

THREE HUNDRED YEARS OF ASSAYING AMERICAN IRON AND IRON ORES

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It can reasonably be argued that of all of the industries that made the modern world possible, iron and steel making holds a pivotal place. Without ferrous metals technology, much of the modern world simply would not exist. As the American iron industry grew from the isolated iron plantations of the colonial era to the complex steel mills of today, the science of assaying played a critical role. The assayer gave the iron maker valuable guidance in the quest for ever improving quality and by 1900 had laid down a theoretical foundation for the triumphs of steel in our own century.

Yet little is known about the assayer and how his abilities were used by industry. Much has been written about the ironmaster and the furnace workers. Docents in period dress host historic ironmaking sites and interpret the lives of housewives, miners, molders, clerks, teamsters, and hostlers. The assayer goes unrecognized. Part of the reason for this is that the assayer did not become an integral part of the works until after the Civil War. Hard won empirical knowledge guided the operation of furnaces and any need for detailed analyses could be provided by outsiders. Finally, a better understanding of metallurgical chemistry, combined with increasing process sophistication, more demanding industrial applications, and rising production costs made on-site laboratories both practical and desirable.

Between the early colonial period and the end of the nineteenth century, American iron production progressed from a tradition based, empirically directed enterprise to a scientifically managed industry. The assayer played an important role throughout this process. Even though assaying was an established branch of metallurgy by the mid 1500's, laboratories were not incorporated into most ironworks until after the 1860's. A number of

factors were behind this development; increased process sophistication, a better understanding of how impurities affected iron quality, increased capital costs, and a generation of chemically trained metallurgists entering the industry. This paper describes the major advances in analytical development. It also describes how the 19th century iron industry serves as a model for the way an expanding industry comes to rely on analytical data for process control.

1500's to 1800

By the mid 1500's the operating principles of assay laboratories were understood and set forth in the metallurgical literature. Agricola's *De Re Metallica* (1556), Biringuccio's *Pirotechnia* (1540), and the *Probierbüchlein* (Assaying Booklet, anon. 1510) all describe assaying techniques. (1, 2, 3) The use of cupels, fluxes, acids and quantitative analysis were understood and applied even though it would be several hundred years before a theoretical framework was available to the practicing assayer (1).

Agricola and Biringuccio both believed in direct observation and had a modern appreciation of practical experience. Both men assured their readers that if the assay were done carefully, the orebody's yield could be accurately predicted. Agricola went on to say that great care must be taken because a small error will be multiplied many times in bulk processing. He recommended two or three determinations and averaging the results (1). Biringuccio admonished the assayer to trust no one and weigh everything (2).

Although these works describe the analysis of precious metals in great detail, their instructions for iron

analysis seem rudimentary. Biringuccio states that since tin, lead, copper, and iron could be smelted to determine purity, less care is required than with the more valuable precious metals. None the less, he does give directions for evaluating iron ores. A sample of ore is soaked in a strong solution of lye. Afterwards, it is placed on a well burning fire and develops the color of the "fumosities" (volatile impurities?) which issue from it. The assayer can employ a small bellows or blowpipe after soaking in order to study the bubbles which form. They are an indication of the "evilness" (2).

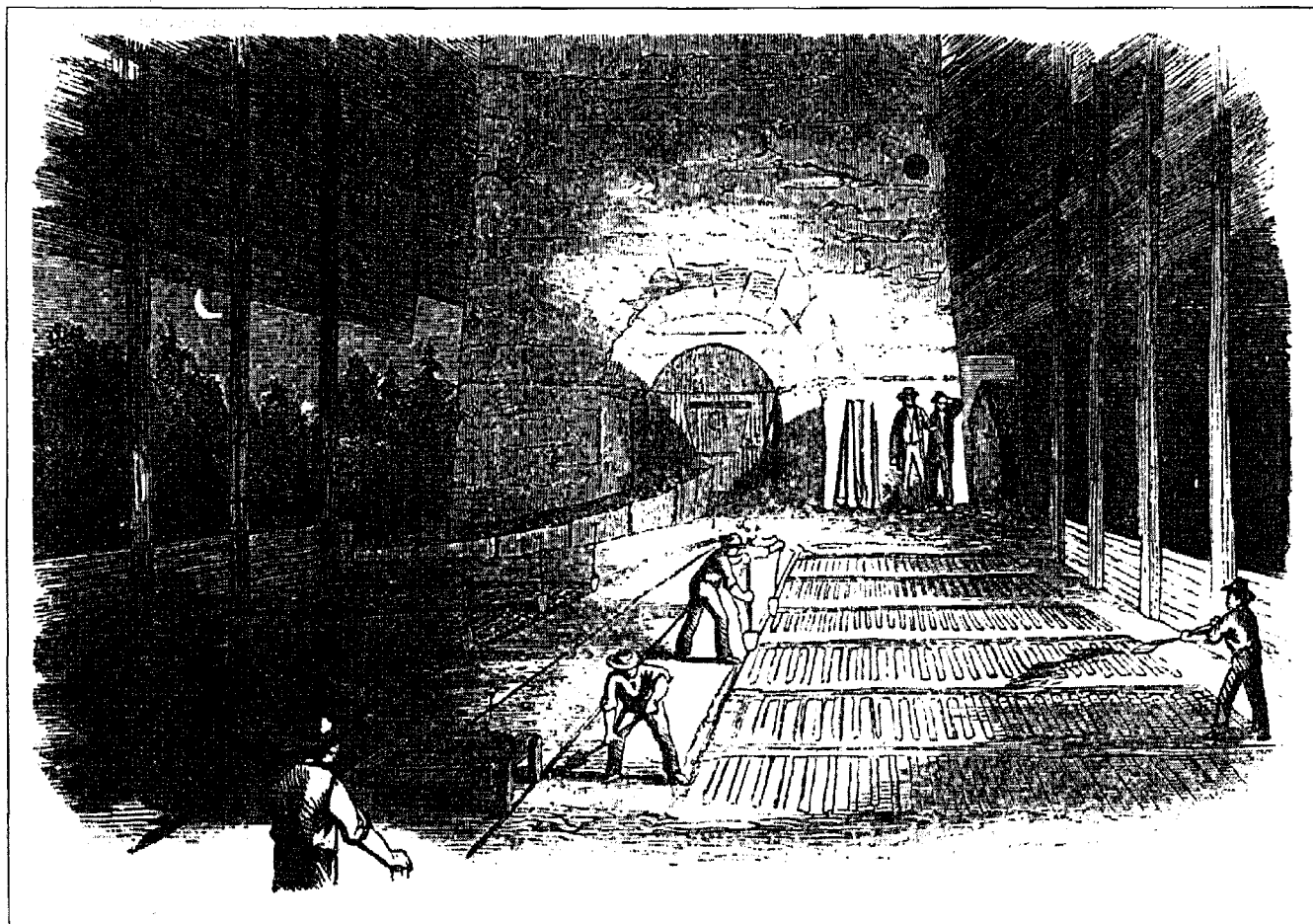
Biringuccio's discussions of iron include visual descriptions intended to help the miner select good ores. Color, porosity, foreign inclusions, and texture are described (2). Agricola takes Biringuccio's idea of smelting ores to obtain their metallic content one step further by giving detailed instructions for iron. They are worth noting since they will be essentially unchanged for another three hundred years. The ore is first burnt. Then it is crushed, washed and dried. The assayer then uses a magnet to concentrate the iron-rich particles and sweeps

them into a crucible with a small brush. Saltpetre is added to the crucible which is then heated until only pure iron remains. The whole operation can be performed in a blacksmith's forge (1).

