THE UNITED NATIONS UNIVERSITY UNIVERSITÉ DES NATIONS UNIES

Project on Technology Transfer, Transformation, and Development: The Japanese Experience

Projet sur l'expérience japonaise en matière de transfert, transformation et développement de la technologie

Distribution: Limited

HSDP-JE Series

This working paper was prepared within the framework and as part of the Project on Technology Transfer, Transformation, and Development: The Japanese Experience (JE) of the United Nations University's Human and Social Development Programme. The views expressed in the paper are those of the author and not necessarily those of the United Nations University.

The JE project is co-ordinated by UNU Project Co-ordinator Dr. Takeshi Hayashi, with the support of the Institute of Developing Economies, Address: UNU Project on Technology Transfer, Transformation, and Development: The Japanese Experience, c/o Institute of Developing Economies, 42 Ichigaya-Honmuracho, Shinjuku-ku, Tokyo 162, Japan. Tel: (03) 353-7501. Cable: AJIKEN TOKYO.

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Printed in Japan

ISBN 92-808-0099-x
ISSN 0379-5780

HSDRJE-24/UNUP-99

MODES OF TRADITIONAL MINING TECHNIQUES

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CONTENTS

This paper is being circulated in a pre-publication form to elicit comments from readers and generate dialogue on the subject at this stage of the research.

INTRODUCTION

This paper examines the modes of traditional mining techniques in Japan in the light of the development of the mining industry. The period covered in this study is from pre-modern times to the beginning of the twentieth century.

Japan's mining industry already showed considerable development in its pre-modern days. In the words of Curto Netto, who taught mining and metallurgy during the early Meiji period in the Department of Science, Tokyo University, "The Japanese search for minerals in their country has been more extensive than I anticipated. In many parts of the country there are hardly any mountains without a trace of prospecting. The fact that they compiled a very dependable report on mining points to their deep concern about mines" (Mines in Japan).

According to Netto, Japan's mineral production on a price basis amounted to about 17 million marks in 1876, of which coal accounted for 6,850,000 marks, copper 5,740,000 marks, silver 1,800,000 marks, gold 930,000 marks, and crude iron 430,000 marks. This distribution of mineral products did not change throughout the nineteenth century. According to statistics compiled in 1902 (17th Agricultural and Commercial Statistics), mining production in 1900 was as shown in Table 1.

As the table shows, coal accounted for most of the total mineral production on a price basis, and copper for one-third, followed by gold and silver. Of these, coal mining was a new mining industry that developed during the Meiji period. As regards the traditional sectors of mining, the table shows that Japan's major mining industries were copper, gold, and silver.

TABLE 1. Japan's Mineral Production (1900)

Mineral product	Quantity (unit)	Cost (yen)	Ratio
Gold	565,535 (momme)	2,438,687	4.98
Silver	1,568,595 (momme)	1,993,557	4.07
Copper	42,182,353 (kin)	15,715,807	32.10
Lead	3,130,080 (kin)	294,720	0.60
Iron	6,624,447 (kan)	959,946	1.96
Antimony	716,477 (kin)	126,258	0.26
Coal	7,429,457 (ton)	25,294,296	51.67
Crude oil	767,092 (koku)	1,628,901	3.33
Sulphur	24,064,196 (kin)	337,233	0.69
Others		169,265	0.35
Total		48,958,670	100.00

Table 2 shows that Japan's 15 major mines in 1900 were producing copper (annual production of over 100,000 kin), gold (over 10 kan), and silver (over 1,000 kan). These mines alone accounted for 33 per cent of the total gold production, 52 per cent of the silver, and 61 per cent of the copper. Further, these mines occupied a total area of 22,550,000 tsubo (1 tsubo = 3.305 m^2) with 24 mining permits, accounting for 21.9 per cent of the total operating mining areas for gold, silver, copper, and lead and 2.5 per cent of the total mining permits. It is thus clear that a small number of large-sized mines in good-quality mining areas were producing these metals in large quantities. These statistics also imply that the production was low at numerous small and medium-sized mines in poor-quality mining areas. This tendency was most clearly manifested in copper mines.

The total number of workers at metal mines was 54,805 as of June 30, 1900, and their working man-days totalled 376,177. Most deaths and injuries in mine disasters and accidents were due to suffocation, cave-ins, and surface as well as underground explosions. No other statistics are available, but it is worthy of note that explosives caused major disasters, as did the more traditional causes of the pre-modern days, such as suffocation and cave-ins.

