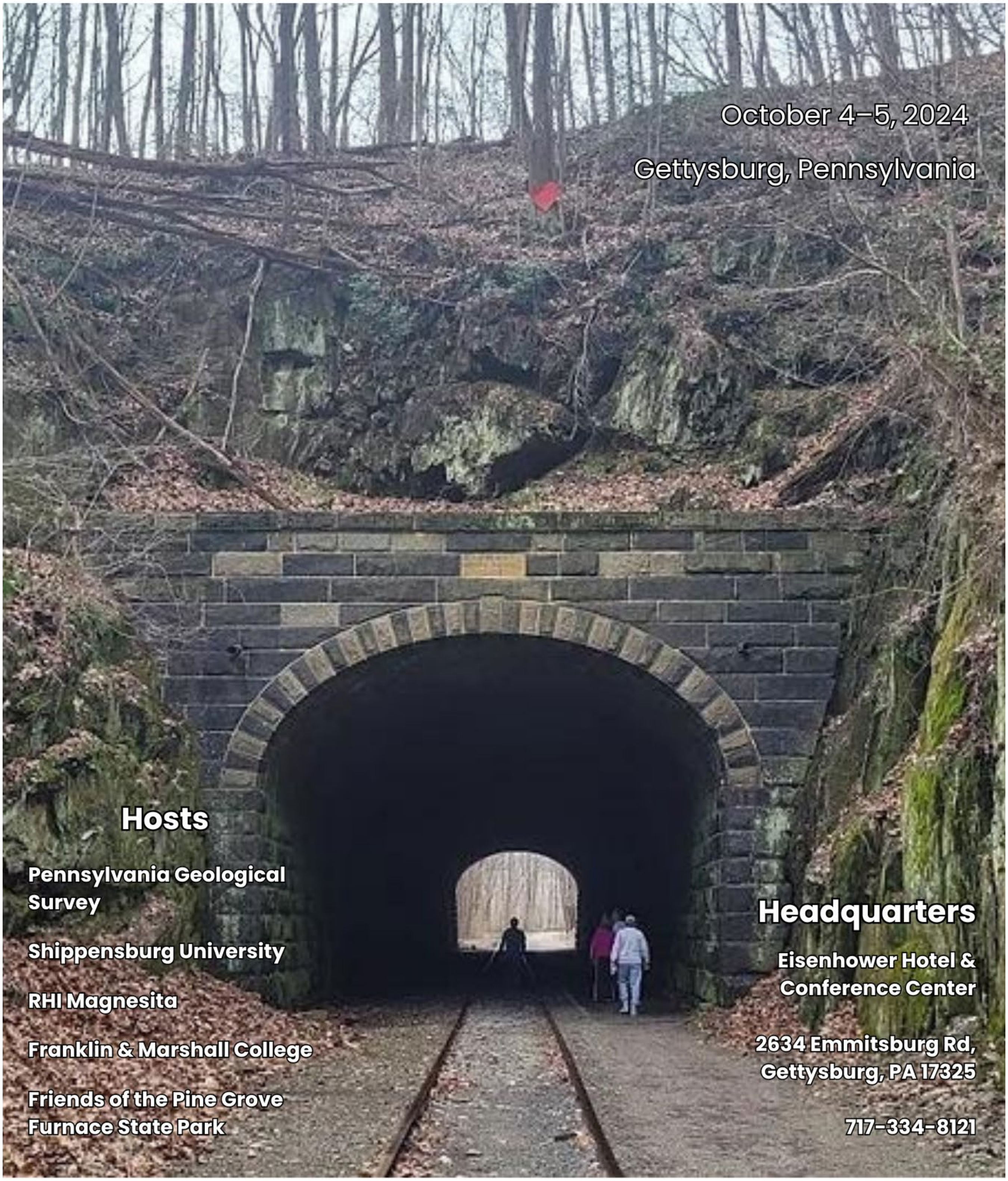
PIEDMONT AND SOUTH MOUNTAIN GEOLOGY IN SOUTHCENTRAL PENNSYLVANIA



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GUIDEBOOK

Pine Grove Furnace State Park

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Introduction

Located along Mountain Creek in the South Mountain region of southwestern Cumberland County, Pine Grove Furnace State Park is a relatively small park (696 acres) surrounded by the Michaux State Forest (almost 90,000 acres). The park encompasses the core of an 18th-19th century industrial operation with a blast furnace (Figures 1-3) that smelted local iron ore, a finery forge (Figures 4) that converted the furnace's pig iron into wrought iron, and a commercial brickyard.

A visit to Pine Grove Furnace State Park is an opportunity to consider Pine Grove Furnace and its associated Laurel Forge (together, PGF) though the lenses of history, industrial archaeology and economic geology, the "study of the Earth's sources of mineral raw materials and the practical application of the acquired knowledge" (Pohl 2020). To that end, what follows is a brief review of mineral resources at or near PGF relating to the production of pig iron and wrought iron (1770s-1896), and later brickmaking (1892-1907), as well as comments on the key impact of transportation on these industries.

Pine Grove Furnace State Park was part of the Field Conference in 1991 and 2014. The current article particularly acknowledges guidebook articles by John H. Way in 1991 and Noel Potter Jr. in 2014, local historian Randy Watts' 2019 book specific to the charcoal iron industry in Cumberland County PA, and observations about local geology offered to the author over the past decade by Noel Potter Jr. and Helen Delano.

Way 1991 provides an extended introduction to the history of iron production which will not be repeated here. Potter 2014 concisely summarizes the geology that allowed a thriving ironmaking community to exist here. A summary of the chemical process of smelting is given in the Appendix (Weltman 2022a).

Figures 1-3. PGF smelter in operation c.1878-1895, in ruins c.1914, and in 2023.

(Credits: Cumberland County Historical Society and Andre Weltman)

Figure 4. Laurel Forge from east. Laurel Dam is not visible at left rear.

(Credit: Cumberland County Historical Society)

Pine Grove Furnace, 1770s-1895 and Laurel Forge, 1830-1896

The origins of ironmaking at PGF are obscure in the historical record. Claims by several generations of historians about the earliest iron operation here range from 1764 (Bining 1979) vs. 1770s (many 19th century observers) vs. early 1780s (Flower 2003, implied by a land sale deed and tax records). Each claim to a founding date can be contradicted by other evidence. This author suggests 1771 or soon thereafter as the most plausible year for the establishment of PGF, but firm data are lacking. Unless forgotten documents newly emerge from some dusty archive or closet, the question will never be settled to mutual satisfaction. In any event, the establishment c.1762 of a successful blast furnace and forge called the Carlisle Ironworks nearby in Boiling Springs proved that workable iron ore was to be found in abundance along South Mountain in Cumberland, Adams and Franklin Counties in Pennsylvania.

The forests near PGF had first been exploited by Europeans to supply a sawmill c.1762. An unknown person at some point thereafter recognized that all the ingredients necessary to smelt iron were locally available, as well as a perfect “mill seat” to facilitate loading the raw materials into the top of a furnace while also convenient for a headrace to turn a waterwheel (Watts 2019a, Weltman 2022b). The earliest names associated with construction of the furnace at PGF include John Arthur, George Stevenson, and Robert Thornburgh, but their roles are disputed by modern historians.

It is sometimes erroneously claimed that PGF and similar ironworks in the South Mountain region were remotely situated to hide from British officials enforcing mercantile regulations such as the Iron Act of 1750 (resented by American businessmen and a contributing cause of Revolutionary fervor). However, these regulations did not prohibit the production of pig iron and plain wrought iron bars (Bining 1979). Furnaces and forges were built in relatively remote locations simply because that’s where the raw ingredients and waterpower were to be found. Comparing the cost of transporting a heavy finished product from production site to market, vs. the cost of hauling voluminous raw materials which were also heavy on poor road networks, it often made economic sense to build early furnaces close to the raw materials (Birkinbine 1903, Schallenberg and Ault 1977, Knowles 2013).

Successive ironmasters and iron companies at PGF repeatedly purchased land through the late 18th into the 19th centuries, so that they directly controlled their primary sources of iron ore, dolomitic limestone quarries for flux, and eventually 27,000 acres of hardwood forests for charcoal fuel production. These resources were convenient to the blast furnace at the base of a furnace bank or hill of the proper height to load materials into the 33-foot stack. The steep topography of South Mountain also provided adequate water power for multiple purposes. Water powered the furnace blast machinery as well as a drainage pump at the largest ore pit, ore washers, a sawmill, and a gristmill all owned by the iron company. When Laurel Forge was constructed in 1830 downstream on Mountain Creek, its new timber-crib dam powered two additional water wheels at the finery forge.

PGF was among the last of the Pennsylvania blast furnaces to still use an outmoded water wheel system—although not the very last as sometimes claimed (Pearce 1876). Prominent engineer John Birkinbine, hired to upgrade the antique iron operation in 1877-1878, expressed amazement to find water-powered blast still in use. He replaced it with a modern steam boiler and Weimer Company “bull style” blast engine which along with other improvements vastly improved annual output. By the final years of PGF operation, the furnace (with a rated capacity of 6,000 tons/year) could potentially produce an order of magnitude more pig iron compared to its earliest days (if a furnace in the colonial era made more than 500-600 tons/year, it was doing well indeed).

In summary, we can definitively claim only that this blast furnace made pig iron starting before or during the American Revolution, and went “out of blast” for the last time in April 1895, i.e. exactly 30 years after the American Civil War. The finery forge at Laurel may have continued to process stockpiled pigs into early 1896. This long span, interrupted just a few times by external economic factors, makes PGF one of the more successful of the iron operations along South Mountain in southcentral Pennsylvania.

A note on terminology

The construction of Laurel Forge in 1830 changed Pine Grove from a “furnace” to an “ironworks.” Strictly speaking, a smelter all by itself is just a furnace, while the addition of other metallurgical operations allows the combined site to be called an ironworks. The other operations might include finery forges (or a similar technique called puddling) to convert pig iron into wrought iron; rolling mills for making railroad rails, boilerplate and similar products; slitting mills to make nails; steel mills; and so forth. (PGF never included those other types of facilities; it had only a blast furnace and finery forge.) Even more confusing, an earlier technology for extracting usable iron from ore, the bloomery may also be called a forge or furnace. The fact that the terms furnace and forge both begin with letter F may contribute to confusion with the word foundry which typically describes a freestanding operation where iron is remelted to make fine castings. In reviewing historical documents, one should be cautious in interpreting these various terms which can carry different meanings depending on the context, year of writing, and technical sophistication of the writer (Brothers 2009). In summary, prior to 1830 PGF was properly called Pine Grove Furnace, then after 1830 it formally became Pine Grove Ironworks, at least in strict terminology.

The development of mass steel production (beginning with Bessemer/Kelly in the decade before the Civil War) introduced yet another term, the steel mill where pig iron is converted into steel. Modern integrated hot metal plants include blast furnaces located close to steel converters. The thermal energy involved in smelting iron from iron ore is not lost by allowing the metal to cool—rather, the still-liquid metal at almost 1,600°C is directly transported from the blast furnace to the steel converter. Though an entire operation of that type is often casually called a steel mill, this ignores the integral blast furnace component. Note that neither PGF nor the other ironmaking sites in the South Mountain region made steel even after the invention of the Bessemer process and successor technologies. With the introduction of mass steel production and adequate quality control, wrought iron became increasingly obsolete and is no longer produced today. "Wrought iron" used by artisan blacksmiths today is typically mild steel (low carbon steel) or was recovered from a pre-20th century source.

Ironmaking at PGF

The nucleus of PGF was the furnace stack, a 10-meter-high pyramidal masonry structure (Figures 5). A columnar space runs vertically up the center, narrow at the top or throat and widest at the 3-meter-wide bosh about ¾ of the way down, before narrowing again at the crucible and hearth at the bottom. (The term bosh is sometimes also used to describe the entire furnace interior). The column is lined with refractory material its entire height. In a furnace of this type, the refractory lining's circular arrangement is often visible between the masonry support legs at the bottom of the stack, enclosing the crucible or hottest part of the smelter near the tuyeres where air blast is introduced, and the hearth where molten iron and waste slag collected.

In the early decades of iron making at PGF, the interior refractory lining was locally quarried sericitic phyllite, further described below. It served as "an admirable material for the in-walls of a furnace and is used in that at Pine Grove" (Rogers 1858). At some point in the later 19th century, perhaps after 1870, PGF switched from phyllite to imported high-silica firebrick for its refractory lining. The bricks visible at the bottom today are a facsimile added during repairs 1985-1986, but the original firebrick-lined crucible and hearth remain inside the modern bricks, and the original lining from 1895 is still present the entire height of the structure (former park manager William Rosevear, personal communication). The furnace is still filled to half its height with reactants abandoned in place when PGF went out of blast for the last time in April 1895.

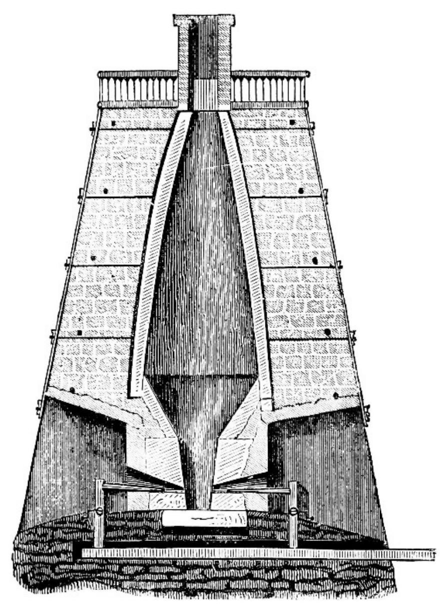


Figure 5. "Vertical Section of a Charcoal Blast-Furnace." (Durfee 1891)

Between the inwall with its refractory lining and the exterior masonry providing support and insulation, a loose mix of rubble allowed the inner structure to expand during high-temperature smelting.

