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and
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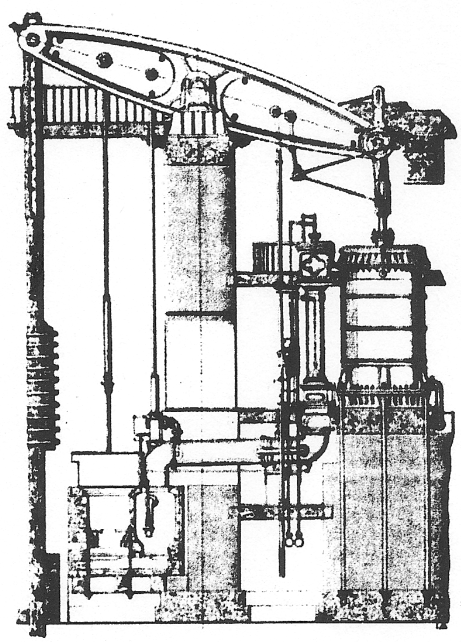
Dale Chadwick and Jan W. Matousek



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The Gap Nickel Mine, Lancaster County, Pennsylvania and The American Nickel Works, Camden, New Jersey -- 1860 - 1890

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ABSTRACT

Between 1860 and 1890 -- from the time of the American Civil War to the last decade of the 19th Century -- nickel production in North America was dominated (even monopolized) by the output of the industrial complex of the Gap Nickel Mine near Lancaster, Pennsylvania and the American Nickel Works in Camden, New Jersey. In some years, from one sixth to one third of the world's metallic nickel supply came from this enterprise. Mining and smelting were conducted at Lancaster; a matte of high iron content was shipped to Camden for pyrometallurgical and hydrometallurgical refining to produce nickel metal, copper sulfate, and cobalt oxide. The high purity nickel product was rolled into sheet for marketing, primarily for coinage, as nickel had few other uses at that time.

The undertaking experienced all of the problems that face the mining and metallurgical industries of today: declining reserves, high labor and fuel costs, high transportation costs, fluctuating demand and prices, pollution concerns, and foreign competition.

The technical features of the geology; the mining, smelting, and refining operations; and some of the economic aspects are assessed. The view is taken from that of the present time -- seeking those lessons from history that we are supposed to learn or face the prospect of repeating the mistakes of the past.

INTRODUCTION

Between 1860 and 1890 -- from the time of the American Civil War to the last decade of the 19th Century -- nickel production in North America was dominated (even monopolized) by the output of the industrial complex of the Gap Nickel Mine near Lancaster, Pennsylvania and the American Nickel Works in Camden, New Jersey. Mining and smelting were conducted at Lancaster; a matte of high iron content was shipped to Camden for pyrometallurgical and hydrometallurgical refining to produce nickel metal, copper sulfate, and cobalt oxide. The high purity nickel product was rolled into sheet for marketing, primarily for coinage, as nickel had few other uses at that time.

Known from the American colonial period, local tradition dates the discovery of acidic springs in the area to 1718. In 1744, the first attempts were made to produce copper by plating it from the springs onto iron bars. In 1849, a Philadelphia group created a stock company and formed the Gap Mining Company. A steam engine was installed to pump water from the mine, hoist ore to the surface, and to crush the ore. A sulfide mineral called "mundic" (discarded as waste) was discovered in 1853 to be the mineral millerite (NiS), and nickel then became the focus of attention. In its first year of operation, the renamed Gap Nickel Company produced 90 tonnes of ore, and during the two-year period 1858 to 1860 it produced 2700 tonnes of nickel ore and 140 tonnes of copper ore. A smelter was built nearby to treat some of this, and some of it was shipped to England. Part of the initial success was the result of the United States adopting nickel for coinage, but the impending American Civil War ruined the company in 1860.(20)

In 1862, Joseph Wharton (1826-1909), a Philadelphia industrialist with previous experience in zinc production, bought a majority of the shares in the Gap Mining Company and built (or rebuilt) a refinery at Camden, New Jersey to treat the matte from the mine-site smelter; Overman in an 1852 publication noted the presence of a refinery near Philadelphia recovering nickel from Pennsylvania ores.(1) The capacity of the smelter was around 600 tonnes a month of hand-picked ore, yielding on an annual basis about 100 tonnes of refined nickel. This level of production was generally sustained in the decade of 1873 to 1883. It represented from one sixth to one third of the world's nickel supply. Cobalt deliveries, as cobalt oxide, were around three to four tonnes of metal a year through this same period.(7,8,20)

