GEOLOGY AND HISTORY OF IRONMAKING IN WESTERN PENNSYLVANA

Mt. Vernon Furnace, Bullskin Township, Fayette County, Pennsylvania

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Introduction

The geology of western Pennsylvania played a major role in the establishment of the iron industry in the late 1700's and 1800's when numerous furnaces were built and operated (Figure 1). Iron provided many of the basic needs associated with the rapid expansion westward into the interior of the country, including a myriad of items such as nails, horseshoes, plow shares, pots, axes, and tools of all description. This market demand was met by small stone blast furnaces that utilized the abundant supply of local raw materials – iron ore, coal, limestone, fireclay, and sandstone. The extensive forests provided wood for the production of charcoal that was the initial source of fuel necessary for the smelting operation. Later, the furnaces were fueled by coke, which is derived from coal. The region's innumerable streams provided a source of power, with the rivers used to transport products to industrial centers such as Pittsburgh for further processing and distribution.

Geology and Paleoclimate

Iron ore, limestone, fireclay, sandstone, and coal are the raw materials or key ingredients needed for ironmaking. In western Pennsylvania, these raw materials formed during the Mississippian and Pennsylvanian Periods.

The Mississippian and Pennsylvanian Periods lasted approximately sixty million years, from 359 to 299 million years ago. Both the climate and landscape of western Pennsylvania were much different than what is seen today. The Appalachian Mountains were forming along the east coast of what is now North America due to collision of the African and North American continental plates. In what is now western Pennsylvania, river systems, coal swamps, lakes, and inland seas shifted back and forth across a broad coastal plain as global sea levels changed. These sea level fluctuations were due to the advance and retreat of glaciers in the Earth's polar regions. This was the result of Earth's climate repeatedly changing from cool to warm and back to cool.

When the global climates warmed, polar ice caps melted, adding large volumes of water to the oceans. This caused the oceans to submerge the continents, forming vast shallow seas. Lime muds deposited in these seas became marine limestones such as the Vanport Limestone

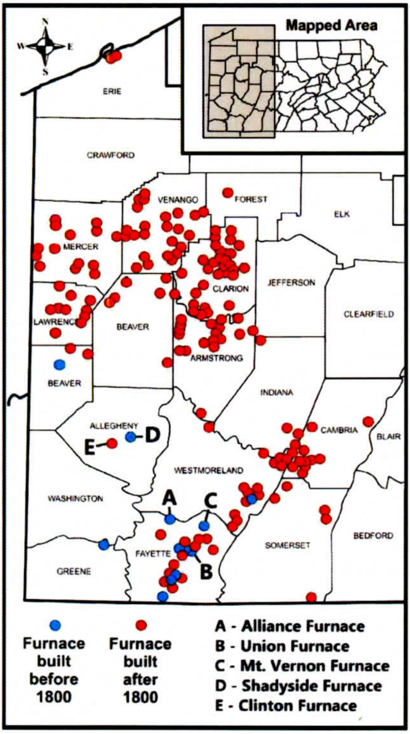
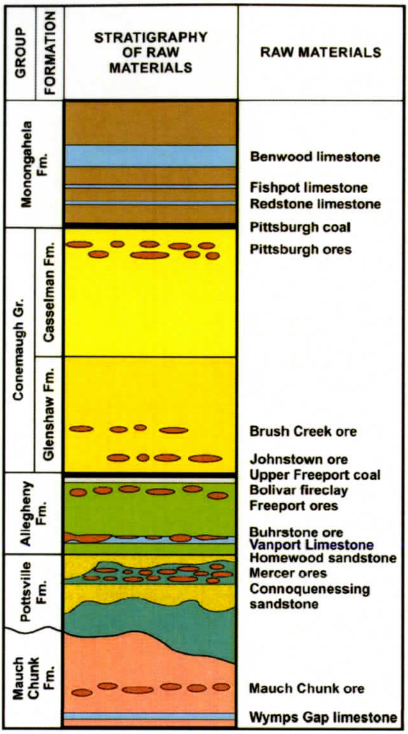


Figure 1. Map of western Pennsylvania showing locations of historic iron furnaces built before 1860.