The exterior masonry of the PGF furnace stack today predominantly demonstrates blocks of quartzite. The historic stack was modified and repaired several times in the 20th century, most notably 1985-1986. As a result of 20th century restoration, the stack exterior includes a few randomly intercalated blocks of other local stone including sericitic phyllite. This phyllite is not generally desirable for construction because, while easy to shape, it is quite friable. The structure was typically bolstered by a series of long metal bars wrapped around and through the masonry; these bars rarely remain at still-standing furnaces, but an intact example can be seen at Cornwall Furnace, a site operated by the PA Historical and Museum Commission. At PGF the rods are long gone though an attachment point is visible as a metal flange on the exterior.

A 15 cm. concrete layer was added across the top in 2014 to prevent water infiltration into the furnace throat, replacing a failing wood and rubber barrier installed in 1985. An object lesson in what freeze-thaw cycles and unchecked ruderal vegetation can do to neglected 19th century furnaces can be observed at Big Pond Furnace, 8 km. northwest, with successive collapses in 2011 and 2023.

On the west side of the PGF stack, a masonry platform supports the crumbling ruins of a brick Player stove (named for English engineer John Player) which used anthracite to pre-heat air blast. Installed probably c.1883 at PGF, this type of blast heater is described in Gordon 1996. On the east side of the stack and continuing along the furnace bank, dry-laid masonry shows the location of raw material storage areas, used when the railroad imported coke and anthracite after the upgrade in 1877-1878. An elevated rail spur ran 5 meters off the ground, crossing through a large barn-like building adjoining the stack to the north.

Contrast old furnace stacks with modern blast furnaces, which surround their interior refractory lining with water cooled metal plates which can be swapped out even as the furnace remains in blast. These plates form the exterior of the furnace—no masonry is needed. By cooling the refractory material, a modern furnace prolongs its useful lifespan so that blast “campaigns” may run unabated for 1-2 decades.

When “in blast” early furnaces would typically make iron nonstop for 6-8 months or longer if possible before the water-driven blast was hindered by freezing weather, and until the refractory lining needed to be replaced. Furnaces of this type are almost always built next to a steep furnace bank to facilitate dumping the raw ingredients into the top; the hillside at Pine Grove Furnace is visibly stained from a century’s worth of spilled charcoal. After 1877 when fuels other than charcoal could be used, the height of the stack was increased with a 7 meter sheet-metal and firebrick cylindrical addition, requiring a steam-driven elevator to facilitate loading. A stack ≥12 meters tall was not possible with charcoal fuel, which would crush under the weight of the layered reactants thus blocking upward gas movement, plus the relatively weak blast pressure in early furnaces also limited their height. A taller stack is possible with coke and anthracite which are physically stronger in compression.

The solid raw materials were loaded in layers into the furnace throat 3-4 times/hour by workers called fillers, considered a semi-skilled task. In addition to weighing and moving the correct amounts of ore, charcoal and flux, fillers needed to take care to avoid hang-ups and scaffolding, conditions in which the materials became stuck part way up the furnace interior instead of descending as smelting progressed. A sudden collapse of large amounts of material might cause an explosion, or might block movement of gases and “chill” the liquid metal at the bottom potentially requiring the crucible to be broken open, emptied and rebuilt. Massive plugs of iron called salamanders resulting from such an accident are today displayed on the east side of the furnace stack and along Quarry Road south of Mountain Creek.

A blast furnace or iron smelter can be considered a high-volume, high-temperature chemical reactor. The process depends on not only sufficiently concentrated iron ore, but also the flux of limestone or dolomite, and a carbon source for heat and as a critical part of the chemical reactions (see Appendix). A hidden but essential fourth ingredient for smelting iron is the oxygen in air, which comprises the largest single ingredient by weight. Without a steady flow of air to promote combustion, the furnace interior could not reach temperatures approaching 1600°C necessary for iron smelting. In early furnaces a large waterwheel next to the furnace turned constantly to power the blast machinery, forcing air into the bottom at an opening called a tuyere. Water-powered leather bellows (obsolete soon after the American Revolution), and later water-powered wooden blowing tubs, were not capable of generating much more than ½ to 1 p.s.i. of air. Tuyere pressures generated by steam-driven metal pistons were an order of magnitude higher.

Early furnaces used air at ambient temperature or cold blast. Through the 19th century technical improvements allowed for more efficient pre-heated air or hot blast, though at PGF truly effective hot blast was not available until late in its lifespan (Weltman 2022b). A blast furnace requires hot blast to run on coke or anthracite.

A generalized ratio for smelting, by weight, is 2 parts iron ore, 1 part carbon fuel, and ½ part limestone, plus 5 parts of air. The ratio of these three materials varied at different furnaces at different times depending on the concentration of iron in the ore, what carbon fuel was used, blast temperature, and the overall efficiency and management of the smelter. At PGF in 1879, with blast preheated only to a relatively low 300°C, the specific amount loaded at one time was reported as 880 pounds of iron ore, 378 pounds of charcoal, and 200 pounds of limestone; to make 1 ton of pig iron at that time, the furnace needed 2,531 pounds of charcoal (Birkinbine 1880).

The furnace was tapped every 12 hours. Workers under the direction of the founder or keeper broke open a clay plug to allow the molten iron to flow into the casting house, either to be cast into useful shapes or to solidify into rough metal bars called pigs (the pigs were later transported to Laurel Forge to be made into wrought iron merchant bars). Floating atop the iron in the crucible was the molten waste product of the smelting process, slag, which flowed out separately and cooled before being discarded.

Due to the commingled raw ingredients, high levels of carbon (typically 3-5%) are unavoidably dissolved into the resulting pig iron. Though this carbon conveniently lowers the melting point of pig metal, carbon plus slag inclusions result in a crystal structure of pig iron which is strong in compression but also very brittle. Wrought iron formed in the forge at Laurel, on the other hand, with extremely low concentrations of carbon (typically ≤0.1%) and stretched slag inclusions, is malleable and flexible. Blacksmiths and rolling and slitting mills worked with wrought iron, not pig iron.

Of particular importance in finished ferrous products are sulfur and phosphorus. Excess sulfur results in “red short” metal, i.e. brittle at high temperatures—obviously undesirable in boilerplate, for example. The impact of sulfur in iron is moderated in a complex way by other elements including manganese; but the less sulfur the better (Cain 1924). Phosphorus in very small amounts may be acceptable for some types of castings, as it creates hard cast iron and tends to make molten iron flow more freely into molds. However, too much phosphorus, typically ≥0.2-0.5% depending on the intended use of the finished product, results in unacceptably “cold short” metal, i.e. brittle at cold temperatures (Bauerman 1868). Other elements such as manganese might play either a beneficial or detrimental role, depending on their levels and the intended use.

Iron ores along the Mountain Creek valley were very low in sulfur and were never reported to produce red short metal. Phosphorus, on the other hand, was a potential problem locally, and tended to be higher in ores mined upstream along Mountain Creek such as the Wild Cat Pits at the south end of the PGF property. Manganese levels tended to increase proceeding downstream along the creek, such as the ore banks near Laurel Forge.

Iron Ore at PGF

> *In South Mountain, the ore was limonite, often referred to as brown hematite or mountain ore. Concentrated by processes operating as local limestone units slowly weathered, "ore banks" tended to accumulate along the edges of the valley at the foot of South and Piney mountains.*
>
> –John H. Way, 1991 Field Guide

> *PGF and the valley of Mountain Creek SW of PGF are underlain by the Cambrian Tomstown dolomite, the first carbonate unit above the Cambrian Chilhowee Group. Precambrian metarhyolite is faulted against the Tomstown just to the N of PGF. The iron ore here was lumps and nodules of limonite and related iron oxides, which occur within the clay residuum formed from chemical weathering of the Tomstown.*
>
> –Noel Potter Jr., 2014 Field Guide

The ore deposits in the South Mountain region were described by Lesley 1873:

…the ore deposits of the South Mountain face must necessarily be geologically continuous… the ores are in fact nothing but the original rocks themselves from which all or nearly all the limestone has been dissolved out, leaving the clay, sand and iron behind. They are not washings of ore from distant regions, dumped down at hazard in hollows of the surface and therefore of uncertain occurrence and quantity. They are perfectly well-defined and continuous strata, occupying the position they always occupied, and following the sides of the mountains, the course of the principal stream, and the strike of the harder limestone ledges, along the whole course of the valley.

Transportation was critical to full development of the resource. As noted by a Carlisle newspaper advocating for an extension of the South Mountain Railroad south beyond Pine Grove Furnace (which did not occur):

The iron deposits of the South Mountain seem to be exciting considerable interest among the iron manufacturers throughout the State… the ore of our South Mountain is greedily sought after by Iron men from all over the State, and is recognized as the most valuable ore that can be obtained; and as it is well known that the entire north slope of the South Mountain is almost a continuous bed of ore for thirty miles… There are fine beds of superior ore all along the South Mountain which can be reached by simply stripping the surface. They are now undeveloped, because they lie so far from railroad transportation, but would amply repay the road which would take their hidden treasures to market.

(American Volunteer 1870)

The major ore quarries or banks owned by PGF are briefly described below. In PGF's last two decades of operation, the South Mountain Railroad allowed easy importation of ore from elsewhere, whether from leased mines downstream along Mountain Creek or from further away. Importing ore was not only a result of possibly uneconomical extraction at the closest ore deposits; it was common practice for furnaces to mix ores from multiple sources to achieve desired qualities in the resulting iron. In various contemporary reports the usable ores in this area ranged from 38-44% metallic iron (McCreath 1881). This was economically adequate though ores ≥50% are preferred. The interested reader is referred to Watts 2019a for detailed discussion of the many other iron ore mines in Cumberland County.

Iron ore in South Mountain has been historically described as brown hematite, limonite, mountain ore, etc. It is today generally classified as residual limonite, derived from quartzite, dolomite, and phyllite of the Antietam-Tomstown formation. Summarized in the 2014 Field Guide:

A good review of the origin of both iron and manganese oxide ores is in Hack (1965) on the ores in the Shenandoah Valley. According to Hack the Tomstown Dolomite contains small amounts of both iron and manganese carbonates, but sufficient to concentrate as oxides over a long period of weathering and time. Rain that falls and runs off from sandstones remains acidic (low pH). When it reaches the carbonate rock it dissolves the carbonate and becomes neutral or alkaline (high pH), and yields ions of Ca+2, Mg+2, and HC03- that are carried away in solution. Meanwhile the now low acidity of the water causes Fe and Mn to precipitate as oxides. Of course, when the carbonates dissolve, insoluble residue, mostly clays, are left behind. It is these clays over the Tomstown Dolomite in which much of the iron ore is found.

(Potter 2014)

The dissolution of the Tomstown Dolomite was perhaps linked to "a period of intense weathering in the Late Cretaceous to early Tertiary (approximately 70 to 40 million years ago)" (Inners 1999).

Magnetite was not found at PGF. Although small amounts of magnetite have been reported in the Toland quarries downstream along the Mountain Creek valley (Hosterman 1984) the closest commercially significant magnetic ores were to the northeast at Dillsburg (Spencer 1908) as well as south of Route 30 closer to the Caledonia and Mont Alto Ironworks, and in Adams County towards Gettysburg.

As an aside, consider the modern beneficiation of low-grade magnetite at the western end of Lake Superior (Fine 1968). Beginning in the mid-20th century, ore containing ≤35% magnetite is crushed, separated from gangue with magnets, and heated to create taconite pellets with ≥65% iron plus flux baked into each pellet. In addition to being self-fluxing, pelletized ore is convenient for automatic machinery to load and unload from bulk transportation and then lift to the top of tall blast furnaces. (The furnace fillers of the 18th-19th century would have been amazed to see machinery completely replacing their noxious task at the furnace throat!) In May 2023, singer-songwriter Gordon Lightfoot died. His famous song The Wreck of the Edmund Fitzgerald (1976) reminds us of the staggering quantity of taconite pellets hauled by the large ore carriers on Lake Superior: "With a load of iron ore twenty-six thousand tons more / than the Edmund Fitzgerald weighed empty." Rough calculations suggest that the extractable iron contained in a single load of taconite in a boat like the Mighty Fitz could hypothetically match the pig iron output of the old furnace at PGF for as much as ten years in the 1770s, or perhaps one to two years in the late 19th century. Such are the efficiencies of large cargo vessels. Unfortunately, PGF did not have any navigable waterways nearby.

At PGF, surprisingly few workers were needed to extract iron ore even at the largest quarries. The earliest surviving business records from the 1780s show that only around a dozen men worked in the "mine bank" (presumably Old Bank as we call it now), while business records and photographs from later in the 19th century suggest that three to four dozen workers were adequate at each of the major excavations. In general, the iron ore consisted of lumps embedded in a clay matrix, and often could be extracted with no more than pick and shovel. Large machinery was apparently not used until late in the 19th century. Blasting to loosen ore and gangue was occasionally necessary as a first step. For example, at Pine Grove #1 "by the use of gunpowder, 50 tons have been brought down at a time" from the working face (Harden 1873). However, it seems that explosives were not regularly needed for mining at PGF, at least in the earlier decades, and purchases of blasting powder are not prominent in the surviving business records reviewed by this author.

