Experimentation in 19th century bloomery iron production: evidence from the Adirondacks of New York

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Abstract

Research into the company records and correspondence of the Clintonville, New York, iron works (1824-1890) has revealed that bloomery forge management had a constant concern for improved efficiency and economy in iron production. This concern is evident in several aspects of forge operation, including experimentation in the application of hot blast, the size and number of tuyères in bloomery forges, recovery from river sands of ore lost in the separation process, the employment and modification of new techniques of processing raw ore, and the utilization of waste heat from the forges. It is also evident that information about developments in the industry spread rapidly from one region of the US to another, as well as across the Atlantic. Adirondack bloomery forge production of iron in the 19th century is thus seen as having been a dynamic and creative endeavour that made significant contributions to the industry overall.

Introduction

It is now recognized that the United States charcoal bloomery iron industry of the 19th century was a relatively efficient means of producing high quality wrought iron in areas where there was an abundance of woodlands, water power, and relatively pure ores (cf Gordon 1996: 98-99; 1997, Allen *et al*. 1990, Gordon & Killick 1992, 1993: 251f, Gordon and Malone 1994: 78-79). The spongy iron formed in the small forges was normally hammered into thick bars, called billets, that could be rolled locally into merchant bars or plate, or simply shipped to other iron plants for working into steel. This process was instrumental in helping to make New York state one of the top iron producers in the U S, placing the state third only behind Pennsylvania and Ohio in total production in the 1870s and 1880s (Swank 1884: 382).[1]

The Adirondack-Lake Champlain region of extreme north-eastern New York was particularly committed to the bloomery method of iron making, with 84% of the national output of such iron, in 1880, coming from this region alone. The counties of Clinton and Essex comprised most of this region, which by 1864 contained 28 bloomery sites with a total of 136 forge fires (Figure 1, and Neilson 1867: 259-62, 265-29).[2] Charcoal blast furnaces were occasionally employed, but were rare compared with their use in other parts of the state (see Lesley 1866).

Despite a long period of fluctuating success, the vast majority of the smaller iron industry sites in the Adirondacks were out of business by the early 1890s, due to a variety of national economic trends and industry developments. However, a few large concerns linked to blast furnace operations were able to operate profitably until the late 1960s. These were the Republic Steel mining, separation, and sintering operations at Lyon Mountain, which continued until 1967, and the Mineville/Witherbee iron operations near the shore of Lake Champlain, also owned by Republic Steel, which were the last to close down in 1971 (Farrell 1996, Moravek 1976).

While the basic technology of bloomery iron production seemed to change only minimally during the 19th century, it is becoming increasingly clear that iron producers were constantly concerned about any modifications or improvements to the process that would either decrease production costs or enhance product quality. This is particularly revealed in company records and documents that happen to have survived for one of the largest bloomery forge sites in the Adirondack–Champlain region, which was located at Clintonville in the Ausable River valley (Figure 2).[3] Operating under various company names from 1824 to 1890, the works included 20 forge fires, 16 of which were in one building, and turned out an average of 2243 long tons of iron billets per year between 1837 and 1881. The range for a year's production varied from a low of 1095 tons to a high of 3336 tons (production is calculated from Peru Steel and Iron [PS&I] Company papers 64.3 4/2 'Reports' ledger, in combination with figures in Neilson 1867: 267). The main forge building's foundations and associated features ('lower forge' in Figure 2) are the primary archaeological remains of this once-impressive operation, and the author and his students have so far conducted two field seasons of investigations there. Preliminary findings from the 1994 and 1996 investigations were presented by Pollard (1995b, 1997).

