	37.0	38.70	36.1	38.2	39.3	38.0	36.2	37.4
Fixed Carbon	59.8	60.7	57.3	60.9	58.6	58.4	57.4	59.5	59.1
Ash	3.5	1.7	3.4	2.4	2.5	1.8	4.1	3.7	2.9
Sulfur	0.8	0.7	0.6	0.6	0.7	0.6	0.5	0.7	0.6

*By Frank Galletta and Robert Pristera, Research and Development Laboratory, Youngstown Sheet and Tube Company.
**Includes water.
†Figures, rounded to nearest tenth, are percentages by weight.

TABLE 3
*Early analysis of 19th century coals from Columbiana and Trumbull Counties, Ohio**, %*

Specimen/Locality	Moisture (H_2O)	Volatile Matter (gas)	Fixed Carbon	Ash	Sulfur
Church Hill Slope, Liberty Township	5.9**	35.0	55.7	3.4	0.8
Cleveland Shaft, Brookfield Township	4.6	38.4	50.4	6.6	2.0
Chew Bank, Brookfield Township	4.4	36.2	49.8	9.7	3.1
High Tone Shaft, Liberty Township	4.7	35.8	48.6	6.9	1.0
California Slope, Hubbard Township	5.8	36.7	54.9	2.6	0.7
Anderson Bank, Salineville	3.3	37.5	53.7	5.5	1.2
Hussey Bank, Salineville	2.3	39.1	52.8	5.8	2.9
State Line Mine, East Palestine	2.1	39.4	53.5	5.1	2.9
Leetonia Bank, Leetonia	3.6	37.9	56.1	2.4	0.8
Washingtonville Bank, Washingtonville	4.4	35.5	57.9	2.2	0.7
Brier Hill, Liberty Township	5.4	36.9	56.0	1.8	0.7

*By N. W. Lord, Chemist of the Ohio Geological Survey in 1884.
**Rounded to nearest tenth. Figures are percentages by weight.

dicate that the furnace operated at the minimum temperatures necessary to smelt iron i.e., between 1176 C and 1232 C. Fortunately the slags were of a low refractory nature, thereby allowing production at such a "cool" temperature. However, while such a primitive furnace with bottomline temperatures might operate effectively using charcoal as the sole fuel, the addition of bituminous coal went too far. Of "high quality" or not, the technologically primitive Eaton could not handle the charge mixture. The additional sulfur input, though in small proportion for coal, was yet too much for the poor desulfurizing Eaton slag. Cast iron was produced with a sulfur content between 0.055% and 0.22% and a mean of 0.086% (White 1978). Ultimately the furnace became choked with the tarry residue that resulted from the heating but incomplete combustion of the bituminous coal.

The fluxing agent used at the Eaton Furnace was a very poor quality native limestone having a much higher than desirable silica content (33.8%) and low lime content (27.5%). Premium blast furnace limestones are selected for the opposite proportions, i.e., high lime—low silica. Use of a limestone of this poor quality resulted in creation of a poor desulfurizing slag and undoubtedly created problems for the Eaton ironmakers.

Two important requirements of the slag in ironmaking are to have an effective desulfurizing capacity and a low viscosity. Desulfurizing capacity increases in the order $SiO_2 < Al_2O_3 < MgO < CaO$. The optimum compositional ratio for desulfurization will have a low SiO_2-Al_2O_3 content and a high CaO—MgO content (White 1977). Fortunately, low viscosity is met by the same set of circumstances that provide a high sulfur-removing capacity. To a point, the viscosity decreases with the increased ratio of lime and periclase to silica and alumina. Unfortunately, the Eaton flux had a reverse, or unsatisfactory proportion of calcium to silica. The Eaton operators, producing cast iron in a furnace only marginally efficient in other ways, were not helped in their endeavors by their choice of a readily available but poor quality fluxing limestone.

The Eaton furnace was successful for the first few years of its operation because it used high grade ore and charcoal, both of which were initially in abundance locally. The poor choice of local limestone was of no real detriment as the purity of the charcoal left little for it to do, particularly in its desulfurizing capacity. When timber supplies ran short and local deposits of bituminous coal were utilized in combinatory manner with the charcoal as a furnace fuel, the technologically primitive furnace (low temperature) and poor desulfurizing slag (due to the use of the low quality limestone) failed to maintain the necessary levels, and the earliest furnace west of the Alleghenies went out of blast.

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