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HISTORY OF TECHNOLOGICAL AND ADMINISTRATIVE DEVELOPMENT IN THE ASHIO COPPER MINE

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INTRODUCTION

JAPAN's industrial revolution began about one hundred years after that of Europe and the United States. It began not with the development of the textile industry but with mining. In Europe, too, mining and metallurgy had been prominent activities predating cotton manufacturing, but it was the rapid modernization of the cotton industry that heralded the advent of the Industrial Revolution. Although the steam engine was originally invented to meet the need in mines, the wholesale mechanization of the mining industry had still not begun in Europe by the mid-nineteenth century. In Japan, however, following the major political reforms of the Meiji Restoration of 1868, mining mechanized rapidly in comparison with other industrial activities.

With respect to cotton, however, imports of European machine-processed cotton fiber overwhelmed endogenous, hand-made cotton goods, driving them out of business. Only in the last decade of the nineteenth century was the Japanese cotton industry able to stand up to Western imports, reorganize and modernize itself, and strengthen its economic base.

In this essay, I shall examine how, after Meiji, the Ashio Copper Mine, the most advanced in Japan, developed a managerial and technological strategy enabling it to attain a level of performance comparable with Western mining operations.

Prior to the Meiji Restoration, Japan was primarily an agricultural country, but a well-developed market system enabled commodities to circulate everywhere. While manufacturing was not as widespread in Japan as in Europe just before the Industrial Revolution, nonetheless, every fief government gave the handicraft industry its financial backing and encouraged its growth. As a result, endogenous handicrafts associated with the manufacture of metal and wooden agricultural implements, cast iron goods, copper, bronze, and tin; ceramics; roof tiles; items of wood and bamboo; paper; cloth and textiles; paints and dyes; mechanical

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clocks; marionettes; waterwheels; and sailing vessels developed rapidly throughout Japan, attaining a high level of perfection.

Because the Tokugawa government restricted the use of wheeled vehicles, transportation by horse-drawn carriage never developed as fully as in the West, and, as a result, road-construction technology did not advance beyond a certain point. By contrast, water-control technology, necessary to safeguard farmland and urban areas from flooding, and hydraulic technology for irrigation and waterworks were quite sophisticated.

When, in 1853, Matthew C. Perry, commander-in-chief of the East Indian Fleet of the United States, arrived in Japan to demand that the country open its doors to trade, the modern Western technology that had evolved out of the Industrial Revolution had a profound impact on the central and fief governments. These immediately set about manufacturing metal cannons and gunpowder, and some fiefs began importing spinning machines and steam engines from the West. All felt strongly that unless they took such measures, Japan would not be able to meet the military and economic threat posed by Western countries. With the Meiji Restoration a flood of new technology was unleashed, and, building on its traditional technological base, Japan began to modernize, assigning priority to the mining industry.

However, the fact that Japan had a technological base on which to build did not mean that the process of technological modernization was a smooth one. Modern technology depends for its full development and effectiveness on factory organization which instills social order and discipline and makes rational use of time and space. However, in the case of Japanese society with its long apprenticeship to the handicraft industries, neither managers nor workers could easily adapt to modern organized management practices.

Anyone with sufficient capital could purchase machinery and equipment abroad and introduce it to Japan on short notice. But it took time to create the organizational infrastructure and train the personnel necessary to properly use these machines. People first had to be trained in organizational methods and techniques of personnel management.

This essay takes the Ashio Copper Mine as a case study in the process of modernization in Japan. Unlike state-run mines which, in a period of rapid technological change, underevaluated the importance of traditional, endogenous handicraft technology, Ashio is noteworthy in that it followed the opposite path to modernization. Ashio owner Ichibei Furukawa first raised productivity by perfecting traditional technology and then as the market gradually expanded, slowly introduced modern technology as it became feasible and necessary while at the same time training personnel in new factory techniques and discarding old forms of organization. In this way, modernization advanced at a steady pace. With the discovery of ore-rich veins, the purchase of bankrupted state-operated mines (Furukawa bought the Ani and Innai mines in 1885), and the expansion of the copper market that accompanied the development of the electric industry, the wholesale modernization of excavation and smelting was undertaken. This prudent approach to modernization saw the successful introduction of advanced technology and, indeed, was responsible for accelerating the modernization process itself.

However, concerning the organization of the Ashio Mine, respect for workers' rights, the crux of modernization, was not observed, and, as in the past, the pre-modern practices of the pre-Restoration period were not discarded. So long as the modern rights of workers were not respected, corporations ignored the basic rights of local inhabitants living near their factories. This was one of the principal causes of the Ashio pollution incident which became a major political problem in the last decade of the nineteenth century.

Even today, in the postwar period, Japan has not adequately dealt with this problem, which remains much as before. While postwar Japan has experienced a phase of high economic growth with few parallels in the world, the unprecedented environmental pollution that this process has produced indicates that, in a real sense, modernization has not been fully realized in Japan. This essay hopes to show the negative consequences that attend rapid economic progress, of which the Ashio Copper Mine is the prototype.

I. THE BEGINNING OF MODERNIZATION IN MINING

The modernization of Japanese technology and management began in 1868, the year of the Meiji Restoration. It was during this period that the Industrial Revolution in the West, symbolized by cotton, the steam engine, coal, and railways, reached its apex. By this time, the second Industrial Revolution, symbolized by steel, electricity, oil, and the automobile, had already begun. Industrial capitalism under free competition was being transformed into monopolistic capitalism.

Copper had already become one of Japan's major export item prior to 1868. The Tokugawa government bought up nearly 90 per cent of the copper produced throughout Japan and used it to settle trade accounts with Holland and the Ch'ing dynasty. The development of copper mines was therefore of supreme importance not only for the Tokugawa government but also for the fief governments and merchants. Nevertheless, mine development had nearly reached its limit by the time of the Meiji Restoration. As was the case in Europe immediately before the Industrial Revolution, the deadlock was primarily caused by the flooding of mines due to lack of adequate drainage. As the demand for metal and coal gradually increased on the eve of the industrial revolution, mines were inevitably exploited with greater intensity at greater depths. However, no measures existed for coping with water seepage, which occurred day and night.