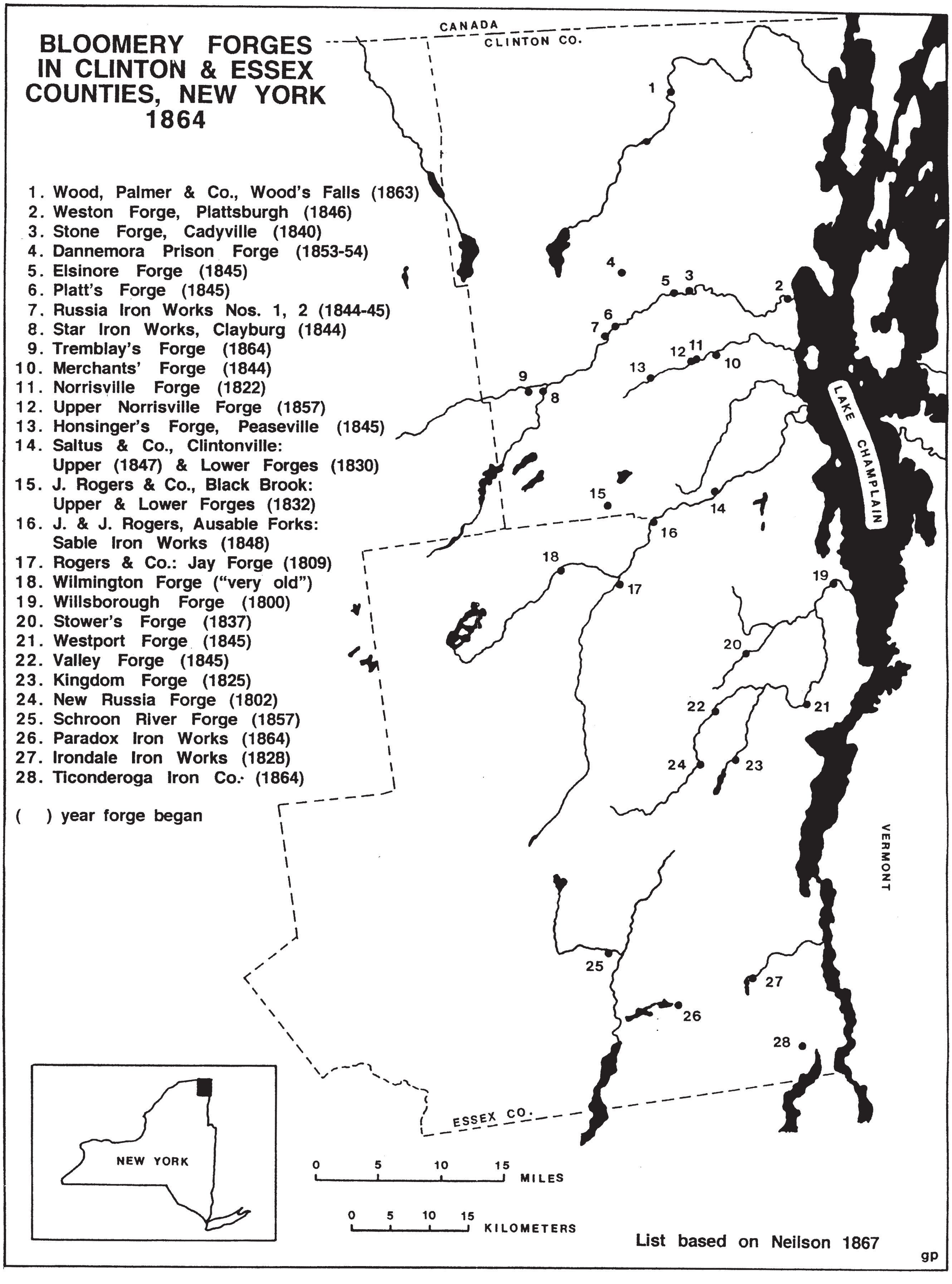

Figure 1: Bloomery forges operating in Clinton and Essex Counties, New York, 1864.

Experimentation

Hot Blast

One of the most important developments in iron smelting was the application of hot air blast to the forge or furnace fire, resulting in a substantial saving in fuel costs. The earliest such application in the US seems to have been at the Oxford blast furnace in New Jersey in 1834, following earlier efforts in England (Swank 1884: 326; Gordon 1996: 109-12). Its earliest use in bloomery forges is yet to be resolved, but the manager of the Clintonville forge in 1875, looking over the previous owners' company documents from 1826 to 1845, wrote that hot blast was first used at Clintonville in 1837.[4] To my knowledge this is the earliest documented application of hot blast to bloomery forges anywhere. Thirty-eight years later, in 1875, the forge manager was so sceptical of the original records of fuel savings that he undertook experiments to verify these by operating one forge on cold blast and another on hot. Several runs were made by each process over a period of days, and the results showed a dramatic difference in the amount of charcoal required to produce a ton of iron: between 246 and 298 bushels of charcoal with hot blast, and 595 bushels with cold.[5] Despite the conclusion that 'cold blast iron hammered softer and is probably better quality in some respects,' the company of course opted to continue hot blast production given the substantial fuel savings.[6] Hot blast forge operation was probably common in most regions, and as far south as Alabama, by the mid- to late 1840s (cf Gordon 1996: 279, note 14), and involved building 3 to 5 arches of pipe in the stack of the forge to preheat the blast air before it was forced into the fire below (Figure 3). Descriptions and engineering drawings in Egleston (1879-80) nicely detail variations in these arrangements. Blast air was heated to between 315 and 425°C (600-800°F) by these means, and hearth smelting temperature was about 1200-1250°C (2190-2280°F).

