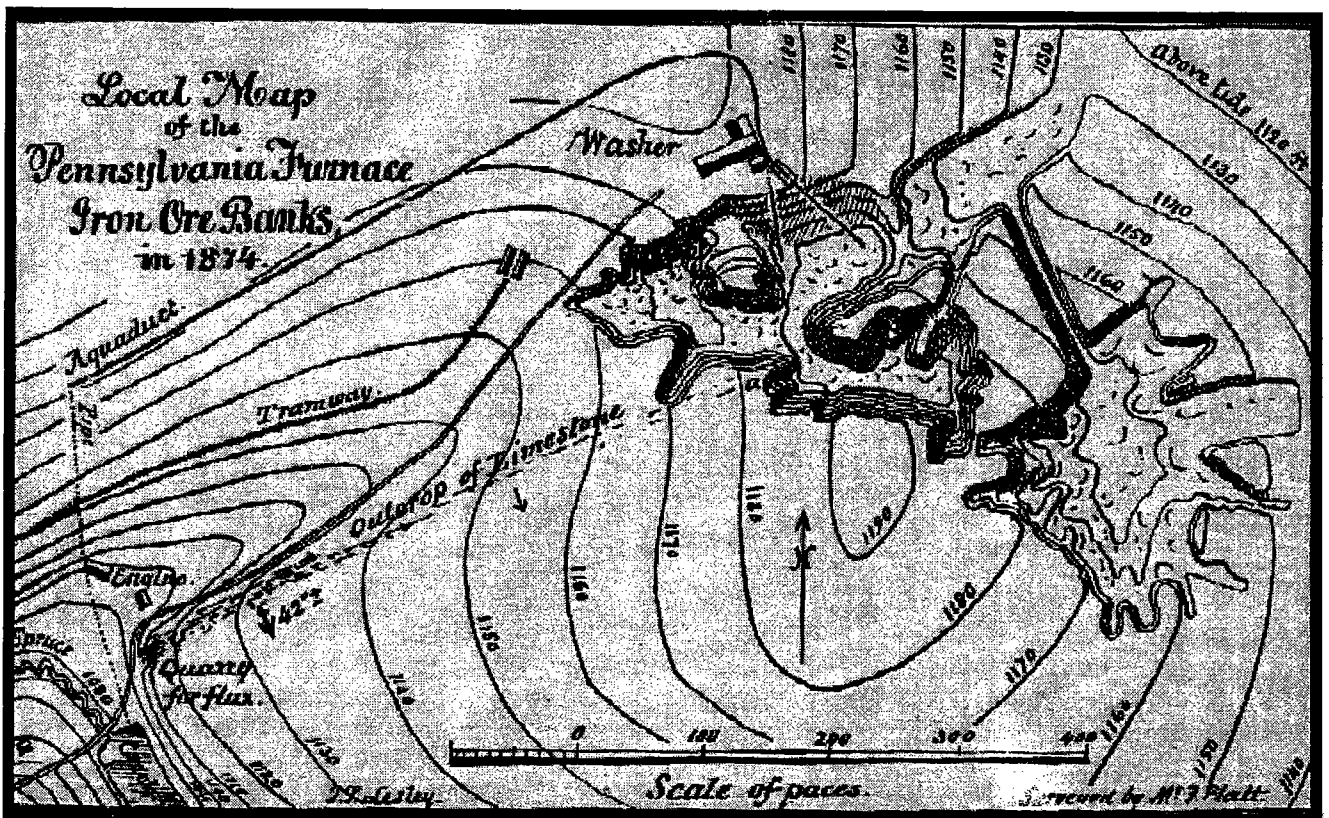

Geology and History of Iron Production in Centre County, PA

Guidebook for the V. M. Goldschmidt Conference
An International Conference for the Advancement of Geochemistry



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The Pennsylvania State University

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FOR MORE INFORMATION

Chapter 2 contains excerpts from a 100 page booklet, *The Iron Industry in Pennsylvania*, by Gerald G. Eggert, published by the Pennsylvania Historical Association. It and additional copies of this guidebook may be ordered from:

Roland Curtin Foundation
Curtin Village
Milesburg, PA 16853

Cost of *The Iron Industry in Pennsylvania* is \$8.43; cost of this guidebook is \$10.00. Please make checks out to Roland Curtin Foundation.

Cover

J. P. Lesley etching from Lesley (1874)

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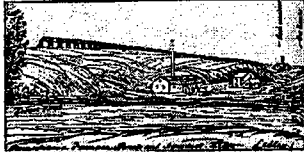
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INTRODUCTION



Rudy Slingerland

In the 17 years following the American Revolution (1784-1800), the fledging United States experienced an explosive growth in the nation's iron industry, and the state of Pennsylvania led the way. Eighty-three new iron works were established here, with nearly a third of the growth in central Pennsylvania between the Susquehanna Valley and the Allegheny mountains (Eggert, 1994). Of these the majority were in the "Juniata Region," which included present day Centre County, site of State College, as well as Huntington and Blair Counties. By the 1850's, Pennsylvania was producing more than half of the US total output of iron, and the Juniata Region constituted the largest iron-producing area in the United States.

That the nation's iron production would be centered in such an inaccessible region was due almost entirely to the mutual availability of ore, charcoal, limestone, and water power. Although much richer ores were discovered in Michigan in 1844, their greater distance and the scarcity of local carbonates delayed their exploitation until the later half of the nineteenth century.

The ores in the Juniata Region consisted of two types, limonite or "brown ore" and hematite. The limonite ores which are the focus of this field trip, formed on Cambro-Ordovician carbonates, presumably from supergene enrichment. The hematite ores on the other hand, were primary sedimentary deposits consisting of thin beds of ferruginous bioskeletal limestone and sandstone, in places oolitic. The iron occurred as hematite or chamosite coatings on grains and shell fragments. Typical analyses for both ores ran 20 to 50% ferric oxide. Charcoal was readily available in

the form of dense hardwood forests, and limestones in many cases could be quarried in the same pit as the ore. Water power was provided by the numerous streams draining the ridges.

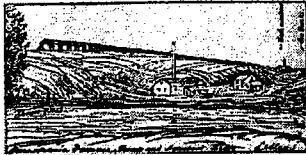
Because the reign of Juniata iron was short-lived, and the genesis of the ores so poorly studied, many questions remain regarding this historically important iron range. Numerous studies describe the economic and social characteristics of the furnace plantations (cf. Eggert, 1994; Williams, 1992; Sternagle, 1986), but very little has been written on the ores themselves. What is the protore? What is the original source of the iron? How did the iron become concentrated? What geological and paleoclimatological conditions favored ore development?

This half-day field trip is designed to address these questions as well as review the industry of 19th Century iron making. Literally hundreds of ore banks dot the countryside surrounding State College, but most are now little more than sodded depressions. We will visit two, Pennington bank and Pennsylvania Furnace bank, in which the protore is exposed and float ore can be picked off tailings piles. Lastly we will visit Curtain Village, an iron plantation with a restored furnace and forge.

ACKNOWLEDGMENTS

We thank the State College Water Authority and the Pennington Hunt Club who gave us permission to visit abandoned mines on their properties. Mary Barnes acted as intermediary with Curtin Village, a task for which we are grateful. Dr. Gerald Eggert kindly granted us permission to use excerpts from his book on iron production in Pennsylvania.

HISTORY OF PRODUCTION



Excerpts from *The Iron Industry in Pennsylvania*, by Gerald G. Eggert, 1994, *Pennsylvania Historical Studies* No. 25, The Pennsylvania Historical Association

INTRODUCTION

No State played a greater role in the industrialization of the nation than Pennsylvania which pioneered most of the nation's basic industries: iron, steel, timber, coal, oil, and railroads. This chapter sketches the history of the foremost of those early industries, iron manufacture, especially as it developed in the "Juniata Region" of Central Pennsylvania.

THE BASIC INGREDIENTS

Iron Ore

"Outcroppings of iron ore were widely distributed in Pennsylvania, the heaviest concentrations being in the southeast, southern, and central parts of the State. Four kinds of ore predominated: magnetite in the southeast as far north as Columbia County and as far west as Adams County; red hematite also in the southeast from Northampton County in the east to Huntingdon County in the west; brown hematite (60 percent iron and containing varying amounts of water) [*ed. note: by which here is meant limonite and goethite*] in both the southeastern and central portions of Pennsylvania; and carbonate (containing less than 50 percent iron and varying

quantities of water) in the eastern counties from Lackawanna and Lycoming in the north to Delaware, Chester, Lancaster, and York in the south.

“Most iron deposits were near the surface and pits or trenches for digging out ore rarely exceeded forty feet in depth. In effect, they were quarried rather than mined, and required little if any boring or blasting. During the colonial era three or four miners could keep a single furnace supplied with ore. Once loosened and broken up, the ore was hauled by horse-drawn carts to the furnace for smelting. Over the years efforts were made to remove as much waste from the ore before hauling it as possible. Workers, for example, would “flat” the diggings by rolling horse-drawn cast iron breakers over them to separate clay from the ore. In the 19th century it became common to wash clay, soil, and other wastings from the ore, sometimes by special machines, before transporting it to the furnace.

Limestone

“In addition to ore, iron smelting required the addition of crushed limestone to serve as a flux. As the temperature of the furnace increased, the impurities in the ore separated from the iron and united with the limestone to form a molten slag that could be drained off easily. Like the iron deposits, beds of limestone generally were near at hand and abundant in Pennsylvania. Also near the surface, they too could easily be quarried.

Fuel and Reducing Agent

“Prior to the 1820’s, both the furnaces where iron was smelted and forges where it was refined, required large quantities of charcoal for fuel. Maintaining a steady supply was not easy. Although forests were everywhere in the early years, “coaling” (making charcoal from wood) involved a great deal of hard work. It began with the simple unskilled task of cutting the wood. Inasmuch as a furnace each day consumed as much charcoal as could be produced from an acre of forest, large numbers of full and part-time workers chopped wood. As nearby forests were gradually cleared, the work had to be carried on at ever greater distances from the furnaces and the workers’ homes.

“Hard woods such as hickory, ash, oak, chestnut, beech, and walnut were preferred because they yielded high quality charcoal. Charcoal produced from hickory was best, but the supply of that wood was limited. Black oak was most commonly coaled because it was most plentiful. Although soft woods such as pine made poorer charcoal, they too were sometimes used. Most wood cutting occurred in late

BLOOMERY IRON

fall, winter, and early spring when farmers and farm laborers could help. As it was chopped, the wood was stacked in cords in the forests to dry for later use.

“The greater part of the actual coaling was done between May and the end of October by teams of workers, usually consisting of a pair of highly skilled colliers and several helpers. As many as six such teams might be required to supply a single average-sized furnace. The colliers first selected a dry, level place in the woods that was sheltered from the wind. After completely clearing all stones and vegetation from a circular spot between thirty and fifty feet in diameter, they constructed a six to eight foot high chimney of sticks in the center. Around this chimney the helpers carefully stacked the cut wood on end in layers, forming a cone about twenty-five feet in diameter at the bottom. They then covered the pile with a tight layer of sticks and wood-chips, a layer of leaves, and finally dry soil. This made the mound nearly air-tight except for a few small holes poked through the covering at intervals on the sides near the ground.

“The “burn” began when the chimney was filled with kindling and lighted by adding a shovelful of live coals from another fire. Once well underway, the flame was smothered by capping the chimney with a board and covering it with leaves and dry soil. With the supply of oxygen thus limited, wood in the mound only smoldered rather than burned. A constant watch was kept to prevent any flaming during the ten to fourteen days required to complete the process. The purpose was to drive all water and soluble minerals from the wood, leaving behind nearly pure carbon. Because the mound would shrink by about one-third during the burn, workers several times each day tramped it down to prevent the formation of gas pockets. When the collier judged the coaling at last finished, the fire was put out by cutting off all air. The mound then cooled for ten to twelve days before workers removed the outer covering. The still-warm charcoal was taken out and raked into small piles to reduce loss in the event that sparking or a breeze started a fire. Finally, when sufficiently cool, teamsters hauled the “coal” by wagon to the furnace site and stored it in charcoal sheds for future use.

BLOOMERY IRON

“The technologies used to separate iron from unwanted materials in the ore came chiefly from England. The English, in turn, had earlier borrowed these techniques from the continent. The simplest but least efficient of these produced “bloomery” iron. Blacksmiths or forgers, using their forge bellows, heated small chunks of ore in their fires. Although inadequate to melt the iron, the process did turn it into a

spongy, half-molten ball. Collecting these balls on the end of a long bar, the forgerman alternately reheated and hammered them into a small "bloom" of wrought iron. The process not only wasted both iron and charcoal, it required much labor and produced only small quantities of poor quality metal. Although early New England ironmasters commonly produced bloomery iron, their counterparts in Pennsylvania made relatively little iron in forges, by far preferring charcoal-fueled blast furnaces.

CHARCOAL-FUELED, COLD-BLAST IRON FURNACES

"From the early colonial period until the 1850s, charcoal furnaces produced nearly all of Pennsylvania's and the nation's iron. Until the late 1830s the basic technology in America underwent no significant change. Once an ironmaster decided to build a furnace, he first had to raise several thousand dollars of capital to finance the enterprise. Next he had to acquire a location suited to the technology. Transportation was difficult and costly and the quantities of raw materials that would be used were infinitely greater than the quantity of iron produced. It made sense, therefore, to locate the furnace as near the raw materials as possible and to haul the iron to market rather than to locate the furnace near a market and haul the ore, limestone, and charcoal to it.

"Initially, the prime consideration in locating a furnace was nearness to ore. Of the three principal ingredients, it was the most difficult to find and heaviest to transport. Limestone deposits, stands of timber, and streams for powering the waterwheel needed to produce an airblast for the furnace were all more common. The longer a furnace operated, however, the supply of wood for charcoal gradually emerged as the key factor in its continuing success. Access to a market, though secondary to availability of raw materials, was also taken into consideration in locating a furnace. Finally, the setting for the furnace had to be dry, yet near a stream adequate to supply waterpower for compressing air for its blast. Because the ore, limestone, and charcoal would be fed into the furnace from the top, it had to be erected beside a natural hill or a constructed earthen bank to facilitate loading.

"The outer stack of a furnace was a flat-topped, truncated, hollow pyramid. Usually constructed of quarried stone or brick, it was about 25 feet square at the base and stood from 25 to 35 feet high. The tops of the early furnaces often were open to the air. Workers called "fillers" brought the ingredients to the furnace in baskets over a bridge from storage sheds on or beyond the hill or bank. Later, wooden or

CHARCOAL-FUELED, COLD-BLAST IRON FURNACES

stone superstructures built directly atop the furnaces housed the raw materials, making the fillers' work somewhat easier. Although the remains of many stone furnaces can be seen today in Pennsylvania, few still have wooden superstructures. Over the years they burned, rotted away, or were torn down.

"The function of the heavy stack was to support the hollow, bottle-shaped, central portion of the furnace where the iron was separated from the ore (Figure 1). That center (at first lined with fine-grained sandstone, in later years with fire-bricks made of special clays) ran from the bottom of the stack to the top. Its upper portion (the "tunnel head" or "throat") was narrow, approximately two feet in diameter. Through it the fillers fed the raw materials into the furnace. Near the middle of the stack, the inner furnace widened gradually to a maximum of about nine feet. Here, from the widest point to the "crucible" below, was the heart of the furnace (or "bosch") where the smelting took place. The crucible, a small, narrow chamber from five to six feet in height and about three feet in diameter, extended from the bosh to the "hearthstone" or bottom of the furnace. The hearthstone, specially quarried from sandstone for that purpose, was the floor of the crucible. As the smelting took place in the bosh, the molten iron collected in the bottom of the crucible. The purpose of confining it there was to prevent cooling and solidifying.