Before steam engines were introduced to mines in both Europe and Japan, drainage laborers had to relay wooden buckets of seeping water by hand from the site via a sump to the surface where the water could be disposed of. Another drainage method was to draw water by hand pump into a wide tub (a wooden basin was used in Japan). Another group of laborers pumped that water up into another tub until the water reached the surface. In other words, from the site of seepage and the sump to the portal, mines were full of drainage laborers working in queues. There was no other means apart from such human wave tactics to cope with the drainage problem. In the case of the Besshi Copper Mine, another large mine located in the Shikoku region, 447 water drawers were hired as against 481 excavators in 1861.

The deeper the extraction site, the greater the amount of seepage and the greater the distance between the seepage site and the portal. If manpower did not prove adequate to the task and lost the battle against water, even mines with rich veins flooded. Watt's steam engine therefore responded first and foremost to the need for drainage at metal and coal mines. The first steam engine moved up and down in a vertical rather than rotational motion. This type of steam engine was adequate for powering the piston-model pump of the time.

When the Tokugawa government found it had no choice but to open its ports to the West, steam engines were already in full operation throughout Europe. It thus seemed that drainage problems could be solved by the immediate introduction of steam-powered pumps to Japanese mines. Nevertheless, the social system in Japan was such that, politically and economically, this was almost an impossibility. Mine management at that time was in the hands of foremen who were employed by mine owners such as the Tokugawa government, fief governments, and big merchants. These foremen were allotted extraction sites and contracted to undertake the extraction and smelting of ore. Foremen therefore excavated galleries independently from separate portals. Even upon reaching a prospective deposit and beginning ore extraction, they would abandon the face when they could no longer cope with the seeping water. They would then begin excavating from another portal. It is said that the number of portals created in this manner at the Ashio Copper Mine had numbered as many as 1,484 by 1751. (The excavation of the Ashio Mine is said to date from 1610).

It is extremely inefficient to install steam engines at such mines. Inclined shafts, pits, and horizontal galleries, which comprise the structure of the mine, must first be excavated. Small adits can then be extended from these to reach deposits. If the movement of manpower and goods can be directed from each working face to major galleries, dirt and water can also be collected at the same sites which can then be equipped with steam engines and pumps. However, in order to implement such a project, mine owners must dispense with foremen. They must directly employ workers who can be allocated and reallocated effectively throughout the mine, and this requires a system for recruiting new workers. Viewed from the workers' side, labor mobility must be ensured.

Although such capitalistic practices were indispensable for the introduction of steam engines, labor mobility was not possible under the feudal system prior to the Meiji Restoration because one's vocation was set for life according to the premises of ascriptive social status. The Tokugawa government as well as fief governments must have earnestly desired the steam engine. However, local and central governments fell into a trap set by themselves: in order to introduce the steam engine, they would have had to alter the feudal system itself, which they naturally could not or would not do.

The Meiji Restoration marked the beginning of capitalism in Japan and the modernization of mine management. In 1870, the Restoration government established the Ministry of Industry which controlled all mineral resources and, in

1873, enacted the Japanese Mining Law, which stipulated that the Japanese government had sole title to and full management rights over all mineral resources found in Japan. The majority of metal ore and coal mines formerly owned by the Tokugawa and fief governments became state-owned, and the Meiji government took the initiative in inviting Western engineers and introducing modern plants into Japan, thereby preparing the modernization of mines at one stroke.

Extremely high salaries were paid to Western engineers. J. C. H. Godfrey, chief mining engineer, received a monthly salary of 1,000 yen, middle-ranking engineers were paid several hundred yen a month, and even the miners who came along received stipends of not less than 100 yen. On the other hand, Saihei Hirose, the general manager of the Besshi Copper Mine, only earned a monthly salary of 100 yen. Laborers who handled pit timber at the Ashio Copper Mine were paid a daily wage of 0.55 yen (a mere 10.40 yen a month). There was, then, a great discrepancy between the salaries of the two groups.

At first, main haulage ways were excavated at each state-run mine. Tracks were installed to carry manual or horse-pulled carts; steam engines were also installed and came to be used widely for purposes of drainage and winching. For smelting, brick blast furnaces and reverberatory furnaces were introduced in place of the conventional bellows hearths.

A bellows hearth was a hole dug in the ground whose walls were solidified with ashes and which was equipped with bellows. Ore was smelted with the use of charcoal. The output was very small, and the hearth had to be completely rebuilt after each smelting operation.

Although, before Restoration, some engineers retained by several fief governments studied every detail found in Dutch technical books and managed to construct not only a blast furnace but also a reverberatory furnace which somehow successfully smelted ore, such successes were very rare. On the other hand, the objective of the state-run mines from the Meiji Restoration onward was to totally modernize the entire production process, from the extraction of ore to smelting. This was a radical change which could never have been realized without the backing of new authorities who overthrew feudal society.

II. STATE-RUN AND PRIVATE MINES: A CONTRAST

Private capital could neither employ a large number of foreign engineers, who earned incredibly high salaries, nor purchase Western technology. Nevertheless, the development of modern technology at state-run mines was not at all smooth despite large funds invested. The main source of these funds was tax revenues taken from farmers. Although it appears that government capital should have spurred technological development, matters did not evolve so simply.

In order for technology to develop, there must first be a demand for new technology in the market. Then, in response to this demand, there must be sufficient accumulation of capital which can be invested in technological development and plant facilities. Moreover, high wages which trigger mechanization and automation are also indispensable. Persons in charge of economic policy and economists tend to think that technology evolves automatically when all these economic conditions are met. However, the fact that money alone cannot develop technology, that creativity and skills are also indispensable, is forgotten and thus it appears as if the truly essential factor is omitted.

Mining is governed by the fact that the physical and chemical characteristics of natural resources differ greatly from one area to another. Thus modifications were necessary in any application to the Japanese situation of the plant designs and technical operations which brought success to mining efforts in the West. This is why, although well-paid foreign engineers came to Japan, almost all of them failed to achieve their objectives satisfactorily.