Tuyère Size and Number

A second attempt to improve forge efficiency involved reducing the size of the blast pipe tuyère. This is a tapered nozzle that in the 1870s was about 12 inches long, projecting $1\frac{1}{4}$ to 4 inches into the firebox of the forge at a slight downward angle, and giving a $1\frac{1}{2}$ to $2\frac{1}{2}$ lbf air blast to the fire (Egleston 1879-80: 10). Earlier tuyère configurations were apparently larger, and presumably with a lower blast pressure, because at Clintonville in 1840 the manager writes that he had reduced the size of their forge tuyères, the results being fully equal to his expectations.[7] Our excavations at the Clintonville forge in 1996 unexpectedly produced two firebox side plates that had been discarded beside the base of a bloomery forge; one was a tuyère plate whose nozzle opening had been reduced by more than half its size with cemented-in brick. This may well be a remnant of one of the experimental units referred to in the manager's 1840 letter. The hole through the water-cooled tuyère plate tapers, producing a flat-bottomed, D-shaped opening that is $7\frac{1}{2}$ inches wide and $5\frac{1}{4}$ inches tall on the outside, and 6 inches wide by $3\frac{3}{4}$ inches tall on the inside. The angle of insertion, measured by the bottom edge, is 14 degrees off horizontal, exactly the angle cited as the norm by Egleston (1879-80: 11). Egleston also says the tuyères usually did not have to be repositioned for several months.

Another element of experimentation with the forge involved increasing the number of tuyères per fire. One tuyère was the norm, but in November of 1840 the Clintonville iron works president directed his forge superintendent to make a trip to New Jersey to inspect

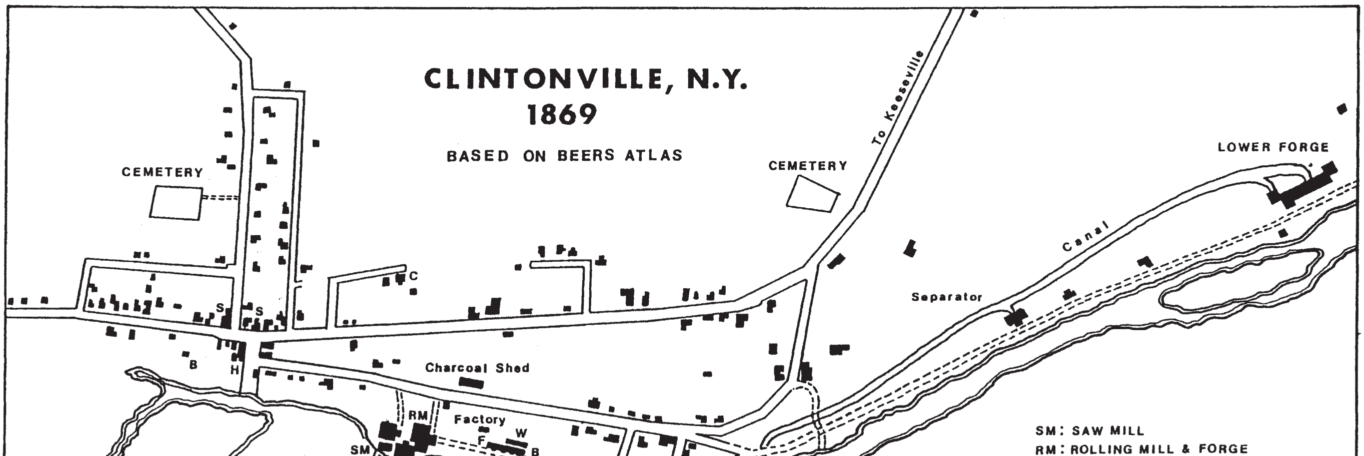

Figure 2: Clintonville, New York, 1869. Waterwheels at the main forge building ('lower forge') at the right were powered by water coming half a mile down a canal fed by the river.

several forge sites where two and three tuyères were being employed, to determine if such modification would be worthwhile at Clintonville (CCHA Bailey Papers 85.34.1, letter from F Saltus to J Bailey, Nov 10 1840). The superintendent was directed to take stationery for making drawings of the fires inspected, and to share diagrams of the Clintonville forges with forge masters in New Jersey in exchanging ideas (CCHA Bailey Papers 85.34.1, letter from F Saltus to J Bailey, Nov 5 1840). Forty years later, Egleston (1879-80: 10) gives only passing mention to multiple-tuyère use: 'The attempt was made to have as many as five small ones but it does not appear to have been successful.'