The ore in Pine Grove #1 (today, Fuller Lake) was described as "…varying from a soft, greasy, ferruginous, maroon-colored, impalpable mud (which, if properly mixed for the purpose, would make good paint), to the hardest of hematite ore in rock, projecting from the face. The intermediates being made up of balls, shells, shards, flat pieces, and amorphous masses, the whole grouted in with clays and red earths…" (Harden 1873). The description of "balls, shells, shards" is consistent with this author's personal observations exploring PGF's ore banks. Occasionally ore is found tightly adherent to rocky gangue, but the majority seen today is in discrete chunks from 2 to 30 centimeters in diameter, easily extracted manually from the surrounding clay matrix. Larger discrete pieces of hematite could also occur: describing the limestone quarries at PGF, Frazer noted that "Limonite was taken out of these larger excavations many years ago, one block thus taken out weighing 30 tons" (Frazer 1877).

Once transported out of the quarries, tailings were piled up where convenient, exemplified by a tree- and brush-covered longitudinal mound approximately 10 meters high, immediately east of Fuller Bathhouse in the modern State Park. To the discerning geologist or industrial archaeologist, the relationship of this artificial topography to the iron industry is obvious, though the general public probably assumes numerous small "hills" in the State Park are just a natural part of the mountain landscape.

On a similar note, across the Michaux State Forest one can occasionally find cone-shaped excavations, typically ≤2-3 meters in diameter and ≤1-2 meters below the surrounding forest floor. They are distinct from natural "crib and pillow" features created by wind-thrown trees, and are instead assumed to be remnants of abortive exploration for ore. These historic "try pits" (try meaning test) are often solitary—perhaps prompted by a few pieces of "mountain ore" randomly detected at the surface—but occasionally multiple try pits can be found in a line along a contour of elevation leading away from a known iron ore source; even less often they are in a grid pattern across the forest floor. We may imagine that these minor relics of industrial exploration were deliberately not filled in when no more iron was dug up: why waste the time and energy restoring the just-excavated soil? Two centuries later the empty try pits dot the landscape.

As excavations deepened, skip-hoists were used at several mine banks to lift material for further processing. A network of light rails crisscrossed the floor of Pine Grove #1, with ore carts pushed by hand over to the skip hoist which was approximately where the sandy swimming beach is today.

Ore could be efficiently cleaned in a "log washer," an invention of central Pennsylvania ironmaster Abraham Valentine in the 1840s (Coppock 2015). Log washers were used at PGF to recover "wash ore," small pieces of ore embedded in the clay matrix which would otherwise not be economical to extract for furnace use (Miles 1886, Keefer 1934). The modern mining industry still calls ore-cleaning mechanisms log washers though they no longer include a rotating wood log in the center.

Iron ore at PGF and most other furnaces was typically roasted or calcined. Though this could be done in a purpose-built kiln, it is also readily performed in open-air heaps in which layers of ore and charcoal are piled up then ignited—drying out the ore while helping to crumble it into sizes suitable for smelting, as well as promoting removal of sulfur as SO2 gas (Bauerman 1868). The famous painting Coalbrookdale by Night by Philip James de Loutherbourg (1801) shows an ironworks in England with a glowing mass in the background, which appears to be heaped iron ore being calcined in the open air. The smaller the pieces of ore and flux filled into the blast furnace, the greater the ratio of surface area to volume which is desirable; however if too many very small pieces are loaded into a furnace, a compacted mass might block the air blast and other gases from percolating upwards through the solid reactants. This was especially a potential problem with the low blast pressure of early furnaces.

The ore was filtered using metal mesh. As explained in 1873, paraphrasing PGF co-owner Jackson Fuller:

> *Mr. J.C. Fuller, the President of the South Mountain Iron Company, attributes these favorable results to the regular treatment of the furnace in every particular, and to the manner of preparing the ore for the tunnel head [the top of the furnace]. The lump ore… is calcined in open heaps, and broken into pieces of about three inches cube. The small ore is put through a double screen, the upper mesh of which is a quarter of an inch square, the lower mesh less. By this means much of the sand and dirt which would otherwise go to the furnace is separated and kept out.*
>
> (Harden 1873)

The major sources of ore closest to the PGF blast furnace were Old Bank and Pine Grove #1 (today, Fuller Lake). Old Bank at PGF should not be confused with the same name given to early workings elsewhere such as near the Carlisle Ironworks at Boiling Springs.

Old Bank

The use of the word Old implies this approximately 150 meter long unflooded open-pit mine was the original source of ore used at PGF. This cannot be confirmed today as surviving documentary evidence from the earliest years of furnace operations are not specific enough to pin down a location for the first "mine bank." As described a century later, it was "situated immediately on the south side of the hill against which the No. 1 bank is developed, and is but a short distance from the larger opening" and "no ore had been taken from here for many years and only the fact of a large excavation being visible remains to confirm the reports of the large tonnage formerly won here" (D'Invilliers 1886). Though a map of Cumberland County shows Old Bank due west from "No. 1 Bank" (D'Invilliers 1886), this is an error and does not match the contemporary text nor modern field observations (Figures 6).

Extant records do not clarify when Old Bank was abandoned in favor of Pine Grove #1, nor if Old Bank continued to be worked at the same time that Pine Grove #1 was first being developed.

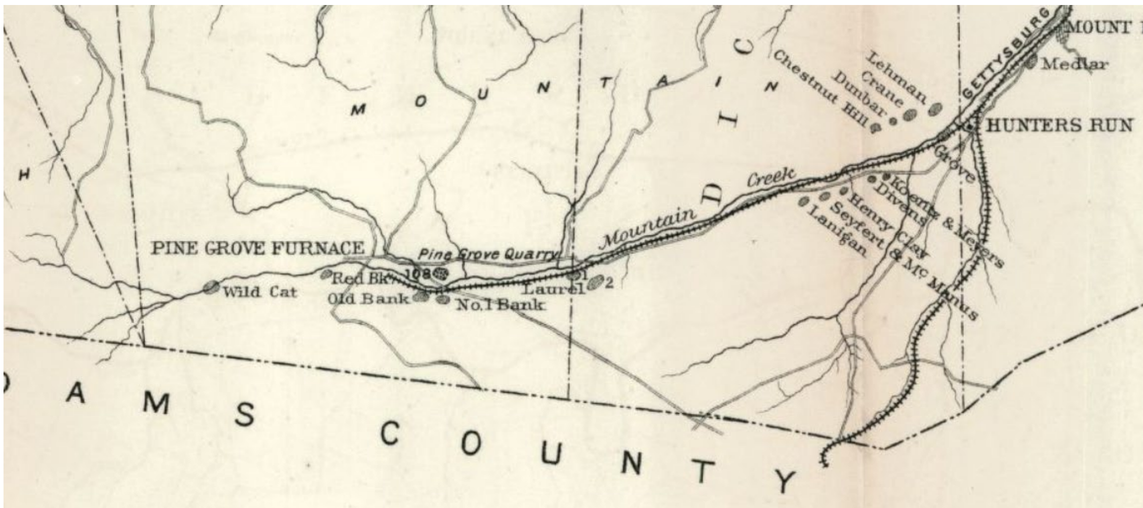


Figure 6. Detail of "Reference Map to the Iron Ore Mines and Limestone Quarries of Cumberland County" (D'Invilliers 1886). Relative locations of extraction sites in the PGF furnace area in this map should not be relied upon.

D'Invilliers disagreed with the open-pit methods used at PGF to exploit the ore and adjoining limestone, noting that "but a small amount of development by an open cut to increase the overburden to such an extent as to make it practically impossible to obtain the ores beneath without having to remove a vast quantity of barren material and make the ores cost more than they will bring" (D'Invilliers 1886). We may speculate that working Old Bank only by open cuts, with an ever increasing overburden to remove as the iron ore vein went deeper, contributed to the abandonment of this particular site.

Contemporary and modern descriptions of Old Bank sometimes seem to conflate it with PGF's source of flux also located south of Pine Grove #1; it may be that one of the two limestone/dolomite quarries (described below) was once congruent with the far southeast end of Old Bank adjoining the historic cemetery. (This is the only place in Old Bank where this author has found limestone fragments). Confusingly, a summary for the Second Geological Survey briefly describes a limestone quarry of "a little more than five acres" that is not inconsistent with Old Pit (Frazer 1877).

All across Old Bank's floor and walls, ore nodules embedded in a clay matrix are easy to find today. The large amount of remaining iron reminds us that mines may be abandoned not because the mineral resource has been completely removed, but rather that continued extraction is no longer economically viable.

State Park visitors can easily walk into Old Bank using an adit accessed off a cabin driveway along Quarry Road, just past the south end of the Brickyard Day Use Area. The adit is immediately south of masonry marking the wheel pit for a 9 meter diameter water wheel that powered an 18 meter plunger pump to drain nearby Pine Grove #1. The adit was once presumably wide enough for large teamster wagons hauling ore to the furnace and dumping tailings nearby, though today the walls have eroded inward. The entrance is maintained by a volunteer to allow public tours, but caution is warranted due to uneven footing and large overhanging tree trunks. Standing in Old Bank, one's feet are at about the same level as the surface of Fuller Lake, the edge of which is 50 meters to the north—children playing on the beach on the far side of the lake can be heard, but are invisible from within Old Bank (Figures 7). Casual exploration is hampered by invasive plants such as Japanese barberry. The adit and the mine bank are crisscrossed by deer hoofprints in the clay, including directly up the steep walls.

Figure 7. Old Bank seen from entrance adit in 2018. (Credit: Andre Weltman)

Pine Grove #1 (Figures 8-11)

Visitors to PGF often wrongly assume that this large, flooded ore bank was the only local source of iron ore. Documentary evidence does not clarify when it was first opened. It was abandoned and allowed to flood at the end of 1886, i.e. a decade before the furnace permanently went out of blast in 1895. The surface area of the resulting Fuller Lake is approximately 5 acres, though State Park public maps prior to 2022 incorrectly reported the lake's area as 1.7 acres.

Figure 8. Pine Grove #1 in 1870s from east. Note network of light rails for hand-drawn mining carts. Skip hoist is not visible on right side of image. Plunger pump is at center rear. Tailings pile, still extant today at edge of Brickyard Day Use Area, is at top right. (Credit: Cumberland County Historical Society.)

As a consequence of low iron prices after the Panic of 1873, iron smelting at PGF stopped for almost four years beginning in July 1874. The water pump at Pine Grove #1 was halted. Natural springs at the bottom producing 250 gallons a minute, plus rain, completely flooded the workings. Engineer John Birkinbine reported that the bank was "70 feet deep" when he arrived to upgrade PGF in 1877. Simple back-of-the-envelope calculations suggest the excavation would have taken 1-2 months to fill, depending on how steep the sides were at that time. In 46 days in 1877, Birkinbine drained it with a large steam-driven pump floating on a raft; he discussed this feat in detail in a technical publication

Figure 9. Pine Grove #1 in 1883 from south. Smoke plume at right comes from a railroad locomotive underneath skip hoist machinery, and plume in left background shows location of blast furnace. (Credit: Cumberland County Historical Society)

(Birkinbine 1879) but did not bother to photograph the raft and its pumping apparatus.

Described in 1886:

This is situated about half a mile E.S.E. from the furnace and was not being worked at the time of inspection. At the west end, the cut shows about 60 feet deep. The stripping here was only originally about ten feet of clay and sand, under which 25 feet of wash ore and clay occurred and then 25 feet additional of a solid but soft lump ore to the bottom of the cut. A drift was driven S.W. for about 200 feet at this point, and at 150 feet a left hand cross-cut was driven fifty feet to the S.E., all of which development was through ore… Any drift driven S.W. from this bank will come out in the "Old Bank," and it is fair to assume that the ore body is continuous between the two openings. All along the south side of bank No. 1 a splendid face of lump-ore was partially exposed during the fall of 1886, since which time the mine has been allowed to fill up… A large 'horse' of white clay still occupies a place in the east workings; but ore occurred disseminated all through it and around it and excavation on both sides of this generally barren dome of clay show excellent ore. A rotten dolomite limestone crops to the south of this clay mass. Its dip is obscure. The banks probably show an extreme length of 1,000 feet; it is 200 feet wide and averages 60 feet in depth.

(D'Invilliers 1886)

The choice to abandon Pine Grove #1 was not due to a lack of remaining ore, rather presumably it was not convenient and economical to continue resource extraction. "The floor of this excavation is still on the best and hardest of ore, and a bore-hole put down two years ago, 107 feet, was yet in it. The bit of the boring tool broke, and now remains in the hole. The depth of the ore, then, is not proven" (Harden 1873).

The western half of Fuller Lake is currently around 15 meters deep, while relatively shallow benches are in coves to the northeast and southeast (DCNR bathymetry map, 2008). SCUBA divers, occasionally permitted to explore Fuller Lake while removing garbage, report thick silt covering the bottom, which severely limits visibility of wooden platforms, wagons, and abandoned mining gear that was evidently not profitable to remove in the late 19th century when the mine pump was halted for the last time.

Occupational fatalities include a miner who died in 1849 from falling rock (whether in Old Bank or Pine Grove #1 is unclear), a worker crushed in 1860 on the pump water wheel at the western edge of Pine Grove #1, and a miner crushed by the skip hoist in 1880 (Carlisle Herald 1849, Star and Enterprise 1860, Valley Sentinel 1880). See Watts 2019a for other accidents and fatalities at PGF. There is no evidence that a miner drowned while he retrieved his wife's pumpkin pie after the mine pump failed, as recounted in the "Legend of the Hairy Hand" ghost story repeated annually at Fuller Lake during the State Park's Fall Furnace Fest each October.