Such was the state of the art when the English began to explore North America in the late 1500's. Assayers often accompanied early expeditions to America. A German assayer, as well as "mineral men and refiners," accompanied the 1583 expedition to Newfoundland. We may never know exactly what was discovered because both samples and scientists were lost in a shipwreck (4).

The first recorded trial of North American iron ores by an English assayer was in 1585, during a reconnaissance prior to the establishment of the Roanoke Island Colony. According to Thomas Hariot, colony historian and servant of Sir Walter Raleigh (5),

...in two places of the country specially one about four score and the other six score miles from the fort or place where we dwelt, wee found near the water side



Interior of Blast Furnace from "Among the Nail-Makers," *Harpers*, June, 1860.

the ground to be rockie, which, by trial of a mineral man, was founde to hold iron richly. It is founde in manie places of the countrey else. I know nothing to the contrarie but that it maie bee allowed, for a good marchantable commoditie...

The mineral man was Jacob Ganz, a Czechoslovakian Jew who emigrated to England (6). The orebody was located on the main land of present-day North Carolina.

In noting the numerous false starts and errors made by her explorers, historian James Mullholland speculates the arts of prospecting and assaying were particularly backward in 16th century England (4). Recent archaeological discoveries may tell a different story. Excavations carried out by the National Geographic Society and Colonial Williamsburg Foundation have uncovered a 16th century assay laboratory at the Roanoke Island Colony. Records show that several assayers, including Jacob Ganz, accompanied the colonists. Remains of a small wooden shed were excavated and the artificial evidence shows that the laboratory appears to have been well equipped. Archaeologists have not completed the final report on the site (7). No doubt it will shed much light on 16th century analytical chemistry. The Roanoke Island assay laboratory vanished with the rest of the lost colony. With the exception of this facility, assaying as recognized by a modern chemist seems to be almost nonexistent in Colonial America. Whether it was unrealistic optimism on the part of mine promoters, difficulty in inducing skilled assayers to emigrate, or some other factor, the reasons that America lagged behind Europe deserve additional study.

A few years later, in 1608, Captain John Smith sent two lots of iron ore samples back to England for evaluation. The first consisted of two barrels of stones described as "such as I take to be good iron ore at the least." He also sent along notes describing the location of the stones. His comment prompts one to wonder whether he was sending back rocks with no clue as to what they were and hoping for the best. Later in the year, a shipment of ore sent for trial yielded 16 or 17 tons of iron (8).

For most of the colonial era, small scale laboratory assays seem to have been rare. Visual examinations and simple tests probably were the best way to judge ore quality. The only really certain evaluation would be to produce test batches of bar stock in a bloomery or furnace. The Saugus Iron Works in eastern Massachusetts provides a good example. These works operated during the mid to late 1600's. According to the records, John Winthrop the Younger, who managed the works, constantly searched the nearby bogs for good quality ores.

In his book on the works, *Iron Works on the Saugus*, Hartley mentions several techniques that could have been used during the period. These include measuring the specific gravity, judging by appearance, magnetic attraction, or crushing followed by magnetic separation. A touchstone method was also available. A streak was made on a piece of black marble or other stone with the ore, the color of which was indicative of the ore type. Bog ore or limonite leaves a yellowish/brown streak (9). Although these techniques were identified as being available, none of them was identified as being used. Winthrop's correspondence indicates that at least at Saugus, metallurgy had not yet outgrown alchemy (9).

No formal analysis of Saugus ores was made until the 1950's (10). Despite this, Winthrop's search for good ores was successful as archaeological specimens typically tested between 35 and 55% (9). Hartley claims that ores were tried by Winthrop's "finer" (9). Normally used to remelt pig iron, a finery could also have been used to smelt small pilot batches of ore by the bloomery process (11).

It is worth pausing here to examine this process in some detail. A bloomery is a small scale-plant to smelt iron ores. Although it was frequently mentioned as the principal method of evaluating a new orebody prior to the mid 1800's, it should not be thought of only in that context. With capital scarce, many iron producers began with a bloomery and built a blast furnace afterwards. This was often the only practical way to earn revenues in the early stages of an iron enterprise. The bloomery was usually constructed as a block of brick, about 3 or 4 feet high and at least as deep and wide. At the back, a large bellows fed air through a tube set in the brickwork. Also at the back end, the outermost courses of brick were carried upwards to make a tall wall that shielded the bellows. A hearth was set into the center of the top. Layers of charcoal and ore were stacked there and the coal ignited. As the ore became soft, it was taken out of the fire and hammered, usually by a water-powered trip hammer. This process consolidated the metal and squeezed out slag. Reduction of the iron was accomplished by the reaction of carbon monoxide, a by-product of incomplete fuel combustion, and the oxygen contained in the ore (11).

The bloomery process has one important advantage over the blast furnace. Because the metal is worked at sub-melting point temperatures, it does not absorb appreciable amounts of carbon from the fuel. Consequently, the final product is a low carbon, highly malleable wrought iron. The iron was so malleable that, until the late 1800's, it remained competitive with blast

furnace iron whenever ductility was desired (12). As an assaying technique, the bloomery process had the advantage of being cheap, easy and familiar. While the operating conditions did not accurately reflect those in a blast furnace, any malignant impurities would still manifest themselves (12).

At about the same time that Winthrop was producing iron at Saugus, Dutch settlers were prospecting in present day New York and New Jersey. In 1644 Henrick van der Capellen reported the discovery of copper, iron, and lead. Samples were sent to the Netherlands but proved worthless once assayed (4). This sort of oversight was not unique; reports of "mines" often did not even indicate what sort of orebody was being explored (13).

The English entrepreneur Peter Hasenclever undertook an ambitious program of industrial development in the 1760's and 1770's. Smitten with the potentialities of the new world, he founded the American Company with extensive iron and agricultural lands. Before taking ship for the New World, Hasenclever purchased several thousand acres in Northern New Jersey and Southern New York. His agents went to Germany to recruit experienced miners and iron workers (14). The company immediately launched a dramatic construction program, building five furnaces, several forges, roads and reservoirs. Miners opened 53 workings. Some of what happened next is recounted in Hasenclever's own memorandum (14):

Heaps of fine iron-ore lay on the surface of the earth, and there never was a finer prospect for success. But after the Miners had worked a while, some of the mines which produced excellent ore vanished, other mines turned sulphurous, copperish, coldshear, full of mundic and arsenical matters, so that the ore could not be made use of. These circumstances might appear incredible if the places could not be shown. In short, the appearance was so certain that we began to build a dam for a great reservoir and some log houses, we cut coal wood and made an expensive road, which after all, we were obliged to abandon...

Hasenclever seems to have understood the importance of having pure ores, but he never seems to have made any kind of preliminary testing. Perhaps he relied on a visual inspection to locate his mines. Of the 53 original mines, all but 7 were eventually abandoned. Hasenclever cannot be judged too harshly, for the situation was not at all uncommon. Exposed portions of an orebody, washed by rain and snow, are often much purer than deeper portions (14). (Variations of assay data over time are frequently attributed to this phenomenon.) Know-

ing what he did about ore quality, Hasenclever would have certainly overcome that problem. The record shows that his enterprise was defeated by incompetent middle managers, tremendous capital demands, and a shortage of skilled workers.

Hasenclever recognized that education was vital to the industry's growth. Before leaving Europe, he collected specimens of ores (including South American silver ores) along with books about mines and metals. In America he added to the collection, intending to present it to a college in New York or Philadelphia. Financial troubles forced his return to London and much of the collection was lost en route. Fortunately, the American specimens were lent to a London friend and eventually found their way to the British Museum (14).