The next month, from December 12 to 17 1840, an experiment running one forge at Clintonville with two tuyères was undertaken, with the result that 293 bushels of charcoal were used in producing a ton of iron: no savings in fuel over a one-tuyère forge. The experiment was tried again in April of 1841, this time rigging two forges with two tuyères each, and running eight forges with one each. The double-tuyère forges each consumed 271

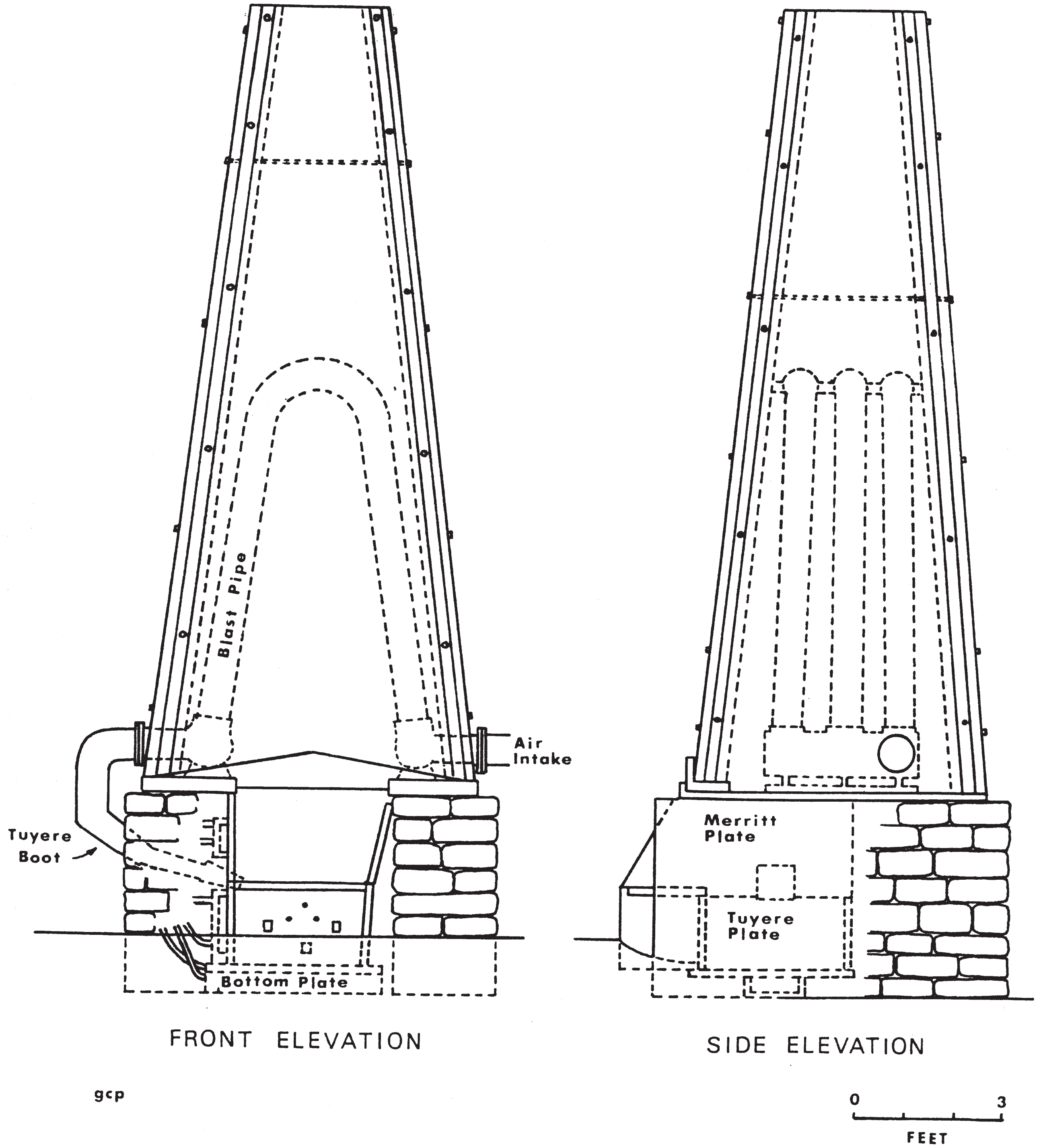

Figure 3: A typical bloomery forge with the blast being heated by three arched pipes in the stack. The tuyère enters the left side of the firebox. The Merritt, tuyère and bottom plates are water cooled.

bushels per ton of iron made, and the others used an average of 286 bushels (PS&I Papers 64.3 4/3 'Reports' ledger 1842-1847). Again, no significant difference was obtained. There is no further reference to multiple tuyère use, and the Clintonville works apparently abandoned the idea. Importantly, however, the correspondence on this matter demonstrates that knowledge of individual operations was widely shared throughout the industry.

Ore Sand Recovery

A third direction of an attempt at economy involves the ore that was smelted in the forges. Ore was crushed, and separated with water, in a separate facility adjacent to the river. This resulted in an undetermined but substantial amount of fine ore being washed into the river itself and essentially being lost in the sand. The Clintonville management was certainly aware of this, and late in 1873 began conducting experiments to recover the fine ore and test its use in the forges (PS&I Papers 64.3 4/2 'Reports' ledger 1847-1884). Such fine ore derived from other iron works further upstream, in addition to that produced by the Clintonville operations. Sand from a mile upstream of the rolling mill was dug and screened, as well as 'down river' of the forge. Costs were carefully monitored, including labour for digging and screening the sand, hauling, and washing the ore. The sand yielded an estimated nine per cent fine ore, and over 150 tons of ore were recovered. The cost per ton worked out between \$15.65 and \$16.84, while the average cost per ton of regular ore at the separator in 1873 had been \$13.72. This was obviously not an economical undertaking, and costs would only increase the further one had to go from the forge to acquire the sand.

Despite this, experiments were carried out in July 1874 to work the fine ore in the forges. Again, costs were monitored, especially charcoal consumption per ton of iron made, and different combinations of fine ore with regular coarse ore were tried in addition to working just the fine ore. Straight fine ore required an extra 100 bushels of charcoal to make one ton of iron, as well as a substantially higher amount of ore. Ratios of 1:2 and 1:5 fine to coarse ore were tried, and all required higher-than-normal amounts of fuel.[8] Quality of the iron was also judged to be no better than that from normal production. The company records give no further mention of sand ore recovery or use, so the idea was presumably abandoned. The undertaking nonetheless demonstrates a concerted effort to explore ways of maximizing resources and reducing costs.