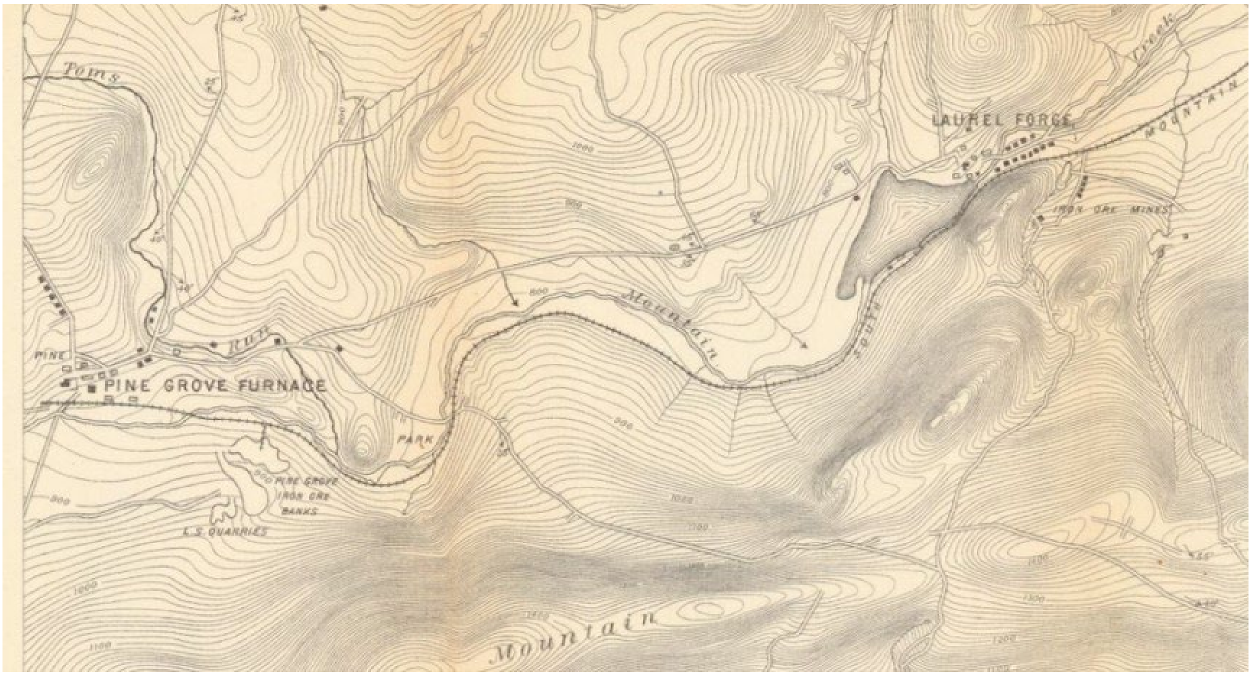


Figure 10. Detail of 1889 "Topographic Map of South Mountain" by Ambrose E. Lehman, Assistant Surveyor for the Second Geological Survey and Chief Engineer of South Mountain Railroad, surveyed c.1885. On left, Pine Grove #1 is south of railroad with a spur leaving the main line (this short vertical mark actually shows skip hoist and elevated trackway for mine carts). Old Bank is next quarry to south, and below that smaller "L.S. Quarries" are sources of flux. The furnace is a black square to left of first letter in PINE. At right of center is triangular Laurel Forge Pond, with Laurel #1 and #2 to east. Compare to Light Detection and Ranging (LiDAR) maps below. (Lehman 1889)

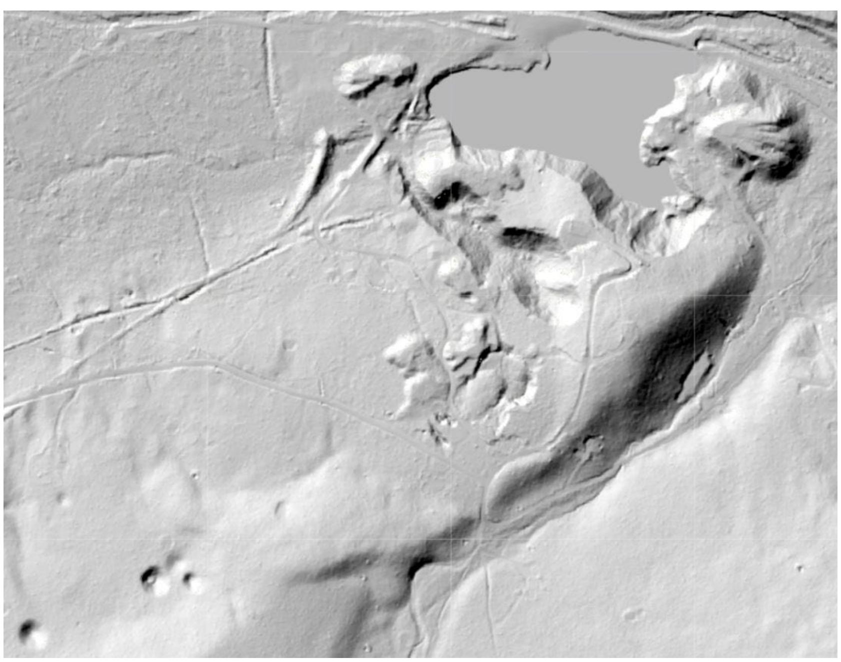


Figure 11. (Left) LiDAR map showing flooded Pine Grove #1 (Fuller Lake) at top right. Unflooded Old Bank is south of lake, with adit entrance apparent at northwest end. The limestone quarry is less distinct disturbed area south of Old Bank. Thomas Iron Company Red Banks are circular features at bottom left.

(https://maps.psiee.psu.edu/preview/map.ashx?layer=1802)

Other ore banks near the furnace

Several other small quarries in the furnace area were of lesser economic importance; these are discussed by Watts 2019a. Most notable were the "Thomas Company Red Banks" exploited for just a few years in the mid-1870s (Frazer 1877). The Thomas Iron Company, a conglomerate based in Lehigh County, purchased PGF after the Panic of 1873 primarily to export ore to their blast furnaces elsewhere in Pennsylvania. These conical quarries (Figure 12) can be visited by walking uphill into the State Forest behind cabins on the south side of Murphy Road (east from the State Park family campground and southeast from the group campground). Only trace amounts of iron ore can be found with difficulty today, nor is there any above-ground archaeological evidence to explain to casual visitors the presence of these large excavations in the forest floor. The same name, Thomas Banks, is also confusingly linked to shallow excavations west of the family campground (D'Invilliers1886); it seems that area was also worked by the Thomas Iron Company in the mid-1870s but was not very productive.

Figure 12. Author in one of Thomas Red Banks ore pits off Murphy Road, 2018. (Credit: Randy Watts)

Ore banks near Laurel Forge (Figures 13-15)

Three km. downstream from the blast furnace was Laurel Forge, built in 1830. The forge sat in what is today a triangular gravel parking lot below the concrete dam, which in 1968 finally replaced the original (and often-repaired) timber-crib dam. In contrast to Fuller Lake, which is a flooded quarry, 25-acre Laurel Forge Pond (today Laurel Lake) was created solely to power the two water wheels at the finery forge. Thus, Laurel Lake is also a direct consequence of the iron industry but is much shallower than Fuller Lake.

East from Laurel Lake are two important quarries.

Laurel #1, closest to the forge area, was approximately 15 meters deep when abandoned. It was conveniently adjacent to the 1870 railroad line as it approached the dam.

The Laurel bank which is the most recent opening, has been worked for a number of years, and contains an inexhaustible deposit of good neutral ore, above water level. Improved hoisting and washing machinery, erected by Col. Ames, is now in active operation. Here Laurel Forge is located, busily engaged hammering the raw pig from Pine Grove furnace into the blooms which have attained such celebrity in the iron market.

(Carlisle Herald 1869)

The ore found here is a mixture of a hard-lump bottom ore, yielding readily to the pick, and a hard-lump bottom ore requiring blasting. Both classes of ore here are richer in metallic iron than the Pine Grove ore; but neither, it is claimed, so pure or neutral as that which was formerly mined at the large bank near the furnace. At present, however, the company depends largely upon this Laurel No. 1 ore, together with a mixture of the Lehman ore, near Hunter's Run station, for the manufacture of their neutral pig. The excavation lies on the north slope of a terrace of the main mountain, and shipments have run as high as 150 tons a day, although rarely averaging that.

(D'Invilliers 1886).

Laurel #1 continued to be a commercially viable source of iron ore even as late as 1899, four years after the PGF furnace shut down (Watts 2019a). Laurel #1 mining including tunnels through the thick clay to reach the abundant "wash-ores." When the commercial brick company operated 1892-1907, the clay—formerly an impediment to ore extraction—became as important as the ore itself.

The ore at the Laurel banks included relatively high concentrations of manganese, especially at #1, and was lower in phosphorus than the openings upstream on Mountain Creek:

According to Mr. King, the lump-ore in Laurel No. 1 bank give 3.50 per cent. of manganese and about .150 per cent. of phosphorous, with 42 per cent. of metallic iron; so that by using this ore the resulting pig metal can be made with 50 per cent. less of phosphorous that that worked in the Pine Grove No. 1. The Pine Grove furnace depends largely upon this ore for the production of their neutral pig iron, the present practice being to mix about 50 per cent. of Laurel No. 1 with the softer brown-hematites near Hunter's Run, which are practically free from manganese.

(D'Invilliers 1886)

Some of the ore found today at Laurel #1 is black, in contrast to the yellow or dark red color of most other ore at PGF. As explained by Way 1991: "Two common manganese-oxide minerals, pyrolusite and cryptomelane, occur locally with the limonite. Both tend to be gray-black to black in color and frequently appear as nodules or in grape-like clusters. Pyrolusite is softer with a dull, earthy luster and cryptomelane is harder and more dense. A variety of other minerals occur in these residual iron-manganese deposits including wavellite, beraunite, cacoxenite, strengite, and turquoise."

The manganese at Laurel was considered valuable long after the South Mountain iron industry ended. During World War I and again World War II, the ferro-manganese ores of South Mountain attracted interest, especially at mines close to Mount Holly Springs and Boiling Springs as well as near Laurel Lake on the PGF property. A newspaper account in 1916 claimed that the mining economy would flourish:

> *Reopening Rich Iron Deposits—That Cumberland County has one of the richest deposits of manganese iron ore in the world, which will soon be put on the market commercially, is the statement of Charles Wharton, Jr., of Pittsburgh, present owner of the lands on which the veins are located, who inherited them from his father, formerly extensively interested in the mining industry in this section. The property, some 450 acres in extent, is located near Pine Grove on the Philadelphia and Reading Railroad. It [Laurel #1] contains veins 50 feet thick, which assay 40 to 45 per cent. pure ferro-manganese. Mr. Wharton says the veins are among the most valuable in the world and believes that Pennsylvania is soon to become again the chief iron producing State of the Union. The demand due to the war has made the product highly valuable. On the property are several old mines operated in the middle of the last century…*
>
> (Harrisburg Telegraph 1916)

Not much came of these boosterish claims for PGF, though ferro-manganese was briefly mined at the other South Mountain quarries to the northeast.

During WWII, local ferro-manganese deposits again attracted interest "with a view to their possible commercial exploitation because of the imminent need for production from domestic manganese ore resources to meet the growing needs of a nation at war" (Foose 1942). Surveys found that significant ferro-manganese existed in the area of South Mountain close to Boiling Springs (Foose 1945) but ultimately the local ferro-manganese was only briefly exploited 1939-1940 (Watts 2019a). Other domestic sources such as the Valley and Ridge Province of Virginia attracted more activity around that time.

Laurel #1 is today visible as a one-acre pond on the south side of Old Railroad Bed Road as you turn off Pine Grove Road. A part of the Michaux State Forest, the edges of the flooded mine may be approached, but with caution: the banks are steep and slippery. An eroded cut on the southwest side affords the best access for ore and clay samples.

Laurel #2 is 0.5 km. southeast from Laurel #1. Like Laurel #1, ore from this bank was embedded in considerable clay. The large mine was "vigorously worked" from 1878 to 1881, but abandoned by 1886 and "its tracks and machinery torn up and removed elsewhere" (D'Invilliers 1886). A worker died in one of the two Laurel ore mines, possibly this one, in 1879 when "a portion of the bank fell upon him" (Gettysburg Compiler 1879). Though not worked for an extended number of years, the resulting excavation is similar in size to Old Bank and is an impressive sight in the middle of the forest. The approach to this excavation is wide open in contrast to the narrow adit at Old Bank.

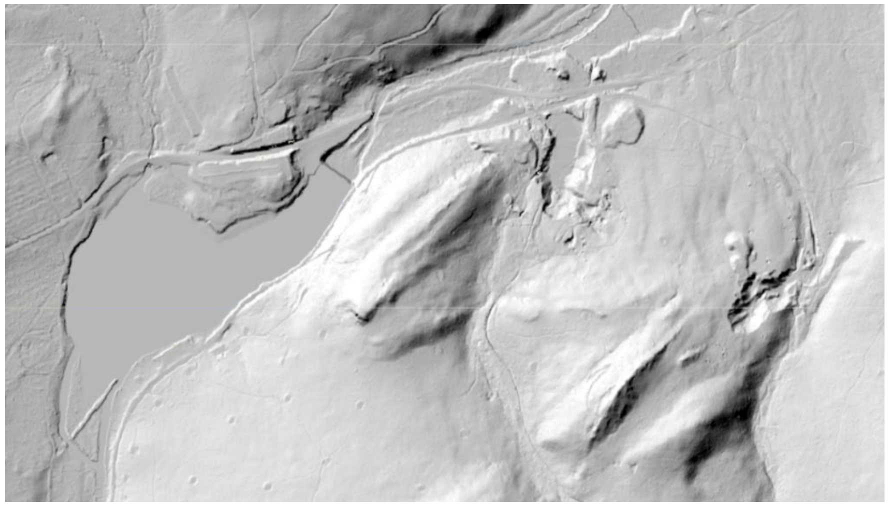


Figure 13. LiDAR map with Laurel Lake on west; Laurel Dam is thin line at northeast of lake. Flooded Laurel #1 is east from dam, and unflooded Laurel #2 is southeast from #1. (https://maps.psiee.psu.edu/preview/map.ashx?layer=1802)

Laurel #2 can be visited by driving up Ice Cutters Path, a narrow gravel lane that starts at the junction of Pine Grove Road with Old Railroad Bed Road. Ascending past several cabins, the road terminates after a short steep hill (there is room for one vehicle to turn around at the end of a cabin driveway at the top). The ore bank is ahead to the right across a mountain seep. With care, the visitor can climb clockwise up and around the edge of the quarry to look across the vegetation-covered mine. Chunks of iron ore can be found at the surface along the top edge, especially to the southwest. Though this quarry, like Laurel #1, is part of the Michaux State Forest and open to the public, very few people ever visit it today.