"At least two sides of the base of the furnace stack consisted of open arches giving access to the crucible. One, the "tuyere arch," contained a pipe that ran into a hole (the "tuyere") in the wall of the crucible. Through it passed a steady blast of compressed air. As the forced air bubbled up through the melting raw materials, it fed oxygen to the fire, increased the heat, and hastened the separation of the iron from the ore. At first a nearby bellows, powered by a water wheel, compressed the air. Beginning at the start of the nineteenth century, closed blowing cylinders or blowing tubs, still powered by water wheels, began to replace them. After the 1850s, water turbines or steam engines compressed the air for the blast.

"The second ("cast" or "work") arch at the front of the furnace was sheltered by a wooden or stone room called the "casting house." In that room the furnace was tapped, usually twice a day. A large sandstone block ("tymp stone") served as a barrier between the upper part of the crucible and the workers, while a "dam stone," with two holes plugged with clay, held the molten iron and slag in the bottom of the crucible until time for tapping. Between the tymp and dam stones was an open space, the "cinder notch" over which workers called "keepers" removed large cinders that formed in the slag as the smelting progressed. In the mixed sand and clay floor of the casting room, directly in front of the crucible, lay the molds into which the molten iron would flow when the furnace was tapped.

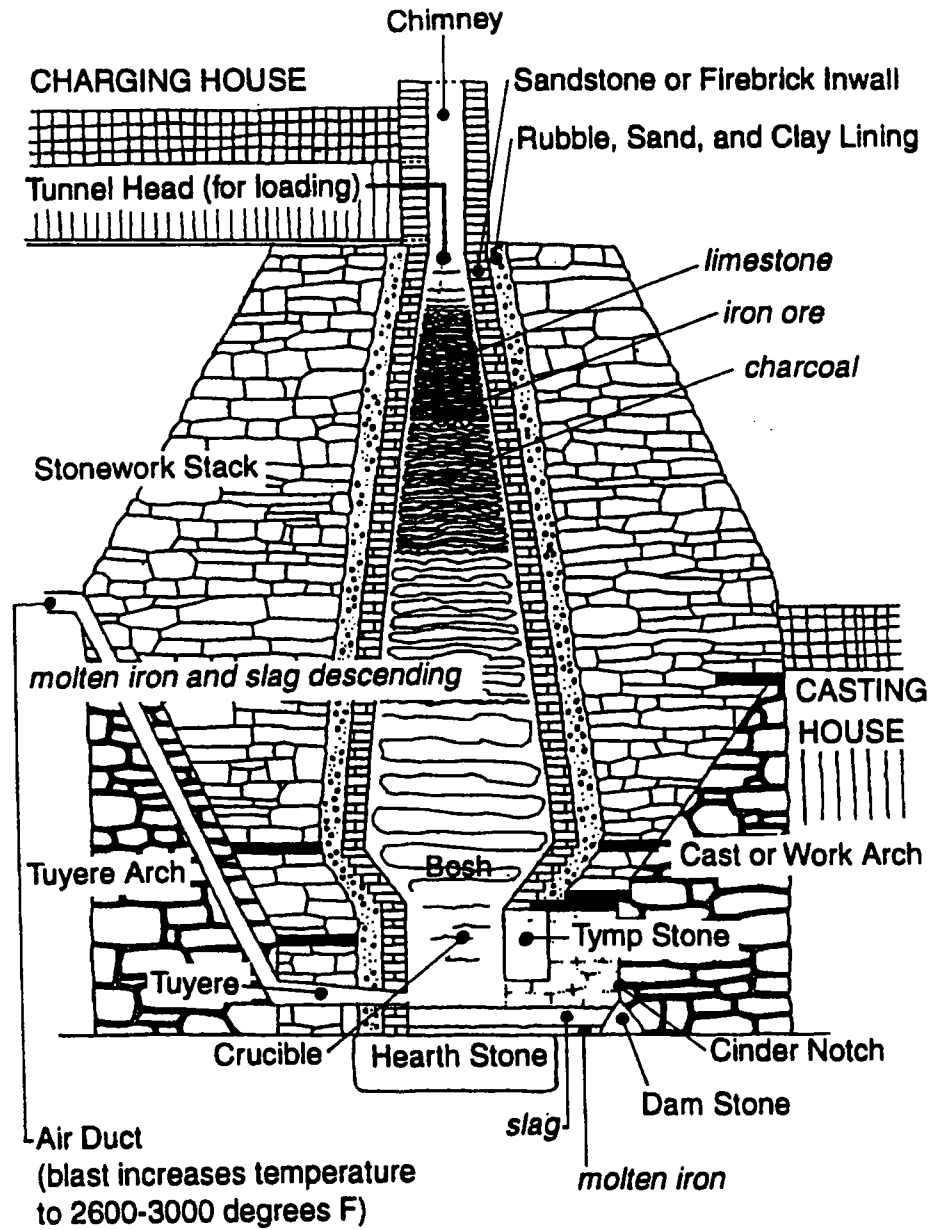


FIGURE 1. Schematic cross section of a cold-blast, charcoal-fueled iron furnace (from Eggert, 1994).

CHARCOAL-FUELED, COLD-BLAST IRON FURNACES

“To “blow in” a new furnace (or restart one that had “blown out”), fillers loaded charcoal into the tunnel head until the furnace was completely full. The charcoal was set afire at the top of the furnace and allowed to burn all the way to the bottom. The fillers then dumped in more charcoal until the furnace again was full. The burning continued, this time from the bottom up, until nothing but glowing coals remained. Into this fiery mass the fillers next poured alternate layers of charcoal, iron ore, and limestone at regular intervals, day and night. As the temperature approached 2700 degrees Fahrenheit, the iron in the ore began to liquefy. Being heavy, it trickled downward into the crucible. Meanwhile, the less heavy limestone, acting as a flux, united with the other impurities in the ore to form liquid slag that floated atop the molten iron. This process continued until the furnace was ready to be tapped, a period of about twelve hours.

“When the “founder” gave the signal to tap, a bell called the workers to their places in the casting house. First the keeper unplugged the top hole in the dam stone, allowing the liquid slag to drain off to one side. When it cooled, workers broke it up and hauled it away as waste. To the founder the slag was more than waste, however. Its texture (from rough clinkers to smooth glassy pieces), but more especially its color, testified to the quality of the iron, the kinds of ore used and their impurities, and conditions in the bosh during the smelting. Dark gray slag indicated a high grade of iron, for example; protoxides of iron produced green or black slag; magnetic oxides [*sic*], brown; peroxides of iron, a dirty yellow or reddish color; carbonate of iron, white or yellow; while light blue indicated the presence of manganese.

“Once the slag was removed, the lower plug in the dam stone was removed. Workers called “guttermen” guided the flow of molten iron into a channel consisting of a series of large molds in the sand. Attached at right angles to each of the large molds were similar small molds into which the flow would continue once the large mold was full. The earliest ironworkers, living in an agrarian age, created the terminology of the process. To them, the smaller molds attached to the sides of the large ones resembled piglets nursing from a mother sow. Thus the large ingots were called “sows,” the little ones pigs, and the product became known as “pig iron.” At some furnaces part of the output was cast as iron ware. Ladling small quantities of molten iron from the furnace, workers poured it into special molds in the sand floor, producing common cast iron items such as hollow ware, skillets, kettles, and ornate stove plates.

“Operation of an iron furnace involved a hierarchy of jobs. At the top was the ironmaster who owned and directed the entire operation. He was assisted by a clerk who kept the necessary records. At the furnace itself perhaps thirty men and boys, fifteen for each twelve-hour shift, worked around the clock. The founder supervised

the work of the whole force. On his experience, skill, and judgment rested much of the efficiency and success of the operation. Considering the quality of raw materials being used and the temperature he wanted maintained during the smelting, the founder fixed the proportions of ore, limestone and charcoal fed into the furnace. He also determined when the iron was ready to pour, and the amounts to be made into pigs or cast in molds.

Each shift also had one or two fillers, a keeper, a gutterman, one or two molders (or potters), and their respective assistants or helpers. The latter were usually young men or boys learning the trade from the older, skilled (or at least experienced) workmen. The fillers and their helpers regularly fed the charcoal, iron ore and limestone into the tunnel head. The keeper and his helper, among other things, raked cinders from the furnace during the smelting and removed the slag just ahead of the tapping. The gutterman and helper or helpers shaped and maintained the sand and clay molds for the "Pigs" and, when the furnace was tapped, guided the molten iron into the forms. If much casting was done, molders and their helpers carried molten iron in ladles from the crucible and poured it into the special sand molds. If little iron was cast at a particular furnace, the molder might be an itinerant who carried his forms with him on a circuit of such furnaces pouring items to order at each. A furnace also usually employed a blacksmith and a carpenter who made and repaired furnace parts and tools as needed. A few common laborers were usually on hand to assist with a variety of jobs requiring strong backs.

"Charcoal furnaces ordinarily operated about nine months of the year, shutting down during unbearably hot periods in the summer and in winter months when freezing interfered with the water wheels that produced the blast. They also closed for breakdowns. During these periods furnaces were repaired, boshes relined with sandstone or firebrick, waterways repaired, and wood cut for charcoal. On average a charcoal iron furnace produced from one to one-and-a-half tons of pig iron at each tapping, or about 600 to 900 tons per year.

THE REFINERY FORGE

Pig iron, hard because of carbon and other impurities remaining in it, was also brittle, unmalleable, and once cold could not be bent. To be useful for blacksmiths to fashion into tools or other articles, it had to be changed into wrought iron by removing part of the carbon. Throughout the eighteenth and early nineteenth centuries, this was done by reheating the pig iron and working it at a refining forge.

THE REFINERY FORGE

“Such forges usually consisted of two charcoal-heated hearths, a “finery” (or “refinery”) and a “chafery.” The process of forging pig into wrought iron began with pigs from the furnace being “softened” (reheated) in the finery hearth with a strong oxidizing air blast. This burned out some of the carbon, silicon, and other impurities. A skilled “finer,” using a long iron bar, would then work the semi-molten iron into a lump called a “half-bloom.” Placed on a large anvil, the half-bloom would next be pounded by a massive power driven hammer until it cooled. Half-blooms were repeatedly heated and pounded until they became flat, thick bars of wrought iron (called “anconies”) which had knobs on each end.

“Sometimes marketed at this stage, anconies more often were further refined at the forge. This consisted of skilled workers called “chafers” reheating the anconies in the chafery hearth and continuing to hammer them into long bars of “decarbonized” iron. These bars were then fashioned and cut into shapes and lengths to meet the requirements of blacksmiths, wheelwrights, coopers, and others who would turn them into consumer goods. By the early nineteenth century, forges produced not only this bar iron, but also larger slabs called “blooms” that went to rolling mills for still further processing.

“Initially forges employed waterwheels to power their machinery. Not until the 1850s were as many as half of Pennsylvania’s forges using steam engines to run their hammers and generate air blasts. Forges usually employed between twenty and thirty men and boys. The limitations of charcoal fires and the size of hearths kept the average output of forges at from 200 to 300 tons of iron annually.

“Because local blacksmiths ordinarily used only a portion of a furnace’s output, the rest was shipped to Philadelphia, Pittsburgh, Baltimore, New York, or even to England where both the selling price and demand were greater. But the risk involved in shipping such distances was also higher. In the early days bars made for distant markets were curved at the forge so as to ride more easily on the backs of the pack horses or mules that carried them.

“Forges, like furnaces, were usually located in remote rural areas near the sources of their raw materials (furnaces that produced pig iron, and forests where charcoal was made). They also had to be very near fast-flowing streams to supply power for their hammers. Early forges employed three or four skilled workers (liners, chafers, and hammermen), one or two apprentices, and a few laborers. The size of a forge, its equipment and number of employees, however, varied widely, ranging from little more than ‘smithies to precursors of modern factories. In the colonial period a small forge might have one “fire” for reheating the iron, and one large power-driven

hammer. The largest had four fires and two hammers. Because forges were usually constructed of wood, few remain today even as ruins.

IRON PLANTATIONS IN ANTEBELLUM PENNSYLVANIA

“The production of iron in cold-blast charcoal-fueled furnaces and refinery forges on remote rural plantations remained characteristic of the industry until the 1850s. After helping to win Independence, iron-masters in southeastern Pennsylvania, where ironmaking was well established, expanded existing works or erected new ones. At the same time, entrepreneurs among the many settlers pouring across the Susquehanna River and Allegheny Ranges into the central and western portions of the State began carving out new iron plantations in those thinly settled areas.

“As might be expected, the nature of the plantation system gradually adapted to changing conditions, especially in the newer districts. An increasingly quasi-industrial quality, for example, diluted the system’s once dominant manorial agrarian character. As the industry expanded it also encountered new difficulties. Transportation problems, for example, particularly plagued the ironmasters of central Pennsylvania, while competition from British iron in American markets led most ironmasters to clamor for and get tariff protection.

“At the onset of the Revolution, Pennsylvania had outranked the other colonies in iron production. By the 1850s it would produce more than half of the nation’s total output. In those same years the rapid growth of the domestic market and the beginnings of the industrial revolution induced further expansion of ironmaking. The resulting general prosperity of ironmasters in the early 1830s caused many to overbuild their operations. Then, midway through the decade, the industry reached a major turning-point. Reduced tariff protection, combined with severe depression, slashed the incomes of most ironmasters, ruining many. Although new technology by that time was revolutionizing ironmaking in America, it did little for the existing system of iron production. In retrospect, the rural plantation stage had peaked and soon would be displaced by an urban industrial stage.

“In only seventeen years following the Revolution (1784-1800), eighty-three new iron works were established in Pennsylvania. This was one fewer than had been set up during the sixty-seven years between Thomas Rutter’s first bloomery in 1716 and the close of the Revolution in 1783. Moreover, nearly half (46 percent) of this new growth occurred in the southeastern counties and two-thirds of that in the

Schuylkill and Delaware Valleys. There ironmasters constructed another seven furnaces, sixteen forges, and three slitting and nail mills. The other gains in the area were two furnaces and four new forges in Lancaster and Lebanon Counties, a slitting mill in Montgomery County, and three steel furnaces and a slitting mill in Philadelphia.

Expansion Into Central and Western Pennsylvania

"Nearly a third (30 percent) of the industry's new growth occurred in central Pennsylvania between the Susquehanna Valley and the Allegheny Mountains. The remainder (24 percent) took place west of the Alleghenies. In those areas, new works clustered in a few regions rather than being distributed evenly. In central Pennsylvania, for example, eighteen of twenty-four new ironworks were in the "Juniata Region" (present day Centre County with eight, Huntingdon with seven, Mifflin with two, and Juniata with one). Two others arose in each of the south central counties of Bedford, Cumberland, and Franklin. Of nineteen works west of the Alleghenies, sixteen were in Fayette County and one each in Allegheny, Greene, and Westmoreland counties.

"A swelling population west of the Susquehanna accounted in part for this remarkable growth. The area's plentiful supplies of iron ore and especially its hundreds of thousands of acres of virgin hardwood forests were of even greater importance. On average, every one of Pennsylvania's furnaces each year consumed all the charcoal made from approximately 300 acres of woodland. The State's numerous forges also used large quantities of the same fuel. Wherever iron-making had been carried on for a half century or longer, as in the southeastern counties, a crisis was pending. In those places, land cleared for charcoal rapidly passed into agriculture, forests were not replanted, timber for coaling was running low and charcoal prices were advancing. If nothing else, the dense forests surrounding the new settlements in the west attracted ironmasters.