Direct Ore Reduction

Yet another example of the eagerness of the industry to come up with and try new approaches involved what was called a deoxidizing furnace. Originally patented in 1871 by Edgar Peckham, and apparently touted by a partner by the name of Joel Wilson who in 1872 and 1873 had letters patent for his own version,[9] the device claimed to preclude the necessity of roasting the iron ore prior to its crushing and separation as was standard for bloom iron production. An article in an 1876 newspaper described the process as follows:

> 'Adjoining two ordinary forge fires at the rear is a brick structure eighteen feet high, eleven feet deep and the width of both fires including the space between them. The interior space of this brick structure is occupied by twelve air tight retorts each 11 feet long, 3 feet high and 11 inches wide, and each holding a ton of ore. They are constructed of the best fire brick, tongued and grooved and laid in fire clay. These retorts are arranged in four tiers, three one above the other in each tier, and surrounded by a series of fire flues, also of fire brick, connected with the forge fire below and a single smoke stack above. The ore as it comes from the separator is mixed with an equal bulk of the waste charcoal (*braze*) and piled upon the top of the retorts, then a slide is drawn, opening a row of holes in the top of the upper retort and the ore and braze runs in, filling it. Here it remains twelve hours, subjected to a dull red heat, very small crevices being left open to allow the escape of steam from moisture, and gases. After twelve hours another slide is drawn covering a similar row of openings connecting this with the second retort directly underneath and the ore runs down into the next retort below, while the upper one is filled as before with fresh ore from above. In the second retort the ore remains twelve hours subjected to a little higher temperature when it is let down into the third one by means of another slide which like the others fits tightly, where it remains twelve hours more at a bright red heat when it is run into an oven underneath, which is tight with the exception of an opening in front before which a sheet of flame from the forge fire is constantly ascending in its passage to the flues above. From this oven it is hauled out by the bloomer as he needs it, falling upon the forge fire when it is readily reduced, forming a loop which is then drawn as usual under the hammer. Thus the ore is subjected to a red heat for 36 hours in air tight retorts, together with pure carbon, and it is claimed that this process results in the thorough deoxidizing of the ore, which is just the necessary preliminary chemical process...
>
> No less than thirteen shapes of fire brick are used in the manufacture of the retorts in order to give them the right form and requisite degree of strength, and the greatest care is used in the construction of every portion of the works.
>
> One advantage which is no slight one is that the consumption of coal is very materially lessened by the process, and this would abundantly pay for the extra outlay even if the quality of iron was not improved. The