The most typical example was seen at the Kamaishi Iron Mine. This became a state-run mine in 1874, and the construction of the plant was begun the following year and completed in 1880. However, after operating for only three months, work stopped due to a lack of charcoal which was used as fuel. Although the operation resumed in 1882 with the use of new fuel, a mixture of charcoal and coke, the plant closed down again the following year, 1883. This was because molten iron stopped flowing out of the furnace spout due to coagulated slag which created shelf-like accretions in the furnace.

The major facilities of this mine consisted of two twenty-five-ton blast furnaces, three hot blast stoves, twelve puddling furnaces, five metal rollers, and two steam-powered hammers which were invented during the Industrial Revolution. Despite the fact that the government invested large amounts of capital there between 1874 and 1883 (a total of 2,370,000 yen), the plant facilities were sold as scrap to Chōbei Tanaka, a rice merchant.

At that time, Japan did not yet have a national parliament, and public opinion could not openly criticize government failures. This tremendous waste of the nation's assets was covered up without ever taking any high ranking official to task.

It would appear that a simple calculation by the engineers could have clarified the amount of charcoal required for the daily maintenance of two twenty-five-ton blast furnaces and thus the amount of timber needed from the mountains surrounding the iron mill as well. Nevertheless, no survey of this nature seems to have been carried out. How could iron be successfully smelted if the operating conditions were changed at the eleventh hour by mixing coke with the fuel?

Despite the fact that all the state-run mines incurred large debts, managerial officials could move to other offices and continue their careers. Private capitalists, however, could not do the same. Plant facilities at private mines were few and far between and those that existed were several paces behind the state-run mines. The private mine managers who were intent on utilizing both endogenous and new technology to the maximum pursued technological development. Moreover, they invested as much of their capital as possible in plant facilities as well as in the training of personnel and thus came to accumulate capital.

Private mine managers were proud of the fact that they themselves were achieving the objectives of mine management as they became familiar with the conditions of the state-run mines. For example, although Saihei Hirose of the Besshi Copper Mine employed a French engineer, L. Larroque (at a monthly salary of 600 yen), he did not renew Larroque's contract when a plan for technological reorganization was compiled. Hirose used the plan to carry out the reform himself. In this regard, Hirose was very explicit:

> It should be known that even the so-called mine engineers cannot completely meet the objectives and make a profit from mines since they neither have long practical experience nor do they know the hardships entailed in mining. If I were to raise more doubts, I would question the operation results of various mines under direct government control. Few would be encouraged by the performance of these mines. [1, p. 45]

Of 673,000 yen, the budget drafted by Larroque, Hirose cut off 138,000 yen which comprised foreigners' salaries, or as much as one-fifth of the total budget.

As the Besshi Copper Mine was managed by Sumitomo capital, it was possible to secure a large investment sum for this civilian mine, and a foreign engineer was made to compile a reorganization plan using Western technology. In contrast to Besshi, the Ashio Copper Mine, placed under the authority of Tochigi Prefecture after 1868, was managed at different times by a number of miners who secured mining rights there. In 1876, Ichibei Furukawa obtained rights to the mine. Although Furukawa was a rich merchant, the capital he was able to muster fell far short of Sumitomo's. He thus had no other choice but to manage the mine steadily by himself with the use of conventional technology.

Pre-Meiji technology should be described as endogenous technology. It was precisely this endogenous technology that Furukawa made use of. Nevertheless, Furukawa first aimed at the rational use of portals, which was a Western method. He also began to transfer technological leadership from the contractors to himself. This was because Furukawa was aware of the fact that even some state-run mines had been forced to revive the traditional "ore-purchase system" as a stopgap measure to overcome deficits even though modern plants had been introduced, a measure that led to the devastation of some mines. Chōshichi Kimura who later became chief miner at the Ashio Copper Mine made the following comments concerning conditions at the state-run Innai Silver Mine. He made these observations when sent by Furukawa to inspect the feasibility of operating the mine:

> During the period of state management, ore was bought from contractors [because the production plan directed by government officials had not worked out and] because finances were always in the red. . . . Extraction was carried out by contract with a grade prerequisite of more than one-thousandth [contractors naturally excavated only the high-grade ore deposits and abandoned the site after the rich ore was totally depleted], and the mine was thus gradually ruined. [2, pp. 182–83]

Complying with directives of Furukawa, Chōbei Kimura, then Ashio's chief miner gradually phased out the "ore-purchase system" prevailing at Ashio and at the same time developed a comprehensive prospecting plan for the entire mine. As a result of this policy, a rich ore deposit, the Takanosu deposit, was discovered in 1881, and the mine finally became profitable. Furukawa capital first placed the Takanosu Pit under its direct control. Prior to this, Furukawa had entrusted ore extraction and smelting to contractors, buying crude copper from them. At the Takanosu Pit, a contract system in which extracted ore was bought directly from the excavators was in use.

Subsequently, an even larger rich deposit, the Yokomabu deposit, was discovered in 1883. This discovery created the sufficient natural conditions for the development of a modern excavation plan applicable to the entire copper mine at Ashio. Excavation of the main haulage way as the key structure for excavation and transportation was begun in 1885. In this regard, a company record of the time preserved by the Furukawa Company notes that:

> As there has been a sudden increase in output since the discovery of the Yokomabu deposit, the prosperity of the mine can be built on this basis. As a result, the mine's Arinoki Pit was excavated to the deepest level in preparation for depth extraction. The pit was also used for the purpose of examining several hundred veins running through the mine. A big plan was worked out aimed at the extraction of the rich deposit and the excavation of a main haulage way began. Furthermore, both the Kotaki Portal (known as the Urayama Pit) and the Mochigi Pit in the Kakeibashi area were excavated. Consequently, it was possible to develop the entire Ashio Mine in an ideal way. [4, p. 85]

For the first time, the problem of seeping water which had played havoc with mines prior to the Meiji Restoration was fully solved. At the Ashio Copper Mine, two kinds of Western hand pumps had been used to draw water from the deepest pit to the pit at the next level and so forth until the water was collected in a higher pit from which it could be drained out of the mine. It was necessary to hire about 310 workers to run several score of manual pumps day and night. However, these workers finally disappeared in 1888 due to the installation of a steam engine. The transition from endogenous mining technology to Western technology was obviously under way.