The case of the Rocky Hill Copper Mine may also prove instructive. The mine, located in the hills of Northern New Jersey, was originally explored in 1744. Samples were taken from all parts of the mine and sent to London for assaying. Once the relative values were determined for different parts of the orebody, all subsequent shipments were classified by their exact origins in the mine. Because of restrictive trade laws, the mine shipped unprocessed ore to England for smelting. As excavations progressed, ore quality deteriorated. Finally, transportation costs exceeded the value of the refined copper. Unfortunately, this was not discovered until worthless ores began arriving at the smelter (13). Had even rudimentary assaying been a regular practice, this might not have happened.

One of the few first-hand descriptions of an iron trial during the colonial period came from Jarad Eliot, a Connecticut clergyman and physician. Eliot was a true renaissance man and a firm believer in the scientific method. He is principally remembered for extensive agricultural experiments but he also dabbled in iron making. Eliot was aware of the extensive deposits of black, iron-rich sands along the Long Island Sound and New England coasts. He determined to test their suitability as a source of raw materials for an iron works owned by his son; but he was also keenly interested in the sand's geological origins and much of his manuscript is devoted to his ideas on the subject (15). He began by collecting from a nearby beach some forty pounds of the sand which was carried home in saddlebags.

The iron particles were first separated with a hand magnet. Eliot assured his readers that if this had proved impractical, he would not have given up because he knew that not all ores are magnetic. Once separated, the metallic iron would have had to be reduced. For this purpose, the actual trial was carried out by the bloomery

process (15). Eliot took the iron particles to a local forge. Upon presenting the fine sands to the founder, Eliot was told, one, the founder was forge man, not a bloomer and two, that it probably wouldn't work anyway. Being both an idealistic and practical man, Eliot countered with a compliment and a bribe. The forge man was told that he was very skillful in his art. It could be supposed that the differences between a forge man's and a bloomer's work were not so great that a talented worker could not overcome them. The bribe was a bottle, offered if the process could be made to yield good iron and in the full knowledge that a sober and judicious man would not abuse the gift. For several hours the assembled company waited for the iron to melt. Then a bar was thrust into the hearth and when it was withdrawn, small amounts of metallic iron were sticking to it. Later a pasty mass of iron was produced, taken from the fire and hammered into a bar that weighed 52.5 pounds. A blacksmith tried the bar and pronounced it to be the equal of the best Swedish iron.

Eliot continued both his experiments and geological observations. In another experiment he mixed the iron sands and a poor quality bog ore. The mixture produced a "tolerable" quality bar stock. Despite encouraging results, large-scale utilization of the sands was impractical because they contained 1/3 common grit. It made the material hard to flux and produced only glass. After a cartload full sat overnight in a rain storm, the grit was washed away. This discovery not only gave Eliot a practical method of purification, but it caused him to revise his geological theories on the sand's movement and origins. His hopes were high for the widespread use of iron sands in blast furnaces. Working iron sands ultimately proved impractical because they took longer to smelt than other ore sources. His record of the trial clearly illustrates the scientific application of assay techniques (15).

In evaluating finished iron for quality, colonial iron masters often employed fracture analysis. In this procedure, a bar of wrought iron is mechanically fractured and the metal's quality judged by grain size. Directions for fracture analysis appear in a 1741 assaying book (9). This method is still in use today (12).

During the 1700's, a number of talented chemists turned their attention to ferrous metallurgy. Among the first was the French chemist Reaumur. He published a scientific textbook in 1722, describing his experiments with iron and steel. In his experiments he described how different refining operations produced varying amounts of slag. Reaumur knew that different types of iron had different amounts of "earthy matter" (silicon)

and how the addition of sulfur affected the quality of the iron (16).

In 1781, Torben Bergman published "Dissertatio Chemica de Analysi Ferri." The work was prefatory to a doctoral defense by his student Johann Gadolin at Sweden's Uppsala University. Bergman sought explanations for the different types of iron and steel in terms of the metal's chemical composition. He reasoned that only elements commonly found in the ore were responsible for the changes in the metal: sulfur, plumbago, arsenic, zinc, and manganese. His experiments, by wet chemical methods, were both quantitative and careful (17). Other Swedish chemists made significant advances in metallurgical and mineralogical analysis during the 1700's. Among their most notable achievements was the development of blowpipe analysis between 1746 and 1820. This technique was already in use in Germany by 1700, but the Swedes transformed it into a versatile tool for many types of chemical analysis. They used the blowpipe for thermal decomposition, oxidation, reduction, glass formation and colonies, as well as observing flame colors. Several treatises were published on their techniques, and the best practitioners were able to achieve good qualitative results (18).

Blowpipes were used in American laboratories in the 1800's (19). The technique declined in importance as spectroscopy became popular in the 1860's but continued to be an important tool for geologists and mineralogists. Textbooks on the subject were still being published even after the second world war (18).

The question naturally arises as to how much metallurgical literature crossed the Atlantic and was available to Americans. North Americans made every effort not to become an intellectual backwater. But the fact remains that many important books in this field were not available in English until the twentieth century.

Jarad Eliot conducted a single experiment on the role of sulfur in iron and he urged others to take up the task. We do not know whether he was influenced by any European examples (15).

During the American Revolution, the need for sulfur in gun powder manufacture caused the Continental Congress to authorize assays of iron pyrites. Several sources were examined in a search to find the highest sulfur content (20).

1800 to 1860

The first six decades of the 1800's were pivotal in the development of assaying facilities in the American iron industry. Technological, economic, and political forces all played important roles in this period. Both state and

national governments needed to identify and evaluate mineral resources. Many states established an assayer's office and/or a state geological survey. These offices were not only instrumental in advancing the science of assaying, they promoted much valuable geological research, fostered economic development, and left a chronicle of industrial development. At the federal level, government departments sought information on iron resources. The Navy in particular needed metal for ordnance and ship fittings. Civilian agencies also consumed iron for public buildings and other uses. In the academic community, metallurgical chemists were learning how impurities and chemical composition affected iron quality. Just as importantly, they were disseminating this information by means of technical journals, textbooks, and college-level courses for mining engineers, analytical chemists, and metallurgists.

As new sources of ore were discovered assayers were frequently employed to make preliminary evaluations. However, regular assaying over the life span of a mine was not a common practice until the end of the century. Occasionally an assay was performed for an established mine, such as those supplying Pennsylvania's Hopewell Furnace.

The principal testing methods employed during the first half of the 1800's fall into three not mutually exclusive categories. First was laboratory analysis. Second was the production of a pilot batch in either a bloomery or a blast furnace. Third was testing a small quantity of finished iron in some demanding application. For the most part, iron consumers relied on the reputation of the mine or furnace that supplied the metal and not on any extensive knowledge of the metal's chemical composition. Alternatively, the consumer might depend on the experience of an iron broker.

State and Federal Geological Surveys

The New Jersey State Geologists Office can serve as an example of this type of organization. It was established in 1835 to "provide a geological and mineralogical survey of the State of New Jersey". Throughout its history, the survey published information on New Jersey's mineral resources. Beginning in 1835, the survey proceeded by irregularly until 1868 as funding levels fluctuated. Only four "annual" reports were issued during these years (21). After an eight-year hiatus, funding was restored in 1864 and the survey placed on a statewide basis. The 1864 to 1867 reports culminated in the monumental 900-page *Geology of New Jersey*. After its publication, the State Legislature authorized an extensive program which continues uninterrupted to this day (21).