Figure 14. Laurel #2 in operation c.1880s and in 2023. (Credit: Cumberland County Historical Society and Andre Weltman)

Figure 15. Laurel #2 in operation c.1880s and in 2023. (Credit: Cumberland County Historical Society and Andre Weltman)

Wild Cat Ore Pits

In 1880, Jackson Fuller, co-owner of PGF, issued excited reports to local newspapers about abundant iron ore newly discovered 4 km. southwest from the furnace along Mountain Creek (Watts 2019a). The location was dubbed the Wild Cat Ore Pits, and a number of drift mines openings (Figures 16) were dug as well as linear open cuts closer to the creek. Fuller talked about extending the South Mountain Railroad to the Wild Cats, but soon recognized that the ore was high in phosphorus and thus produced cold-short castings. As summarized a few years later, "While the percentage of iron found here was sufficiently high (50 percent), the phosphorus was excessive (1.3 percent) for the purposes for which the company would have required it" (D'Invilliers 1886). Ore is still abundant between Route 233 and Mountain Creek on the forest floor and in the open cuts, and the realization it was not usable must have been a huge disappointment.

Figure 16. (Right) Wild Cat drift mine entrance at bottom of 3 meter deep opening in forest floor, 2013. Timber cribbing from 1880 can be observed by visitors standing at top. This mine entrance is often flooded. Location is off north edge of Route 233 across from house #1576, near intersection with Woodrow Road. (Credit: Andre Weltman)

Flux

The term flux in smelting relates to the word flow: in other words a flux helps anything that is not desirable in the ore to flow away from the metal. Iron smelters typically use a calcium-containing mineral such as limestone ($CaCO_3$) or, historically, oyster shells when convenient; however dolomite (rich in $MgCO_3$) works just as well in blast furnaces. The chemical role of flux is described in the Appendix.

PGF was fortunate to own an easily mined source of flux only 0.7 km. southeast from the blast furnace. During a full century of operation PGF never needed to import flux (such as from the karst geology of the Cumberland Valley), an obvious economic boon. Contemporary reports mention two limestone quarries near the PGF blast furnace, which is confusing as today only a single open pit is evident. Perhaps the original quarries merged as they were excavated, suggested by their shape on an 1889 map (Lehman 1889). Or, as noted above, there may have been some overlap or confusion with the southeastern end of Old Bank which is very close. Today, the topography is further confused by silt which was legally dumped into the bottom of the limestone quarry when Laurel Lake was dredged, 2006-2007 (Figures 17).

Figure 17. East face of limestone quarry south of Old Bank, covered by Japanese barberry. PGF cemetery is beyond top edge. Quarry bottom is silt dredged from Laurel Lake. Quarry can be entered by stepping off Quarry Road below junction with Murphy Road. (Credit: Andre Weltman)

The earliest description comes from the first Geological Survey, which noted “Immediately south of Mountain Creek, near the furnace, occurs a thin interposed belt of limestone, used as a flux, and also taken across the mountain, into Adams County, for lime for the fields… The calcareous rock is only developed to any extent near the furnace, though it is said to be visible at Dull’s Saw Mill, three miles higher up Mountain Creek” (Rogers 1858). Dull’s mill was near what is today the Tumbling Run parking area on Route 233, south from PGF at the Adams County line;

there is no evidence of limestone ever being mined in that area. The use of PGF limestone for agriculture presumably was not limited to Adams County, since the iron company ultimately owned five small farms all in Cumberland County on its own mountain property, in an effort to be as self-sufficient as possible. An 1871 survey and resulting map (Beers 1872) places a small limekiln on the road between the limestone quarries and the furnace. Three minor depressions in the ground are all that remains of the limekiln today, east off Quarry Road just north of its crossing of Mountain Creek.

The local quarries at PGF were historically called either "limestone" or "dolomitic limestone" and are in the Tomstown Formation, which is "dominantly dolomitic with some minor limestone" (Key 1991). Analysis of two samples from PGF found relatively low amounts of $MgCO_3$ at 6.4-11% (Frazer 1876). The output of the PGF limestone quarries was described as "whitish blue, yellowish, and blueish white" and "is said to be very pure and good" (Frazer 1877). A few years later, a different sample from PGF was deemed "rather hard; light grey and brownish grey; more or less coated and seamed with oxide of iron" and contained 21% $MgCO_3$ (McCreath 1881), more typical of Tomstown dolomite; unfortunately, the exact location of the 1881 sample was not recorded. Dolomitic limestones readily found today in the opening south of Old Bank are blue and white in color, with occasional iron staining. Yellowish or grey deposits in the PGF quarry may have been buried under the silt from Laurel Lake in 2007.

A story was recorded in 1933 that as the limestone quarries expanded in the 19th century, the edge intruded into the cemetery to the east: "…workmen came too close to the burial ground and a number of graves were lost in the deep ravine which the undermining of stone produced" (Flower 2003). The date of this occurrence is unknown, but the cemetery was not much used after the Civil War, while mining for flux at PGF continued until the end of smelting in 1895.

Fluorite was twice reported here. In an early description of limestone at PGF, "This rock contains disseminated crystals of fluorspar" (Rogers 1858). Also, "Violet Fluorite has been observed by Prof. Persifor Frazer, Jr., as a coating of the upper surface of auroral limestone in Thomas' quarry, Pine Grove, Cumberland County" (Genth 1875).

In addition to the historic source of flux immediately south of Old Bank, a different site in Pine Grove Furnace State Park, 1 km. south from the old furnace, is sometimes erroneously called a "limestone quarry" by local residents and is even marked on Google Maps (hardly a reliable source) as "Tomstown Dolomite Quarry" (Figures 18). However, examination reveals sandstone of the Antietam Formation and associated colluvium (Mark Tucker, personal communication). The small quarry is labeled "State Borrow Pit" on a map in a 1985 report for the PA Geological Survey (Berkheiser 1985). It is not known when this location was first opened, but in the 20th century this borrow pit provided "rock that is used mainly by lumber companies to top-dress haul roads in Michaux State Forest. In the past, rock from this pit has also been purchased and used by several local townships for fill and road base" (Way 1991). No quarrying has occurred here in recent decades. Today the area serves the State Park's maintenance department as a "burn pile" and for bulk storage; small blocks of limestone found at the foot of the quarry face were imported to this quarry in the 21st century for use as stream riprap and were not mined at PGF. The quarry is on the east side of Bendersville Road, 0.1 km. south of the campgrounds, opposite the entrance to the park amphitheater overflow parking lot. Visitors may walk into the quarry without special permission so long as park staff are not working there; do not block the gate.

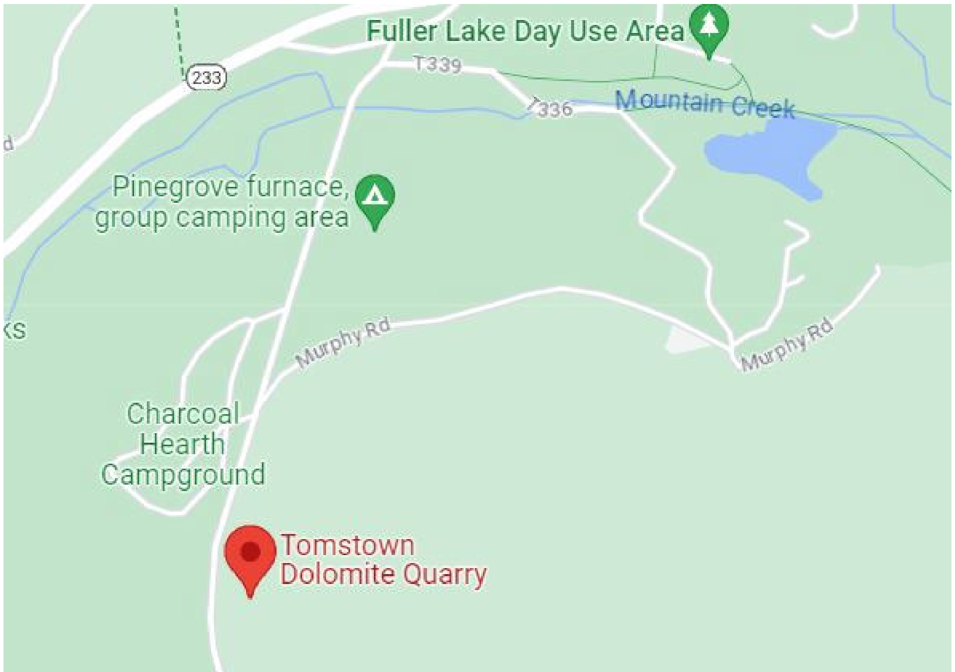


Figure 18. Erroneous Google Maps tag for "Tomstown Dolomite Quarry," 1 km. south of blast furnace, which actually contains Antietam sandstone. (Google Maps also labels Laurel #1 as Fuller Lake… caveat lector.) Web accessed June 28, 2023.

Slag

Slag is the general name for waste products of metallurgical processing. Various operations such as copper smelting, bloomery iron production, iron smelting in a blast furnace, finery forge production of wrought iron, steel mills and so on each create a distinctive slag. Archaeologists can identify metallurgical processes at historic sites by close examination of remnant slag. A blast furnace produces about as much slag as it does iron. This manmade silicate mineral, abundant at furnace sites, is worth extended consideration though historically it was considered waste.

Blast furnace slag, rich in Si and Al, is the result of the flux binding to silica, alumina, and other unwanted components of the ore. Detailed discussion of the mineral composition of ferrous slag and its natural mineral analogues is available in Piatak et al. 2021. The color, viscosity and porosity of slag served as important clues for early ironmakers, who smelted as an art not a science; slag remains a useful marker of blast furnace activity even today (White 1980). An abrupt alteration in slag characteristics was a cause for concern and might warrant adjustment of the process such as mixing ores from various sources, increasing the amount of flux, etc.

Blast furnace slag from charcoal furnaces like PGF was often a dull grey, dull green or black, but white, jade green, dark blue and sky blue are sometimes found (Figures 19). "Dark gray slag indicated a high grade of iron… protoxides of iron produced green or black slag; magnetic oxides, brown; peroxides of iron, a dirty yellow or reddish color; carbonate of iron, white or yellow; while light blue indicated the presence of manganese" (Eggert 1984). "The color of the slag is due to any of a combination of factors including chemical constituents, temperature of formation and rate of cooling; with slags that are high in earthy bases (especially MgO and CaO) tending to be light gray to blue and with high silica slags generally having a darker color than basic ones" (White 1980).

Figure 19. Convenience sample of slag, surface collected in vicinity of blast furnace at Pine Grove Furnace State Park. (Credit: Andre Weltman).

At only some historic furnaces, including PGF, slag was produced with a brilliant sky blue color, attributable to high levels of manganese in the ore as just noted. Slag of this color is not found at other historic furnace sites along South Mountain. Presumably at PGF this visually attractive waste product arose from smelting the manganiferous ores from the Laurel Forge area. The Leland furnace, in operation 1870-1884 along Lake Superior in Michigan (Dickinson 1996) also produced copious sky blue slag, and the name "Leland Blue" has been given to its slag now highly valued by amateur mineral collectors; the name Leland Blue is sometimes used for any similarly colored slag from other furnaces, too.

Texture of historic slags varies from vitreous, resembling manufactured glass or obsidian with which it may be confused, to dull and stony resembling volcanic scoria (Way 1991). Many slag samples demonstrate gas bubbles, arising from trapped air blast as well as gases produced during smelting such as CO, CO2 and NOx. Though S is present in local ores only at very low concentrations, slag incorporates MnS and SO2, and modern artisans using PGF slag to make jewelry report a smell of sulfur when opening their rock tumblers.

Being less dense than iron, slag accumulates as a liquid directly above the molten metal in the bottom of the furnace. Close examination of slag reveals occasional embedded iron prills 0.5-2 mm. in diameter, representing droplets of freshly smelted pig iron which happened to be descending through the molten slag at the moment it was drawn off. Less often, one may find unreduced iron ore fused directly onto historic slag, perhaps indicating a problem with smelting chemistry or that the furnace was too cool. Slag samples incorporating unreduced ore are very rarely found at PGF.

Periodically slag was drained from the furnace, allowed to cool and solidify, and carted away. Properly operating blast furnaces have such low amounts of iron in slag (<1-2%) that recovering the metal was not economical in the past. This contrasts with slag from finery forges which incorporated enough iron to be worth eventual extraction; hence historic forges often lack abundant slag deposits today, in contrast to blast furnace sites.

Slag at PGF was occasionally used as road fill for the extensive network of wagon haul roads that carried charcoal to the furnace, or as ballast between ties of the South Mountain Railroad constructed 1868-1869. As a result, slag is widely present on modern hiking trails built along historic wagon haul roads in the State Park and State Forest.