III. THE COEXISTENCE OF WESTERN AND ENDOGENOUS TECHNOLOGY

A. *The First Stage*

From the point of view of both technological and economic history, the late nineteenth and early twentieth centuries are characterized by the transition from Industrial Revolution to more advanced levels of technology. Without having enough time to digest the newly introduced Western technology, corporations in Meiji Japan, whether state-run or privately owned, had to incorporate the much advanced technology of the second Industrial Revolution. In the case of iron manufacturing technology, the Kamaishi Iron Works, completed in 1880, was equipped with two twenty-five-ton blast furnaces and twelve puddling furnaces, whereas the Yawata Steel Works, completed in 1901, was equipped with much larger blast furnaces (capable of producing 160 tons of pig iron per day) and Bessemer's converter and Siemens's open hearth in lieu of puddling furnaces which were already obsolete.

As the modernization of the Ashio Copper Mine finally got under way, a great change occurred in the international copper market. There was an obvious worldwide glut of copper in the early 1880s due to the development of copper mines in the western United States. However, copper wire was adopted in 1886 instead of conventional iron wire for telegraph line in England, France, and Belgium, and the demand for electric wire grew rapidly as electric machinery became prevalent. The market for copper expanded significantly. Ichibei Furukawa, who recognized the new wave, concluded a long-term contract with Jardine Matheson of England, and was able to secure adequate capital from banks. This occurred in 1888 just as hand pumps were disappearing.

Furukawa requested that Jardine Matheson secure facilities from the Siemens Electric Company of Germany, and in this manner a hydroelectric power plant was constructed as early as 1890. The demand for copper, which had increased with the spread of electric machinery, could only be met by using electric machinery. The hydroelectric power plant supplied the electricity to run the eighty-horsepower pumps, twenty-five-horsepower winches, and twenty-five-horsepower electric lights. Steam pumps, then, had already been replaced by electric pumps.

It was during this year that the modernization of smelting began at the Ashio Copper Mine. Although brick smelting furnaces were introduced to state-run copper mines and to the Besshi Copper Mine at an early stage, Ashio had relied upon the endogenous bellows hearth for a long time. Ashio's modernization was supported by the coexistence of both endogenous and Western technology. The delay in the introduction of a brick smelting furnace at Ashio was partly due to the fact that it was unnecessary because of the small output and also because highly skilled labor was needed to run a brick smelting furnace. Highly skilled labor was required because slag (mainly $FeS \cdot SiO_2$) reacted so violently with the silica contained in bricks that it corroded the furnace walls. On the other hand, when the furnace temperature was lowered in order to prevent the corrosion of the walls, zinc oxide and lead monoxide could not react sufficiently with silica. As a result, slag either coagulated on the walls or formed accretions in the furnace. Furnace control in accordance with each smelting process was very delicate, and since the Japanese ore differed from that of the West, stable operations became ever more difficult to ensure. For this reason, chief miners like Chōbei Kimura and Chōshichi Kimura must have found it more reliable to use the bellows hearth with which they were familiar.

Furthermore, although private capitalists appeared bold and daring, they were at times more hesitant than necessary when it came to introducing foreign technology. Around 1881, Ichibei Furukawa was noted for his dislike of machinery, and it was said that he would use a hand crusher when a steam-powered crusher should have been used and preferred foot bellows to steam-powered fans. At the Besshi Copper Mine, also, Saihei Hirose committed an indiscretion which caused a great delay in the completion of the Tōen Inclined Shaft which was to be the key structure of the mine. This was due to his reckless reliance on manpower. He stated that "all can be achieved through determined willpower," even after Larroque had stipulated that a steam-powered winch be used.

At any rate, the difficulty entailed in using a brick smelting furnace had also been a problem worldwide. The Detroit Copper Company in the United States put a square water-jacket blast furnace to use in 1882 and solved the problem of wall corrosion. The main structural feature of a water-jacket blast furnace was the fact that it was lined with double layers of iron sheets which were joined together at an interval of about ten centimeters. The furnace wall was cooled by water which circulated in between the double layers of iron sheeting. Furnace control became much easier because of the fact that there was extremely little damage to the wall of a water-jacket blast furnace, and that shelf-like accretions of slag in the furnace could easily be removed from the top of the furnace with an iron rod.

Monnosuke Shiono of the Ashio Copper Mine studied further and devised a water-jacket blast furnace of his own design. After a successful test run, he constructed twelve water-jacket blast furnaces in 1890 when the hydroelectric power plant was constructed and was able to discard forty-eight endogenous bellows hearths at once. The full-scale modernization of smelting technology thus began.

The main components of copper ore consist of copper sulfide (Cu_2S), iron sulfide (FeS), and silicic acid anhydride (SiO_2). In the first smelting process, matte, whose main component is copper sulfide, is created. Then the matte is reheated and desulfurized in a reverberatory furnace to produce crude copper.

The endogenous technology of pre-Meiji Japan recognized two methods of smelting. Ōshū smelting was practiced at the Ashio Copper Mine and at various mines in the northern region. According to Ōshū smelting, copper matte produced in a bellows hearth was first roasted in a furnace to desulfurize it. The roasted matte was then reheated and melted in a bellows hearth until the matte was reduced to crude copper. The other method of smelting was Yamashita, or Iyo, smelting which was practiced in the Chūgoku and Shikoku regions. According to this method, copper matte obtained in the initial smelting process was put in the bellows hearth without being roasted again. While the matte was being smelted by charcoal heating, a blast of air was gradually introduced, oxidizing the iron sulfide first to form iron oxide, which was then turned into slag as a result of the bonding between iron oxide and the silica contained in the ashes of the hearth. The use of the exothermic reaction in this process and the sending of a continuous blast of air over the copper sulfide oxidized the matte to copper oxide which was then reduced to crude copper. This operation was known also as *mabuki* smelting.