From the viewpoint of the theme of the present paper, it will be necessary first to ascertain that technical development to deal with

TABLE 2. Japan's Major Mines (1900)

Prefecture	Mine	Gold		Silver		Copper		No. of tsubo (gold, silver, copper, lead)	No. of mining permits
		Value (momme)	Ratio (%)	Value (momme)	Ratio (%)	Value (momme)	Ratio (%)		
Niigata	Sado	58,020	10.26	(981,538	6.26)	(54,963	0.13)	1,835,786	1
Hyōgo	Ikuno	29,620	5.24	1,260,932	8.04	(752,942	1.79)	5,927,253	1
Akita	Innai	22,665	4.01	2,886,195	18.40			1,902,193	2
Niigata	Hashidate	18,890	3.34					235,332	1
Kagoshima	Ōguchi	18,819	3.33	(7,238	0.05)			3,152	1
Kagoshima	Yamagano	18,547	3,28	(15,521	0.10)			1,539,883	1
Ishikawa	Kuragadani	18,196	3.22	(288,539	1.84)			197,301	1
Okayama	Yoshioka			1,722,000	10.98	(825,455	1.96)	572,420	1
Akita	Kosaka	(858	0.15)	1,059,653	6.76	1,655,539	3.92	366,368	1
Tochigi	Ashio					10,231,092	24.25	1,778,513	1
Ehime	Besshi					6,107,061	14.48	1,811,500	1
Akita	Ani	(896	0.16)	(379	0.00)	2,094,582	4.97	2,620,330	8
Akita	Osarizawa	(2,107	0.37)	(388	0.00)	1,529,144	3.63	1,191,483	2
Miyazaki	Ninodaira					1,350,762	3.20	596,347	1
Akita	Arakawa					1,324,063	3.14	1,981,073	1
Others		376,917	66.65	7,459,212	47.57	16,256,750	38.54	80,650,670	933
Total		565,535	100.00	15,681,595	100.00	42,182,353	100.00	103,209,604	957

TABLE 3. Accidents Occurring in Japan's Metal Mines (1900)

Causes of accidents	Number	Instant death	Major injury	Minor injury	Injury of unknown degree	Aggregate
Total	173	171	106	117	83	477
Underground:						
Cave-in	5	3	1			7
Explosives	6		3	4		7
Suffocation	1	12		4		16
Mine cars	1	1				1
Others	8	16	2			
Total	21	32	6	12	72	122
Surface:						
Explosives	3	8	8	13		29
Others	19	22	3	7		32
Total	22	30	11	20		61

the situations at various mines, including those listed above, was possible throughout the Edo period. To be sure, the development of traditional mining and metallurgical techniques was limited in nature from the viewpoint of the history of science as summarized in Nihon no Gijutsu no Rekishi [History of Japanese technology] and Nihon Kagaku Gijutsu-shi [History of Japanese science and technology]: "With science becoming stereotyped, technology, too, could not free itself from the level of crafts."

However, it cannot be denied that there was some technical progress which had a very important effect both on the way western mining techniques were adopted from the Meiji period onward and on the results they produced.

Let us now examine the emergence and characteristics of the mining industry in Japan and the development of traditional mining and metallurgical techniques together with their significance in social history.

I. EMERGENCE OF THE PRE-MODERN MINING INDUSTRY

If one excludes those reports of historiographical interest by Adolf Mezger, Curto Netto, and François Coignet (Mines in Japan by Netto and Notes on Mineral Resources in Japan by Coignet have been published) and books on mines such as Kōzan Hisho [Secret book on mines] by Akō Mitsunori and Kōzan Shihō Yōroku [Summary of important mines] by Kurosawa Motoshige (partly reproduced in Nihon Kagaku Koten Zensho, the first comprehensive work on the history of Japan's mining industry is probably Hompō Kōgyō to Kin'yū [Japanese mining industry and finance] by Ueno and Mikami Tokusaburo (1918), followed by Meiji Kōgyō-shi: Kōgyō-hen [History of the Japanese industries of the Meiji period: mining] (1925-1931), Nihon Kōgyō Hattatsu-shi [Development of the Japanese mining industry] (1932), Nihon Sangyō-shi [History of Japanese industries] (1938), and Nihon Kōgyō Shiyō [Outline history of the Japanese mining industry] (1943). Kōzan no Rekishi [History of mines] by Kobata Atsushi has been the only outline history published since World War II.