blast is reduced from $2^{1}/_{2}$ to $1^{3}/_{4}$ pounds pressure to the inch and even with this reduction considerably more iron is made in a given time from each fire than by the ordinary method.' (*Plattsburgh Republican,* August 5 1876, 1).

Prior to 1875, Wilson and Peckham had already sold and set up two of their installations at Adirondack forge works, and by the summer of 1876 convinced the Clintonville owners, in New York city, that they too would profit from investing in such a unit.[10] The cumbersome furnace was constructed as an appendage to four bloomery forges in the rolling mill, and used the waste heat from two of the forges to slowly heat raw crushed and separated ore, mixed with equal parts of milled charcoal, in a series of airtight retorts as described above. The 'deoxidizing' seems to have worked to remove undesirable emery and sulphur from the ore, and when working well the unit was judged to produce iron that was 'better and more uniform' than the usual forge product (PS&I Papers 65.5 9/2, 335, letter from D Cady to F Dominick, April 12, 1877).

Despite this, the whole undertaking at Clintonville was plagued from the beginning with a series of design, construction and operational problems, and unforeseen costs, that made the endeavour unworkable. The unit had a high initial cost ($6000), and required Wilson to come back more than once to oversee construction and repairs. As revealed in letters from the forge superintendent, Daniel Cady, to the company vice-president in New York City, problems included poor workmanship and excessive weight on the unit's iron castings, and poor top and flue design and construction, particularly for cleaning and maintenance:[11]

> 'I never saw so poor a job of castings. A large amount of labor has been expended in chipping and drilling. So many blunders have been made that it has taken extra time and will not be a workmanlike job at all. Wilson tells me that at least 10,000 pounds more weight is in the castings than ordered…'(Nov 30, 1876). 'Mr Wilson was obliged to stop one fire last night for fear of the top of the deoxydizer melting. Mr Lucy had taken part of the heat of two fires direct to the stack but this did not prevent it heating too much. Wilson seems to know very little about it…' (Dec 28, 1876).
> 'There have been so many blunders in getting the thing up that its cost will be more than it ought to be. A new top must be put on. The shoots from retorts to treating furnace should have cast iron heads & tunnels of same. The water pipes should be iron pipes fixed to a place so as to put on and let off water so they will not freeze. The fires will not stand but a short time as one of them has already given out and we shall put in new plates with water opening…' (Dec 30, 1876).
> We have been obliged to feel our way along with the Upper Forge hot ore business the best we could until by experiment we could determine what was best to say. We have been terribly annoyed by Wilson's wanting knowledge from the first and have had everything to learn. Before a very long time I think we shall understand all the points' (April 12, 1877).

Things went so poorly that Wilson agreed to cover all costs against royalties above $4,000. The original contract had specified that the iron works pay Wilson 25 cents for each ton of iron produced with the unit, and that a plaque stating the patent dates had to be mounted on the furnace once erected. The Clintonville works also had to devise a way of producing the large quantity of milled charcoal necessary for the furnace. They initially used the company grist mill for this, but had to cover it to keep charcoal dust from getting into grain and shoots.

Used for less than a year, and producing a total of only 257 tons of iron, the deoxidizer and its associated forges were shut down. The usual ore roasting procedure was continued for the production of iron in the 16 fires of the main forge building. The forge manager had never been in favour of installing the unit in the first place, and would have had the company invest in a blast furnace instead (which it never did). The deoxidizer experiment in fact may be a prime example of the industry's willingness to move too fast in unproved directions in an effort to reduce costs and raise product quality.