Figure 2. Generalized stratigraphic column for western Pennsylvania, showing iron ores, limestones, sandstones, coals, and fireclays discussed in text.



of the Allegheny Formation (Figure 2). This formation was an important source of both flux and ore for the iron industry in northwestern Pennsylvania. At the margins of the shallow seas, tropical coastal swamps produced abundant peat that formed layers of coal such as the Pittsburgh coal (Figure 2). Non-marine limestone that formed in lakes, such as the Benwood limestone of the Monongahela Formation (Fig-ure 2), was another source of flux for the furnaces. Refractory fireclays and iron ores formed during the prolonged periods of intense rainfall and leaching typical of wet interglacial stages. The Bolivar fireclay in the Allegheny Formation (Figure 2), a premium refractory clay, is an intensely weathered and leached paleosol (fossil soil) containing high levels of alumina.

During periods when the Earth's climate cooled, the polar glaciers expanded. Because so much water was tied up in glacial ice, global sea level fell, and vast areas of the continents were exposed to erosion. It was at these times that large volumes of sand carried by rivers across the coastal plain formed sandstones such as the Homewood sandstone of the Pottsville Formation (Figure 2). These sandstones would become useful in the construction of stone blast furnaces and associated structures.

Western Pennsylvania's Early Iron Industry

Western Pennsylvania's iron industry began in Fayette County in the 1780's and 1790's and expanded along Chestnut Ridge into Westmoreland County. In the 1830's and 1840's, the industry became concentrated mostly in northwestern Pennsylvania. Over 180 stone blast furnaces were constructed in western Pennsylvania prior to 1860, 11 of them in the late 1700's (Figure 1).

The first iron furnace in western Pennsylvania was the Alliance Furnace built in 1789 near Perryopolis, Fayette County (Figure 1A). Other early furnaces in Fayette County included the Union Furnace in Dunbar, 1791 (Figure 1B) and the Mount Vernon Furnace in Bullskin Township, 1798 (Figure 1C and front cover). The latter furnace, listed on the National Register of Historic Places, has been restored. Most of these early furnaces were located on the west side of the Chestnut Ridge anticline close to deposits of iron ore. One exception, the Shadyside Furnace in Pittsburgh's East End (Figure 1D), built in 1793, operated for only one year. It was abandoned because of a lack of local ore. After 1830, the majority of new furnaces was concentrated in Armstrong, Clarion, and Venango counties as other local iron ore deposits were exploited.

The age of the western Pennsylvania stone blast furnaces ended in the 1860's with the development and use of coke as a replacement fuel for charcoal, coupled with the importation of higher grade Precambrian (2.5 to 2.7 billion years old) iron ores from the Lake Superior region.

Early Iron Furnaces and Iron Manufacturing

Figure 3 illustrates a typical stone blast furnace, such as those built in the late 1700's and early 1800's. It consisted of a stack that resembled a hollow, truncated pyramid approximately 30 feet high. It was usually constructed of local sandstone blocks and lined with refractory fireclay bricks or blocks to protect the furnace walls. The furnace was continually charged from the top with charcoal, iron ore, and limestone. While the charge materials descended towards the bottom of the furnace, a hot reducing gas (carbon monoxide), generated by the combustion of charcoal with air, transformed the iron ore into liquid iron at temperatures on the order of 1,500 to 2,500° F. The air, provided by water-powered bellows, was blown into the furnace through tuyeres (blowpipes) located at the bottom of the furnace. The water that powered the bellows typically came from nearby ponds or dammed streams, and flowed through a sluice to the water wheel (Figure 3), then back to the stream. The limestone acted as a flux to remove impurities from the ore, forming a liquid slag. Every six hours or so, the furnace was tapped by opening a refractory-sealed hole in the hearth area. Liquid iron flowed into parallel rows of depressions in the casthouse floor that, when solidified, resembled piglets attached to a sow – hence the name "pig iron". Solid pig iron was processed into bars by successive reheating and forging to produce stock for making nails, wheel rims, tools, etc. Alternatively, liquid iron was removed in ladles and cast in molds into articles such as pots and stoves (cast iron products).