In 1910 the survey issued a comprehensive summary of all its data on the state's iron industry and resources, "Iron Mines and Mining in New Jersey." The volume contains assay data from both state and private laboratories. Not only was this data used to evaluate the economic value of the state's iron resources, it was also used as the basis for geochemical investigations into the origins of the orebodies (21).

Among the noted scientists working in the agency was Henry Wurtz, a chemist and mineralogist. His is most remembered for his contributions on iron ores and mining in the 1858 annual report (21). The widely distributed 1868 report of the New Jersey State Geologist contained hundreds of assays; most consisted of only five analyses: iron, silica and insoluble matter, sulfur, phosphoric acid, and magnetic iron ore. A much smaller number of more complete assays reported aluminum, magnesium alkalis, and water (23).

Writing in 1910, State Geologist W.S. Bayley felt that the earlier analyses done at the state laboratory were less trustworthy, especially with respect to titanium, phosphorus, and sulfur. Titanium was generally not analyzed until after 1879 (22). This was a serious oversight as titanium was a troublesome contaminant in many New Jersey ores (12).

As new orebodies were discovered in the Lake Superior Region, state assayers in Boston and Paris were called upon to evaluate the ores. Their reports reveal something about the assayers and the range of analyses available to them. The state assayer in Boston reported on 13 September 1856:

	Peroxide of Iron	
(68.044% pure iron)		98.02%
Oxide of Manganese		1.28%
Silica		0.44%
Lime		0.32%
Total		100.06%

Also tested for, but not found were titanium, phosphorus, sulfur, arsenic, chrome or other "injurious substances." The ore was estimated to yield 69% metallic iron in a blast furnace. It is interesting to note that the report was signed C.T. Jackson M.D., Assayer, etc.. There is no mention of what the "etc." included (24).

The French state assayer's report from Paris was not dated but was issued from the School of Mines. It was signed by L.E. Rivot, Professor of Analytical Chemistry and Director of the Assay Office. The list of analytes included:

Metallic iron	Carbonic acid	Alkalies
Oxygen	Water-soluble silicates	Water
Magnesia	Phosphorus	Arsenic
Oxide of iron	Lime	Sulfur
Oxide of magnesia		Alumina
		Gangue

The last item, gangue, is a mix of quartz, alumina, iron oxides, lime, and alkalies (24).

The Federal Government was also interested in promoting the growth of the industry and inventorying the nation's iron resources. One early and ambitious project was undertaken in August, 1857. Concerned that iron being used in public buildings would rust, the Treasury Department began a nationwide search for iron with low oxidation rates. Congress appropriated \$2,500 for the study (25).

All iron manufacturers were asked to provide 2-3 small samples of both iron and ore from each mine being worked. Each would be tested for resistance to rust. They were also asked to provide the location of the mines and furnaces, extent of deposits, types of fuel used, distances from raw materials and markets, annual production statistics, the locations of rolling mills, and applications data (25). As the US Navy was one of the principal government iron consumers, it often evaluated samples of finished iron for strength and other physical properties.

By far the most important federal project on ore analysis was the 10th census. Published in 1886 by the Bureau of the Census, the final report was a complete study of America's mining industry, excluding only precious metal production (26).

In 1879, agents of the US Geological Survey were empowered to act as agents of the census bureau in order to collect data on the industry. There was at that time not even a preliminary list of mining concerns. Data would be collected by special agents working in the field and by correspondence. The agents were to be assigned areas where they were familiar with the mining operations. It was considered important that all data be as uniform as possible (26). Back in Washington, one chemist and six assistants analyzed 1,377 samples of ore for a total of more than 4,400 individual determinations.

Exploration and Assaying of New Orebodies

Perhaps the most engaging accounts in the metallurgical literature are those describing prospecting in remote and undeveloped areas. Some are widely reprinted and read by a general audience, such as the tales of early

geological surveys in the Adirondack Mountains. These accounts are among the earliest descriptions of hiking, climbing, and camping in the region. In the instances reported in this paper, and in several others, Native Americans are credited with knowing about the ore deposits and calling attention to them. The prospectors employed them afterwards as guides.

Many letters and documents survive from the Adirondack Iron Works near Lake Placid, NY. These documents illustrate the relationship between the discovery, evaluation, and exploitation of an orebody in the period prior to 1860. The proprietors first learned of the ore bed in October of 1826 while prospecting for silver. After a field examination, the ore was analyzed and found to be free of sulfur; no record is available to show how this was ascertained. By 1830 the company had secured title to the land and was making preliminary arrangements for development. Near the end of 1830 Archibald McIntyre, one of the owners, wrote that he anticipated good results from the ore trials and he was thinking ahead to appointing an ironmaster. In the winter of 1831 a test batch of six tons was extracted and sent for processing. The Adirondack snow proved too severe for the crude road haulage and the ore had to be abandoned and retrieved in the spring (27). It is not clear whether the tests proved entirely satisfactory. The ore was described as "found to make an excellent iron for every purpose, except that, requiring polishing...." (27). But in June 1833, McIntyre wrote that "I cannot avoid sometimes of having my fears. For the ore has not been tested, the roads are abominable and coal wood in the vicinity is very scarce" (27). The comment that the ore had not been tested may refer to a laboratory assay or perhaps to large scale production in either a furnace or bloomery. Later it was suggested that finished iron be sent to the New York Navy Yard for trial in actual applications. Earnest development began in 1832. Among the supplies sent to the works were two volumes of Cleaveland's *Mineralogy*, and one volume each of Bakewell's and Eaton's *Geologies* (27).

As mining began, several bloomers were hired to begin experimenting with reducing the ores. It was a long and arduous process. Although the quality was good, the production rate was slow. Both the bloomers and their employers were becoming discouraged. It was not until August of 1834 that good loops began emerging from the bloomery. It was then suggested that bloomers be brought up from New Jersey who would have experience with "mountain Ores". The bloomery was coming along so slowly that it was suggested in September, 1834 that the ore be shipped to a blast fur-

nance for trial. Other suggestions included abandoning the works (27). They were indeed abandoned. But when the State Geological Survey explored the area between 1837 and 1841 new impetus was given to reviving the works. The ore was again evaluated and again found to be of good quality. Finally, the company resumed operations in 1838 with a blast furnace (27). For all of the tests, evaluations, and reports of good quality, the ore continued to be extremely difficult to work. Finally in 1848 it was found to contain 10% titanium. Not finding it sooner was described in one letter as "a rather extensive oversight" (27). The bloomery struggled for three years to produce good iron and the blast furnace did not have much more success. Another furnace was built in 1844, and ten years later a still larger furnace was erected. It was hoped that the 1854 furnace would save the company but it came too late (28). There has always been some controversy about the exact cause of the company's troubles. One side maintained that the presence of titanium dioxide in the ore rendered it unworkable, and the other side countered that labor troubles, transportation difficulties, and the Adirondack winters were responsible (27, 28).

It was not until the 1890's that experiments were performed to discover a way of smelting the ore. The successor to the Adirondack Company was trying to sell the property, but the ore's titanium content discouraged many potential buyers. Company President James MacNaughton hired French metallurgist August Rossi, who tried the ores in both large and small furnaces and published favorable results (27). Despite the favorable press, negotiations dragged on; and it was not until 1914 that a dramatic trial was made to settle the issue once and for all. The company leased a furnace belonging to the Northern Iron Company at Port Henry, NY, hauled tons of ore out of the woods, built a magnetic concentrator, and began large-scale production. Favorable results were again reported at the October, 1914 meeting of the American Iron and Steel Institute (27). Many years later Bruce Seely would write that the persistence shown by the Adirondack Company was due in large part to optimism and a faith in science to solve problems, rather than to any real potential of the ores (28).