The Juniata Region

"The last fifteen years of the eighteenth century and first three decades of the nineteenth witnessed the establishment of iron production in the Juniata Region. The region included four ironmaking districts, with most growth occurring along the Juniata River and its tributaries in Huntingdon and Blair Counties, and on the Bald Eagle Creek and its branches in Centre County. Both of these streams drained the very center of the State eastward into the Susquehanna. Lesser iron districts grew up around Lewistown in Mifflin County and Orbisonia in Huntingdon County

“Would-be entrepreneurs had sought to determine the regions potential for iron production even before the Revolution. In 1767, surveyors hired by the Juniata Iron Company discovered iron ore, but development had to await the coming of peace. Finally in 1785, Bedford Furnace, erected at present day Orbisonia, became the first blast furnace west of the Susquehanna Valley. It was a small affair, constructed mostly of wood, and stood only fifteen to seven- teen feet high, with a five-foot bosh. In addition to the pig iron poured there, stove plates and utensils were also cast. Within six years the firm constructed a forge nearby where most of the areas iron for horseshoes, wagon tires, harrow teeth, and other agricultural implements was made. By 1800, six additional forges (Licking Creek, Barree, Freedom, Juniata, Spruce Creek and Massey) and two furnaces (Huntingdon and Hope) had been established south of the Juniata River. These developments were followed early in the new century by extensive new forges, furnaces, and such secondary facilities as slitting and rolling mills and a nail factory along Spruce Creek and the Little Juniata.

“Meanwhile, in the Bald Eagle Valley to the north, wealthy patriot leaders and former Revolutionary War officers were introducing iron production in Centre County. Robert Morris and Dr. Benjamin Rush of Philadelphia, both signers of the Declaration of Independence, held vast tracts of land there that they now sold for iron plantations. Samuel Miles and John Patton, both colonels during the War, erected Centre Furnace, the county’s first. Located just east of present day State College, it went into blast in May 1792. That same spring, another Revolutionary War colonel, Philip Benner, bought land a few miles to the east for the county’s first forge. His Rock Forge began operations the next year. Benner experimented with vertical integration of his business, engaging not only in forging, but also in slitting, rolling, nail making, and finally moved backward into mining ore and operating his own charcoal-fueled smelting furnace. As in the Juniata watershed, other iron-works quickly followed in Centre County. In 1795 alone, three new forges and a furnace were established.

“By 1826, Centre County boasted eight furnaces. Half were partially integrated: two had forges, the third a forge and rolling mill, and the fourth a forge, rolling mill and nail factory. There were also three independent forges. Fast rising among the area’s ironmasters was Roland Curtin, an immigrant from Ireland. He began his iron kingdom in 1810 with a forge on Bald Eagle Creek. Then copying the pattern set by Benner, he erected his own furnace in 1818, a rolling mill in 1830, and within three years a second furnace. By 1832 he also possessed at least 30,000 acres in the Bald Eagle Valley and on neighboring mountain ranges.

The Problems of Transportation

“The advantage that plentiful forests west of the Susquehanna gave to iron producers---and it diminished with each year of “coaling”---was largely offset by transportation costs. This was especially so in central Pennsylvania. Not only were that area’s furnaces and forges frequently miles from one another, but all major population centers were from 150 to several hundred miles to the east or west. Unless a furnace and forge were part of the same operation (and that was not common at first), an expensive and time-consuming haul from one to the other was necessary. Centre Furnace in Centre County, for example, supplied two forges with pig iron in the early years: Rock Forge, eight miles from the furnace, and Barree Forge, some thirty miles over a mountain range. Tussey furnace, in the same area, was at least thirty miles from Roland Curtin’s Eagle Forge which used its pig iron.

“These costs were slight, however, compared with those occasioned by shipping iron to a major population center. According to responses of furnace and forge owners from Centre County to questions asked by the U.S. Secretary of the Treasury in 1832, only between one-seventh and one-third of their output was used locally. The balance had to go either to Pittsburgh or Louisville in the west, or to Philadelphia, Baltimore, or New York in the east. Often these ironmasters preferred to sell in the west because the lack of foreign competition there kept prices higher. The Iron City was also closer for many of them. The first American-produced bar iron brought to Pittsburgh came by pack animal from Bedford Furnace, a distance of nearly 200 miles.

“In the era before roads, the all-land trip across two major mountain ranges from the central region to Pittsburgh was extremely difficult. First, forge workers had to prepare the iron for loading on the backs of pack horses or mules. This consisted of hammering the six-to-eight-foot long bars into a “U” shape to fit the backs of the animals and ride more easily. Once the burdens were in place, the ironmaster or his agent would lead the string of animals westward over crude trails originally laid out by the Indians. The coming of turnpikes would ease the task because teams and wagons could be employed. Tolls for using such roads were costly, however, and travel still relatively slow. Iron from the Juniata Valley to Pittsburgh sometimes went by a variant method of transport. It was hauled over the mountains, usually by horse-drawn sleds in winter, to Johnstown. From there it was floated down the Conemaugh, Kiskiminetas, and Allegheny rivers to Pittsburgh with the spring and fall freshets.

“Iron sent to Philadelphia from the Juniata or Centre County districts, went 200 miles or farther and chiefly by water. That trip, too, began with pack animals or

teams and wagons carrying the cargo to a navigable point on the Bald Eagle Creek or Juniata River. The iron then proceeded in box-shaped arks down those relatively shallow streams to the Susquehanna River, thence along its rock-strewn course to the town of Columbia. There it was loaded onto wagons and hauled eastward another eighty miles to the great port city.

“Shipments to Baltimore travelled approximately the same distance but went entirely by water except for portages around the hazardous rapids of the lower Susquehanna. New York was accessible only by first shipping the iron to Philadelphia or Baltimore and then along coastal waters to its ultimate destination. Water transport, though faster and cheaper than by land, was seasonal. It was only possible when heavy showers and melting snow in spring or autumn rains filled the waterways enough to float the heavily laden arks. Moreover, rocks, falls, and currents in the Juniata and Susquehanna rivers rendered them treacherous at any time. In summer when the streams were at their lowest, farmers with teams of horses would drag out bars of iron that had fallen in earlier during shipping.

“Conditions for traveling by water improved in the mid-1830s with the completion of the Pennsylvania State Works system of canals. Wherever possible, the canals used the channels of the larger streams and rivers. However, locks and by-passes facilitated getting around falls and rock-filled passages in the rivers. Although there were tolls to be paid, shipments could usually be made by canal for a longer part of the year. They, of course, closed during seasons of extreme drought and during the winter months when waterways froze.

“Ultimately the coming of railroads solved the transportation problem for central Pennsylvania and gave its iron a wider market. Curtin, for one, did not wait for the railroad to reach him. In 1857, he sent iron by mule wagon to the railroad in Lewistown, a round trip requiring five days. Unfortunately by the time rails reached the region (depending on place, sometime between 1850 and 1865), changes in the mode and location of iron manufacture had already shifted the greater part of the industry to other parts of the State.

“How much transportation ‘added to the overall costs of central Pennsylvania ironmasters is not easy to determine. Record-keeping was frequently informal and spotty and often made no distinctions between transportation costs, production costs, and even family expenses. The costs of a marketing voyage were not usually recorded as such. Rather, the expenses were listed in the separate accounts of the various persons involved. Inasmuch as the names and number of persons in a particular party, their reimbursable expense along the way, or allotments, if any, for

IRON PLANTATIONS IN ANTEBELLUM PENNSYLVANIA

food and other supplies were not given, accurate calculations of costs cannot be made.

“Samples from the records of Roland Curtin’s Eagle Ironworks although providing useful bits of information, illustrate the problem. In May 1830, Curtin paid one employee \$655.25 (about \$16.20 per ton) for carrying more than forty tons of blooms and bar iron overland to Pittsburgh. Inasmuch as a shipment of that size would require several pack animals, it seems improbable that only one person made the trip. Who may have assisted and how much they were paid is not known.

“The records of transport by water left even more unanswered questions. Not only were costs recorded in individual account rather than by shipment, but much was omitted. The cost of the arks, for example, was sometimes shown (\$80 each in 1829, \$85 in 1831); the amount received when they were sold for lumber at the end of the voyage was not. Similarly, toll charges along the way, of food and other expenses of the person or persons in the crew were not uniformly recorded.

“Persons in charge of shipments down the river by ark received \$6.50 per ton to Baltimore in 1829 and Philadelphia in 1830. A similar trip to Port Deposit (just east of Harrisburg) paid only \$5.50 per ton in 1831. Apparently those who assisted on such trips received a flat trip rate: for “going down the river,” \$119 (April 1830), \$123 (May 1830), \$110 (January 1831); for delivering an ark at Port Deposit (January 1831) and “running an ark to tidewater” (spring 1836), \$120.

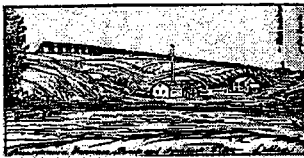
“With completion of the canal system, Curtin turned his iron over to canal boat captains for delivery, paying them, of course, for their services. One uncommonly detailed account in the Curtin papers reports on a delivery of iron to Baltimore and return home by Curtin’s son, Roland, Jr., in June 1841. Young Curtin sold the cargo of approximately 14 tons of iron to four different firms for a total of \$1,270. Expenses amounted to \$100 to the boat captain, \$6.25 for “freight,” \$5 for weighing and wharfage, \$2 for storage and weighing a “lot of iron at Harrisburg,” \$8 for tolls, and \$59.75 for unspecified expenses. Based on this report, the cost of transporting the iron amounted to slightly more than fourteen percent of its sale price. In completing his accounts, young Curtin reported buying \$130 worth of fish and salt for the company store, paid \$12 for subscriptions to two Harrisburg newspapers, loaned \$25 “which I never expect to get,” and paid \$10 for breaking a colt. He had \$56 worth of Tide Water notes in his pocket and turned over \$244 to his father.

THE SHIFT TO STEEL

“Throughout the 19th century iron played a large part in making Pennsylvania the nation’s second most industrial state. It also counted much in elevating the United States to fourth place among the world’s industrial powers by 1860. Before the end of the century the United States would surpass the others, achieving status as first sometime during the 1890s. By common agreement America’s iron and steel industry stood at the heart of that achievement. The term “iron and steel industry’ should be noted. Increasingly it replaced “iron industry’ as the output of steel grew, caught up with, and eventually surpassed that of iron. Steel, an alloy of iron, began its challenge to iron’s dominance soon after the close of the American Civil War. Within thirty years the Age of Steel was fast subsuming the Age of Iron. Although Americans had made steel since early in the colonial era, quantities were limited by extremely high production costs. Then, after 1865, new technologies suddenly reduced these costs by speeding up steel-making, increasing its scale of output, and substituting machine technology for much of the skilled human labor essential to iron-making. Because steel was better than iron for railroad rails, it first stole that large and important market. Later it took over structural forms and eventually most other iron products because it was cheaper.”

Thus ended the role of the Juniata region in America’s iron and steel industry. By 1884, when E. V. d’Inwilliers wrote his *Report of Progress on the Geology of Centre County*, (D’Inwilliers, 1884), only three furnaces were in blast, “whose combined necessities could be satisfied by one good mine.” (*ibid.*, p. 133). The local industry limped into the 20th Century, but the magnitude and richness of the Michigan and Minnesota ores, and the growth of industrial cities with a ready labor force and water transportation, such as Pittsburgh, PA and Hamilton, Ontario, made its eventual death all but certain.

GEOLOGICAL SETTING OF THE ORES



Arthur W. Rose and Rudy Slingerland

GENERAL GEOLOGICAL HISTORY OF THE APPALACHIAN OROGEN

The Central Pennsylvania Region is part of the fold and thrust belt of the Appalachian Orogen. The Appalachian orogen *sensu stricto*, was created as a result of Late Proterozoic (610-630 Ma) rifting of Gondwana (Africa and South America) and Laurentia (proto-North America) (Cook et al., 1983; Cook and Oliver, 1981), along a trend approximately coincident with the axis of the present Appalachians. Metamorphic and plutonic rocks of the Grenville Province, with radiometric ages of 1.3 to 1 Ga, were stretched to produce a series of grabens filled with thick sequences of Eocambrian sedimentary rocks such as the Chilhowee Gp. and volcanic rocks such as the Catoctin Fm. in southeastern Pennsylvania. As the large, near-surface thermal gradients associated with rifting decayed, a passive margin developed upon which a thin Lower Cambrian transgressive clastic sequence (e.g. Antietam Fm.) was succeeded by a 4 km thick sequence of Cambro-Ordovician platform carbonates (Figure 2) which are the parent rock for the ores of this field trip.

The passive margin in the central Appalachians was disrupted in Caradocian time when eastern Laurentia (North America plus Greenland, Scotland, and northern Ireland) collided with an island arc and a set of microcontinents along an outboard-dipping subduction zone (for a detailed account in New England see Stanley and

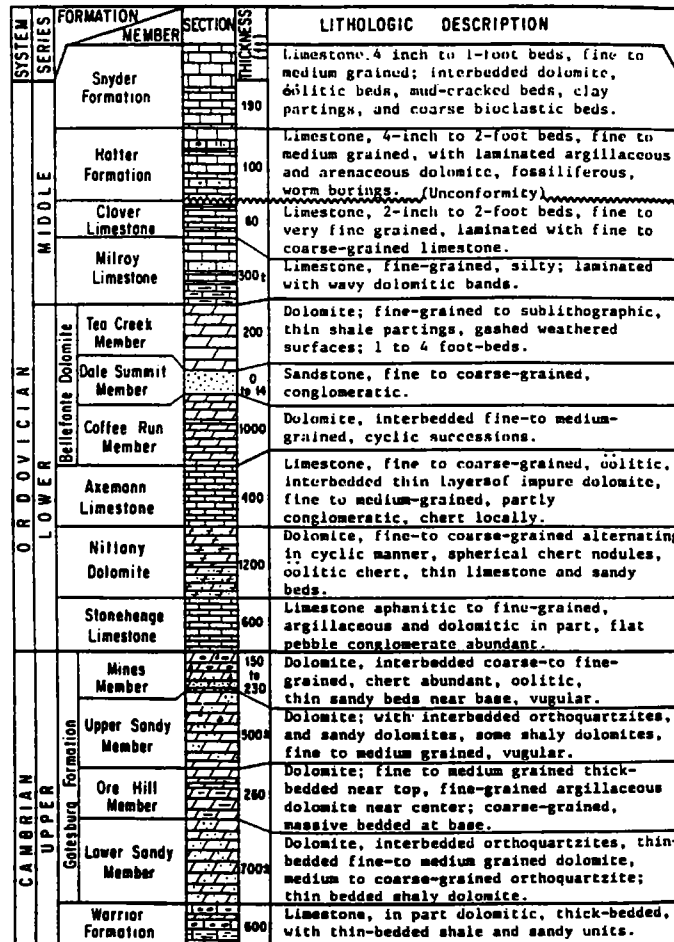


FIGURE 2. Stratigraphic column for central Pennsylvania (after Parizek and White, 1985)

Ratcliffe, 1985). The resulting overthrusting event, called the Taconian orogeny, depressed the foreland and allowed accumulation of over 1.8 km of sediment in Pennsylvania between Middle Ordovician and Early Silurian time. This is the first of three eastward-derived clastic wedges, the Taconian wedge, represented in central Pennsylvania by the Antes Shale through Tuscarora Formation (Figure 2) (Lash, 1987; Lash and Drake, 1984; Rodgers, 1970). Modelling by Beaumont et al.