Utilization of Waste Heat

Robert Gordon's studies have shown that there were many early attempts and variations at utilizing the waste heat from blast furnaces, both by Europeans and Americans, with US iron makers actually moving more quickly in applying the principles that Europeans had devised (Gordon 1996: 110-16). To this we can add one last example of Clintonville New York's early role in demonstrating the utility of such principles in charcoal bloom iron production. Company records list the production of a 'gas furnace' for making finished bars and billets, the earliest entries for which are August 10, 1844. It was located in the main forge building and seems to have been used at least until the early 1850s, undergoing periodic rebuilding (PS&I Papers 65.10, vol 18 [Daybook], pp 121, 281, 376, 417, 470, 474). It was also referred to in an 1849 summary of New York state iron manufactures, described as '...one oven for reheating the blooms, which is heated by the gas and hot air from the other fires' (Poor 1849: 559). It seems to have been operated in conjunction with its own finishing hammer, separate from those associated with the bloomery forges; the number of forge fires providing the waste heat is not specified.

This application of waste heat at Clintonville seems to come slightly earlier than the innovative use of blast furnace waste heat that was being implemented by German engineer Christian E Detmold at the Lonaconing works in Maryland (see Gordon 1996: 112, 161; Harvey 1977: 66; Swank 1884: 196, 328). News of such developments obviously spread rapidly within the industry, however, as indicated by recently discovered correspondence between Detmold and the forge manager at Clintonville, Jerome Bailey (CCHA Bailey Papers 85.34.1, letters of January 5, October 17, 1846). By early January of 1846, Detmold and Bailey entered into a partnership in which Bailey agreed to serve as Detmold's agent in licencing the construction and use of Detmold's patented gas furnaces in two counties of northern New York and one county in Vermont. Profits from such licencing were to be divided between the two, with two thirds going to Detmold and one third to Bailey (CCHA Bailey Papers 85.34.1, agreement dated January 5, 1846). It is not known how long this arrangement continued, or whether any licences were actually sold, but by July of 1847 Bailey filed his own petition in Washington DC for a patent on a reverberatory furnace to be used in conjunction with bloomery forges, also utilizing waste gases, for 'heating iron for rolling or other purposes.'

Documents in the Bailey Papers indicate that Detmold was having difficulty keeping other iron makers from infringing his patents. One lawsuit was already in progress in 1846 against Horace Gray in Boston for using Detmold's patent without licence '...in all the furnaces at the Pompton Works N J of which he is the leasee. Mr Gray was one of the first to adopt my improvements & purchased of me the right for the Eastern States also for the Ulster Works NY for which he paid me $7,500' (letter from Detmold to Bailey, Oct 17 1846). Detmold was also considering suing a Mr Lawrence of Keeseville, NY, near Clintonville, for attempting '...to obtain a patent for the application of the waste gases from bloomery fires.' The lower works at Keeseville were apparently using waste heat for heating iron in the rolling mill as early as 1840 (Hurd 1880: 230). At Clintonville, Bailey obviously felt his own ideas for configuring waste heat use were distinct enough from Detmold's to warrant applying for a separate patent in 1847. The records, unfortunately, do not include confirmation that Bailey actually received the patent.

From these accounts we can see that the 1840s were a very important time for the development of the use of waste heat in bloomery forge production, as well as in blast furnaces.

Conclusion

Spanning six decades, the Clintonville iron works records portray a company sometimes struggling to survive, but always informed of, and sometimes contributing to, developments in charcoal bloom iron production. Developments were sometimes small and incremental, with an effort to modify and refine existing technology.[12] Experimentation was viewed as a valuable approach to assessing the efficacy of methods and practices in terms of both capital and labour investment. Management may not have always made the best decisions about these investments, but its willingness to learn, and freely to share what was learned, reflects an industry that was far from stagnant throughout much of the 19th century.

The evidence reviewed here should serve as a reminder of the dynamic nature of the former bloomery iron industry, and of the likelihood of encountering possibly complex and unique configurations of archaeological remains at 19th-century iron industry sites. Our work at the Clintonville forge will continue with a broadened appreciation of the site's potential, and with an even greater respect for the efforts of the people who pursued and shaped the potential of the industry itself.