As mineralogical prospecting became more sophisticated, specialized professionals were utilized. Some 45 years after the discovery of ore deposits at Adirondack, chemistry professor Albert H. Chester was sent to northern Minnesota's Vermillion Lake in search of new iron deposits. The conditions under which the prospectors labored were just as rugged, but the level of organization was vastly improved. Charlemagne Tower,

a patent attorney, and his partner Alfred Munson, a wealthy iron manufacturer, decided to sponsor an investigation of this region. Albert H. Chester, professor of mineralogy, geology, and chemistry at Hamilton College of Clinton, New York, was hired to perform the field work. In addition, he would analyze the samples in the college laboratory. His salary was \$250 per month plus expenses (29). Chester arrived in Duluth early in the summer of 1875. He would be guided by George Stuntz. Stuntz, trained in mathematics, chemistry, and surveying had worked as a civil engineer and surveyor in the region before opening a successful trading post. His interest in the state's iron reserves dated from the mid 1860's. Tower's son-in-law, Richard Henry Lee, a competent surveyor with a rudimentary knowledge of chemistry, also accompanied the expedition (29). There was a total of eight men in the party who departed Duluth on July 13 for a ten-day canoe trip to the Ojibway Indian Agency on Vermillion Lake. They spent two days inspecting hematite exposures before moving southwards to the Mesabi Hills. They were charged with examining the ore and mapping suitable routes to bring it out of the hills (29). Field examination of the Mesabi samples revealed an iron content so low as to render them commercially unproductive. In an understandable oversight that would later return to haunt him, Chester dismissed the entire Mesabi Range. He had in fact only explored its leaner eastern end. The better quality ores lay farther to the south and west. He did however send two Ojibway Indians with Stuntz and John Mallmann, an experienced miner, back to Vermillion Lake (29). They sunk their first test pit near what is now known as Stuntz Bay. Three holes were drilled about 42 inches deep and filled with 18 inches of black powder. The resulting explosion opened a crack about 40 feet long and 4 to 5 feet deep. Working with sledge hammers and soap covered ash wood wedges, the crew exposed the ore and prepared for a second blast. This second blast, for which all their remaining powder was used, uncovered 60 tons of high grade ore (29). That fall, analysis of the ore samples back at Hamilton College revealed that the Vermillion Lake samples, in addition to being as high as 76.77% iron, were very low in phosphorus and thus well suited to the Bessemer process. Assays of the Mesabi ores confirmed the conclusions reached during the field examination (29).

Assaying and Iron Consumer, 1800-1860

Locating an orebody is only the first step in its exploitation. Depending on the time period and the resources available to the mine promoters, different kinds of "tests"

and "trials" followed. Generally a mine owner requested a formal assay early in the process and seldom followed it up with periodic rechecking of ore quality. Pilot batches of ore were also smelted and sent to potential customers. After the mine was established, iron consumers relied on its reputation to tell them whether the ore or metal made from the ore was suited to their needs. This was the case whether the iron consumer was a furnace, foundry, or manufacturer. The Adirondack iron mines serve as one excellent example of this process. Iron production began in the region about 1798, although local tradition places the date as early as 1776. By 1879, 23% of American total iron output came from the Adirondacks (30). Mineville or Port Henry ores were magnetically surveyed in 1810. The surveys confirmed the presence of large deposits and samples were taken for analysis. There is no record of what was done with the samples (30).

Andrew Williams, a founder of the Chateaugay Ore and Iron Company, had a background working at a local forge. He was noted for his constant efforts to locate good quality ores. Around mid century, he secured test lots of ore and processed them at his forge on the Saranac River. This was probably done by the bloomery process. He shipped the test batches to selected customers who in turn reported favorable results (30). By the end of the century, the Adirondack iron mines and furnaces had complete assay laboratories. The 1884 assayer's record book from the Witherbee-Sherman Company is now preserved in the Adirondack Center Museum. Just before the first world war, an extensive survey was made of the Chateaugay Ore Bodies. It included magnetic surveys, geological, diamond drill sampling, and chemical analysis as well as surveying and mapping of the existing workings (30).

In 1824 when James P. Allaire purchased an iron works near Freehold, New Jersey, one of his first steps was to contact Professor Silliman of Yale and send him four samples, two of the local bog ore and two of the bog soils. His decision to send the samples to Yale came as a result of an earlier visit. Allaire had noted that the geological specimen collection contained no bog ores. Silliman analyzed the ores and sent the results back to Allaire (31). Silliman tested for oxyd of iron, aluminum, manganese oxide, water, silica, and iron phosphate. Perhaps Allaire did not trust Silliman's favorable report. The first furnace charge contained ore from Milton, Delaware in addition to the ore from the local bog (32). Allaire was not the only 1820's furnace operator to turn to an academic for assistance in evaluating a new orebody. Two rival claimants for the Adirondack

company's ore beds took their samples to Union College for comparison with the college's geological specimens (27).

A number of private laboratories eventually began operating in conjunction with mining engineers or promoters. The Belvedere Iron Company's prospectus from 1865 survives and gives an example of the exploration and assaying practices at that time. The company employed Messrs. Partz and Buck, Practical Mining Engineers and Metallurgists (33). Partz and Buck mapped veins of Pipe Ore, a variety of hematite, and computed 900,000 tons were available. A few shallow pits were excavated but most of the initial reconnaissance was done on the surface and comparisons were made with nearby excavations. Chemical analyses were conducted at Partz and Buck's laboratory at 39 Nassau Street, NY (33):

Proto-peroxide of iron	95.56%
(yielding metallic iron	65.12%)
Silica	0.55%
Alumina	3.49%
Phosphoric acid	0.18%
Lime	0.22%

"Faint traces" of sulfur were also detected and it was reported that neither phosphoric acid nor sulfur was present in large enough quantities to be troublesome. The report also recommended more exploratory pits (33).

Mine promoters frequently made small batches of finished metals and then sent them to be tested. Franklinite from Sussex County, New Jersey was reduced in a bloomery. The finished iron was then sent to the National Forge in Paris. There it was tested in a hydraulic press and found to withstand pressures of 40kg/mm (34). Other tests were carried out at Washington's Navy Yard in 1859. Because Franklinite pig iron was found too hard to be cut, it was mixed with other iron samples and fused in a crucible. The mixture was subjected to tests of density and tensile strength. The work was carried out under the superintendence of Commander John A. Dahlgren, better known for his ordnance work during the Civil War (34). (A number of other furnace operators also sent samples to the Navy Yard for evaluation.) Another, less scientific evaluation, was to send some finished iron to a dock constructor who used it as an iron band on a pile driver. The contractor later offered a favorable testimonial (34).

Large manufacturers had the financial resources to buy either their own iron mines or at least a major interest in someone else's. In the period before regular as-

saying became part of the quality control routine, they thus insured a dependable supply of good iron. The Phoenix Bridge Company, a supplier of pre-fabricated truss bridges, was one of these. But the smaller concern did not have this luxury. In some cases they were able to make special arrangements with a specific furnace. In other cases, the manufacturer would stockpile selected iron, and still others relied on commission brokers to get the metal they needed.