GENERAL GEOLOGICAL HISTORY OF THE APPALACHIAN OROGEN

SYSTEM SERIES	FORMATION		SECTION (THICKNESS (ft))	LITHOLOGIC DESCRIPTION
	MEMBER			
DEVONIAN	Helderberg Formation		130 to 350	Shale, thin-bedded, calcareous. Limestone, thin-bedded, cherty. Sandstone, locally medium to coarse-grained.
	Keyser Formation		155	Limestone, thick-bedded to nodular.
SILURIAN	Tonoloway Formation		400+	Limestone, thin-bedded to laminated, fine-grained, some calcareous shales.
	Wills Creek Formation			
	Bloomsburg Formation		1500+	Shales, calcareous in part. (undifferentiated)
	McKenzie Formation			
	Rose Hill Formation			Quartzitic Sandstone, fine to very coarse- grained, thin to thick bedded, mountain former.
	Tuscarora Formation		400 to 550	
	Juniata Formation		1000+	Sandstone, fine- to coarse-grained, impure; interbedded siltstones and shales.
UPPER	Oswego Sandstone		700 to 800	Sandstone, fine- to coarse-grained, interbedded shale near base.
	Readsville Shale		1000	Shale, sandy in upper portion.
	Antes Shale		200	Shale, calcareous, soft.
	Coburn Limestone		275	Limestone, thin-bedded, fine to coarse grained, shale partings.
ORDOVICIAN	Salona Limestone		175	Limestone, thin-bedded, fine-grained, shale partings.
	Nealton Formation		70	Limestone, impure bioclastic, fine to medium grained near top; thin to thick-bedded impure, fine-grained limestone near base.
				(Unconformity)
	Valentine Member			Limestone, thick to thin-bedded, very fine to medium-grained. (Valentine Mb. laminated thick to thin bedded units.); (Valley View, Mb. 2-inch to 1 foot bedded well laminated limestone, thin clay laminae.); (Oak Hall, Mb. thick-bedded, fine to coarse-grained limestone.)
	Oak Hall Member		100	
	Valley View Member			
	Stover Member			Limestone, thick bedded, bioclastic zones, thin bentonite beds, dolomite streaks.

FIGURE 2. (continued).

(1988) as described in Slingerland and Beaumont (1989), indicates that between 8 and 12 km of overthrust load is necessary to accommodate the maximum 3 km of Taconian detritus preserved in the basin. As explained later, the outboard region of a rifted cratonic margin can accumulate up to about 20 km of overthrust material before a mountain range of any consequence is created. This arises because seaward of the Bouguer gravity gradient marking the continent-ocean crustal transi-

tion, thrust sheets replace water and load an attenuated continental crust and oceanic lithosphere. Thus the Taconian overthrusts loading the Cambro- Ordovician slope and rise probably were of modest subaerial topographic relief.

Following the Taconian orogeny, sedimentation rates declined in the basin. Approximately 900 m of carbonates, salt, fine-grained clastics, and thin, mature shelf sandstones were deposited during Middle Silurian to Early Devonian time (Figure 2), reflecting relative tectonic quiescence along the orogen. Although plate convergence continued along the eastern Laurentian margin during this interval (Van der Voo, 1988), crustal loading by overthrusting apparently was minor. Commencing in the Early Devonian in New England and ending in the Early Mississippian in Pennsylvania, convergence between Laurentia and an unspecified plate (Ferrill and Thomas, 1988) produced a metamorphic, plutonic, and loading event called the Acadian orogeny. The resulting foreland basin fill in the central Appalachians is called the Catskill- Pocono clastic wedge, comprising the Marcellus through Pocono Formations.

Closing of the proto-Atlantic continued during the Mississippian to Permian, culminating in the collision of Gondwana with eastern North America and the third Paleozoic deformation event, the Alleghanian orogeny. Outboard loading rejuvenated the Acadian foreland basin, and it received a minimum of 7.5 km of sediments from the orogenic highlands to the east (Mauch Chunk through Conemaugh Fms.). Subsequently the whole eastern half of the orogen was subjected to folding and thrusting, and, to a lesser extent, metamorphism and plutonism from relative transpression.

The Permian and Early Triassic history of the Appalachian orogen is uncertain, because there are no preserved deposits of that age. It is clear however, that by the Carnian or late Landinian (230-225 Ma) sediments had begun accumulating in basins along reactivated strike-slip and thrust faults (Manspeizer and Cousminer, 1988; Traverse, 1987), recording the initial breakup of Pangea. Rupture occurred roughly along the present continental shelf edge (see Manspeizer and Huntoon, 1989, for details) and sea-floor spreading began between late Early to Middle Jurassic (190-175 Ma) (Klitgord and Schouten, 1986, p.364). A second passive margin developed, of broad platforms having fairly thin sediment cover and basins whose margins probably mark the sites of transform faults active during the initial breakup. Jurassic sediments of the passive margin tend to be terrigenous lagoonal, fluvial, or deltaic nearshore lithosomes ponded behind widespread carbonate build-ups at the shelf edge. During the Cretaceous and into the Cenozoic, a thick sequence of fluvial, deltaic, and shelf sediments prograded seaward to form a well defined slope and rise. The result is an eastward-thickening wedge of primarily

GEOLOGY OF THE CENTRE REGION

unconsolidated sediments, about 2.4 km thick in the Delmarva area, thickening to 9 km in the Baltimore Canyon Trough (Folger et al., 1979).

GEOLOGY OF THE CENTRE REGION

A thick section of Paleozoic sedimentary rocks (approximately 6700 m) extending from Cambrian through Pennsylvanian is exposed in the field trip area, deformed into a series of anticlines and synclines. The folds are eroded to form ridges where resistant sandstones are exposed, and valleys where shales and limestones are exposed (see Plate I), producing the classic Ridge and Valley Province known to geographers. The very large valley in which Penn State is located, called Nittany Valley, is developed on Cambro-Ordovician limestones and dolomites.

The limonite ores of the Nittany Valley occur as enrichments near the surface where Cambrian and Ordovician limestone and dolomite have been extensively weathered. The ores are members of a class of residual limonite ores recognized from Vermont to Alabama, and utilized for ore during the 19th century (Ries, 1942). Prominent examples occur in eastern Pennsylvania (Prine, 1875). These ores were divided into mountain ores and valley ores. The mountain ores occurred as pockets overlying Cambrian quartzites that occur stratigraphically below the Cambro-Ordovician limestones, whereas the valley ores occur in residual clay above limestones and dolomites. The ores generally occur as small pockety bodies, rarely exceeding 500,000 tons.

Stratigraphy

The stratigraphy of the region is illustrated in Figure 2. The lowest unit exposed in the region is the Upper Cambrian Warrior Formation, composed predominately of limestone and lesser interbedded shale and sandy limestones. Above this is the Upper Cambrian Gatesburg Formation, a major parent material for the iron ores. The Upper and Lower Sandy Members of the Gatesburg Fm. are composed of interbedded dolomite and dolomitic sandstone. The Ore Hill and Mines Members are thick dolomite units similar to the dolomite of the Sandy Members. The Gatesburg Fm. was evidently deposited in a broad slowly subsiding passive margin of shallow water southeast of exposed Precambrian igneous and metamorphic rocks in Canada which were the source of the sands. The Gatesburg Fm. is about 500 m thick, and now forms a low wooded ridge in the middle of the broad valley. It is an important source of iron ore.

Above the Gatesburg Fm. is a Lower Ordovician section composed of the Stonehenge Limestone, a fine-grained and argillaceous limestone with distinctive zones of flat pebble conglomerate, overlain in turn by the thick cherty Nittany Dolomite, Axemann Limestone, and the Bellefonte Dolomite. These formations totals about 1000 m in thickness and underlie most of the broad valley area in farmland. Some iron ores, such as the Pennsylvania Furnace deposit visited on this trip, have developed by weathering of these dolomites and limestones.

Strata of Middle Ordovician age consist of a series of limestones about 450 m thick, above which lies 400 m of Upper Ordovician Reedsville Shale, forming the slopes of the major ridges. Stratigraphically above the Reedsville Shale is 250 m of Bald Eagle (Oswego) Sandstone, 350 m of red shales and sandstones of the Juniata Formation, and 150 m of Silurian Tuscarora Sandstone. The Oswego and Tuscarora Formations make up the double ridge bordering the broad Nittany Valley. In the shales overlying the Tuscarora Sandstone are thin beds of sedimentary iron formation, the Clinton iron ores, that were also used as ore in the region.

Structural Geology

As noted above, the sedimentary rocks of the region were folded into large anticlines and synclines during the Alleghenian Orogeny. The Nittany Anticline in the area of this field trip is the largest of these anticlines, with the Cambrian units exposed along its axis (Figure 3). In places, the Nittany Anticline includes one or more subsidiary synclines and anticlines within the major fold. In general, the northwest limbs of the anticlines are steep, in some cases overturned, whereas the southeast limbs are moderately dipping. The folds are interpreted as fault-bend and thrust-tip folds formed above a regional decollement zone in the Cambrian, as indicated by exposures a few miles south of the field trip area, drillholes in the region, and seismic interpretation (Figure 3B). The Birmingham fault, which juxtaposes Upper Cambrian against Middle Ordovician rocks along the northwest edge of the Nittany Anticline, is an especially prominent feature (see Plate I). Northwest-trending tear faults also cut the section locally.

Erosion and Weathering History

The Appalachian Mountains are thought to have been Andean in scale during their active growth in the late Pennsylvanian and Early Permian (Slingerland and Furlong, 1989). Between the end of the Early Permian when orogenesis stopped and the Carnian, when the rift basins of eastern Pennsylvania developed, approximately 9 km of cover rocks were removed, as indicated by fission track geochronology and

GEOLOGY OF THE CENTRE REGION

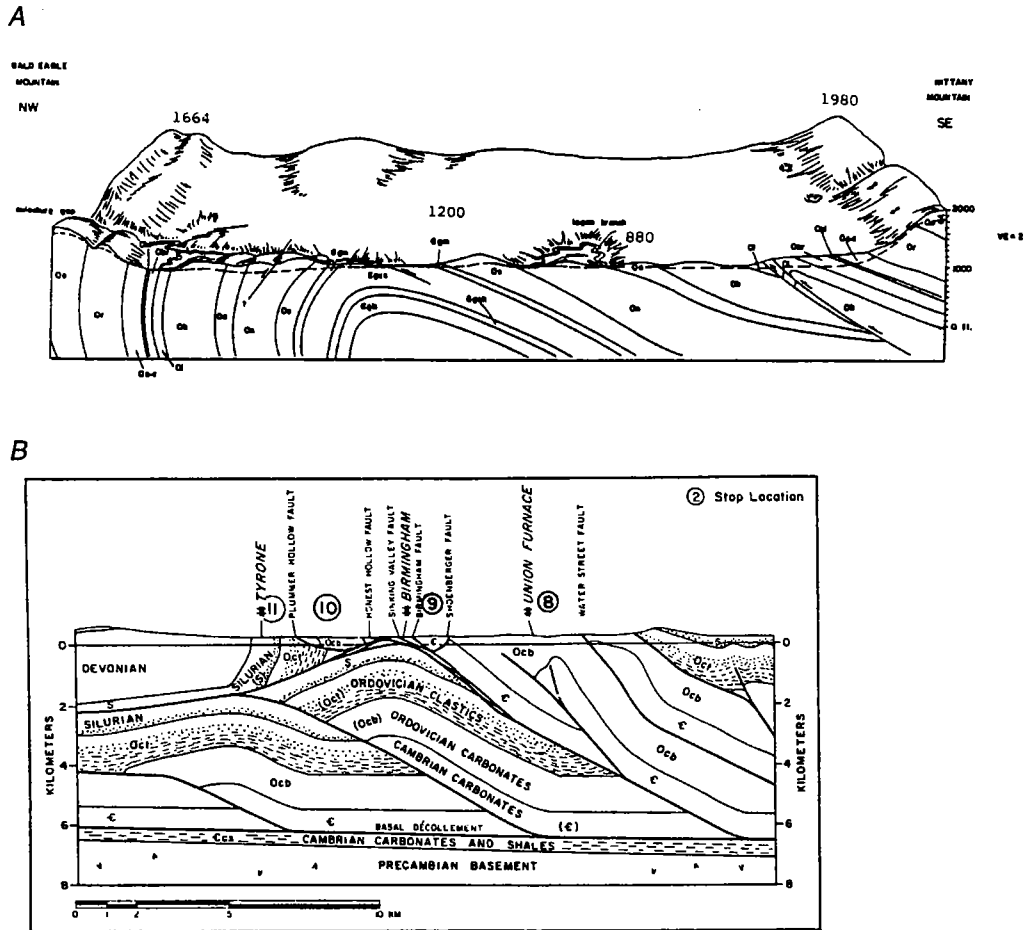


FIGURE 3. Geological cross sections of Nittany Valley. A) Section A-A' on Plate I (from Parizek and White, 1985); B) Section B-B' on Plate I (from Fail, 1987).

strata preserved under the rift sediments (Slingerland and Furlong, 1989), resulting in a topography of subdued relief. The climate during this time was predominately arid (Hay et al., 1982).

Based on the depositional record in the offshore mid-Atlantic (Poag and Sevon, 1989), the mid-Early Cretaceous (Barremian) was a time of uplift in the central

Appalachians, intense weathering under a warm, sub-humid, equable climate, and rapid erosion. Traditional thinking suggests that at this time the Centre County region was eroded to a gently sloping low-relief surface related to the present mountain summits (Sevon, 1985).

Offshore sediments and terraces along the lower Susquehanna River (Pazzaglia and Gardner, 1993) indicate a second period of intense weathering and rapid erosion occurred in the Middle Miocene. At Harrisburg, this set of terraces is about 60 m above the present Susquehanna River, indicating incision of that amount over the last 15 Ma. Weathering of the upland areas containing the iron ores of the Nittany Valley seems likely to have continued for at least the period since the Miocene, while zones nearer the trunk streams were eroded more deeply, particularly during the Pleistocene.

The intensity and character of this Tertiary weathering in the area is suggested by the extensive development of kaolinitic clays in association with the Fe ores (Leighton, 1934), and by the development of pisolitic gibbsite at the Blair Clay Mine near Scotia (Roger Pollock, Personal Communication; Gold et al., 1993). Parent materials for the clay (including gibbsite) are siltstones containing K-feldspar and illite. Quartz accompanying the clay is etched or completely dissolved.

In the present climate the extensive limestone and dolomite of the Upper Cambrian and Early to Middle Ordovician, making up most of the floor of the Nittany Valley, are drained largely in the subsurface, and form an excellent example of karst terrane (Parizek and White, 1985). Large areas contain no streams, or have streams only during severe storms. Streams flowing off the mountains disappear into sinkholes at the base of the mountains, and commonly appear a mile or more away as much larger streams. The water table is commonly 50 to 100 m or more below the surface.