Most often, however, blast furnace slag was considered a useless byproduct. After solidifying as a single mass in a pit at the casting house, it was smashed into manageable sizes then dumped at some convenient spot near the furnace. At PGF, a 10-12-meter-tall ridge of slag extends >100 meters parallel to the north bank of Mountain Creek, southwest from the Ironmaster's Mansion. Along with unevenly dumped slag north of this high ridge, there is an approximately 2-acre slag heap or cinder pile evident on LiDAR, though difficult to explore today (Figures 20). A century of weathering has created enough soil from the slag to support large pine trees and other vegetation. In 2022 a self-guided history trail was opened through dense thickets of invasive barberry and privet to allow visitors to access the tallest portion of the slag heap; a trail guide is available at the trailhead on Bendersville Lane, 80 meters southwest from the Ironmaster's Mansion (Weltman 2022c).

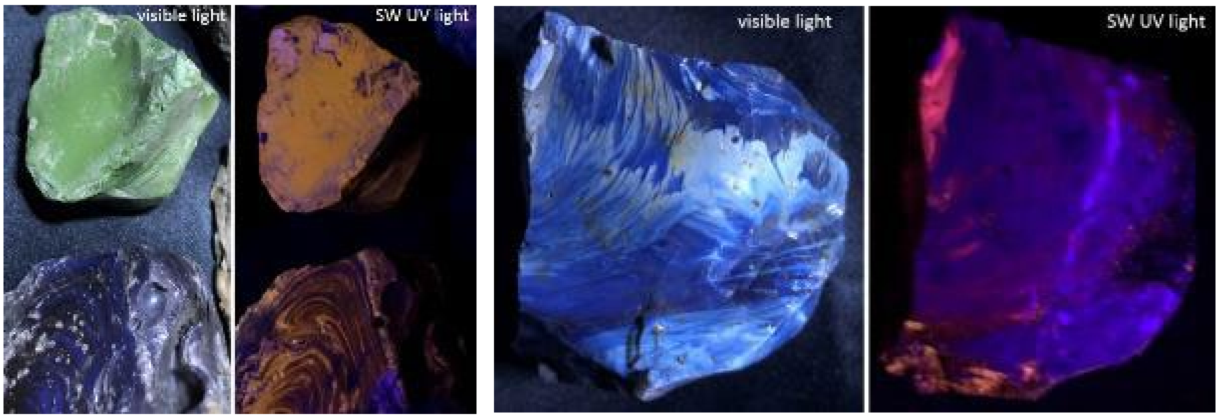
Figure 20. LiDAR map of PGF slag heap, distorted terrain at bottom left, directly north of Mountain Creek. Furnace head race parallels heap's north side. Ironmaster's Mansion is rectangular area at top center, with Route 233 running west-east to its north. Furnace bank abutting furnace is at far right. (https://maps.psiee.psu.edu/preview/map.ashx?layer=1802)

Slag tends to concentrate As, Cd, Cr, Pb, V, Zn and other trace elements in the ore, as well as more abundant Al, Fe and Mn (Piatak 2015, Piatak et al. 2021). Note that potentially toxic elements vary in slags from different metallurgical processes, and caution is warranted in interpreting the literature reporting on slag from blast furnaces fueled by charcoal vs. coal, steel production, non-ferrous metallurgy, etc. Moreover the concentrations of elements in ore used at a specific site necessarily influence the resulting slag, as do smelting conditions inside specific blast furnaces at any particular time, in a complex manner.

Though one might expect that the manmade silicates in slag would "lock in" various potential toxic elements, slag eventually breaks down into soil adequate to grow trees as clearly demonstrated at PGF. Hence it is reasonable to wonder whether historic slag piles represent a threat to health and the environment. This question was studied at Hopewell Furnace, a Pennsylvania blast furnace site roughly contemporary to PGF and now a National Historical Park restored and managed by the National Park Service (Piatak and Seal 2012). Leachates from Hopewell slag contained potentially worrisome concentrations of Al, Cu, Fe and Mn compared to drinking water standards. Other elements of potential concern were generally not detected above regulatory thresholds for water and soil. At least at the Hopewell site, "historical Fe slags appear to be more environmentally benign when compared to historical and modern base metal slags." Whether soil and leachates from the slag heap at PGF represent a local source of contamination has not been investigated and is a ripe topic for study.

Modern coke-fired blast furnaces tend to produce a stony, uniformly grey slag. Slag is not simply discarded by modern ironworks. It is processed to become an aggregate in concrete, among other purposes, thus rendering valuable an unavoidable byproduct. Modern slag is typically granulated or pelletized using air, water or steam while the slag is still a molten liquid fresh from the furnace (USDOT 2016).

Curiously, some though not all ferrous slag fluoresces, most prominently under shortwave UV light. This phenomenon can be readily demonstrated in random samples from PGF which shine orange, purple or red under shortwave UV (Figures 21 and 22). Some slag from other historic furnace sites reportedly also shines orange. Longwave UV light on specimens from PGF reveals a few whitish specks but not much else.



Figures 21-22. Slag from PGF under visible and shortwave (254nm) light. (Credit: Andre Weltman)

Charcoal vs. Coal

The blast furnace at PGF and other iron smelters of that era were fueled by charcoal made from local hardwoods such as oak and chestnut. The rule of thumb was that one acre of forest, clear-cut, produced enough charcoal to operate a typical furnace for one day. For details of this open-air meiler process see Kemper 1987. Through the 18th and 19th century, increased efficiency by pre-heating the air blast, higher blast pressures, and other technical improvements demanded less charcoal per ton of iron produced, but “an acre a day” remains a useful rule of thumb for the acreage necessary to fuel a traditional blast furnace. It was said that early ironmasters would never admit to owning enough forest land. The freshly cut tree stumps were coppiced—naturally producing new sprouts from tree stumps that, after a period of 20-25 years, were ready to be cut again (Birkinbine 1896, Straka 2014). This cyclical timber harvest implies that almost all the trees surrounding PGF were cut down two to five times between the 1770s and 1890s. Charcoal was needed at the forge as well as the furnace, and wood was used by the ironmaking community to keep warm in the winter, to repair buildings, etc. Hence as much as 1,000 acres/year might have been clearcut at PGF through the 19th century.

The legacy of this intense use of the mountain forests is reflected across the modern landscape. The educated hiker can notice large round openings in the Michaux State Forest, typically 10-15 meters in diameter, representing hearths deliberately cleared and flattened on the forest floor where charcoal was produced by pyrolysis. Because massive quantities of charcoal were needed over a period of more than a century, hearths are quite abundant in South

Mountain, as demonstrated by LiDAR (Figure 23) (Potter et al. 2013, Marr and Wah 2019, Bayuzick 2022). Using the latest high-resolution LiDAR dataset, a current estimate is ≥7,600 relic charcoal hearths in the Michaux State Forest (Samuel Bayuzick, Penn State University, personal communication). Less often found by direct observation, and difficult to locate on LiDAR, are hundreds of smaller associated platforms that once held crude collier huts where the charcoal burners or colliers, skilled artisans who made the charcoal, lived through the spring, summer and fall coaling season.

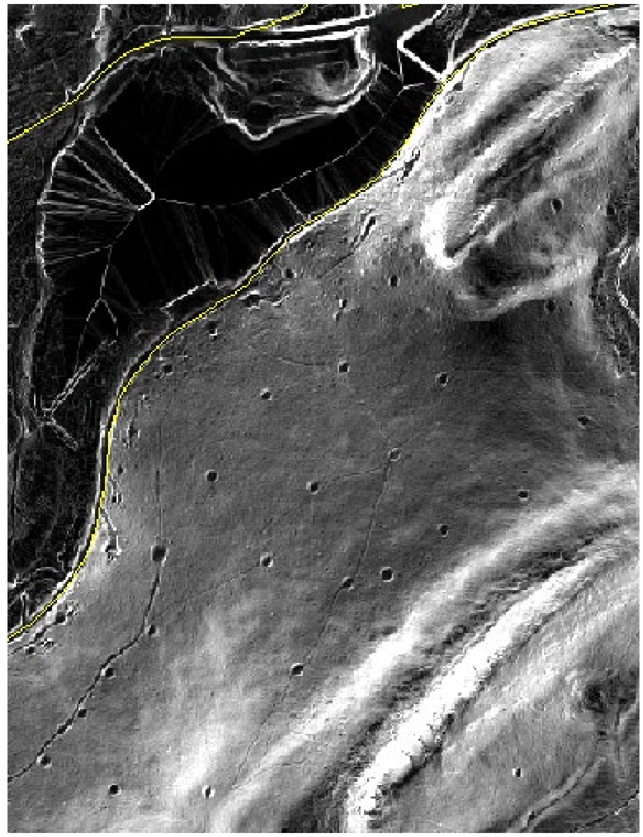


Figure 23. High-resolution LiDAR showing round charcoal hearths on slope south of Laurel Lake. Pole Steeple overlook is at bottom center. Hiking trail up from lake is a thin vertical line winding through middle of image. Historic wagon haul road modified for 20th century logging is diagonal at bottom left. (Credit: Samuel Bayuzick, 2019)

To transport fresh charcoal out of the forest and down to the furnace, an extensive network of wagon haul roads was developed. Hiking trails and roads often follow the path of the historic haul roads, including the Appalachian Trail as it traverses this part of Pennsylvania. Thousands of hikers unknowingly walk across industrial archaeological relics deep in the forest.

The land- and labor-intensive production of charcoal for metallurgy has been cited as a major incentive for England to establish colonies in North America, as the mother county became progressively deforested (Pluymers 2021). Deforestation in England and elsewhere in Europe spurred the transition from biological carbon (charcoal from trees) to geological carbon (anthracite, and bituminous coal converted to coke). For a long time this transition was resisted in Pennsylvania, Connecticut and other major ironmaking areas of North America for the simple reason that forests remained abundant (Gordon 1996). Pennsylvania ironworkers claimed in the late 19th century that, unlike the wasteful attitude of the lumber industry in the northern tier of the state, their forests were maintained as a renewable resource by an industry which could not relocate blast furnaces with the same ease that the lumber industry moved sawmills (leaving a wasteland of cut forest in their wake). That fact acknowledged, the coppiced forests during the industrial era on South Mountain would not resemble the Michaux State Forest enjoyed by visitors today:

> *Pennsylvania is undoubtedly indebted to the charcoal iron works for a large portion of the forests that are spared. These are not however, the magnificent grove of half a century ago—*

> *but rather considerable areas of coppice or small growth of timber, yet they serve a good purpose in possibly influencing the climate and water supply of adjacent territories.*
>
> (Birkinbine 1896)

At PGF, upgrades to the antiquated furnace in 1877-1878 included the ability to operate on charcoal, or coke, or anthracite, depending on which carbon fuel was cheapest and most easily obtained at any given time (Birkinbine 1880). In 1883, for example, PGF business records indicate a rapid switch between all three fuels over the span of a few months. Use of coal was only possible because the South Mountain Railroad had been completed in December 1869, connecting PGF to the Cumberland Valley Railroad at Carlisle. This marked the first time that goods could be easily transported to and from the ironworks other than by slow-moving animal-drawn wagons. Thanks to the new railroad, during its last two decades of operation PGF could occasionally import anthracite from Schuylkill County and coke made in the massive bituminous coal fields south of Pittsburgh. Consider the fact that coal mined elsewhere in Pennsylvania, and its transportation by rail, was often more cost effective for PGF than using local skilled labor to produce charcoal on the iron company's own lands just a few kilometers from the furnace.

PGF co-owner Jackson Fuller spoke in 1889 of building a new anthracite-fired blast furnace here, made possible by importing anthracite on the South Mountain Railroad (Harrisburg Telegraph 1889). It never happened. The efficiencies of massive iron and steel plants built near population centers, combined with superb transportation networks using lakes, rivers, canals and railroads—think of Allentown and Bethlehem, Pittsburgh, and cities on the Great Lakes from Detroit to Buffalo—ultimately doomed small, remotely sited ironworks like PGF.

Sericitic Phyllite

As already mentioned, the interior lining of the PGF blast furnace for many decades was a locally quarried material historically described as a talcose schist, sericite schist or soapstone (Rogers 1858, Stose 1907). However the rock does not contain talc and is not actually soapstone. It is predominantly composed of sericite, a fine-grained mica, and sometimes contains subsidiary quartz as small relict phenocrysts; it is more properly called a sericitic phyllite or sericite-quartz phyllite (Mark S. Tucker, personal communication).

The furnace lining probably needed to be rebuilt frequently until the friable phyllite was replaced with imported high-silica firebrick. Starting in 1892 phyllite was also used in commercial brickmaking at PGF.

It is light green, very soft and has a silky or soapy feel especially when wet, hence the local name soapstone. As described in 1907: "The 'soapstone' used at Pine Grove Furnace in the manufacture of brick is a light greenish sericite schist with quartz phenocrysts, an altered rhyolite rock similar to other schist seen in the volcanic belt, which crushes readily to a fine white clayey powder…" (Stose 1907). This material is an aluminum silicate with 73% SiO2 and 14% Al2O3, similar in composition to the white clays found downstream along the Mountain Creek valley (Stose 1907).