The career of Dr. Charles Stewart, M.D., provides some examples of how manufacturers selected iron. He had received his medical degree from the University of Pennsylvania in 1853. But before he began practicing medicine, his father brought him into the firm of Rodenbaugh, Stewart and Company. The company originally set out in the mid-1830's to make cut nails. Within a few years, they diversified into making iron wire and, as nail prices fell, switched exclusively to wire production in 1845 (35). This proved to be an excellent decision: wire was needed for the telegraph, suspension bridges, wire ropes, hoopskirts and later, barbed wire. When Rodenbaugh withdrew from the partnership, Dr. Stewart took his place; it was the beginning of a fifty-year career (35). Charles Stewart was not only concerned with business affairs; he also was deeply involved in the technical aspects of production. The Stewart family kept adapting their operations to changing technology. As manager of the wire drawing works, Charles introduced many innovations and process improvements (35).

Because of its great ductility, bloomery iron was used for drawing wire. But Stewart often had trouble finding suitable stock. By studying the technical literature, he learned that ideally the stock should consist of "neutral iron," i.e., containing neither sulfur nor phosphorus. This metal would remain flexible over a wide temperature range. Flexibility was especially important in wire drawing since the stock had to be heated and cooled repeatedly (35). The company was buying iron from the Adirondacks via commission brokers in Troy and Albany. The company also bought iron from banks, which, by advancing money, came to own large accumulations of iron, ore, and even charcoal. In a departure from the usual practice, Stewart decided that he should visit the bloomeries and meet directly with their managers. He wanted personally to explain the specific requirements of his company and get a sense of which producers could meet them. His first step was to copy the trade marks from the bar stock on hand. When he had identified the makers, Stewart departed for the Adirondack mountains (35). On the train north, Stewart

met a Mr. Witherbee, a well known mine manager in the area. The two began talking over Stewart's plan and Witherbee enthusiastically endorsed it. Witherbee not only identified all of the maker's marks that Stewart had copied from the bar stock, he wrote out the chemical composition of most of the region's major ore beds. Stewart was thereby able to pinpoint exactly the suppliers that were best suited to his needs. His tour of the region was as eventful as it was productive. One of the bloomery managers with whom he met was delighted to learn first-hand about customer requirements because commission brokers in Albany and Troy had kept him in the dark about such things (35). In a separate incident, Stewart was asked by another wire manufacturer to testify in a lawsuit alleging that a certain bloomery was selling inferior metal. Years later Stewart would recall that he had previously hired a chemist to assay the metal, and a copy of the results was on file in Stewart's office. Stewart told the plaintiff that he was unprepared to testify against the supplier since both the assay results and his experience with the metal spoke eloquently for the defense (35).

Advances in Metallurgical Chemistry

Although Stewart and his company did not employ a full-time chemist, they were able to take advantage of a number of important developments in metallurgical chemistry. During the 1840's and 1850's several important discoveries were made about iron quality and its chemical composition. The two most common problems with iron produced in the 18th and 19th centuries were being either "cold short" or "hot short". Cold short iron is brittle at low temperatures and hot short iron is brittle at higher temperatures. These problems are the direct result of phosphorus and sulfur, respectively. In the case of hot short iron, iron sulfide crystals form on the grain boundaries within the metal. The crystals weaken the adhesive forces between the grains and fractures result (12). Perhaps sulfur was the first impurity recognized for its detrimental potential. The practice of washing and roasting ore to remove sulfur is an old one. Once sulfur and other impurities were recognized for the damage they caused, assay laboratories started looking for them. It is difficult to establish an exact date when this began. But in the 1840's, published studies began describing various impurities, their effect on ore quality, and techniques for detecting them.

In October, 1849, *Scientific American* reported on a paper presented to the British Scientific Association. Phosphorus was already known as a detrimental impu-

urity; now precise determinations were available to confirm its role in producing cold short iron. The analysis was highly labor intensive, involving two acid dissolutions/evaporations, smelting, and two filtering steps before calcium phosphate was precipitated by a calcium chloride/ammonia mixture (36). A few months later, another report appeared in *Scientific American*. It was taken from the *London Mining Journal* and related iron strength to composition. Strength was found to be the result of carbon content and freedom from other impurities. Arsenic was thought to give Berlin Iron its fluidity but also to make wrought iron hard and brittle. Manganese, when alloyed with iron, was found to close the grain and improve both iron and steel. In wrought iron, however, manganese produces a hot short effect. This report also reiterated phosphorus as being the cause of cold short iron (37). By the 1850's just about all assay reports listed at least iron, sulfur, phosphorus, and manganese. On or two others were often listed, usually alumina or silica.

The New Jersey Geological Survey's 1856 report announced plans to investigate the chemical changes occurring during the puddling process. Survey chemists had obtained samples of ore, furnace cinders, samples from the puddling process, and finished iron. In the puddling process, pig iron is converted to wrought iron by burning out the excess carbon. In the 1850's this process was not well understood, and this would have been one of the first efforts to study the phenomena scientifically. It is unclear whether this work was actually carried out. However, in 1857, English chemists working with Staffordshire Iron did publish results from a similar experiment (38). The importance of these experiments was that they shed light on the role of carbon in regulating iron strength. It was known in 1850 that strength was inversely proportional to the percentage of carbon. More work was needed to understand the underlying chemical mechanisms (39). This eluded metallurgists because strength is not merely dependent on the amount of carbon, but also on its form. By the end of the decade, it had been discovered that it was graphite that made cast iron brittle (39).

The availability of scientific assay data was no guarantee that the data would not be misapplied or misinterpreted, however. A well known case involved wheels for railroad cars. It was a demanding industrial application as well as a lucrative market. Beginning in the 1830's, American railroads adopted cast iron wheels with a chilled tread and flange. Although cast iron is more brittle than wrought iron, the chilled tread gave the wheel extraordinary durability. When being cast, the metal

rapidly cooled where it came into contact with the mold. Iron and carbon remained mixed and the resulting metal resembled steel with a 3.5% carbon content. In the center of the mold, the metal cooled slowly and the carbon separated to form graphite (40). Improving safety and durability meant employing the best metals available. Without a detailed knowledge of metallurgy, wheel foundries were forced to rely on the reputation of the pig iron, such as from the Carwheel Mine in New Jersey. In the 1830's and 40's, this usually meant a mix of Baltimore and New Jersey ores. Wheel makers typically selected material free of sulfur and phosphorus, but these elements were effective in producing a good chill. On the other hand, silicon had a detrimental effect (40). By the 1880's wheel foundries kept stockpiles of different types of ores and mixed them for obtaining the best metal. Samples were pulled daily from the furnace and tested for strength and chilling properties (40).

By far the single most important metallurgical discovery that led to the widespread adaptation of assay laboratories was the Bessemer Converter. Prior to the introduction of the Bessemer process, steel was manufactured in relatively small lots by the crucible process. Although a great advance in steel production, it was discovered almost immediately that the method did not work if the ore contained any phosphorus. The original, or Acid Bessemer Process, made use of a silica-based furnace lining. Later, the Basic Bessemer Process was developed. It used a limestone furnace lining that reacted with the phosphorus and carried it off in the slag (11).

In May of 1868 the Freedom Iron Company of Greenwood, PA opened the 4th Bessemer steel plant in the United States. Proceeding without a preliminary assay, the company spent a year trying unsuccessfully to manufacture steel. According to later sources, a \$50-analysis would have revealed the phosphorus. The company's problems were not solely attributable to ore quality. A labor force untrained in steel making and a poorly designed physical plant were also to blame. The need for assaying as a preliminary to steel making did not originate with the Bessemer process. In 1852, Frederick Overman advised that in selecting iron for conversion to steel, "color, strength, and hardness are not unerring guides." The material may contain "more than one-two thousandth part of silex or silicon, phosphorus, sulfur, calcium, copper, lime tin, or arsenic and will never make first rate steel." Overman advised that a professional assay was needed and even included the address of a Philadelphia academic who would be will-

ing to do the work. Conversely, a pilot batch, while the surest way of ascertaining suitability, required six to ten tons of iron (41). In August, 1860 the Cambria Iron Works established what was claimed to be the first assay laboratory as an integral part of an iron works. Robert Woolston Hunt was employed for \$20 a month. Although the Civil War interrupted operations, it was re-established in May, 1866. The Cambria Works eventually produced the first commercially rolled steel rails and it was for this effort that the laboratory was established (42).