As can be seen, Yamashita smelting not only included one less process than Ōshū smelting, but it also required no fuel for roasting. Furthermore, since it utilized the exothermic reaction of the raw material wisely, the quantity of charcoal consumed in the hearth was small. As a result, all smelting operations at the Ashio Copper Mine switched to Yamashita smelting in 1885, and other mines in the northern region also adopted it in quick succession. Mines, then, did not rush to introduce modern Western technology; instead they attempted to first improve upon existing endogenous technology.

The smelting method used in Europe at that time resembled Japanese Ōshū smelting in that copper matte was roasted again and made into crude copper in a reverberatory or smelting furnace. Consequently, although *mabuki* smelting had a fatal drawback, the bellows hearth, the advantages it offered should be highly evaluated. Ashio, Besshi, and other copper mines continued to rely upon *mabuki* hearths for the production of crude copper even after the adoption of blast furnaces for the production of copper matte for technological reasons. It can be said that this coexistence was in accordance with the objective of both Western and endogenous technology. Modernization based on dual technology is not necessarily unique to China but is a natural outcome of technological development which can be observed in any country at any time.

B. *The Second Stage*

When Bessemer of England successfully devised a steel converter process in 1855, opening the era of mass produced steel, the question arose whether or not the same device could be applied to the production of crude copper from copper matte. In the Bessemer converter process, an exothermic reaction occurs when the carbon in molten iron and oxygen react with each other to produce carbon monoxide gas after a blast of air is introduced from the bottom of the furnace. Because the volume of gas is doubled during this process, molten iron boils more rapidly and promotes a reaction.

The same process was feasible for copper matte, as it was almost identical to the chemical reaction which occurred in *mabuki* smelting. Because copper has a natural affinity for sulfur, the bonding cannot be easily broken when a blast of air is blown at smelted copper matte. Thus, iron sulfide is first oxidized into iron oxide which is then bonded to silica via an exothermic reaction, becoming slag. A blast of air is introduced continuously even after most of the iron sulfide is converted to iron oxide, as an exothermic reaction occurs when copper sulfide, the main component, becomes first copper oxide and then metallic copper.

Monnosuke Shiono was keenly interested in the fact that the principle of the copper Bessemer process, which was successfully devised in France by Manhés, was almost identical to the Japanese *mabuki* process. After successfully creating a water-jacket blast furnace in 1890, he went to the United States to study Bessemer converter process. He set about building a plant immediately after his return to Japan, and operations began in 1893. He thus implemented a system in which a water-jacket blast furnace made copper matte from ore after which a Bessemer converter produced crude copper from the matte. The entire process only took two days while the endogenous process required as many as thirty-two days.

Unlike the water-jacket blast furnace, the copper Bessemer process, however, did not spread rapidly to other mines. This was because copper output at the time was generally so small that a *mabuki* hearth's daily yield of 370 kilograms was quite sufficient. Consequently, there was no urgent need to use a Bessemer converter, which could produce a daily output of two tons.

Furthermore, other mines remained intent on improving the *mabuki* smelting process. The Yoshioka Copper Mine held a successful test run in which smelted copper matte was introduced directly into the hearth as in the copper Bessemer process. Consequently, while the volume of charcoal required for conventional smelting was 30 per cent of the matte quantity, this was henceforth reduced to a mere 5 or 6 per cent. Although attempts were made at many mines to smelt copper with a blast furnace and reverberatory furnace as part of technological modernization, most of miners reverted to *mabuki* smelting as this method was firmly rooted in traditional smelting practices.

Subsequently, it was necessary to convert crude copper into refined copper. An exceptionally high degree of purity was required of the copper to be used in materials for electric machinery. The refining of crude copper in Europe used to be done in a reverberatory furnace. However, in 1856 Elkington of England tested the electrolytic refining of copper (multiple system) using crude copper as anode and electrolytic copper as cathode in a copper sulfate solution as electric bath. In 1886, Hayden, an American, tested the electro-refining of copper with a series system. The mainstream of the world's technology rapidly moved to electrolytic refining due to the fact that electrolytic copper had a higher degree of purity in comparison to copper produced by reverberatory furnace; gold and silver contained in electrolytic slime could also be extracted easily.

Refining by reverberatory furnace was first introduced to Japan in 1873 when such a furnace was installed for mintage at the Osaka Mint. Furukawa's Honjo Refinery began to operate a reverberatory furnace in 1884. However, the majority of mines either exported crude copper to foreign countries without refining or refined copper using pre-Meiji endogenous technology, the so-called "early European" (*namban*) refining process.

It is said that the "early European" refining process was taught to Rihei Izumiya, a founder of the Sumitomo, by a European in 1591. Although the process was originally endogenous to Germany, it is said that Japanese metallurgical artisans modified it entirely to suit Japanese condition. In this process, crude copper was first smelted in a bellows hearth (early European furnace) into which lead was added to make a precious lead alloy consisting of lead, gold, and silver. Then a semi-smelted precious lead alloy was drawn out of the spongy masses of copper. The remaining copper was further refined by the *mabuki* process in order to eliminate impurities such as lead. The purity of refined copper processed by this method at the Ani Copper Mine at that time was 97 to 98 per cent.

An excellent characteristic of the "early European" refining process was that it could not only separate and extract gold and silver, but it could also nearly completely eliminate arsenic, antimony, and bismuth. However, the output per furnace was very small, and the purity of copper obtained by this method alone was definitely low. Moreover, as modernized, large-scale extraction progressed, it was inevitable that the kinds and quantities of impurities contained in ore increased. The "early European" refining process was not able to produce the large quantities of highly refined copper required by the electric machinery industry.

In view of the fact that the worldwide trend was away from reverberatory copper refining toward electrolytic copper refining, it was only natural that the Ashio Copper Mine should adopt the electrolytic process ahead of other mines in Japan. In 1888, Furukawa ordered the purchase of an electric generator and a boiler for electrolytic copper refining made by Siemens Electric Company. After repeated test runs at its Honjo Copper Refinery, an electrolytic plant with 116 electrolytic cells was constructed in 1897, and operations began the following year.