Sericitic phyllite was obtained primarily from two locations on the PGF property. Closest to the furnace is a 1 acre excavation with a deep trench and a more oblong area, visible from the east side of Old Shippensburg Road adjacent to house #99, 0.5 km. north of Route 233. It was also mined from a small quarry apparent today only as a grassy field in the middle of the forest along the Appalachian Trail, 0.2 km. south of Old Railroad Bed Road. This quarry served in the first half of the 20th century as the Cooke Township public trash dump, accessible in that era to motor vehicles driving up the Old Whitestown Road (now the portion of the Appalachian Trail climbing from Old Railroad Bed Road toward Pole Steeple). The quarry/dump was completely filled with silt dredged from Laurel Lake c.1960s. Pieces of light green phyllite may be recovered from the trail itself or in linear excavations to the west which were not filled with dredged lake sediment. Minor outcroppings of phyllite are also present on both sides of the Mountain Creek valley throughout the State Park.

Brickmaking at PGF

Pine Grove Furnace's last owners, Jackson Fuller and the financier Jay Cooke, barely squeezed a profit from pig iron castings and wrought iron even as the industry shifted to steel made at more modern facilities located in more convenient locations, in what is sometimes called the "Second Industrial Revolution." We may be amazed that old-style charcoal furnaces and forges managed to stay in business into the late 19th century (and in rare instances into the 20th). There were still discerning customers who appreciated the high quality of the older types of iron for specific applications and were willing to pay a relatively high price (Tyler 1967, Schallenberg 1975). Nonetheless, the owners of Pine Grove Ironworks were not oblivious to the threat from more advanced technologies with better transportation, which drove them to develop alternative uses of the PGF property. Beginning in 1870, the new South Mountain Railroad allowed development of three non-metallurgical industries: (1) natural ice harvested from Laurel Forge Pond (today Laurel Lake), which in warmer months was the source of water power for Laurel Forge, 1872-late 1920s; (2) an amusement park owned and operated by the iron company in a quiet spot between the furnace and forge, for which more than 20,000 visitors/year bought railroad tickets, 1878-c.1900; and (3) a commercial brickyard located between the furnace and the entrance to Old Bank (today the park's Brickyard Day Use Area), 1892-1907 (Figure 24).

The Fuller Brick & Slate Company made 12,000 bricks/day initially, later increased to >60,000, thanks to recently developed machinery such as two Simpson brick presses and three Eudaly kilns (Watts 2019b). The invention of automated brickmaking machinery in 1884 led to what has been called the "Brick Revolution." Unlike bricks crafted manually on-site to construct the PGF Ironmaster's Mansion 1827-1829, the same mineral resources could now be exploited on a vastly greater scale. As with iron, the railroad allowed the heavy final product to be transported to market.

The necessary ingredients for Fuller's variously colored non-vitreous decorative bricks were all found in exploitable quantities on or near the iron company's own lands on South Mountain. As previously noted, clay was especially abundant at Laurel #1. It is interesting to consider that when the blast furnace was thriving, the thick clay overburden obstructed ore extraction; but by the 1890s, the clay became important in its own right for brickmaking and was no longer an unwanted byproduct of the iron mines.

Figure 24. Brickyard c.1907, looking north. Note rows of kiln chimneys on left. To rear, furnace-area buildings are visible at 0.4 km. Furnace itself is not visible off left edge. View of distant structures is now completely obstructed by State Park trees. (Credit: Cumberland County Historical Society)

Slate for the brickyard came from a quarry south of PGF and north of Wenksville in Adams County, on the south slope of Piney Mountain. A slate quarry was owned by early PGF ironmasters and is mentioned several times in advertisements to sell PGF 1808-1810: "A valuable Slate Quarry, which for several years past, has been used for various purposes in Buildings, and for Tomb and other Grave Stones" (Carlisle Weekly Herald 1810). The location of this early slate quarry is uncertain but it is possible it was the same one rediscovered 8 decades later, as there are no other slate deposits known on the PGF property. No mention is made of PGF slate through the mid-19th century, then in 1890 discovery of "rich black slate" was reported in newspapers as "1800 feet wide and 2 miles long" (Scranton Tribune 1890). However, the slate quarry area actually exploited was much smaller. Mining carts were moved from the working face to the railroad below by a thick wire cable which snapped in 1894, killing a worker (Gettysburg Compiler 1894).

The quarry is located on the west side of Old Railroad Road north of Wenksville in Adams County (not to be confused with Old Railroad Bed Road near Laurel Lake). It is recognizable today as a bench parallel to and uphill from the road. The quarry is on State Forest land and may be freely explored. Fragments of highly fractured black slate can be found in abundance beneath the leaves.

As described by Watts 2019b in his detailed summary of the local brick industry, “The owners were filled with optimism at the start and built a ‘mountain extension’ of their railroad from Pine Grove to the ‘slate belt’—naming it the Hunters Run and Slate Belt” Railroad. A contemporary description of the operation stated:

> *The factory at Pine Grove manufactures ornamental bricks of different kinds. The white clay, along with some colored clay, is used simply as a bond, the body of the material being a black slate for their reddish-colored brick, and greenish talcose shist (‘soapstone’) for the light colored ones. The slate is brought to their works from the slate quarry about three miles south west of the works; the soapstone is hauled by wagon from their quarry a quarter mile from the works, and the clay is brought by rail from Laurel Station, three miles away. By different mixtures of these materials the company manufactures quite a variety of ornamental brick of different colors, shapes and sizes.*
>
> (Hopkins 1899)

Bricks made during Fuller Brick & Slate’s 15 years of operation can be recognized in buildings in the region, especially in Carlisle. The most distinctive product was a thin beige colored brick, 4 cm. thick, 10 cm. wide and up to 30 cm. long. It was used in the First Lutheran Church with its tall bell tower (1901) on East High Street at Bedford Street in Carlisle. The most distant reported use of Fuller bricks was in a 16-story building on Broadway in Manhattan, the St. James building (1896), today an office and condominium, as well as a contract for nine schools in New York City in 1901 (Watts 2019b). Fuller Brick and Slate Co. was driven out of business by the national Panic of 1907, and the buildings were eventually razed.

Today the site serves as the State Park’s Brickyard Day Use Area. Reminders of the brick industry are concrete footers for one of the kilns in grass at the south end of the picnic area, a few vestigial piles of slate south of the footers past the edge of the grass, and a barberry-covered mound of tailings where the Slate Belt extension of the railroad began to climb the mountain southward toward the slate quarry—its route can readily be followed through the woods and briefly south along Bendersville Road, then onto an ATV trail behind a yellow forestry gate leading up and over Piney Mountain Ridge into Adams County (Watts 1991). Numerous fragments of broken bricks may be found between the Brickyard Day Use Area and Fuller Beach.

Vein Quartz

Quartz vein intrusions are frequently visible along the ridges of South Mountain, and while visually attractive, are not of major economic importance. However, a particularly large and pure cap of milky quartz near PGF was reported in a 1985 issue of Pennsylvania Geology with the excited headline "Silica 99 and 44/100% Pure, Waiting to be Mined!" (Smith and Berkheiser, 1985). The authors estimated that "at least 100,000 tons are potentially mineable" while "Little or no overburden removal would be required." Nonetheless, the quartz in that area was not commercially exploited. The feature was included as Stop #11 "Toms Run Quartz Vein" in Way's 1986 public guide. (Figure 25 and 26)

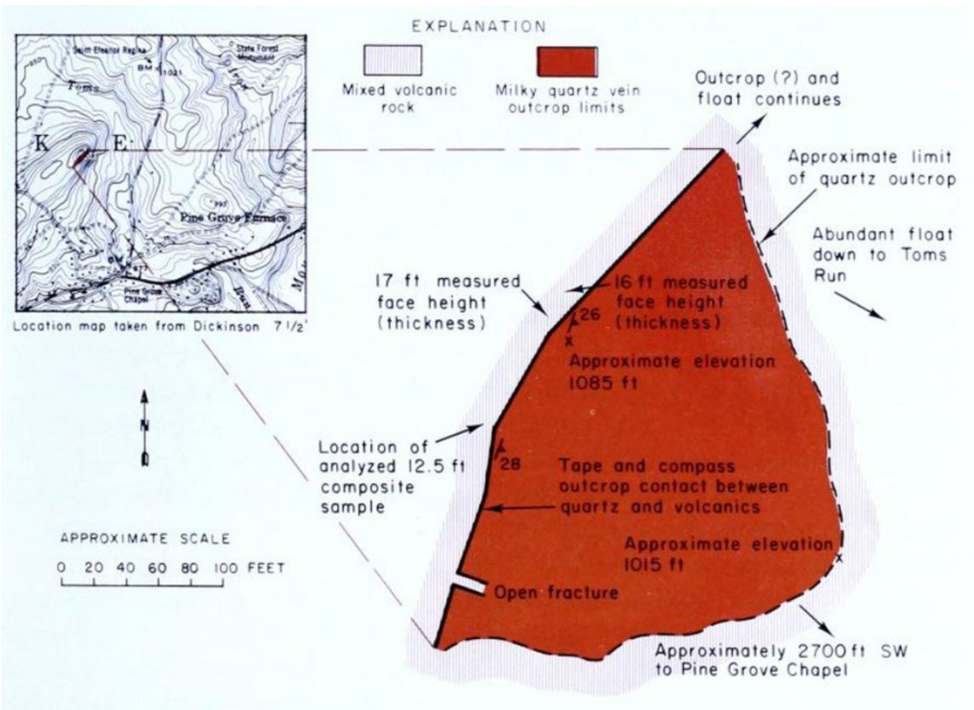


Figure 25. Sketch map of the milky quartz outcrop, reproduced from Smith and Berkheiser, 1985. Using smartphone GPS in 2023, the west end of the area of interest is 40.0397, -77.3075.

Figure 26. A quartz boulder off Old Shippensburg Road, photographed in October 2023 with orange flagging presumably placed by a turkey or deer hunter. Geologists exploring the State Forest during hunting seasons are reminded to wear fluorescent orange for personal safety. (Credit: Andre Weltman)

Why is this material of economic interest? “Potential use of milky quartz such as this range from decorative to high-technology” (Smith and Berkheiser, 1985). Though the milky quartz closest to the old Pine Grove Furnace blast furnace was never developed, other exposures of vein quartz were mined in the early 20th century as a source of “flint,” an industry term for quartz or other minerals to be pulverized as a relatively pure source of silica. A description of northern Adams County in 1925 is instructive:

VEIN QUARTZ

Quartz has been quarried at several places in the northwestern part of the county and in the adjacent part of Cumberland county for silica (or "flint" as it is commonly called in the trade), used in crockery and tile manufacture. Quartz for this purpose must be free from iron and other impurities. Quartz veins are numerous throughout the area of volcanic rocks in the South Mountains and those that are most prominent at the surface are shown on the map (Plate I). The veins are generally associated with soft sericite schist, and as this rock generally weathers readily, the loose residual masses of the inclosed quartz strew the surface and conceal the vein outcrop. The veins are about 1 to 2 feet thick, and masses several feet long are not uncommon.

Quartz veins are more plentiful in the extreme northwestern part of the county. The loose masses of residual quartz have in many places been collected from the fields and several years ago the best rock was picked out and hauled to a quartz mill at Aspers. Much of the field rock is stained yellow by the weathering of the contained hematite and is discarded. Ledges of vein quartz have been opened in places by small pits where the fresh rock has been quarried.

There are several pits and collecting grounds of surface rock in the vicinity of Wenksville and near Idaville. One of the largest quartz quarries in the county was the Moses Black quarry, 1 mile north of Wenksville. A large vein just south of Idaville was formerly extensively quarried and quartz is still exposed in the pits near Gardners station.

Several quartz veins occur on the north slope of Huckleberry Hill near Caledonia Park, and one of these was formerly extensively quarried and the quartz crushed at a mill at Black's Gap just west of the county. The old quarry is 20 feet deep and 70 feet long.

This quartz has some hematite impurities in it and it must be carefully hand picked. Quartz was also formerly quarried from a vein above Hilltown and was reported to have been shipped to Columbia or Lancaster, Pa., for treatment.

Most of the quartz formerly collected in the region was hauled to Aspers on the Gettysburg and Harrisburg branch of the Philadelphia and Reading Railroad, and ground by the Columbia Flint Company, a branch of the plant at Columbia, Pa. This company stopped operation in 1919 and its kilns have been torn down.

(Stose 1925)

The farm of Moses Black was immediately south of the historic PGF iron company lands and 4 km northeast from the slate quarry previously described in relation to the brick industry. The vein there was developed between 1904 and 1919, and as just noted the quartz was shipped to nearby Aspers for use in ceramic tile manufacturing (Gettysburg Compiler 1904; Gettysburg Times 1961) (Figure 27).

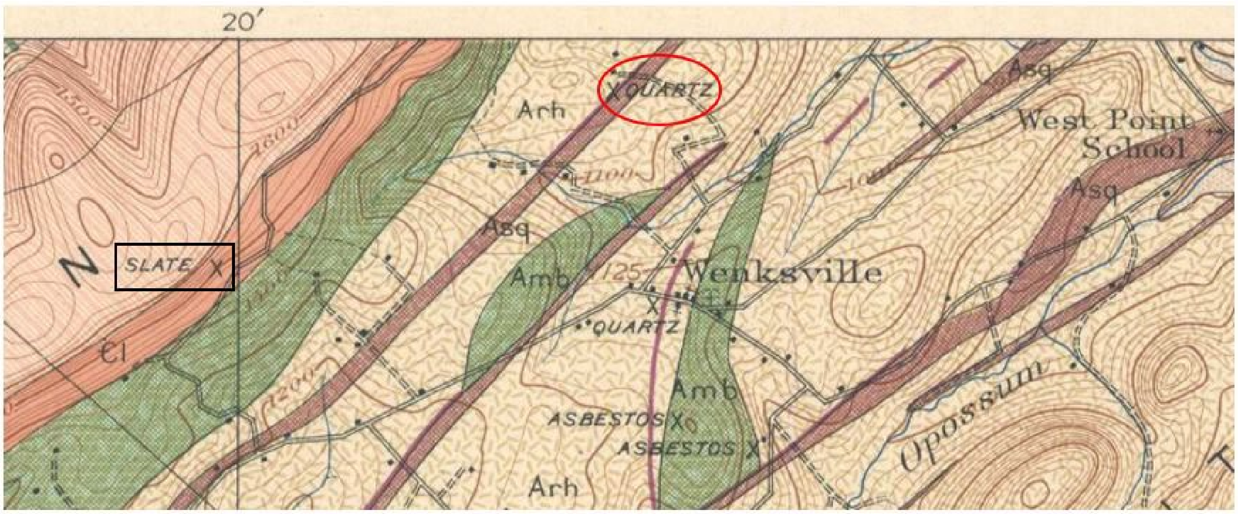


Figure 27. Two of the several small quartz mines in northern Adams County, at southern end of historic iron company property. Moses Black quarry is 2 km. north from Wenksville (added red oval). Slate quarry west from Wenksville (added black box) is described above in relation to brickmaking. Excerpt from USGS Fairfield Quadrangle topographic map, 1929.