GENESIS OF THE ORES



Arthur W. Rose

GEOLOGICAL CHARACTERISTICS OF THE LIMONITE ORES

The location of the main ores of the region along with the geology are illustrated on Plate I. About 65 mines are shown on this map, but the old geological reports (Lesley, 1874; D'Invilliers, 1884) make clear that numerous smaller mines, and still more numerous showings in fields and test pits, are present in the area. The mines at Pennsylvania Furnace (Baileyville) and Scotia are the largest mines, at which the excavations indicate removal of 500,000 to more than a million tons of "ore". For example, about 1.7 million tons of iron ore are estimated to have been extracted from the Scotia Mines (Butts and Moore, 1936).

Two main groups of limonite ores may be distinguished on the basis of the type of bedrock underlying the deposit. One group overlies the sandy dolomites of the Gatesburg Fm. and the immediately underlying Warrior Fm. This group defines a northeast-trending belt near the northwestern margin of Nittany Valley, along the crest of the Nittany Anticline where the Gatesburg Fm. crops out. Deposits of this belt tend to occur in the low wooded ridge marking the outcrop of the sandy members of the Gatesburg Fm. The Pennington deposit, visited on this trip, and the Scotia deposit, the largest deposit of the region, are part of this group.

The second group occurs above the dolomites and subordinate limestones in the Lower Ordovician (Stonehenge, Nittany, Axemann, Bellefonte Fms.) These deposits occur mainly along the southeast side of the Nittany Valley, and include the Pennsylvania Furnace deposit to be visited on this trip.

Three main types of ore are described in the old mines: wash ore, lump ore, and pipe ore, arranged as suggested in Figure 4. Wash ore is composed of many small

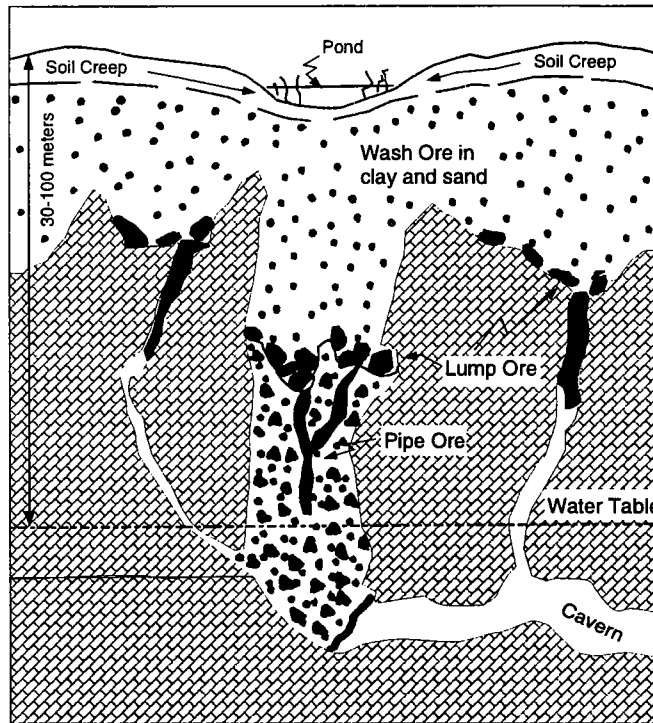


FIGURE 4. Schematic diagram of ore types and their relation to geology.

fragments (up to about 10 cm in diameter) of limonite and limonite-impregnated sandstone and chert enclosed in a larger volume of clay and sand. At most deposits, 1 to 5 m of relatively barren sandy or clayey soil overlies the wash ore, which is generally soft and highly weathered. The wash ore is commonly 5 to 15 m thick, and extends over lateral dimensions of 10 to 100 m. Layers of stiff white to pink clay extend through the orebodies in places, but much of the wash ore lacks any regular structure, and appears to be a jumble of sand, clay, and limonite fragments.

GEOLOGICAL CHARACTERISTICS OF THE LIMONITE ORES

At a few deposits, the clay layers, which are mainly kaolinite, have been exploited for use in refractories, tile, and paper making (Leighton, 1934; Griffiths et al., 1956; Gold et al., 1993).

The limonite fragments appear to be predominantly goethite, based on brown to yellow-brown streak, though minor hematite appears to be present. The fragments show layered, botryoidal and occasionally rod-shaped forms, nearly always appearing to be broken pieces of larger masses. Some botryoidal and rod-shaped pieces are made up of tiny radiating crystals of goethite, but much of the limonite is microcrystalline to earthy.

Lump ore occurs near the base of the wash ore. Larger lumps of limonite-rich material up to 50 cm or more in size characterize this type of ore. The matrix is generally sandy or clayey material. Limonite forming many of the lumps is bounded by broken surfaces. Other surfaces are hard botryoidal goethite. Some goethite is porous, apparently because some material, perhaps carbonate, has been dissolved since limonite deposition. At Scotia, lumps commonly show breccia textures, with angular fragments of chert, sandstone, or in a few cases white clay, cemented with brown limonite. The lump ore near the base of the weathered zone was apparently an attractive target of mining at many deposits.

Pipe ore is poorly described, but typically consists of steeply plunging pipes or vein-like bodies of limonite up to several meters thick, enclosed within limestone bedrock (D'Invilliers, 1884). The name also seems to have been applied to masses of limonite showing linear or pipe-shaped structure.

Rocks in the ore-bearing zones are very deeply weathered. Thirty to 100 m of sandy and clayey weathered material commonly overlies hard rock of the Gatesburg Fm. The current water table is more than 100 m below the surface in many parts of the Gatesburg Fm. (Landon, 1963). This deep weathering and dissolution of carbonate rock and of the carbonate cement of dolomitic sandstone is inferred to have occurred over many millions of years, extending back to at least Miocene and perhaps to the Cretaceous. The weathered zone is generally less thick over the Ordovician limestones and dolomites, but still can be 10 to 30 m thick and highly irregular, with local development of sinkholes where near-surface rock has collapsed into deeper solution cavities.

Chemistry of Limonite Ores

Table 1 shows the chemistry of the ores based on a set of 32 analyses cited by Les-

TABLE 1. Composition of limonite ores (after Lesley, 1874 and D'Inwilliers, 1884), based on 32 samples of selected limonite fragments

Oxide	Mean %	Range %	Median %	Goethite %
Fe ₂ O ₃	71.9	42-83	72	89.9
MnO ₂	0.50	0-6	0.28	
Al ₂ O ₃	1.96	0.28-5.3		
MgO	0.31	0.05-1.6		
CaO	0.20	0-1.1		
P	0.17	0.02-0.73	0.15	
SO ₂ +quartz	15.0	2.5-42		
H ₂ O	11.2	8.6-14.1		10.1
	101.24			

ley (1874). These were apparently samples of picked limonite-rich fragments after washing the clay from the wash ore, or breaking off pieces of lump or pipe ore. The content of Fe₂O₃ ranges from 42 to 83 weight percent, with the main impurity being SiO₂. Typical Mn content is about 0.3% and Al content about 2%. Phosphorus averages 0.17%, so that most ores are too high in P to be desirable for modern steel, although some analyses are acceptable.

Eight limonite samples were analyzed specifically for this study (Table 2). Compositions are similar to those reported by Lesley (1874). The considerable variability in Mn, P, and transition trace elements is notable.

A set of about 40 limonites from about 10 deposits in the Nittany Valley was collected by Prof. M.L. Keith in 1955 to 1958, and analyzed spectrographically by E. Degens (Degens et al., manuscript). Unfortunately, the quality of the data was questionable, so these results were never published, and the data must be regarded as suggestive only. The median concentrations and ranges of the analyses by Degens for a variety of trace elements are listed in Table 3. As part of the Degens and Keith study, a small number of samples were also collected and analyzed from gossans developed on Pb-Zn "ores" of the region, including a vein containing galena, sphalerite, and pyrite in Milesburg Gap (Butts and Moore, 1936), and limestone

GEOLOGICAL CHARACTERISTICS OF THE LIMONITE ORES

TABLE 2. Analyses of limonite samples from Red Bank, Milesburg, Mattern, Gatesburg, Pennington, Pennsylvania Furnace, Scotia

Oxide (%)	Sample #					Fe-11 ^a	Fe-12	Fe-13 ^b
	55-75	58-21	58-33	58-70	58-79			
Fe ₂ O ₃	67	29	73	77	86	83	89	89
MnO ₂	0.03	0.03	0.01	0.68	0.10	3.24	0.11	0.09
Al ₂ O ₃	1.52	0.90	0.99	1.18	0.91	0.68	0.60	0.28
Mg	0.02	0.03	0.0	0.02	0.05	0.02	0.14	0.27
Ca	0.04	0.06	0.05	0.03	0.03	0.05	0.04	0.13
P	0.33	0.20	0.87	0.99	0.26	0.10	0.21	0.09
Ba	ND	ND	0.08	0.08	ND	0.02	ND	ND
Co (ppm)	130	40	60	160	120	420	120	180
Cu (ppm)	90	ND	ND	ND	ND	15	ND	ND
Ni (ppm)	280	50	60	300	150	500	150	230
Pb (ppm)	ND	40	160	ND	ND	50	20	20
Zn(ppm)	1000	24	260	190	90	660	90	70
Insoluble %	21	54	1	7	5	2	3	2

a. Pennington sample.

b. Pennsylvania Furnace sample.

TABLE 3. Iron, manganese, and trace element content of 40 limonites (sampling and analysis by M. L. Keith and E. Degens)

Element	Median	Range	Detection Limit	Sulfide Gossans
Fe	48	30-63		
Mn	1300	500-55000		
Ag	< 1 ppm	0-10	1	1
As	<1000	0-3000	1000	2000
Ba	1000	<500-8000	500	5000

TABLE 3. Iron, manganese, and trace element content of 40 limonites (sampling and analysis by M. L. Keith and E. Degens)

Element	Median	Range	Detection Limit	Sulfide Gossans
Be	8	<5-20	5	ND
Sn	ND	ND-500	100?	ND
Cd	ND	ND	?	ND
Co	20	ND-400	10	ND
Cr	40	ND-100	10	ND
Cu	10	ND-300	1	10
Ga	10	ND-70	5	5
Mo	80	ND-600	20	60
Ni	100	10-600	20	60
Pb	40	ND-1000	10	500
Ti	200	ND-3000	10	300
V	100	Tr-700	10	20
N		40		3

replacement deposits of Pb-Zn in Sinking Valley near Tyrone (Butts, 1939). The median concentrations for 3 samples from Milesburg Gap analyzed by Degens are listed in Table 3 for comparison. In general the sulfide gossans show much higher values of As, Ba, and Pb than the limonite ores, as might be expected from the presence of base metal sulfides and barite in the unweathered ore.

ORIGIN OF THE LIMONITE ORES

The mineralogy of the ores (goethite-hematite-limonite) and their position in the weathering zone above bedrock clearly indicates that the limonite deposits originated by residual enrichment by weathering. However, the details of this process remain controversial. Major questions exist on the following:

1. What was the parent material which was weathered to form the ores?
2. What set of geological and climatic conditions is responsible for the localized concentration of iron at the various locations? In particular, how was iron enriched to such great depths below the surface?

Source of Iron

Regarding source, three main hypotheses have been suggested:

1. The ores are gossans developed by weathering of pyrite in hydrothermal sulfide ores, which are known to occur in the region in the form of the Pb-Zn replacement ores in limestone in Sinking Valley (Butts, 1939; Smith, 1977) and the Woodbury area of Bedford County (Tregaskis, 1979; Smith, 1977), and at the Soister Mine, Blair County (Smith, 1977). This suggestion by Prof. O. F. Tuttle of a hydrothermal parent in bedrock led to the studies by M.L. Keith (Personal Communication).
2. The ores are the result of weathering of sedimentary zones enriched in pyrite, siderite, or ankerite in the underlying dolomite and limestone (D'Inwilliers, 1884, p. 136; Butts and Moore, 1936).
3. The ores result from the enrichment by long-continued and intensive weathering of the normal low amounts of iron contained in the dolomites and limestones of the area.

Several arguments can be made against their origin as gossans. The ores are very widespread, especially if all the showings in prospect pits and test mines are considered. Ores are not limited to a single formation, nor does their distribution suggest any particular structural control. In the mines where bedrock is exposed, base metal sulfides have not been recorded in the limonite ores of the Nittany Valley. Finally, the trace element concentrations in the limonite ores (Tables 2 and 3) do not show elevated values of Ba, Pb, and other chalcophile elements that might be expected to result from weathering of sulfide ores. Although a few limonite concentrations of central Pennsylvania may have originated as a gossan over base metal sulfides (i.e., Soister Mine, Smith, 1977), the numerous limonite ores of the Nittany Valley show no evidence of this origin.

An origin by weathering of pyrite- or siderite-rich zones in the bedrock has been supported by several observations of pyritic zones or limonite with pyrite cores exposed in a few pits. Pyrite in the cores of limonite lumps is reported from the Springfield Mine in Blair County (Platt, 1881, p. 172), and at the Soister Mine (Platt, 1881, p. 201; Smith, 1977), though this occurrence appears to be a gossan developed from zinc ore. Great masses of pyrite were found about 10 m below limonite at the Deano Bank in Blair County (Platt, 1881, p. 236). However, several of the points cited above argue against an origin by weathering of pyritic or sideritic beds as a general solution to the source. The very wide geographic and stratigraphic distribution of hundreds of mines and prospects, without any relation to a particular sedimentary unit does not seem consistent with sedimentary source beds enriched

in iron. Also, no such unit has been recorded in close examination of well exposed sections of the rocks near Tyrone and Bellefonte, and the bedrock exposed in the pits does not show evidence for such a source. Therefore, an Fe-rich sedimentary bed does not seem plausible as a general explanation, though minor amounts of pyrite or other Fe minerals are doubtless present in the bedrock of the region and may have contributed to the deposits.

As a test of the third hypothesis, a set of bedrock samples of the Gatesburg Fm. and the exposures in the Pennsylvania Furnace pit were collected and analyzed. The Gatesburg samples were collected from good exposures along PA Route 350 just east of Birmingham, PA. Chips of little-weathered rock were collected about every 3 m and segregated into four rock types: sandstone, coarse dolomite, fine dolomite, and shale. In this manner, four samples of the Lower Sandy member of the Gatesburg Fm., one sample of the Ore Hill member (coarse dolomite), and four samples of the Upper Sandy member were collected. One sample of many chips from Stonehenge Limestone exposed in the PA Furnace pit was also collected.

Disregarding the shale samples from the Gatesburg, which make up an insignificant proportion of the section, these sedimentary units contain about 0.5 +/- 0.2% Fe (Table 4). If one assumes that a zone of wash ore 10 m thick is composed of 10 to

TABLE 4. Analyses of Gatesburg and Stonehenge Fms (in ppm)

Sample # ^a	Notes ^b	Fe (ppm)	Mn (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	Insol. Res. (%)
Fe-1	L. S., cse dol	5200	180	18	20	20	14, slt/ clay
Fe-2	L. S. fne dol	7800	220	21	20	20	10
Fe-3	L. S. ss	5000	120	9	20	0	55
Fe-4	L. S. sh	12,000	170	29	20	0	42
Fe-5	O. H. cse dol	4000	100	22	25	0	11
Fe-6	U. S. cse dol	4000	120	33	25	0	7
Fe-7	U. S. fn dol	5000	120	42	35	0	12
Fe-8	U. S. ss	3600	70	31	20	35	60

ORIGIN OF THE LIMONITE ORES

TABLE 4. Analyses of Gatesburg and Stonehenge Fms (in ppm)

Sample # ^a	Notes ^b	Fe (ppm)	Mn (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	Insol. Res. (%)
Fe-9	U. S. sh	10,400	100	67	40	6	40
Fe-10	Stohge Ls	4400	140	15	40	12	7

a. Composite chip samples ground to 100 mesh; 0.5 g digested in 20 ml of 1:1 HCL for 30 min., filtered, diluted to 100 ml, and analyzed by atomic absorption by A. W. Rose.

b. L. S. = Lower Sandy Mbr., Gatesburg Fm; O. H. = Ore Hill Mbr., Gatesburg Fm.; U. S. = Upper Sandy Mbr., Gatesburg Fm.; Stohge Ls = Stonehenge Ls.