At Ashio, the great gallery was completed in 1896; electric drills were introduced in 1897; and electric mine carts were brought in. As for ore dressing, the pre-Meiji method of basket concentration was abolished, and another endogenous skill disappeared.

With regard to transportation outside the mine, until 1885, the bulk of the cargo was carried on horseback along either the Jōshū highway or the Nikkō highway. However, in 1888, the road width of the Nikkō highway was widened to 3.6 meters to accommodate horse carts. Then in 1890, the aerial ropeway no. 1 which went over the Hosoo pass began operating with steam power, and more aerial ropeways were subsequently constructed around the copper mine. A horse-powered tramway began operations the following year along the Nikkō highway and, two years later, along the Jōshū highway. The Ashio Railway was not opened until much later, in 1914.

The modernization of the Ashio Copper Mine under Furukawa after 1876 was initially very slow, but the discoveries of rich ore deposits in 1881 and 1883 accelerated the rate of development. As a result of the expansion of the copper market triggered by the rise of the electric machinery industry, modernization was further accelerated. By the end of the nineteenth century, Ashio was equipped with first-rate technological facilities which met international standards. In 1884, the Ashio Copper Mine was already producing one quarter of the total copper output in Japan, and it maintained a share of around 30 per cent up to the end of the nineteenth century.

IV. A LACK OF MODERNIZATION IN HUMAN RELATIONS

The modernization of the Ashio Copper Mine progressed extremely rapidly. This was partly due to the fact that it was possible for Ashio to totally absorb the technology which appeared during the second Industrial Revolution. Electricity promoted mechanization much more easily than did steam power in the case of mine hauling, drainage, winching, lighting, etc.; plant investment costs and personnel costs were also inexpensive. This indicates that latecomers in history can attain advanced standards more readily than their forerunners. However, it should be noted that conventional endogenous technology was not necessarily abandoned as advanced Western technology was fearlessly introduced. They adopted a system in which foreign technology could be assimilated step by step in order to train manpower and accumulate capital while advanced plants were being introduced. There was a tendency on the part of management to cherish and improve endogenous technology in accordance with its own economic and technological capabilities; the transition to modern technology was only made when endogenous technology could no longer meet the market demand. This tendency is thought to have stabilized management and, as a consequence, promoted smooth modernization.

An attempt at modernization in the opposite direction was seen in the state-run corporations. In comparison to private corporations, state-run corporations had abundant capital. Their managerial ability, however, was not appropriate to the amount of capital available. Their modernization was delayed because of the failure caused by the formal introduction of foreign technology without considering Japanese natural and personnel conditions. They wasted much of their capital.

Nevertheless, engineers and workers at the state-run corporations endured many hardships to cope with modern plant structure, and it should be noted that personnel training of great value was conducted there. As a result of management failure at state-run corporations, the government abolished the Ministry of Industry's control over these corporations and decided to sell them to private concerns in 1885. The personnel and facilities which fell into the hands of private capital promoted the rapid accumulation of technology and capital.

As for Furukawa, all the mine managers under his direction came from the raw silk industry. Their knowledge of mining was no more than what they had learned through the instant practical training given by Furukawa. There were only two who could be called engineers, as they had received practical training at the schools attached to mines in Ikuno and Sado. However, when Furukawa's request to purchase the Ani Mine and the Innai Mine from the government was approved in 1885, many engineers from these mines who had acquired a knowledge of modern Western technology came under Furukawa's control and contributed greatly to the advancement of technological conditions at Ashio. Had it not been for the above factor, accelerated modernization could not conceivably have occurred after the discovery of rich ore deposits.

As a result of the sale of state-run corporations, various mines in Japan finally began full-scale modernization. At the same time, government's mining policy had to be changed. In 1890 (the year the hydroelectric power plant was constructed at Ashio), the first national parliament met and the Mining Act replaced the Japanese Mining Law. The modernization of technology and management was synchronized with the modernization of politics.

Although the Japanese Mining Law stipulated that the government possessed the sole rights of mine excavation, the objective of the Mining Act was as follows: "to establish the interest of citizens in mining, to promote the development of the mining industry, and to protect and encourage miners." The ownership of minerals was transferred from the government to the national polity, and the distinction between state and private test boring or excavation disappeared. Moreover, according to the Japanese Mining Law, it was not possible to seek financial aid on the basis of mining collateral because mining itself was contracted by the government. Under the Mining Act, however, such collateral was authorized, and the creditor's right was legally protected.

The promulgation of the Mining Act thus opened a completely new horizon for the free development of mining, which greatly influenced not only the Ashio Copper Mine but also the management of other copper mines. The Besshi Copper Mine was far superior to other mines such as Ashio until 1883 in terms of its technology and the volume of production. However, because of the rapid development of Ashio which began the following year, Besshi fell behind and was eventually surpassed by Ashio. From about 1890 onward, however, Besshi regained its fast pace of modernization. The excavation of the much delayed Tōen Inclined Shaft, which was done manually without using a steam-powered winching machine as suggested by Larroque, was finally pursued actively on a full-scale basis after 1890 due to the installation of a steam-powered winch. An aerial ropeway was constructed in 1891, and two years later, a railway for the exclusive use of the mine was opened between the mine and Niihama port. This laid the basis for the emergence of Niihama as a smelting center.

It was about this time that Mitsubishi capital advanced into copper mining. Mitsubishi began to rival the great copper capital of Furukawa and Sumitomo after establishing its control over Osarizawa in 1893, Makimine in 1894, and Arakawa in 1896. It thus came to own four copper mines including the Yoshioka Mine. Furthermore, following the example of Ashio and Besshi, the copper mines under Mitsubishi's control were intent on rapid modernization.

However, the modernization of medium-sized mines lagged behind that of the larger mines. Most medium-sized mines continued to rely on the *mabuki* process or the "early European" refining process. Small mines with between 40 and 200 workers remained totally unchanged since the pre-Meiji period. The size of most galleries was still 90 centimeters in width and 1.2 meters high, and one had to either walk in a half-sitting posture or crawl into these pits. Ore was transported by twelve or thirteen year old boys in baskets called "scoops" which were carried on their backs. This endogenous method was retained partially due to the excessively low wages paid to workers.