1870's and 1880's

By the 1870's and 1880's assay laboratories were becoming common at both iron mines and furnaces. By this time, not only were there significant advances in metallurgy, thermodynamics, and metal processing technology, but a communications infrastructure was available to disseminate information on these topics. But the overriding reason for the development of the laboratories was economic. Iron consumers, whether they were buying ore or finished metal, would typically continue to use the same sources until something went wrong; only then would an assay be called for. The problem, of course, was to anticipate changes within an ore bed and make adjustments before lots of inferior metal were being sent to customers. The only way that this could be done was to test each shipment of ore leaving the mine or arriving at the furnace (43). At first only the larger producers could afford the facilities to do this. For instance, in the New Jersey Geological Survey's 1910 report, most of the data from furnace and mine laboratories consisted of magnetite analyses. Regarding these, Bayley states that they were mostly from stockpiles or shipments, and therefore they represented only the quality of ore that could be obtained at prevailing prices. Few "complete" magnetite analyses were available, but many partial analyses contained all those elements of interest to furnace operators (19). Earlier analyses from blast furnace laboratories were generally poor, often including no mention of sulfur, although it did show up in later reports. Bayley does go on to say that as a rule, these laboratories managed to get accurate numbers for iron, sulfur, and phosphorus (22).

By the last decades of the century, many mines and furnaces made regular assaying a normal practice. Over a 12-year period, 1892-1904, the Thomas Iron Company tested every shipment of ore from their Richard Mine for iron, phosphorus, silica, lime, and alumina (22). The company also tracked the iron content of each shipment from the Little Mine and was able to determine that in a

375-carload shipment, the average was 53.34%. The highest shipment was 25 carloads in July, 1891, at 62.25% and the lowest was 37.94%. Over a two-year period, June, 1891 to October, 1893, 531 carloads were sampled and the company reported average figures for iron 56.29%, silica 7.94% and phosphorus 0.103% (22). Among other New Jersey and Pennsylvania mines and furnaces that had regular assaying regimen were Empire Iron and Steel, Durham Iron Works, and the Wharton Furnace (22).

Modern chemists would no doubt find much that is familiar as well as unfamiliar in a late nineteenth century assay laboratory. Although many types of instrumentation were still decades away, precise quantitative work was done by wet chemical methods. De Konick and E. Dietz in their 1873 book, *Analysis and Assaying of Iron and Its Ores*, give a number of directions for running an assay laboratory and performing analyses. Originally published in Europe, the book gives an insight into what the daily routine and working conditions were like for a chemist of that period (44). To begin with, there were a number of skills that the assayer and his assistants needed just to obtain supplies. Directions are given for drawing off and condensing steam from an engine as a source of distilled water. There were also a number of tests that had to be done on the water to establish its purity. The assayer and his assistants had to know how to generate and store their own hydrogen, oxygen, and chlorine. Like modern chemists they often prepared special solutions for work in the laboratory, but the solutions had to be tested for purity more frequently than would be done today. For example, bromine water had to be tested for sulfuric acid with a barium chloride spot test. Spot tests were used on solutions of iron, tin, zinc, and other cations that had been prepared by dissolving metal in acid. Acids also had to be tested for impurities; hydrochloric acid, for example, might contain traces of sulfuric acid. Sometimes acids were evaporated in a platinum crucible and the residues measured as a test for purity, acetic acid commonly being evaluated in this way. The assayer had to know which reagents could be purchased pure and which had to be recrystallized or be put through some other process of purification. Commercially available oxalic acid, for example, had to be recrystallized. Other reagents had to be prepared in the laboratory. The titration of iron with potassium bichromate required potassium ferricyanide, which was prepared by the reaction of chlorine and potassium ferrocyanide (44).

Today's visitor to a restored ironworks does not get an accurate idea of the noise, soot, and dust that charac-

terized the ironmaking process. When the furnace was in blast, the assayer needed to take special precautions to protect both laboratory and reagents from airborne contamination. It was suggested that, except under extraordinary conditions, the skylights be kept closed and all air entering the laboratory be passed through a screen made of copper gauze. Ideally the laboratory should be one story or at least a few feet off the ground to avoid rheumatic complaints from cold floors. In colder months the floors may be covered with cocoa-nut matting. Light should be from a skylight. Benches, if space permits, should be placed close to windows, especially when colors had to be compared and titration endpoints determined by color. North-facing windows were best. Although gas light could be used for illumination, the authors felt strongly that natural light was superior. Like most modern laboratories, there were the main work room, a balance room, another room for preparing and storing reagents, and a writing room, with desks and reference books (44). The laboratory needed several small furnaces, muffle furnaces for assay by cupellation and scorifying ores, assay melting furnaces, and a good "wind" melting furnace capable of melting wrought iron and holding a 6-inch crucible. The well equipped laboratory also had a large sand bath, 6- or 7-foot square, 3 feet high, and placed under a large iron hood. Aside from providing heating for experiments, it served several functions. One was to warm the room; glass shelving could be placed nearby for warming cold reagents, and a drying cabinet might be incorporated into the base. The fire that heated the sand bath also served more than one function. Ideally it was best to place the fire outside of the laboratory so as to avoid smoke and soot. The draft from the fire was directed up a tall chimney, and flues leading from the various benches, gas reaction apparatus, and ovens carried noxious fumes to the chimney. There were also small vents along the ceiling leading to the chimney to pull air out of the room. A large wrought iron plate, 5 or 6 feet long by 3 feet wide, could be placed next to the sand bath. This plate was for "combustions, small furnace operations, etc.", presumably smelting small amounts of metal in crucibles; ventilation led from this table to the main furnace flue. Opposite the sand bath and furnaces was a small enclosed chamber for gaseous reactions. Access was provided by a sliding glass door and tubes led below the laboratory floor to a gas generation room. Here "sulphuretted hydrogen" (hydrogen sulfide?), chlorine, and "carbonic anhydride" would be generated and kept under the pressure of two or three feet of water. Six or more rubber tubes would direct the gases into whatever

solutions were to be treated. Water in a cistern, mounted near the ceiling and connected by a pipe to a tank below floor level, provided sufficient pressure to force air from the lower tank through tubing into the work room. This provided the "wind" that enhanced combustion in the laboratory fires. The flow of water from the upper cistern to the lower tank also aspirated a partial vacuum used for filtration, bell jars, or room temperature evaporation dishes. Hoods might be sheet metal, zinc, or iron. Plaster over wooden lath construction was also employed, in which case the plaster would be treated with boiled linseed oil or simply whitewashed. The laboratory thus described was ideal for metallurgical work, and it is safe to say that all laboratories were not so generously outfitted. The authors freely admit that many iron producers failed to appreciate that good laboratory facilities were a sound investment. On this point they said (44):

...make-shift laboratories, like make-shift tools and machinery generally, are the most expensive in the end.

None of these developments would have been possible without trained men and intellectual tools. Many of the more prominent figures had careers that spanned the empirical to scientific eras of the industry. Three of these men are presented for the reader's consideration.