GEOLOGY

The ore body of the Gap Nickel Mine consisted of the sulfides of nickel (millerite, NiS), copper (chalcopyrite, $CuFeS_2$), and iron (pyrrhotite, Fe_7S_8 and pyrite, FeS_2) located along the edge of a lobe of hornblende schist within the granitic Wissahickon Formation. The nickel content of the ore varied from one and a half to five percent; the copper grade was a third to half that of nickel, and cobalt, a twentieth of the nickel assay.(9) The deposit varied in width from one to ten meters at depths of 20 to 75 meters. There are two theories for the origin of the deposit. The first is that metal sulfides settled to the bottom of a gabbro igneous intrusion. The alternate theory, based on the similarity between the metal isotopes at Gap and Sudbury, Ontario, where the presence of copper and nickel is thought to be the result of meteor impact, suggests that a portion of the same meteor landed in Pennsylvania. No evidence exists to conclusively confirm either theory.(20)

MINING

Ten to twelve mines worked the mineralized vein, which was approximately 600 meters in length. They varied in depth from 20 to 70 meters. A 25 horsepower high-pressure steam engine hoisted the ore. A 100 horsepower low-pressure Cornish engine was used for pumping.

The Cornish engine, with a three foot diameter cylinder, had an unequal length beam -- eight feet on the steam cylinder side and six feet on the pump side. The engine was capable of operating at 10 strokes a minute, but only two were required to keep the mines dry. Water was raised from two shafts, 170 meters (550 feet) apart. The engine was connected directly to the first pump and to the second pump by a wooden laminated beam (a "flat rod"), 200 millimeters (eight inches) square by 170 meters long. A "bob" at the engine end of the beam translated the vertical motion of the pump rod into the reciprocating horizontal movement of the flat rod; at the other end of the flat rod another "bob" converted this horizontal motion back to vertical movement to operate the second pump. Approximately 0.6 cubic meters of water a minute (153 US gallons per minute) was pumped from the two shafts of 55 and 70 meters depth while consuming 450 kilograms (1000 pounds) of coal in 24 hours, suggesting efficiencies of 10 percent for the boiler, 40 for the pumps, and an overall efficiency of about four percent. The "duty" of Cornish pumping engines of this era was rated in the number of million pounds of water that could be raised one foot from the burning of one bushel (94 pounds) of "good Welsh coal". One hundred million pounds was the illusive target.(14); the pumping system at the Gap Nickel Mine had a duty of approximately 35 million pounds per bushel of coal.

Mining was done by vertical shafting, horizontal tunneling into the vein (drifting), and upwards and downwards stoping (ore removal) between the drifts, which were separated by approximately 20 meters. The ore quality was variable; some could be extracted with hand picks; other ore had to be blasted; timbering was used extensively. After hoisting to the surface, the ore was sent to a sorting house where the lump material was concentrated by hand picking; the ore to waste rock ratio was approximately two to one. The fines were concentrated by jigging, then agglomerated with lime to form briquettes for feeding directly to the blast furnaces.(2)

SMELTING

Eleven vertical kilns, each with a capacity of approximately 90 tonnes of charge, roasted (calcined) the lump ore. The kilns were fired with wood and burned for approximately five to six weeks after ignition. There were four smelting furnaces of masonry construction -- two in operation at any one time. Blowing air was produced in three air compressors (blowing engines) with 810 millimeter (32 inch) diameter cylinders and strokes of 610 millimeters (24 inches), driven by a 25 horsepower steam engine. Quartz and limestone were added as fluxes; the furnaces were fueled with coke.(3,15)

The flow diagram for the smelter is shown in Figure 1.