As far as the Ashio Copper Mine itself was concerned, labor conditions were not modern. Although the "ore-purchase system" was abolished during modernization process, workers were under the control of bunkhouse (*hamba*) foremen instead of being under the direct control of Furukawa capital. The following record of the Ashio Copper Mine is found in *Miners' Conditions* edited by the Bureau of Mining Superintendence, Ministry of Agriculture and Commerce, and published in 1908:

> This mine is run on the basis of the bunkhouse system which has foremen and subforemen. The former controls miners, pit wood workers, excavators, and mine porters whereas the latter controls other kinds of workers. The foreman's responsibilities are: to employ miners; to provide food, drink, and daily goods to subordinate miners; to accept and distribute miners' wages as a representative; to protect and supervise miners (who, upon completion of a three-month period of employment, become independent miners and receive wages and goods directly from the company). The foreman was paid responsibility wage by the company as well as a commission for the handling of miners. Independent miners were paid on the basis of the number of workdays and the type of job. [3, p. 301]

The bunkhouse system was also called the "barn" (*naya*) system as the miners' sleeping quarters were called the barn; it was under the daily supervision of foremen. It was impossible to secure modern privacy under the bunkhouse system. Most of the barns were wooden bungalows, and each bungalow was divided into right and left sides which were again partitioned off for individual use. At that time, there were 441 bungalows at Ashio containing a total of 2,517 households and housing 5,867 workers. The space allotted per person was about 10 square meters.

V. MODERNIZATION AND THE PROBLEMS OF MINE POLLUTION

Although various facilities at copper mines had been modernized, personnel management and human relations were not modernized at all, as the workers were made to live in communal units under the bunkhouse system. When both the workers' modern sense of privacy and independent personality were disregarded, it was natural for Furukawa capital to remain indifferent to the possibilities of severe damage inflicted upon the farmers living along the Watarase River which flows through the Ashio region. Seeping water tainted with copper sulfate as well as the sulfur dioxide gas which exuded from the refinery turned the fields downstream into wasteland and killed the fish and trees in a vast area.

Although the output of the Ashio Copper Mine in 1877 was only 56 tons, it increased rapidly to 2,308 tons in 1884 after the discovery of the rich Yokomabu deposit, and it reached 6,085 tons in 1891. The greater the output due to modernization, the greater the quantity of copper sulfate-polluted water and sulfur dioxide gas. Since no technological measures were taken to prevent damage, massive environmental disruption ensued.

In 1888, when the hand pump was replaced by the steam engine, the Watarase River flooded extensively. The flood water which contained poison deeply affected fields downstream, and the soil became infertile. There was another major flood two years later in 1890, the year in which the hydroelectric power plant was completed and twelve water-jacket blast furnaces were built to replace the forty-eight bellows hearths. In addition, this was the year in which the first Diet met in Japan and also the year of the Mining Act. It was during this year that the farmers from Azuma Village, which had been seriously affected by copper mine pollution, sent a petition to the governor of Tochigi Prefecture regarding "the Prohibition of Copper Extraction." Congressman Shōzō Tanaka raised the first question concerning the problem of Ashio mine pollution at the second session of the Diet which was held the following year.

Furukawa capital and the farmers who had been victimized by mine pollution began their first private negotiations in 1892 as the transition from *mabuki* to Bessemer smelting began. As a result, the farmers received a small amount of compensation. However, they were forced by Furukawa to sign a contract promising that "the contracting citizens must neither make any complaint nor appeal to any executive or judicial authority under any circumstances."

The construction of an electrolytic plant at the Honjo Copper Refinery in 1897 in many respects put the finishing touches on the modernization of copper mining technology. But the preceding year, great floods had again ravaged downstream area and angry farmers victimized by pollution distributed handbills reproducing the "Petition regarding the Prohibition of Mining Operations at the Ashio Copper Mine." In March 1897, the farmers organized a great demonstration and marched on Tokyo. The government decided to set up the Ashio Copper Mine Pollution Survey Committee inside the cabinet. Based on a report submitted by the committee, the government ordered Furukawa on May 27 to take preventive measures to deal with mine pollution. This, however, demonstrated the government's determination as well as that of Furukawa capital to keep the operations at the Ashio Copper Mine from being discontinued. In view of the fact that the Ashio pollution problem occurred simultaneously with the rapid progress of copper mine modernization, it could easily be surmised that Furukawa capital would have taken every measure to avoid shutting down operations.

Apart from Ashio, such major mines as Besshi, Kosaka, and Hitachi produced pollution in the process of technological and managerial modernization, thereby creating major social problems. They are still causing problems. There had already been cases of environmental disruption in the West, and Western mines had developed pollution prevention technology as a result of pressures from victimized citizens. Thus, unlike the early-comers, managers and engineers of a late-comer to industrialization should have had the technological know-how to prevent environmental disruption. Nevertheless, the fact is that the Japanese were totally indifferent to the introduction of such technology even after violent protests made by the victims. This indifference was a by-product of the inhumanity peculiar to profit-oriented capitalists. At the same time, it was also a by-product of the communal consciousness seen in the bunkhouse system which ignored basic human rights.

It has been already pointed out that Japanese private capital was far more efficient than the government in introducing advanced Western technology and in modernizing management, and that the rate of modernization at the Ashio Copper Mine was fast. However, rapid modernization was made possible by a number of factors. One was historical luck: modernization coincided with the electric revolution and sound management practices which allowed the coexistence of Western and endogenous technology. Another factor was that management policy entirely eliminated investment in pollution prevention. Conversely, it can be said that rapid modernization was made possible precisely because of the management attitude that caused the Ashio mine pollution. This can also be said about the extraordinarily rapid economic growth which occurred after World War II. Such rapid growth was possible because Japan was already an advanced nation in terms of pollution.