Robert Woolston Hunt (1838-1923), already mentioned, was the first chemist to be employed full-time at an ironworks (42). His career began in 1855 when he inherited his father's drugstore. Moving to Pottsville, PA in 1857, he went to work at the iron rolling mill of John Burnish and Company. His cousin was a senior partner and Hunt began as a puddler or roller. He subsequently took a course in analytical chemistry at the Philadelphia laboratory of Booth, Garret, and Reese. Hunt was hired by the Cambria Iron Company in August of 1860, to set up their assay laboratory at a salary of \$20 a month. When the Civil War broke out, Hunt enlisted in the Union Army. After the war, Hunt returned to Cambria but was sent to Wyandotte, MI to study the experimental Bessemer Converter. Hunt unexpectedly found himself in charge of the works after the resignation of several key individuals. When he returned to Cambria in May, 1866, Hunt was placed in charge of rolling the first batch of steel rails made commercially in the United States. In the course of a long career, Hunt developed new grades of Bessemer steel and devised and patented a successful rail mill feed table, a process for handling and rolling red hot blooms. He started a consulting engineering firm in Chicago in 1888;

eventually the firm had offices and laboratories in London, Mexico City, Canada, and several cities in the US. He was particularly interested in developing standards and in materials testing. He became president of the ASTM in 1912 and an officer in numerous engineering societies. He was also a frequent contributor to the technical literature.

Dr. B.F. Fackenthal, Jr. (1851-1939) was another chemist who was instrumental in placing the industry on a scientific basis. He began his 50-year career at the Durham Iron Works. He took a special course in chemistry at Lafayette College in 1874-1875. He was also a member of professional organizations such as the American Institute of Mining and Metallurgical Engineers, the ASTM, and both the British and American Iron and Steel Institutes. Between 1893 and 1913 he was President of the Thomas Iron Company (45). His interest in history combined with his knowledge of chemistry led to an unusual experiment. He took borings from stove antique cast iron firebacks and had them analyzed. By comparing the results with local ores, he had some success matching them to the sources of the iron (46).

Joseph Wharton (1825-1909) was trained as a chemist under Martin Boye of Philadelphia. Over a long career, his knowledge of chemistry allowed him to open up new markets and processes for many metals. After developmental work in the zinc, nickel, and lead industries, he began building a full-scale iron operation (47).

Dr. B.F. Fackenthal published a biographical volume of nineteenth and early twentieth century metallurgical chemists. The interested reader may wish to consult this study for more information about other chemists and their contributions to the industry.

Supplies for Laboratories and Training for Chemists

There were a number of textbooks available to assayers in the middle 1800's. The one most familiar to twentieth century scholars is probably Frederick Overman's *The Manufacture of Iron in All of Its Various Branches* (1854 and 1861) (19). Overman also wrote *The Manufacture of Steel* in 1852. The former book contained detailed assaying instructions which led the reader through a qualitative analysis scheme. Overman also gave detailed descriptions about ore types and how they reacted under blowpipe analysis. Overman's scheme is difficult for a modern chemist to follow. The author was left wondering how an untrained individual would have fared. There are no flow charts or "cookbook chemistry" instructions. There were no directions for sepa-

rating liquids and solids, although several of the procedures required it; nor is it clear whether separate samples should be prepared for different parts of the scheme (19). In *The Manufacture of Iron in all its Various Branches* (1854 and 1861) Overman wrote out a detailed wet analysis scheme for determining iron content, manganese, magnesium, phosphates, sulfur, lime, silicic acid, water, and carbonic acid. He said that, while a quantitative analysis is seldom insisted upon by most manufacturers and indeed seldom needed, qualitative analysis should be done in every case. The techniques are "easily effected" and should not be beyond the abilities of most managers. He gives directions for simple procedures (19).

The Henry Carey Baird Company of Philadelphia published a number of technical books in the nineteenth century. They described themselves as "Industrial Publishers, Booksellers, and Importers." Aside from Overman's *Manufacture of Iron...*, other titles included *The Practical Assayer Containing Easy Methods for the Assay of the Principal Metals and Alloys* (1879) and *The Practical Metal Worker's Assistant Comprising Metallurgical Chemistry, with the Art of Working all Metals and Alloys Including Malleable Iron Castings* (1879). Baird's 1979 catalog was 94 pages of "books for practical men" including works on economics, banking, machinery, textiles, metallurgy, chemistry, social science, politics, and "kindred subjects" (48).

In 1879 *Scientific American* began offering reprints of important papers as supplements. These cost about 10 cents and of 15 advertised, 11 were concerned with iron and steel. Although largely concerned with production, several did include sections devoted to the effects of impurities on iron quality (49). There are a number of cases when an isolated furnace operator obtained technical books for study. David Henderson at the Adirondack Works wrote in 1842 that he devoted many hours to metallurgical chemistry and had become "inoculated with a mania on that subject." He also wrote about making tests and experiments but information on what they were is not available (27). According to the historians currently restoring the Long Pond Ironworks in Ringwood, NJ, ironmaster and furnace owner Abram Hewitt was also known to have conducted extensive metallurgical chemistry experiments. His original notes are preserved in the New York's Cooper Union. In the late 1870's, Hewitt hired a Swedish metallurgist, trained at Uppsala University, to manage the works.

Urbanites had access to a number of technical libraries and college programs. The American Institute's 10,000 volume library was opened at New York City's

Cooper Union in 1859. Library privileges were extended to institute members. Volumes were available on agriculture, commerce, manufacturers, and the arts. Among these were the London edition of Mitchell's *Practical Assaying* and Leslie's *Iron Manufacturer's Guide* (50).

During the 1800's a number of technical colleges were established to provide professional education. Columbia University in New York City was well known for its mining and metallurgy programs. The college curricula followed by most 19th century practicing assayers deserve additional study.

Commercial laboratory supplies were also available in the urban areas. One interesting piece of apparatus was a laboratory-size hot blast furnace. The furnace was set on a flat table with a foot-operated bellows underneath. A crucible is placed inside a two-piece thick walled chamber and fuel packed around it. Air was heated before it entered the chamber. There were three adjustable "wind tubes" which could be pivoted or moved where needed. One of these fed the flame of a spirit lamp, which perhaps was used in blowpipe analysis. The furnace was sold by Barron and Brother of New York City. Their 1849 advertisement offered the furnace to assayers, chemists, dentists, and gold and silversmiths (51). Chemical ware was available from such suppliers as Moro Phillips of Philadelphia, who in 1857 offered "acid- and fire-proof ware of all kinds, up to 200 gallons, made to order, warranted to resist acids of all kinds and stand changes in temperatures from extreme heat to cold" (52). Dr. Lewis Feuchtwanger ran a chemical supply company at Maiden Lane in New York City. His 1859 advertisement listed metals and various reagents as well as "Best oils, cognac, rye, gin, rum." There was also a treatise on fermented liquors with copious directions (53).

Conclusions

Reviewing all of the hows and whys of the industry's gradual adoption of assaying, the reader may hear echoes of the present-day debate on national industrial policy and competitiveness. Many of today's proposals, particularly partnerships between academia, industry, and government have reflections in the 1800's. Some would point to the geological research conducted by the state surveys as an argument for increased funding for "basic" or "pure" research. And no one can downplay the role of education in bringing about this technological change—education that not only included technical colleges and the traditional academic structures, but the motivated furnace operator laboring through a self-di-

rected curriculum. Certainly no one factor or influence brought the modern industrial assay laboratory into being. More than anything else, this story should remind us that such profound changes are possible within an industry only when widely diverse individuals and institutions share their talents and resources.

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