Notes

1. Tonnage estimates are deceptive, however, in that wrought or cast iron that was reworked into bar iron and steel often ended up being counted twice. Much of the New York Adirondack region's bloom iron was shipped out of state in the form of billets to be reworked by steel plants, thereby distorting production figures, particularly for the second half of the 19th century. Linney (1943: 481) states that 23 per cent of US iron production in 1879 came from Clinton and Essex Counties of northeastern NY Iron and steel production figures from Swank (1884: 382), in 2000 lb tons:

	1870	1880
Pennsylvania	1,836,808	3,616,668
Ohio	449,768	930,141
New York	448,257	598,300

2. See also Lesley (1866: 3-211). Moravek (1976: 38, 67, 108, 109) gives additional details on the number, location, and mine associations of the various iron works in Clinton and Essex counties.
3. The majority of these documents, numbering in the thousands, are housed in Special Collections of Feinberg Library, Plattsburgh State University of New York, catalogued as 'Peru Steel and Iron Company Papers.' A small additional collection of important papers for the same iron works resides at the Clinton County Historical Association (CCHA) Museum in Plattsburgh.
4. PS&I Papers 65.5 9/1, p 268, letter from D Cady to F Dominick, Oct 7 1875. In addition, a letter (CCHA Bailey Papers 85.34.1) from company president F Saltus to J Baileyforge manager, in January of 1839, refers to attempts to install a second pattern of heated blast pipes in the forges. The pattern apparently did not last or work as long as planned, and Saltus expressed hope that the pattern '...would have continued perfect for 9 or 12 months.' Another letter, from Saltus to Bailey, dated Nov 10, 1840, indicates that a Mr John M Eddy in Denmark, New Jersey, was making blooms very fast with heated air blast, and that hot blast was also being employed at the forges of S & H Fords on the Hamburgh turnpike near Stockholm, also in New Jersey.
5. PS&I Papers 65.5 9/1, p 280-81 of letter copybook, letter from D Cady to F Dominick, Oct 18 1875. Cady also notes that the

experiment cost them a set of pipes that were in the stack of the forge run by cold blast. The pipes, luckily older ones that were already in poor condition, got badly burned and had to be replaced (letter of Oct 12 1875). In the 1870s the use of hot blast was standard operating procedure for most forges, and 300 bushels of charcoal per long ton of iron made is a commonly cited average for bloom iron production.

6. Egleston (1879-80: 9-10) notes that 'the hotter the air the less fuel will be used, and the greater the product, but the more likely will the impurities go into the iron. Any decrease in the fuel or increase in the make is dearly purchased at the expense of the quality of the iron.'

7. Of course, the 'expectations' were not specified. CCHA Bailey Papers 85.34.1, letter of Sept 1840 from the forge manager J Bailey to the company president F Saltus.

8. The various trials yielded the following results to produce a ton of iron:

	charcoal used (bushels)	total ore required (tons.cwt.qtr.lb)
fine ore only	382	2.06.1.13
1 part fine, 2 parts coarse	380	2.10.0.12
1 part fine, 5 parts coarse	339	2.06.1.01

The average charcoal/ore requirements for all of 1874 were 273 bushels of charcoal and 2.26 tons of ore per ton of iron produced.

9. PS&I Papers 65.5 Box 3/3 contains a copy of the patent licencing record for Wilson, which includes two letters patents issued July 16 1872, No 128.993, and December 9 1873, No 145.471. The process seems to have been developed as early as 1855, and was briefly mentioned in another local newspaper at that time (*Elizabethtown Post* May 4 1855, p 20). The developers named were a Mr Stanley ofTroy, NY, and a Col Williams as well as Mr Wilson. Egleston (1879-80: 35) also gives a brief description of the furnace principle.

10. Bowen & Signor's forge in Saranac, and Nichols & Hull's forge in Cadyville, both in the Saranac Valley west of Plattsburgh, NY, undertook such installations (PS&I Papers 65.5 9/1, p 186; 65.5 9/2, p 223; *Plattsburgh Republican* newspaper Aug 5 1876, p 1). A similar unit was later installed at an iron works further south near Lake Champlain, at Ticonderoga (*Plattsburgh Republican* Nov 30 1878, p 1).

11. A longer summary of the forge manager's correspondence on this matter is given in Pollard (1995a: 20-21).

12. This would tend to confirm Robert Gordon's observations about the American bloomery process (1996: 98; see also Gordon and Killick 1993: 255-56), which paralleled Patrick Malone's analysis (1988) of armoury machine shop improvements.

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