VI. THE DECLINE OF COPPER MINING

After the Meiji Restoration, mining was the first industry to pursue technological and managerial modernization. It is noteworthy that mining became one of the pacesetters for Japanese technology and management because of the trained personnel and the capital accumulated at these mines. Branching out from Ashio, Furukawa capital later started the following businesses: the Furukawa Electric Co. for the production of electric wire; the Fuji Electric Manufacturing Co., a joint-venture with Siemens in Germany for the production of heavy electric machinery; and the Fuji Communication Apparatus Manufacturing Co., again a joint-venture with Siemens for the production of communication machinery. In addition to the Besshi Copper Mine, Sumitomo capital established the Sumitomo Electric Industries for electric wire production; the Sumitomo Copper Works (later Sumitomo Metal Industries) for copper processing; and the Nippon Electric Co., a joint-venture with Western Electric, U.S.A. for communication machinery. Both Fuji Communication Apparatus and Nippon Electric became major companies supplying electric machinery and related goods to the Ministry of Communications (the present Nippon Telegraph and Telephone Public Corporation), and today, both are at the top in computer development.

After World War I, the technology and management of copper mines entered the stage of mass extraction, and such mines as Ashio and Hitachi came to rely entirely upon rock drills, totally abolishing manual excavation. As a result of mass extraction, the ore dressing method also had to change. From 1925 onward, Ashio used the method crushing ore and putting it through flotation. According to the flotation concentration method, ore particles are floated by an absorptive bubble and then separated. Although the minimum amount of copper contained in the ore used to be 2 to 3 per cent prior to World War I, the introduction of this method contributed to the lowering of the extraction limit to 0.7 per cent copper content.

As a result, the smelting process entered a new era in which crushed ore was re-roasted automatically and then processed under high pressure in a blast furnace. The Bessemer process also changed. The earlier process was based on an acid treatment; this was converted to the basic treatment in 1920. It thus became possible to process copper matte having a low copper content.

The period from the late 1920s to the early 1930s was an era of industrial rationalization in Japan in response to the Great World Depression. Rationalization also became a major concern of copper mines. In 1907, there were no more than 7,000 rock drills in use, but by 1928, this number had already reached the 280,000 level, and this trend continued strong. However, as a result of the Manchurian Incident in 1931, the Japanese economy was placed on a semi-war footing, and anything manufactured by industries could be sold because of the huge war demand. Rationalization was therefore immediately curtailed. The mines began to be overworked because of a tendency toward random excavation which ignored the basic plan for the excavation and detection of deposits. Thus not only productivity but also productive capacity itself ultimately declined in every industry, and this was one of the salient causes for defeat in the war. A situation in which anything produced can be sold is not good for technology or management.

American style rationalization was introduced to all industries in Japan after World War II, and full-scale rationalization began in the mines for the first time in their history. Three aspects of rationalization were promoted: (1) increased productivity, (2) increased net rate of extraction, and (3) utilization of residual by-products.

The standardization of the ore extraction process was thoroughly carried out. In addition, with the introduction of the light weight rock drill, only one worker was required to operate it as opposed to the two workers needed to operate a conventional rock drill. Subsequently, the "one-shift, one-round" system was adopted. According to this system, a group of two to three workers could manage the work of drilling, blasting, and hauling in one work shift (eight hours' labor) due to the combination of the jumbo (a large excavation machine), the loader (a machine to load the ore), and the large mine cart.

With regard to ore dressing, a system known as heavy-liquid concentration was used before the ore was sent on for the flotation concentration treatment. This technique is based on the fact that metallic ore sinks deeper than a layer of heavy liquid produced at a certain depth of the water due to the specific gravity obtained by mixing particles such as ferrosilicon. The ore, which is lighter than the heavy liquid, can thus be removed and discarded. The metallic ore which has sunk to the bottom is then put through flotation. Because 20 to 60 per cent of the goaf is eliminated either in lumps or crushed powder prior to flotation, the flotation capability increases, and ore does not have to be crushed unnecessarily. Through heavy-liquid concentration, the grade of ore to be floated was enhanced from 20 to 50 per cent, and various extraction rates increased.

After World War I, the smelting method was such that crushed ore was first sintered and then put in the blast furnace. However, new methods were developed independently at mines such as Kosaka, Ashio, and Besshi (at the Shisakajima Refinery). The common factors in these new methods were the elimination of sintering, an increased recovery rate of sulfur, and a decreased quantity of coke as fuel. However, the main characteristic of the Kosaka Mine was the adaptation of the fluosolid roaster which was introduced from the United States to suit the processing black ore peculiar to the Kosaka Mine. Black ore contained a complicated mixture of copper, zinc, and other metals. The ore was first treated in the fluosolid roaster and then mixed into the acid liquid. The copper sulfate liquid produced by this process was then electro-refined to obtain first copper metals and then zinc metals.

The Ashio Copper Mine introduced the flush smelting method from Finland in 1956. When the crushed ore was put in the uniquely shaped furnace together with a blast of hot air, roasting and smelting were completed instantly. Because of the extremely high content of sulfur dioxide gas in the exhaust, sulfuric acid can be recovered efficiently via the Monsanto contact process. The high content of sulfur dioxide gas made its processing quite simple. In other words, as a result of enhanced democratization after World War II, it can be said that the sulfur recovery technology was improved and reached a near-perfect level.

Nevertheless, while each mine developed efficient technology independently and worked on pollution prevention technology, the Japanese copper mining industry was confronted with a very significant transition. In view of the fact that the new technology was intended to achieve a greater scale of mass production than had hitherto existed, the paucity of domestic copper ore became a pressing concern. While only about 10 per cent of the ore was imported in 1955, the ratio of imported ore increased to 50 per cent in only two years' time. Copper smelting in Japan had reached a stage where it could not function without relying on the smelting of foreign ore.

Furthermore, the cost gap between domestic ore and foreign ore gradually became greater. At first, ore was extracted from rich deposits with a high copper content so that the domestic ore could withstand competition from foreign ore. As a consequence, a massive number of low-grade deposits were left at the end, and the cost of domestic ore went up. Closures of copper mines with a long history became common in the 1970s. Both the Ashio Copper Mine and the Besshi Copper Mine were closed in 1973. It is now only a matter of time until refined copper is imported from abroad in the place of copper ore.

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