Near the end of WWII, a local newspaper was still promoting the potential for renewed development of this mineral resource in northern Adams County, but it apparently never happened (Gettysburg Times, 1945).

Though a high-tech quartz crystal industry developed in Carlisle in the 1930s, became especially significant during World War II for military radios, and continued for half a century, raw material was imported from Brazil or grown synthetically—no quartz was used from South Mountain. For detailed consideration of that quartz industry, see Watts 2021.

The large quartz outcrop described in 1985 is approximately 350 meters east from the sericitic phyllite quarry along Old Shippensburg Road, mentioned in this paper above. The area can be readily accessed by walking through level open woods along the ridgetop northeast off the public road in the vicinity of house #99, 0.5 km. north of Route 233.

Numerous shallow, small openings with scattered fragments of quartz can be visited today in the Michaux State Forest within 100 meters of Coon Road near Wenksville in Menallen Township in northern Adams County.

Remnants of the Iron Industry Today

In 1912-1913, the defunct industrial works with all its farms and forest lands was sold to the Commonwealth of Pennsylvania. Of PGF's massive landholdings, nearly 17,000 acres became a State Forest Reserve (later, the middle portion of the Michaux State Forest spanning Cumberland, Franklin and Adams Counties) while the core industrial areas along Mountain Creek became Pine Grove Furnace State Park. Railroad service shifted to the tourist trade, and continued as far as the furnace into the 1930s while summer service as far as Laurel Dam continued into the 1950s.

Today 350,00-400,000 people/year enjoy the State Park, where they may read wayside displays on local history, partake in public history tours, and examine artifacts in a small museum inside the State Park Office, an 1850s boarding house. The iron company's grist mill built in 1783 houses the Appalachian Trail Museum, and the 1829 Ironmaster's Mansion is an overnight hostel for hikers and occasionally a rental venue for weddings and other social functions. The General Store serving burgers and ice cream is in a former mule stables. "Pine Grove Iron Works" was entered in the National Register of Historic Places in 1977. We can only imagine the noise, heat, dirt and round-the-clock activity of the long-vanished industry.

From Past to Present: Surveys for Rare Earth Metals

USGS is currently conducting the Earth Mapping Resources Initiative (Earth MRI) to map mineral resources in various parts of the U.S., including southcentral Pennsylvania, using remote sensing. Working in conjunction with the Pennsylvania Geological Survey, Earth MRI is focused on rare earth metals and other "critical mineral deposits." Locally, "The Pennsylvania Geological Survey's geologic mapping will focus on Adams County, which has historic mining from the colonial period up until the 1970s" (USGS 2023).

The initiative seeks "to identify areas that may have the potential to contain undiscovered critical mineral resources" to "decrease the Nation's reliance on foreign sources of minerals that are fundamental to our security and economy." Moreover,

> *Information acquired through this initiative could also advance our understanding of other economically valuable mineral resources (such as copper, zinc, gold, and industrial minerals), energy and groundwater resources, and geologic hazards. The newly acquired data also address other pressing societal issues in need of detailed geoscience information, such as identifying earth resources needed for revitalizing the Nation's roads, bridges, and other infrastructure systems.*
>
> (USGS 2023)

Helicopters with long booms housing magnetic probes were observed in 2023 flying low over the PGF area of South Mountain, presumably conducting the Earth MRI survey. It will be interesting to learn the results. Will the South Mountain region turn out to have exploitable mineral resources undreamt of by the ironmasters of PGF?

APPENDIX: Brief Introduction to Blast Furnaces (Weltman 2022a)

This material was collated from numerous sources including Hossford 1998, McMaster 1999 and especially Mandel 2017, to create a short handout explaining the chemical process of ironmaking for college classes visiting PGF as well as the general public.

The example of a blast furnace at Pine Grove Furnace was built in the 1770s, and continued "in blast" to April 1895: in other words, it made iron from around the time of the American Revolution to exactly 30 years after the Civil War. Iron production via blast furnaces played an important early role in the development of our industrial civilization (the "Industrial Revolution"). Blast furnaces are a continuous industrial process resulting in vast quantities of ferrous metals—a major building block of modern industry. This technique is only one of several ways that metallic iron was obtained historically, but other methods (such as bloomery forges to convert raw ore directly into wrought iron) produced much smaller quantities at a time because they were batch processes.

Bloomeries, and techniques that make the special ferrous metal we call steel, are ancient technologies. Evidence of iron- and steel-making can be found in the archaeologic record in multiple places in sub-Saharan Africa, the Middle East and East Asia. However, until the modern era the amount of iron or steel that could be produced was relatively small. The blast furnace as we know it today derives from 14th to 15th century European developments, but other cultures had similar technology even earlier. The blast furnace remains the first step in new steel production in modern times. Differences between a blast furnace of medieval times vs. today are size, automation and quality control… but <u>the underlying chemistry is exactly the same</u>.

The purpose of a blast furnace is smelting ore to produce crude iron. We use the word smelting (not merely melting) to describe a high-temperature, high-volume chemical process. Three raw materials—**iron ore**; **flux**, such as limestone to bind elements other than **Fe**; and a **carbon source** such as charcoal made from wood, or mineral coal such as anthracite or coke—are continuously loaded in layers into the top of the stack. The visible masonry encloses a hollow vertical column lined with heat-resistant refractory bricks. The vertical space is essentially a large counter-current reactor where solids become liquid and descend, and hot gases ascend. Air blast is forced into the bottom via pipes and nozzles called **tuyeres**. The carbon burns energetically, chemical reactions occur as explained below, and **Fe** is liberated from oxygen and other elements it is bound to in the raw iron ore. This reaction is a *carbothermic reduction*. The reduced metal in the furnace is above its melting point of ~1538 °C (2800 °F), so as a liquid it drips down and collects in the circular bottom or "hearth." It is periodically drained into an attached building, the "casting house" with a layer of sand as its floor.

In liquid form, the resulting crude iron is called **hot metal**; when solidified, it is **pig iron**. An operation such as Pine Grove Furnace produced bars about 1 meter long called "pigs," or alternatively the iron flowing from the furnace could be directly cast in molds to form useful shapes such as pots, Dutch ovens and stove plates. Inclusion of as much as 5% carbon from smelting in direct contact with fuel, sometimes called "iron carbide dissolved in iron" (**Fe_3C** in **Fe**), gives pig iron a microscopic structure prone to fracturing. Pig iron is very strong in compression, but is also brittle—even thick pieces can be broken by a sharp blow such as with a hammer. Look for broken legs on the bottom of cast pots as a typical historical example. Other elements such as phosphorus and sulfur play an often undesirable role in the characteristics of the final cast metal. Details of iron-carbon and other alloys are beyond the scope of this brief introduction.

Blast furnaces can be seen as the first step in the "indirect" process of making workable iron. To be useful to a blacksmith or in a rolling mill, brittle pig iron must be transformed into **wrought iron**, which has an extremely low carbon content. This transformation involves first *decarburizing* the pig (burning out the carbon), and then violently squeezing out slag inclusions. The altered crystalline structure of the wrought ("worked") iron yields very different properties from pig iron: it is flexible and can be hammered into various shapes, or squeezed to make plates, and it can be welded. The conversion was performed in a **finery forge** which had massive "helve hammers" with stone & iron heads weighing many hundreds of pounds. Pigs produced in the furnace here were hauled 3 km. to Laurel Forge, built in 1830 as part of the combined operation called an "iron works." Laurel Lake in the modern State Park is a legacy of the need to provide water power for the finery forge; it was not originally built for swimming, fishing and boating! This two-step process—pig iron made in a furnace, then converted to wrought iron at a forge—yielded "bar iron" that could be sold for four times the price of pigs.

A modern "integrated hot metal plant" takes iron from a blast furnace and immediately transports it as a liquid in special "torpedo" rail cars to a steel converter nearby in the same facility, thus preserving almost all the thermal energy in the metal. Steel was not made at Pine Grove Furnace and we will not discuss that aspect of metallurgy here.

Chemistry of iron smelting

Iron ores of industrial importance include hematite (Fe2O3) and magnetite (Fe3O4). In the South Mountain region of Pennsylvania, available ore is hematite or a closely related form, limonite; no magnetic ores are found at Pine Grove Furnace. (The closest magnetite deposits are to the south, or eastward in PA around Dillsburg. An advantage of magnetic ore is that it can be pulverized, then strong magnets separate and concentrate the material before it is added to a furnace. This technology is used today to make **taconite pellets** in the upper Great Lakes region from relatively low-concentration ore deposits. Pellets are also easy to transport and load in a furnace with automatic machinery.)

<u>Here are the essential reactions that occur in a blast furnace:</u>

Oxygen (in the air blast) enters the furnace via the tuyeres. The carbon fuel is ignited in a familiar exothermic reaction:

$C + O_2 \rightarrow CO_2$ + heat

This reaction occurs in the presence of excess carbon at high temperatures; carbon dioxide is reduced to carbon monoxide:

$CO_2 + C \rightarrow 2CO$

The resulting carbon monoxide is a critical reactant in the reduction of iron ore, as shown in the table:

(1) $3\ Fe_2O_3 + CO \rightarrow CO_2 + 2\ Fe_3O_4$	**Begins at ~450 °C (850 °F)**
(2) $Fe_3O_4 + CO \rightarrow CO_2 + 3\ FeO$	**Begins at ~590 °C (1100 °F)**
(3) $FeO + CO \rightarrow CO_2 + Fe$ or **$FeO + C \rightarrow CO + Fe$**	**Begins at ~700 °C (1300 °F)**

At the same time that the iron oxides are undergoing these purifying reductions, they are also beginning to soften and melt until they finally trickle as a liquid to the bottom of the furnace.

Products of the blast furnace other than pig iron

Meanwhile, the limestone flux loaded into the furnace undergoes its first reaction as follows:

$CaCO_3 \rightarrow CaO + CO_2$

This reaction requires energy and starts at about 870 °C (1600 °F).

CaO is useful because it binds with unwanted elements that might give the finished metal undesirable characteristics. For example, calcium oxide combines with silicon dioxide in the ore. SiO2 is a major component of the earth's crust:

$CaO + SiO_2 \rightarrow CaSiO_3$

It also helps to remove some of the sulfur that might be present in the iron ore:

$FeS + CaO \rightarrow CaS + FeO$

Similar CaO reactions involve alumina (Al_2O_3), magnesia (MgO) and other minerals commonly present in the ore.

The products of these reactions are given the general name slag, a waste product of smelting. In the high temperatures of the furnace, slag is a liquid that trickles toward the bottom of the furnace. It floats atop the molten iron, because it is less dense.

Periodically slag is drained out of the furnace, allowed to cool and solidify, and is carted away to form huge “cinder piles,” or used as road fill or as ballast in railroad construction. Pieces of slag are still readily observed on trails (formerly wagon haul roads) throughout the Michaux State Forest today.

Slag can vary considerably in color depending on the details of the acid-base chemistry and temperature at which it formed in the furnace, as well as small impurities. For example, at Pine Grove Furnace a brilliant sky-blue slag resulted from abundant manganese in iron ore obtained from two quarries just southeast of Laurel Forge. In general, a dull grey or dull green slag represented proper activity inside the furnace. These dull colors would make the old-time iron makers happy: they were unaware of all the chemistry going on, and had to adjust their smelting process as an art, not a science.

Finally, a large volume of waste gas or “flue gas” is produced—being very hot, it ascends to the top of the stack (through small gaps between the reactants being loaded into the top, or it bubbles through the liquids). The composition of this gas varies with different furnaces, raw materials and fuels, but will be approximately 56% **nitrogen compounds**, 25% **CO**, 17% $\mathbf{CO_2}$, 2% $\mathbf{H_2}$, and a little water vapor. Notice that smelting creates significant amounts of “greenhouse gases.”

This gas has a considerable energy value. In a modern furnace it is saved as it emerges from the top of the furnace stack so that it can be burned as a fuel in "regenerative stoves" to preheat the air that will be forced into the furnace as "hot blast." Preheating air reduces the amount of carbon fuel needed, thus saving money. Moreover, it is necessary to preheat the blast for furnaces being fueled with anthracite or coke, or air used in converting hot metal into steel, typically to > 900°C (1600°F). Modern hot metal operations may preheat air to even higher temperatures.

A very large flow of air is needed to smelt iron or make steel. Oxygen is a fourth hidden but critical raw ingredient. Consider the technical problem of how to rapidly heat a large volume of continuously flowing air that is forced under pressure into a furnace. This challenge was not easy to solve in the early days of “hot blast” iron-making.

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