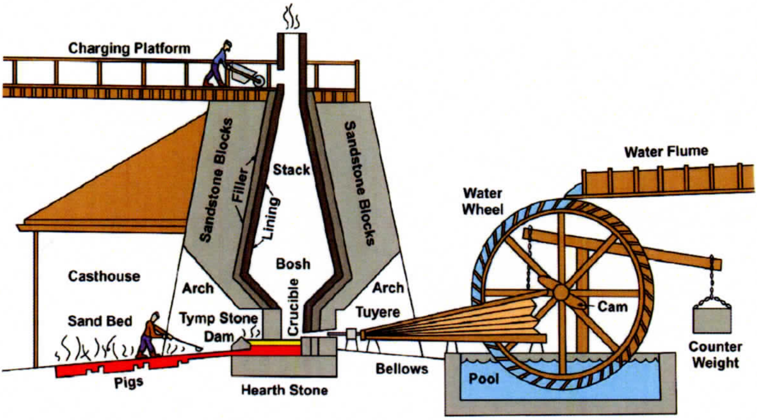


Figure 3. Schematic diagram and terminology of a typical charcoal iron furnace. Red—molten iron. Yellow—slag.

The Raw Materials

Charcoal-based furnaces in the early 1800's produced around two tons of iron per day. Each ton required a total charge of approximately three tons of iron ore, two tons of limestone, and two tons of charcoal.

The readily available iron ores in western Pennsylvania were primarily siderites (iron carbonate – $FeCO_3$). The principal ores used in the Fayette and Westmoreland furnaces included the Mercer ores from the Pottsville Formation and Johnstown ores from the Glenshaw Formation (Figure 2). These are exposed along the western slope of the eroded Chestnut Ridge anticline (Figure 4A). The Pittsburgh ore from the Casselman Formation also was used by some furnaces in Fayette County. Wharton Furnace on the southeast slope of Chestnut Ridge used Mississippian Mauch Chunk ore (Figure 2). Furnaces in northwestern Pennsylvania counties primarily used the Buhrstone and Freeport sideritic ores from the Allegheny Formation (Figure 2). These are exposed in stream valleys carved into the otherwise flat-lying rocks of western Pennsylvania (Figure 4B). The iron content of all these ores varies from 30 to 40%. It was only when the Lake Superior hematite ores, containing in excess of 50% iron, became readily available through rail and water transportation that the iron-making industry shifted to the Pittsburgh area. The Clinton Furnace (Figure 1E), constructed on the south shore of the Monongahela River between the present-day Fort Pitt Bridge and Station Square complex, was the first of these, with operations beginning in 1859.

Limestone, the material used for flux, occurs extensively throughout western Pennsylvania as both marine and non-marine limestones. Deposits close to the furnace operations along Chestnut Ridge include