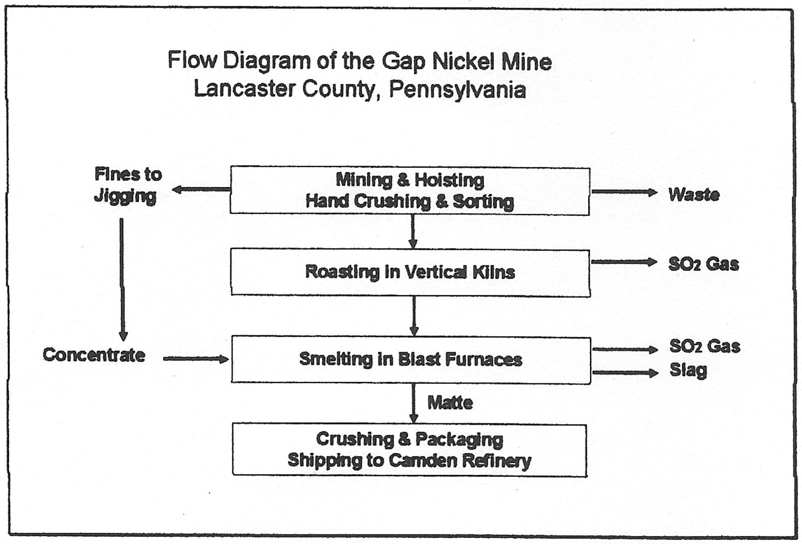

Figure 1 -- Flow Diagram of the Gap Nickel Mine

Three random samples of slag were collected from the dumps in preparation for this publication. The analyses are shown in Table I. These data along with that scattered throughout the literature were used to prepare a tentative mass balance for the smelting works. The results are shown in Table II. Smelter recoveries are estimated to have been approximately 92 percent for nickel and copper and 70 percent for cobalt.

Table I -- Slag Assays

	Sample 1	Sample 2	Sample 3	Average
%Cu	0.059	0.114	0.060	0.078
%Ni	0.102	0.163	0.072	0.112
%Co	0.020	0.030	0.020	0.024
%S	0.181	0.205	0.156	0.181
%FeO	16.65	20.70	16.33	17.89
%SiO_2	46.83	41.89	46.63	45.12
%Al_2O_3	6.82	6.51	6.24	6.52
%CaO	12.90	13.60	14.76	13.75
%MgO	12.57	12.51	12.20	12.43
Balance	3.87	4.28	3.53	3.90

Table II -- Smelter Mass Balance and Assays

	Ore	Matte	Slag
tonnes/month	600	100	640
%Cu	0.90	5.0	0.078
%Ni	1.80	10.0	0.112
%Co	0.09	0.4	0.024
%S	15.0	28.0	0.181
%Fe	24.0	50.0	13.9
%SiO_2	31.0		45.1
%Al_2O_3	7.0		6.5
%CaO	8.0		13.8
%MgO	12.0		12.4

There were 93 men employed in the mines (16 first class miners), 50 at the smelter (12 furnace operators), and 18 teamsters for a total work force of 161. First class miners, furnace operators, and engineers and mechanics were paid approximately $1.50 per day. As seen in Figure 2, this was the equivalent of one pound of nickel in the period 1860 to 1870 and one half pound around 1875.(12)

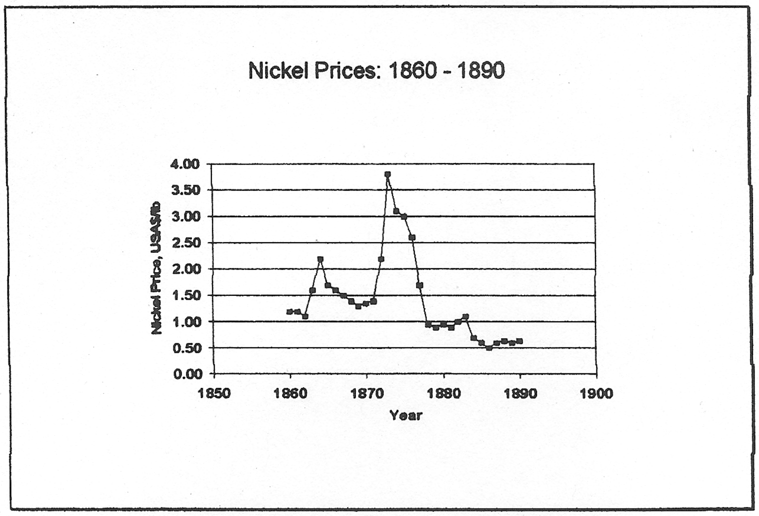

Figure 2 -- Nickel Prices -- 1860 -1890

REFINING

The flow diagram of the American Nickel Works is shown in Figure 3.

Considering the length of time that the mines, smelter, and refinery operated, it is surprising that so little was written on the technical details of the processes. Even Wharton himself, writing in 1897 (7), had little to say, and the classic metallurgical handbooks of Phillips and Bauerman (4) and Schnabel and Louis (9) make no more than passing mention. It seems certain, however, that three cycles of smelting were followed by three of roasting -- not the alternating roasting followed by smelting that was characteristic of the Welsh copper-making process.(17) Wharton does note that successive roasting and smelting and a final dead roast was the practice of the French company "Le Nickel' in treating the mattes received from New Caledonia.(7)

Crushed matte, containing approximately ten percent nickel and five percent copper, was received at the refinery in wooden casks of 450 kilograms (1000 pounds) capacity. There, it was treated through three successive stages of oxidative smelting (melting) in a coal-fired reverberatory furnace to effect the elimination of iron. Smelting was followed by three successive stages of roasting, again in a reverberatory furnace, to remove sulfur -- the final stage being a "dead" roast to eliminate the last remnants of this element.