25% limonite fragments containing 50% Fe (72% Fe₂O₃), then 100 to 250 m of rock must be weathered to furnish the ore, if all Fe remains in the weathered zone. Although 250 m is a lot of rock, the Gatesburg Fm. is about 500 m thick, and the total carbonate section is many times this thickness. Based on this crude estimate, it appears that the amount of Fe available is very adequate. The problem of source is further relieved if some lateral Fe transport toward local sinkholes occurs during weathering, as discussed later.

The proportion of sandstone in the Gatesburg Fm. has been estimated as 10% (Butts, 1939) and 14 to 30% (Wilson, 1952 as cited in Landon, 1963). Based on these figures and the percentages of insoluble residue shown in Table 4, the insoluble residue contains about 2 to 3% Fe. Compared to the estimated 5 to 12% Fe in the wash ore, some selective removal of SiO₂ and Al₂O₃ relative to Fe is evidently needed, but the amount of leaching seems within reason.

Parizek and White (1985, p.103) cite drillhole data indicating about 7% insoluble residue in the Gatesburg Fm., and use this figure to estimate that the 50 m of sand and clay residue observed above bedrock in drillholes near State College required the weathering of 430 m of rock. Based on the solute content of karst drainage, the dissolution of this much carbonate rock would require about 15 my, or the period since Miocene time, which is compatible with the geomorphic history inferred earlier. Based on this reasoning, it appears that the source for most or all of the limonite ore was Fe contained within normal carbonate-rich bedrocks that were leached to make the deep weathered zone within which the iron occurs.

Process of Concentration

The major part of the concentration of Fe evidently occurred by dissolution of dolomite and calcite making up the Gatesburg Fm. and the Ordovician limestone-dolomite sequence. The Fe (along with Al and other insoluble constituents) would be enriched by a factor of 5 to 10 by removal of the carbonate.

In addition to this enrichment, Fe has been separated from the clays and quartz, and redeposited at depth in the weathered zone, or in the case of the pipe ore, within bedrock. How has this separation occurred? As is well known, Fe^{2+} is highly soluble, but Fe^{3+} is insoluble except at pH values less than 2. Yet weathering zones are generally expected to be relatively oxidizing, especially above the water table where air fills part of the pore space. If the Fe separation is to occur by weathering, it is necessary to dissolve it near the surface (in a reducing environment?) and to precipitate it at depth by oxidizing the Fe^{2+} to Fe^{3+} .

A possible solution to this problem is suggested by the present-day hydrology of the Gatesburg Fm. The true water table lies 100 m or more beneath the surface in many areas (Landon, 1963). For example, a well adjacent to the Scotia pit shows a water table at an elevation of about 1000 ft., compared to a surface elevation of 1320 ft. at the drillhole and over 1400 ft. only about 1500 ft. to the north. However, numerous shallow ponds dot the surface overlying the Gatesburg Fm., and many of the old iron ore pits are filled with water. Evidently the ponds and water-filled pits represent perched water tables (Figure 4). Shallow sinkholes are extensively developed in areas underlain by the Gatesburg Fm. and are common in the areas underlain by Ordovician dolomite and limestone. The ponds fill sinkholes developed by dissolution of the underlying carbonate rocks. The presence of appreciable clay in the insoluble residue from the limestone may lead to sinkholes floored by clay-rich residue that result in perched water tables.

The ponds and some of the sinkholes are occupied by abundant organic matter. Water seeping slowly downward through the bottom or sides of the ponds would be expected to be reducing, and could dissolve Fe from the upper part of the weathered zone. Deeper in the weathered zone, where the weathered sandy material is unsaturated, and in cracks and solution opening in the limestone bedrock, conditions are expected to be oxidizing, owing to diffusion of oxygen through the unsaturated zone from areas not occupied by ponds and lateral convection of oxygenated groundwater. In these zones the Fe would be oxidized to Fe^{3+} and precipitate as limonite, to form the pipe ore and perhaps some of the lump ore. This deposition could easily occur as botryoidal coatings on the walls of fractures in the bedrock, or on the surfaces of blocks in zones that have collapsed due to dissolution of underly-

ing caverns. Complexing of Fe by organic ligands originating in the ponds or soil also is a possibility. The passage through a deep oxidizing, unsaturated zone would be expected to decompose the organic ligands and lead to limonite deposition.

Given that numerous sinkholes have been developed in the carbonate terrane of the region, it is expected that clay, sand, and residual material would creep laterally toward the sinkholes, where it would be subjected to very thorough leaching and concentration of insoluble constituents (Fe and Al). The Fe might be expected to be precipitated as the limonite crusts in the subsurface. Observations of streams in caves of the region suggest that some of the clay may be physically transported out of the unsaturated zone in the form of colloidal particles. Thus, some clay is left in the weathered zone and some is transported out, but Fe is precipitated in the lower, aerated part of the weathered zone. As this process continues over millions of years, the deep limestone and dolomite coated with limonite is in turn dissolved. The limonite breaks into lumps and small fragments mixed with the clay and sand residue, thus accounting for the fragmental appearance of the limonite.

Factors Involved in Origin of the Ores

The following factors are regarded as contributing to the development of the ores:

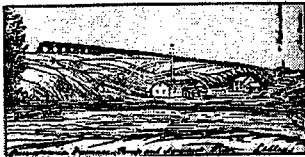
1. An extensive section of carbonate rocks with a low but significant Fe content.
2. The folding of the carbonates and erosion to a surface approximately coinciding with the present ridge tops by about Cretaceous time, followed by uplift and slow physical erosion over millions of years to form the limestone valleys. This history allowed a very long period of slow physical erosion during which chemical processes were active in the carbonate rocks.
3. The accumulation of residual sand and clay, especially over the Gatesburg Fm., that left the surface as a low ridge dotted with ponds and sinkholes, and subsurface karst drainage through sinkholes in the areas of Ordovician limestone and dolomite.
4. The development of decaying organic matter in perched ponds and sinkhole bottoms, so that water in the shallow weathered zones was chemically reducing and capable of dissolving Fe.
5. A deep water table, so that the deeper unsaturated zone was oxidizing, leading to precipitation of limonite.
6. A long period of weathering, so that limonite deposited at depth in the bedrock solution cavities during an early period became freed of its carbonate wallrock owing to continued dissolution.

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7. Lateral transport of weathered material by creep toward sinkholes and ponds, where flow of water was concentrated and extreme leaching and (at depth) Fe precipitation occurred.

CONCLUSIONS

The limonite deposits of the Nittany Valley are residues of a long period of weathering under conditions that have optimized the enrichment of iron in portions of the weathering zone. The main source of iron was the small amount contained in normal dolomite and dolomitic sandstone, though slightly enriched sources may have existed for a few deposits. Separation of iron from aluminum was promoted by the development of perched water tables that led to organic-rich pond water percolating slowly through the weathered zone, followed by oxidizing conditions at greater depth in the very thick unsaturated zone. Channeling of flow through the unsaturated zone, with lateral transport toward sinkholes and intensified leaching, was probably promoted by the karstic nature of the drainage.

FIELD TRIP LOG AND STOP DESCRIPTIONS



LEADERS: Arthur W. Rose, David. P. Gold, and
Rudy Slingerland

INTRODUCTION

The setting for the field trip is Nittany Valley, a broad north-northeast trending valley some 8 to 10 miles across, flanked by Bald Eagle Ridge to the northwest, separating Nittany Valley from Bald Eagle Valley, and Tussy Ridge/Seven Mountains to the southeast. Bald Eagle Valley is the last major valley of the Valley and Ridge Physiographic Province in the Appalachian Fold Mountain Belt. This field trip will examine iron ore deposits in Nittany Valley and visit a restored smelter/foundry at Curtin Village in Bald Eagle Valley.

Nittany Valley is comprised of a breached, doubly plunging, 1st order anticline, that exposes Cambrian and Ordovician carbonate units in its core. As discussed in Chapter 3, these carbonate units are approximately 1950 m thick (see Figure 2). The surrounding ridges are underlain by the more competent clastic units of Upper Ordovician and Lower Silurian age. These include the Reedsville Shale, Bald Eagle (Oswego) Sandstone, Juniata Fm., and Tuscarora Fm. The Seven Mountains region represents the eroded remnants of a synclinorium (see Figure 3B).

The presence of five 2nd order (1 to 3.5 km wavelength) folds in the core of the Nittany anticline ensures that the C-O carbonate units are both widespread and over-represented in the outcrop pattern of the breached valley floor (see Plate I and Figure 3).

Clays (kaolinitic and bauxitic) and iron ores (limonite and goethite) developed on the carbonate units were exploited in Nittany Valley as recently as 1955 (clays) and 1942 (iron ores). Both are supergene in origin and are associated with either residual soils and laterite formed over dominantly dolomitic rocks in a karstic environment, or with the leaching of local feldspar-rich sandstones in both regional and local perched water tables. Although most of the ores were mined from open pits, rarely more than 50 feet deep, some shallow underground operations were attempted. Iron ore production peaked during the early to mid-1800's, and most operations had ceased by 1914. This field trip focuses on the iron ores and the industry established to exploit them.

ROAD LOG

The field trip road log is organized for an 8 a. m. departure from the main entrance of Scanticon Conference Center, lunch from 11:30 a.m., to 1:00 p.m at Curtin Village, and a return to Scanticon at 1:30 p.m. A geologic and topographic map of the field trip region is included as Plate I. Distances below are in miles.

Interval Cumulative

0.0 miles 0.0 miles Assemble at Scanticon at 8:00 a.m.
Drive east on Park Avenue 0.25 miles

STOP 1: OVERVIEW OF NITTANY VALLEY (do not disembark).

THEME: Karst topography, breached anticlines and scale of folds. In this region folds with wavelengths of 10 to 18 km are considered to be 1st order, 1.6 to 3.5 km are 2nd order, < 800 m are 3rd order, up to 10's of meters are 4th order, and microscopic to hand specimen size are 5th order folds (Nickelsen, 1963). This is a good vantage point from which to view Nittany Mountain, a local ridge that peaks at 2070 feet (610 m) and has general relief of 1000 feet (305 m). It represents the axis of a 2nd order syncline in the broad valley of a breached 1st order anticline (the Nittany arch) that preserves shale, siltstone, and sandstone units of Upper Ordovician and Lower Silurian age. The country around us is the typical rolling, underdrained topography of karst terrains, with few streams, many sags, and local sink-holes.

ROAD LOG

		Continue on Park Avenue to east.
0.9	0.9	Hospital on left.
0.2	1.1	View of the Penn State Football stadium ahead. This stadium has a seating capacity of 97,000.
0.3	1.4	Horticultural Show Building on left.
0.1	1.5	Intersection with Fox Hollow Road.
0.1	1.6	<i>Note the sinkhole approximately midway between Park Avenue and the Stadium.</i>
0.6	2.2	Bigler Road intersection.
0.2	2.4	Shortledge Road intersection. State College on the right; University Park to left.
0.3	2.7	Allen Street intersection.
0.3	3.0	Left onto Atherton Street (Route 322). Nittany Lion Inn on left; Penn State Golf Courses on right.
0.4	3.4	Walker Building of Earth & Mineral Sciences College on left; old railroad station (now bus depot) on right.
0.1	3.5	Right onto College Avenue (Route 26 S).
0.9	4.4	<i>Old Struble Iron Bank in trees 150 m to the right.</i>
0.1	4.5	Entrance to Penn State's Blue Golf Course.
0.5	5.0	Veer right onto Pine Hall Road.
0.4	5.4	Turn right onto Science Park Road
0.5	5.9	Turn left onto Old Gatesburg Road.
0.5	6.4	<i>Note the karst topography with ponds and shallow depressions.</i>
0.3	6.7	<i>Trees on the left mark the former railroad bed; the low wooded ridge to the right is underlain by the Gatesburg Formation.</i>
0.6	7.3	Left onto Nixon Road.
1.6	8.9	Cross Whitehall Road. <i>(Old iron ore pit in wooded area 400 m to left).</i>
1.1	10.0	<i>Sinkhole on left behind trailer house captures the water from the stream out of Pine Grove Mills Gap.</i>
0.1	10.1	Right on Route 45 W (Pine Grove Mills Road)
2.0	12.1	<i>Sinkhole 15 m to left of road, opposite white barn.</i>
0.5	12.6	Note the experimental plots on the Penn State University farm.
2.3	14.9	The source for Spruce Creek is at Walker Spring, approximately 400 m to the southeast.

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- | | | |
|------|-------|------------------------------------------------------------------------------------|
| 0.8 | 15.7 | Turn right to Fairbrook, on Deibier Road. |
| 0.3 | 16.0 | Cross Whitehall Road. |
| 0.25 | 16.25 | Turn right onto dirt road, and follow tracks for 0.2 miles into old mine workings. |

STOP 2: PENNSYLVANIA FURNACE ORE BANK

THEME: Transgressive nature of the supergene "iron ore" deposits across the inclined beds of the Mines, Stonehenge, and Nittany Formations on the southeast limb of the Pennsylvania Furnace anticline, a 2nd order fold.

Disembark from vehicles, and walk down into the pits to the east. This was the site of the Baileyville Mines. You have approximately 45 minutes to examine the old workings and collect samples.

This stop is in the abandoned diggings which supplied the Pennsylvania Furnace with much of its ore. The furnace remains are located about 400 yards to the southwest. As seen in Plate I, the ore body lies at the contact between the Mines Member of the Cambrian Gatesburg Fm. and the Ordovician Stonehenge Fm. The rocks cropping out in the quarry are Stonehenge limestones, here dipping 35 to 40° to the southeast. The ore here is of the type called "pipe ore" by the early workers because it occurs between walls of regularly bedded limestones as thin shells or large pipes up to 10 feet thick, mixed with a white or buff-colored clay.

In 1873 this mine was visited by P. J. Lesley of the 2nd Pennsylvania Survey whose account in the American Philosophical Transactions (Lesley, 1874) is still the best description we can offer:

"For about fifty-eight (58) years Pennsylvania Furnace has been supplied with its stock from the extensive excavations on the gently-sloping south side of the anticlinal ridge facing Tussey Mountain; Spruce Creek, above the Furnace, flowing between the ridge and the mountain. See location map (Figure 5, this guidebook) in lieu of further description; and the landscape sketches of the excavations, to illustrate their extent and character (Figure 6, this guidebook).

"The geologist can here study the theory of the formation of the... brown-hematite ores of Pennsylvania to great advantage. I know no better place, and few so good.