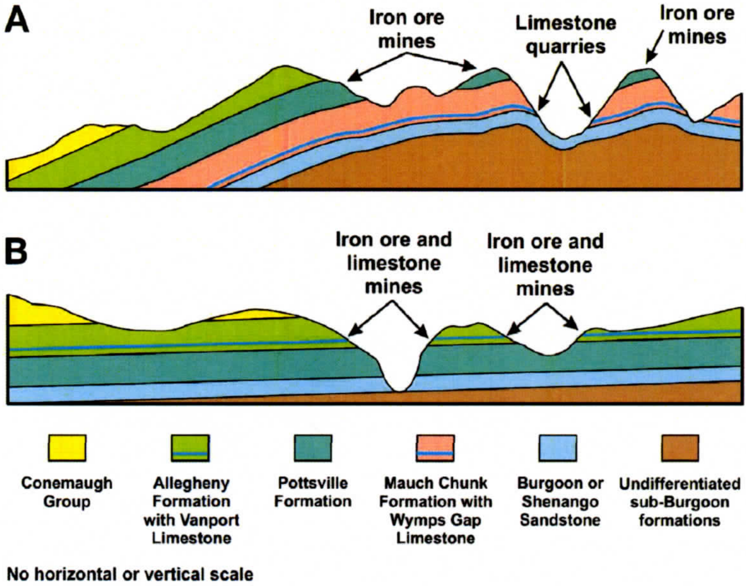


Figure 4. Cross sections of western Pennsylvania showing effect of geologic structure and topography on locations of raw material deposits. A – along Chestnut Ridge. B – northwestern Pennsylvania.

the freshwater Redstone, Fishpot, and Benwood limestones of the Monongahela Formation, and the marine Wymps Gap Limestone of the Mauch Chunk Formation (Figure 2). The primary source of limestone for northwestern Pennsylvania furnaces was the marine Vanport Limestone of the Allegheny Formation (Figure 2).

Iron production spawned major support industries, such as the coke and refractory industries, which also utilized the coal and fireclay resources of the region. Coke made from coal eventually replaced charcoal as the fuel in the furnaces, and refractories made from fireclay provided protective linings for furnaces and coke ovens exposed to destructively high temperatures (often in excess of 2,000° F).

Prior to 1840, 100% of the iron produced in western Pennsylvania was made using charcoal as a fuel, which in turn required vast quantities of wood. In the 1840's, an annual statewide iron production level of 100,000 tons consumed approximately 30,000 acres of forest. After 1840, alternative fuels such as anthracite and coke were introduced that gradually reduced the need for charcoal. In the 1800's, coke was produced primarily in beehive ovens by heating bituminous coal at high temperatures (1,650 - 2,000° F) to drive off volatiles, leaving a fused-carbon structure. Because of the local availability of immense amounts of premium coal for coke-making from the Pittsburgh coal seam (Figure 2), the Connellsville area of Fayette County became the center for coke production in Pennsylvania. There were only 26 beehive ovens in operation in the area in 1855, but that number increased rapidly to 3,000 in 1873, and 20,000 in 1900 when more than 10 million tons of coke were produced from nearly 15 million tons of Pittsburgh coal. (A replica of a beehive coke oven is on display in Dunbar, Fayette County.)

The refractory industry, whose roots also began in western Pennsylvania, is sometimes referred to as "the hidden industry" because it played a major, unrealized role in the growth of the coke, iron, and steel industries. The predominant raw materials for refractory brick are fireclay, sandstone, and ganister (orthoquartzite, a high-silica sandstone). Fireclay (aluminum silicate – $Al_2O_3.2SiO_2$), is widely distributed throughout western Pennsylvania, usually in association with coal beds, where it developed from the soils that supported the coal-forming plants. The Bolivar fireclay, for example, is a premium fireclay that occurs a few feet below the Upper Freeport coal seam in the Allegheny Formation (Figure 2). Fireclay products, in addition to lining blast furnaces, are used extensively in coke ovens. Siliceous refractories from sandstone containing 90 to 96% SiO_2 have been produced from the Homewood and Connoquenessing sandstones of the Pottsville Formation (Figure 2). Ganisters containing more than 98% SiO_2 occur in the mountain ridges of central Pennsylvania. Silica bricks are used in the higher temperature parts of a coke oven. The magnitude of the demand for refractory products and, consequently, for raw materials such as fireclay and sandstone, is illustrated by the consumption in the coke industry. Close to 5,000 refractory bricks were used in the initial construction and rebuild of a single beehive oven. Thus, the 20,000 ovens in operation in 1900 required more than 100 million refractory bricks. More recently, in 1996, 80,000 tons of brick were needed for the construction of a new 268-oven facility. Additionally, in 2012, 2.4 million bricks were laid in the construction of U.S. Steel's new 84-oven coke battery at the Clairton plant near Pittsburgh.