The mixed oxides of nickel, copper, cobalt, and iron were leached in a sulfuric acid solution; copper was extracted as the sulfate and marketed as such; hydrated lime was added to precipitate an iron waste. Cobalt was separated from the nickel with "bleaching powder" and recovered as cobalt oxide. Finally, nickel oxide was recovered by precipitation and reduced to high purity metal with charcoal in a crucible furnace. It was estimated that one year passed between the mining of the ore in Pennsylvania and the production of nickel metal in New Jersey.(2,3,16,18)

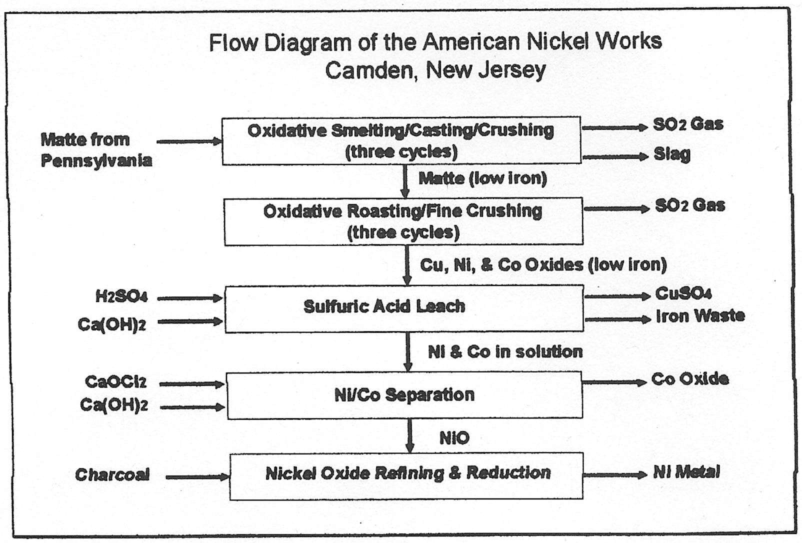

Figure 3 -- Flow Diagram of the American Nickel Works

FABRICATION

The nickel metal from the reduction step was melted and cast into ingots and sent to the rolling shop of the American Nickel Works. There were two trains of rolling mills, each with a roll 460 millimeters (18 inches) in diameter by 1020 millimeters (40 inches) wide, driven by a 90 horsepower engine. The largest sheet of pure nickel produced was 1830 millimeters long by 610 millimeters wide (72 by 24 inches).(3)

Various objects -- axles and bearings, bars and rods, magnets and magnetic needles -- were sent to a number of international exhibitions: Vienna in 1873, Philadelphia in 1876, and Paris in 1878. Few viewers appreciated what they were seeing, and the items drew little attention until it was explained by the judges just how rare the specimens were and how difficult it had been to produce the metal from which they were made.

Wharton's nickel had to have been of high purity to achieve the malleability that it possessed. In some competition to this product was nickel produced by a process invented by a Dr. Fleitman of Westphalia, Prussia in which a small amount of magnesium was added during casting. The product was malleable and could be produced at a much lower cost than that from the American Nickel Works. However, it does not appear that Fleitman achieved any greater commercial success than did Wharton in producing consumer oriented products.

EPILOGUE

By the beginning of the 1890s the ore reserves at the Gap Nickel Mine were coming to an end. Massive deposits of high grade oxide nickel (laterites) had been discovered in New Caledonia, and by 1875 metal from this source entered the market. In 1888, nearly as massive deposits of sulfide nickel and copper were discovered near Sudbury, Ontario.(17) In 1894, the Gap Nickel Mine closed for good. The refinery at Camden continued to run on matte imported from Canada. In 1902, t0068e American Nickel Works was joined with the Canadian Copper Company (the largest operator in the Sudbury district), the Orford Copper Company, and several other metallurgical interests to form the International Nickel Company. Within a few years of this merger production at the New Jersey plant also came to an end.

Joseph Wharton had been in the zinc business before his nickel ventures. He went on to third or fourth careers in iron and steel, gold, and railroads -- not always as successfully as he had been with the Gap Nickel Mine. He did not lose his fortune, however, and generously funded Swarthmore College and what was to become the Wharton School of Business at the University of Pennsylvania.(22) His personal and business associates included Thomas Edison and Andrew Carnegie. In 1981, he was remembered for his philanthropic efforts with a first day of issue stamp by the United States Postal Service. He was elected to the National Mining Hall of Fame (Leadville, Colorado) in 1988.(19)

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