"The ores are evidently not washings from a distance; neither from Tussey Mountain, nor from the present surface of the anticlinal ridge; nor from any formerly existing surface in past geological ages, when the surface stood at a much higher elevation above sea level. They are evidently and visibly interstratified with the soft

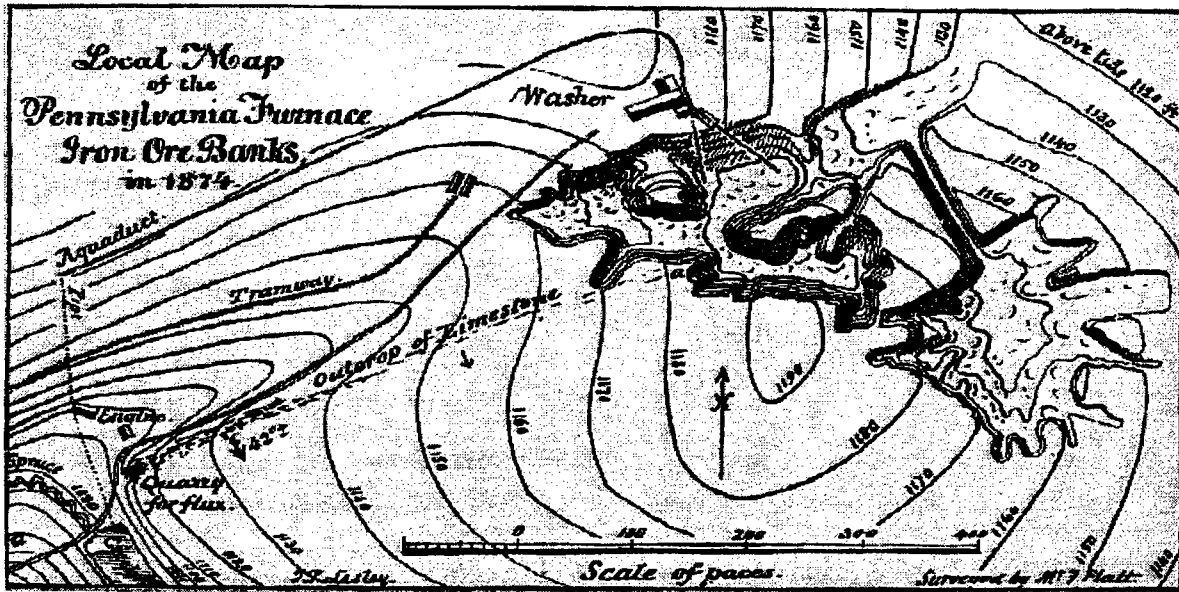


FIGURE 5. Location map of the Pennsylvania Furnace Ore Banks (from Lesley, 1874)

clay and solid limestone layers, and obey the strike and dip of the country; the strike being along the valley, and the dip about 40° towards the southeast.

“Thousands of minor irregularities prevail; the streaks of ore and masses of clay, are wrinkled and bunched, and thin out and thicken again in various directions. But all this irregularity is owing to the chemical changes of the strata, and to the changes in bulk of the different layers during the protracted process of solution and dissolution, during which the looser calciferous and ferriferous sandstone layers have lost their lime constituent, packed their sand and clay more solidly, and perhydrated their iron. In this long process cleavage-planes have been widened into crevices; caverns have been excavated; pools or vats have been created; precipitates of massive (rock and pipe) ore have been thrown down; and a general creeping and wrinkling of the country been effected. But the original general arrangement or stratification has been preserved; and those portions of the whole formation, which had but little lime, have been left standing as sandstone strata; while others having but little sand remain as solid and massive limestone strata; those which had an excess of alumina are now in the condition of streaks, masses, or layers of white or

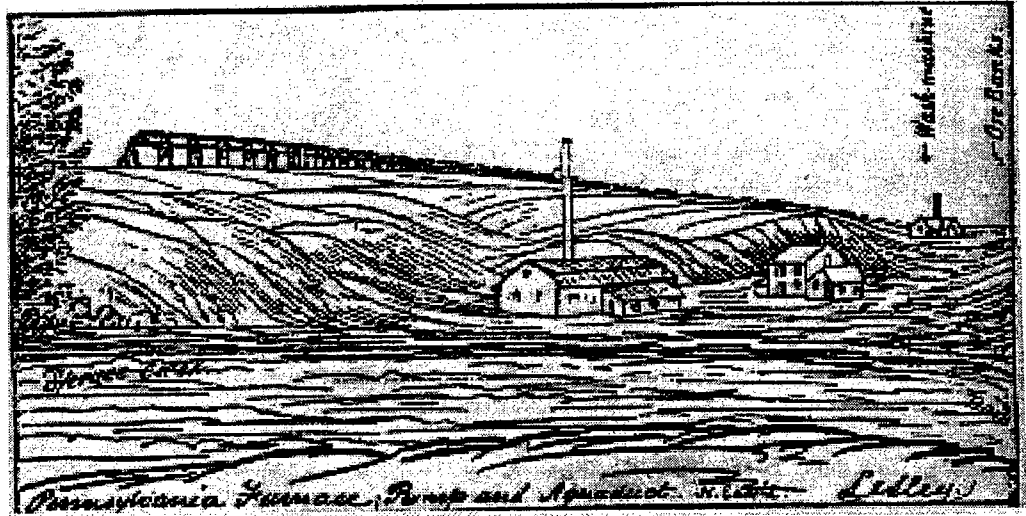


FIGURE 6. Pennsylvania Furnace aqueduct for washing ore (from Lesley, 1874)

mottled clays; and only such as were properly constituted clay-sand-lime-iron deposits originally have so completely dissolved as to permit the lime to flow off, and the iron to consolidate into ore.

“Every stage of this interesting operation, and every phase which it presents in other parts of the Appalachian belt of the United States, from Canada to Alabama, may be seen and studied in these old and extensive ore banks of Pennsylvania Furnace.

“At first sight of the bank the ore deposit looks as if it were a grand wash or swash of mingled clay and fine and coarse ore grains and balls, occupying hollows, caverns and crevices in the surface of the earth and between the solid limestone rock; and some of it undoubtedly has been thus carried down into the enlarged cleavage partings of the limestones; and into sink holes and caverns formed by water courses; where it now lies, or lay when excavated, banked up against walls or faces of the undecomposed lime rocks. But as a whole the ore streaks and “main vein” of ore must occupy nearly the same position originally occupied by the more ferruginous strata after they had got their dip and strike....

ROAD LOG

"The ore is taken out with the clay, and hauled up an incline, by means of a stationary steam engine at its head, and dumped into a large washing machine with revolving screens; whence after the flints and sand stones have been picked out, it is carried on an iron tramway, to the bridge house of the Furnace.

"The ore forms from 10 to 50 per cent. of the mass excavated, and the small amount of handling makes the ore cheap.

"The floor of the excavation is about sixty (60) feet below the level of the washing machine.

"Shafts sunk from 30 to 35 foot deeper, in the floor, to a permanent water level have shown that other and even better ore deposits underlie the workings, covered by the slanting undecomposed lime rocks. This is an additional demonstration of the correctness of the theory above stated.

"The upper ores will furnish stock for yet many years. After that, or in case more furnaces be erected, or distant markets call for the shipment of ore by railway, deep shafts or bore holes must be sunk to drain the underground, and the lower ores may then be lifted to an extent which can hardly be estimated now.

"The prism of ore *in sight*, technically speaking, if calculated roughly from the areas exposed by the old and new open cuts, and by shafts sunk at various times and in various parts of the floor, gives several millions of wash-ore, lump-ore and pipe or rock ore. Thus taking the area exposed at say 550 x 450 yards, and the depth at only 15 yards, we have 3,612,500 cubic yards, which on washing would yield 602,000 tons of prepared ore.

"Of this, about 100,000 tons have been passed through the furnace, yielding nearly 50,000 tons of neutral cold blast charcoal iron of the best quality, leaving 500,000 tons of ore to be excavated.

"But this is only a portion of the deposit; for the ore ranges away beyond the high walls of the open cuts into the surrounding land an unknown distance. The large area stripped last year towards the northeast shows how extensive the deposit is in that direction.

"Add to this the great depths to which the ore is known to descend, and it seems to me certain that a million of tons is as probable an estimate as a half a million. Large quantities of ore are left standing between the hard limestone ledges exhibited in Figure 7 (this guidebook)... The dip of these limestones is to the S. 35°, E. > 35° to

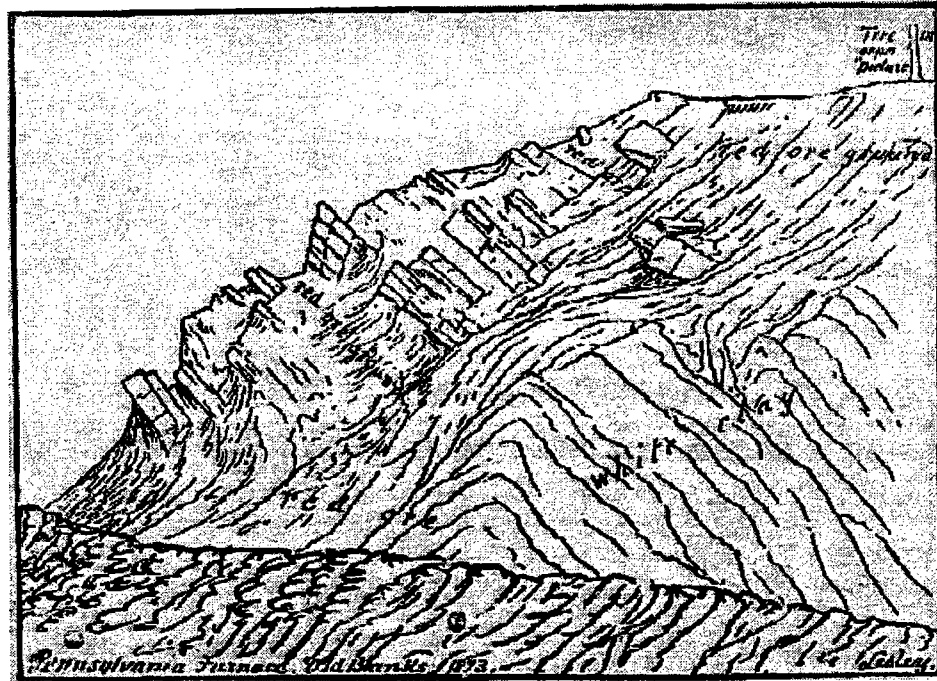


FIGURE 7. View of mine wall from point a in Figure 5 as sketched by Lesley (1874), showing ore intercalated with Stonehenge Ls.

40°; and they are exactly on range with the limestone outcrop along the road, at the quarry, and past the Furnace, as shown in Figure 5 (this guidebook). Slight crumplings of the limestone dip from 18° to 65°; but these are due either to movements in the yielding ore mass or to a deception caused by mistaking cleavage planes for bed plates. No such variations are apparent at a distance from the banks, the whole limestone formation descending uniformly beneath the foot of Tussey Mountain with a dip of something under 40°.....

“The entire walls of the cuts are of wash ore, and it is all torn down and taken to the washing machine. But the tops of pyramids of solid pipe ore are exposed in the floor, and some reached to, or nearly to the sod above. At one of the deepest places

ROAD LOG

the floor, 60 feet below the sod, a shaft was sunk 40 feet further through solid pipe ore, and then limestone, and was stopped by water. Water does not stand in the present floors on account of the free circulation, at a still lower depth, through crevices and caverns communicating with Spruce Creek, which itself issues from a cave.

“The books at the Furnace show as an average for some years, 6 tons of wash ore to 1 ton of ore; 2 tons 1 cwt. of ore to 1 ton of iron; and \$2.25 per ton of ore delivered at the Furnace, represents the cost of mining, inclusive of all expenses. I shall give in an appendix, the opinion of Mr. Harden on some practical points which I requested him to study, for which purpose he visited some of the Banks described above.

- 16.45 Return to vehicles, and retrace route to the county road.
0.2 16.65 Left on Diebier Road.
0.25 16.9 Right onto Whitehall Road.
0.2 17.1 Turn right onto Johnson Road, opposite Post Office.
0.15 17.25 Bend in road; follow valley to southwest. *The southeast dipping limestones exposed in the road-cut are part of the Stonehenge Formation. Ore from the Baileyville Mines was transported by rail approximately one half mile down this valley to the furnace.*
0.45 17.7

STOP 3: REMNANTS OF THE PENNSYLVANIA FURNACE (do not disembark)

Furnace remnants can be seen 10 m to the right, across the stream. Slag was taken by rail downstream, and dumped near the site of the dam.

- 0.15 17.85 Left at intersection
0.05 17.9 Ironmaster's house on the right. They were important businessmen in these early communities, and the quality of their homes reflected their stature.
0.15 18.05 Turn right onto Route 45. The wooded ridge to the right is underlain by cycles of dolostones and sandstones of the Gatesburg Formation.
1.65 19.7 Graysville Church. Note dipping beds of limestones (Stonehenge) and dolostones (Nittany Formation) in the road-cuts.
3.6 23.3 Turn right (west), at Seven Stars intersection, and follow Route 350 N (Truck Route 45) into Warriors Mark.

THEME: As we drive northwest to Warriors Mark we will successively cross 2nd order folds exposed in the core of the Nittany Anticlinorium. They are the Pennsylvania Furnace, Gatesburg, and Birmingham anticlines, with the intervening Hostler, and Marengo synclines. The erosion level in the breached 1st order anticline exposes the Upper Cambrian and Lower Ordovician Formations over much of Nittany Valley.

- | | | |
|-----|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.0 | 24.3 | <i>Axis of Pennsylvania Furnace anticline.</i> |
| 0.4 | 24.7 | <i>Road junction to Huntingdon Furnace. Continue on Route 350 N.</i> |
| 0.7 | 25.4 | <i>Iron ore pits on right, along the axis of the Hostler Syncline</i> |
| 1.0 | 26.4 | <i>Warrior Limestone exposed in road-cuts, near axis of Gatesburg anticline.</i> |
| 0.6 | 27.0 | <i>Bridge, on outskirts of Warriors Mark.</i> |
| 0.7 | 27.7 | <i>Turn left onto Route 550 S in Warriors Mark. Iron ore pits were located near the road.</i> |
| 0.6 | 28.3 | <i>Cross over former railroad bed; old iron ore pits approximately 200 m to the right.</i> |
| 0.9 | 29.2 | <i>There are a number of test pits for iron ore in the wooded area to the left.</i> |
| 0.2 | 29.4 | <i>Turn left on abandoned railroad bed, opposite the Baptist Bible Church.</i> |
| 0.1 | 29.5 | <i>Drive along old railroad bed for 0.1 mile and park in clearing.
Disembark from vehicles, and walk through woods 60 m to east, into a large trench of the abandoned Pennington Mine.</i> |

STOP 4: THE PENNINGTON MINE

THEME: This stop exposes the second principle ore type, "wash-ore", consisting of "wash deposits, caught in vast caverns, of irregular shape, showing mixed sand, tough clay, and rolled ore..." (D'Inwilliers, 1884, p. 134). This ore type is restricted to a region called the "barrens", because of its scrub oak forests, now known to be underlain by the sandy dolomites of the Gatesburg Fm. At this site the ore overlies the Upper Sandy Member.

You have approximately 45 minutes to examine old workings and collect samples. P. J. Lesley also visited this mine and provides the following description (Lesley, 1874):

"The Pennington Range proper consists of a line of outcrops commencing about two miles from the Juniata River, and extending two miles to the railroad, a mile west of Warrior's Mark Village. The northwest face of Pennington Ridge is covered

with wash-ore to a variable depth, below which lie sheets, belts, and masses of ore rock, between ribs of still undissolved siliceous limerock. The more argillaceous lime beds have left intercalated sheets of white clay.

“The Old or East Pennington Bank, supplied Bald Eagle Furnace with stock for many years. The ore was hauled about four miles over the mountain. It was chiefly got from the large open-cut shown in...Figure 8 (this guidebook); but also from

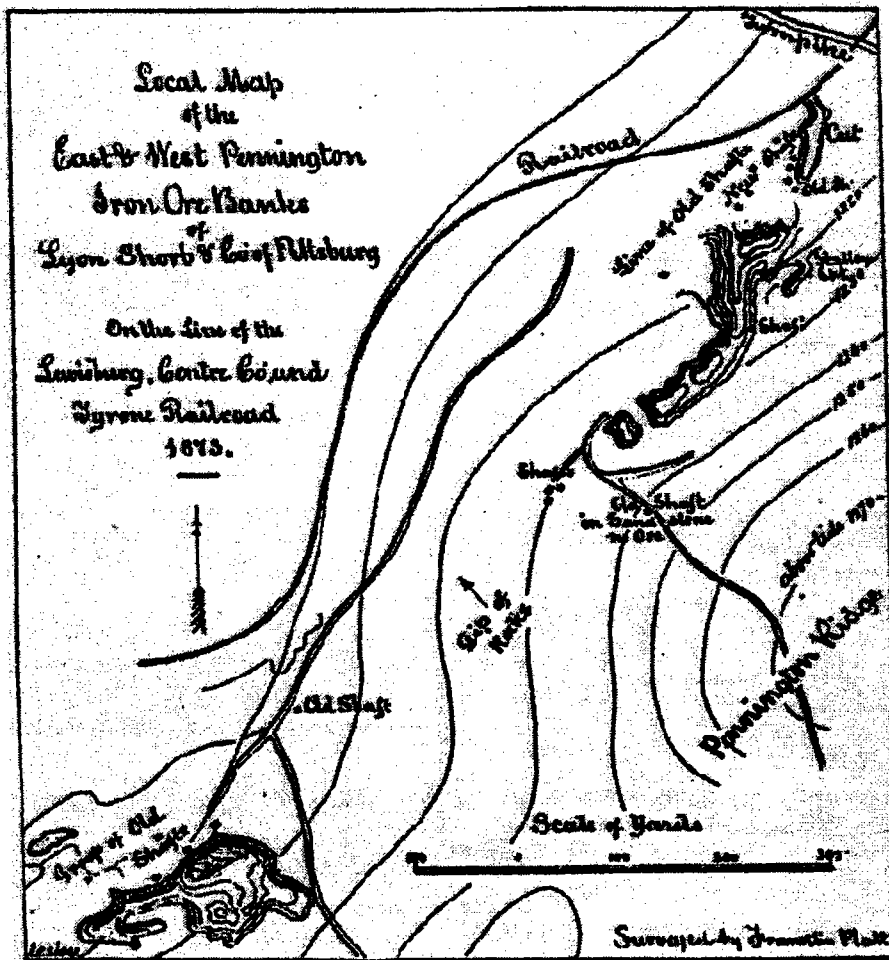


FIGURE 8. Pennington mine workings (from Lesley, 1874).

underground gangways following the ore down the dip (N. W.) beneath a clay covering; and from shafts sunk on that side, tunnels or rooms being driven from the bottoms of the shafts irregularly in every direction at the caprice of uneducated miners, who groped always in the dark, without correct geological ideas to guide them, following what they imagined to be the thickest beds and belts of the best ore, and leaving all the rest to stand and be covered up again by the annual tumbling in of their shallow works. Most of these miners were Irish laborers paid by the ton. Water invariably stopped them, and limited the range of workings to a comparatively narrow belt down hill. The great deposits of ore unquestionably lying to the deep (N. W.) are unexplored. Neither maps nor notes of the old works exist.

"Figure 9 (this guidebook) is a reduced copy of maps made by Mr. H. V. Böcking, mining manager of the Company, to show the position of shafts and direction of tunnels executed under his direction, in a more systematic way.

"At the east end of the Old Bank, Mr. Böcking did much sinking on lower ground. One old shaft which had been abandoned at the depth of 30 feet on account of water, he sunk 30 feet deeper to the sandstone floor of the ore, which drained the mine. A cross-cut from this shaft 75 feet long struck the ore descending (N. W.) but where it was nearly level. Galleries were then driven and much ore won in an irregular way. But the heavy spring rains of 1857 filled the works to the top of the shaft. At this time the large deposit at McAtear's (West Pennington) Bank was discovered. In 1865 a new shaft was sunk, in a dry season, a little north of the caved-in works, reaching the bottom of the ore at 45 feet. The shaft was 60 feet deep, and a steam-pump kept it dry by two or three hours work a day. A good vein of ore had been abandoned (on account of water) in a smaller open cut, near the last mentioned shaft, with only 3 or 4 feet of dirt covering the ore.

"That the rich deposits of ore in the old open cut pass down northwestward, in irregular but continuous floors and layers between the clays, was proven by galleries driven by Mr. Böcking west from the pump-shaft, see Figure 9 (this guidebook). He describes these galleries as driven in wavy ore, meeting several good bodies of ore. No pillar mining was done, as the sinkings were merely tentative.

"In all this no account is made of anything but the better streaks of hard lump or rock ore, which alone a small charcoal furnace is willing to smelt. Great quantities of saleable ore and wash-ore are ignored.

"My assistant, Mr. Franklin Platt, obtained the following information on the ground while making his map:-- Beginning at the Railroad, the first and smaller pit (now filled with water) 70 yards long, by 15 wide and 5 deep, yielded about 5000 cubic

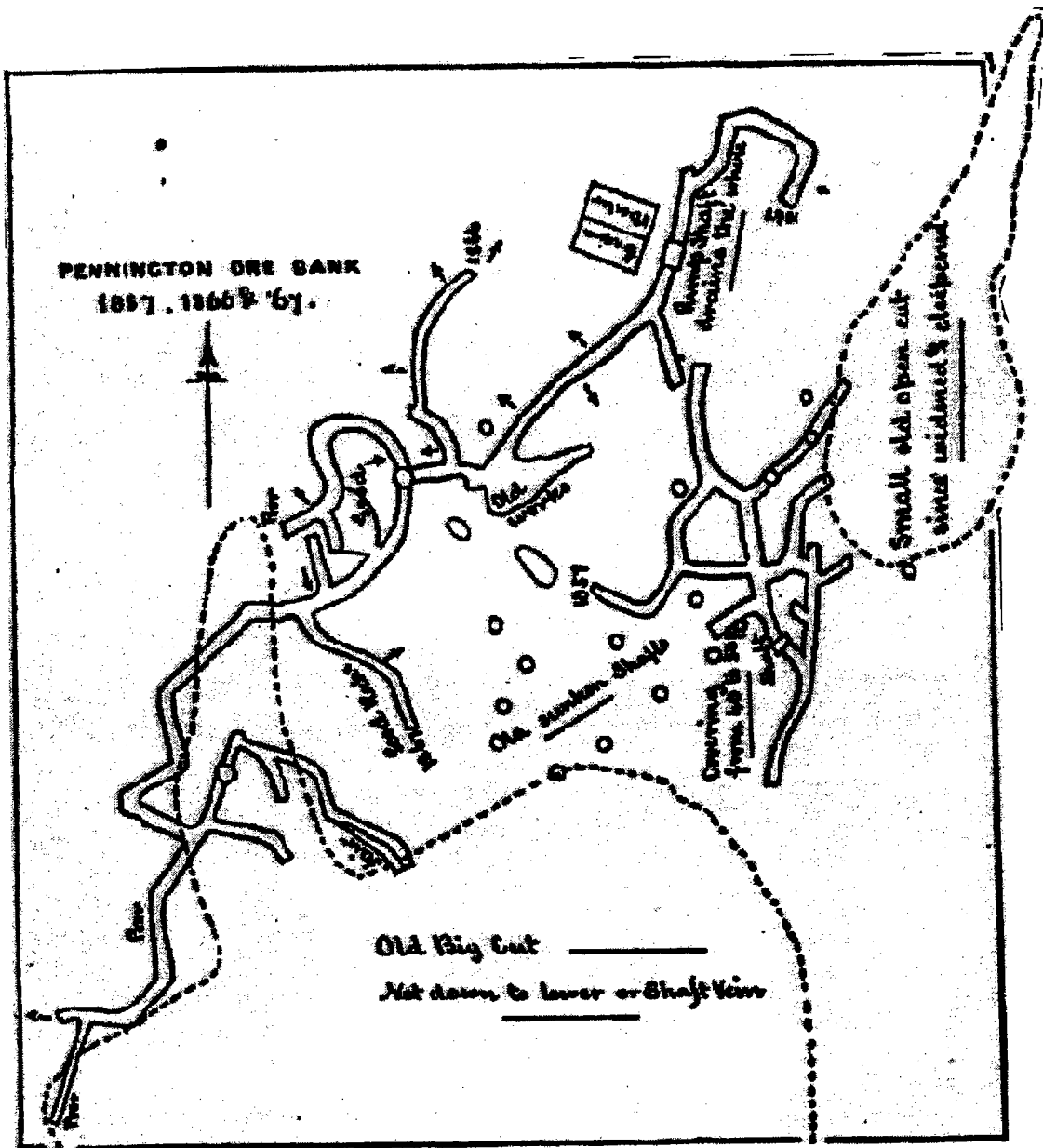


FIGURE 9. Pennington mine workings (from Lesley, 1874).

yards of wash-ore, without any solid lump ore. Shaft No. 1, sunk near it, (N. W.) is said to have passed through

1. Top wash-ore..... 15 feet.
2. Rich lump-ore..... 5
3. Clay with little or no ore..... 25
4. Good lump-ore..... 15

the bottom not reported. Shaft No. 2, (W.) had lean wash-ore on top; clay to 40 feet; good lump-ore thence to bottom at 50 feet.

“The main open cut is 230 yards long, with an average width of 35 yards, as shown in fig. 8; depth from 5 to 8 yards. Wash-ore, sometimes lean, forms the wall of the pit, from the surface to an apparent depth of 15 feet. A shaft midway of the eastern edge, “struck a layer of ferro-manganese ore, 5 feet thick, at a depth of 15 feet.” Two-thirds of the distance from the southern to the northern end of the pit, a massive crop of half decomposed calciferous sandrock charged with more or less of ore, juts from the wall, dipping gently northwest. Some of this rock is genuine iron-ore; the rest ferriferous or merely ferruginous sandrock. The excavated ore lay over, under, and around this rock, having been freed from other similarly dipping, but more ferriferous and more dissoluble strata. It is a place where the genesis of our brown hematites may be studied to advantage.

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|------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.1 | 29.6 | Return to vehicles, and retrace route to the highway, and turn left on Route 550 S. |
| 2.2 | 31.8 | Note abandoned railroads bed on left. |
| 0.65 | 32.45 | Note the abandoned lime workings on left. |
| 0.65 | 33.1 | <i>Entrance to the Narehood Quarry of The New Enterprise Stone and Lime Company. This is a large operation that produces crushed dolostone (Bellefonte Formation) for aggregate, and some limestone (Loysburg to Nealmont Formations) for co-generation power plants.</i> |
| 0.6 | 33.7 | Junction with Route 453. Turn right (northwest). |
| 0.3 | 34.0 | The steeply dipping red shales, siltstones and sandstones, exposed in the road-cuts are part of the Juniata Formation. |

THEME: *The narrows we are passing through exposes the more competent units in the northwest limb of the Nittany Anticlinorium. These Upper Ordovician and Lower Silurian clastic units underlie Bald Eagle Ridge. A thrust fault from the core*

ROAD LOG

of the 2nd order Birmingham anticline, cause a westward vergence to the 1st order anticline, and the beds are overturned (see Plate I). The strike valley we will drive into is Bald Eagle Valley, the last valley of the Ridge and Valley Physiographic Province. The ridge to the northwest, marks the eastern limit of the Allegheny Plateau Physiographic Province, and represents more than 5000 m of stratigraphic thickness between the units exposed on the ridge crests across the valley. The structural boundary between these two physiographic provinces is known as the Allegheny Front, and is a prominent lineament on regional magnetic and gravity maps. The units exposed in the foothill of the Allegheny Plateau, represent a coarsening upward sequence of clastic sedimentary rocks deposited from a prograding deltaic shoreline of late Devonian age.

- | | | |
|------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.4 | 34.4 | Turn right (northeast) onto Route 220 N. Village of Tyrone to the left. |
| 3.4 | 37.8 | <i>Steeply dipping fossiliferous sandstone of the Helderburg Fm. exposed in road-cut.</i> |
| 0.6 | 38.4 | <i>A landslide at this locality displaced the concrete road-bed more than 25 cm and delayed the opening of the highway. A flexible, black top road bed was constructed to accommodate further displacement along this fracture trace.</i> |
| 0.7 | 39.1 | Turn right at traffic light in Bald Eagle onto old U.S Route 220. |
| 5.9 | 45.0 | We have crossed the drainage divide. Note the northeasterly flow of Bald Eagle Creek. |
| 2.95 | 47.95 | Village of Port Matilda. (The nautical flavor to some of the town reflects its linkage to canals and the use of barges for 19th century transportation). |
| 2.95 | 50.9 | Route 322 interchange for State College. Continue on Route 220 N. |
| 4.7 | 55.6 | Village of Julian. |
| 2.3 | 57.9 | Gliderport on right. Record distance flights have been made from here, using the updrafts of the Bald Eagle Ridge and Allegheny Front. |
| 2.2 | 60.1 | Village of Unionville. |
| 3.8 | 63.9 | Junction with Route 144, to Wingate. |
| 1.5 | 65.4 | Junction with Route 144, to Bellefonte. |
| 1.0 | 66.4 | Merge with Route 150 N. |
| 0.3 | 66.7 | Underpass with Route I-80. |
| 2.1 | 68.8 | Turn right to Curtin Village. |
| 0.3 | 69.1 | Disembark in parking lot of Curtin Village. |

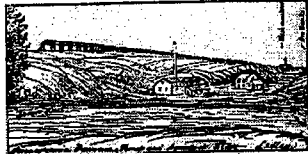
STOP 5. IRONMASTER'S HOUSE AND FOUNDRY AT CURTIN VILLAGE

THEME: *Processing of the iron ores from Nittany Valley.*

Lunch will be served in the refractory of the historic smelter and foundry. Guides will be available to show you the house and foundry. You will have 90 minutes for lunch and tours.

		Return to vehicles. Drive east on Curtin Village Road.
0.5	69.6	Turn right at intersection, onto Water Street (unmarked).
0.9	70.5	Underpass, beneath Route I-80.
2.1	72.6	Turn left (east) at junction with Routes 144 and 150, in Milesburg.
1.0	73.6	<i>Milesburg Gap where you will again cross the competent clastic units of the northwest limb of Nittany Anticlinorium. Note the steep to overturned dip to the beds.</i>
1.1	74.7	Right on Pa. Route 150 S, to Bellefonte.
0.4	75.1	Downtown Bellefonte.
0.2	75.3	<i>Eye of the big spring from which Bellefonte derives its name. This spring has a steady flow of more than 14,000,000 gallons of water a day. The chemistry of the spring water is more consistent with a Gatesburg source than the other carbonate units in Nittany Valley.</i>
0.4	75.7 *	Junction with Route 550 S. Stay on Route 150 S.
3.5	79.2	State Penitentiary on left.
3.4	82.6	Houserville Road intersection.
0.6	83.2	Turn right onto 322 Bypass.
1.0	84.2	Exit ramp to Research Park.
0.3	84.5	Turn right onto Park Avenue at intersection.
0.5	85.0	Penn State Scanticon. End of Field Trip.

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