Of these, those published before and during the war can be more or less described as outline works based on the study of individual mines; Kōzan no Rekishi is primarily concerned with the history of mine management and is extremely weak on the history of mining techniques. It was thus after the war that studies on the history of mining techniques or their characteristics were carried out; these include Meiji-zen Nihon Kōgyō Hattatsu-shi [History of the development of the mining industry before the Meiji period], Nihon Kagaku Gijutsu-shi Taikei [Comprehensive history of Japanese science and technology], volume 20, Saigusa Hiroto Chosaku-shū [Collected works of Saigusa Hiroto], volume 10 and 11, and Nihon Kagaku Gijutsu-shi [History of

Japanese science and technology]. However, these studies in the history of science and technology are not free from those defects already mentioned, and do not necessarily look at the technology in its organic relation to the historical mode of mining labour such as labour organization.

It seems, therefore, that the study of the history of mines has reached the stage where it should be reconstructed by unifying the two lines of study — history of management and history of science — as social history through the study of individual mines. This forms the basic concern of the present paper's review of past studies. If we search for histories of individual mines on this basis, we find several of them. Thus, through either books or monographs we are now able to know to a varying degree about the histories of the following gold, silver, lead, and sulphur mines: Shirane, Osarizawa, Innai, Arakawa, Ani, Hosokura, Sado, Ashio, Akazawa, Wasaho, Mozumi, Nagamune, Azuma, Tada, Abe, Toragaya, Matsukura, Kamegaya, Iwami, Ikuno, Nakase, Yoshioka, Koizumi, Besshi, and Tachikawa.

It is clear from these studies that Japan's major mines were discovered and developed before the seventeenth century, with the exception of a few, including Kosaka. Further, many of the gold and silver mines were developed towards the end of the sixteenth century or the beginning of the seventeenth century, while many copper mines were developed from the middle through the end of the seventeenth century.

It was Coignet who discussed the rise and fall of these mines:

> The development of mines in Japan does not go back beyond 1596. We can assume that techniques of mining operation were imported from China during the period of frequent interchange between Japan and China. We can also imagine that European methods were later introduced with Catholic missionaries entering all parts of Japan. The fact that during the period from 1572 to 1585 under Taiko the most extensive development of mines took place, corresponding to the few years centring on the period when the influence of missionaries was at its peak, and that it requires a certain period of time for new mining and metallurgical techniques to spread throughout the country, facilitating the development of mining, probably not being the

> sole cause of the rapid development of the industry, bespeaks a good deal as to that possibility. [Coignet, Notes, translated from the Japanese edition.]

Coignet's comments are not accurate in detail. However, his extensive knowledge and his insight regarding the history of mining in Japan may be seen in the points he made: (1) Japanese mining techniques developed rapidly from the end of the sixteenth through the beginning of the seventeenth century, forming the basis of the mining industry thereafter; (2) technical development was based on an exchange with foreign countries; and (3) development was also closely related to the establishment of the Toyotomi regime.

In fact the development of mining in Japan from the end of the sixteenth through the beginning of the seventeenth century could be carried out only under the political, social, and economic conditions peculiar to the period, and these conditions were epitomized by the principle of "the mountains of the State." This principle may be interpreted as that of the shogunate's ownership of mines, or ultimately as that of state ownership of mines.

Though it is difficult to ascertain exactly when this principle was established, it was in 1589-1590 that Hideyoshi used it to secure command of the gold, silver, copper, and lead mines throughout the country. Thus, Japan's mines, which had hitherto been under the private control of feudal lords, who provided their main financial support, were now placed under public ownership and controlled by the centralized government.

Many of the major mines were thus gradually placed under the direct control of the Toyotomi regime and the Tokugawa regime. However, not all mines were included, nor was the method of management uniform. In some cases lords or han [clans] were entrusted with the management of mines; in some others yamashi [miners] were contracted. These cases may roughly be divided as shown in Table 4. However, these divisions were by no means constant in respect to individual mines, as the government adopted different methods of management in response to the rise and

TABLE 4. Transfer of Control of Mines in Japan, 1589-1590

	Mine management		
	Managed directly by the government	Managed by clans/lords	Managed under contract by miners
Control of mines: Government ownership	Sado Mine Ōmori Mine Others		Besshi Mine Others
Han (fief) ownership		Ani Mine Innai Mine Others	Common among medium- and small-sized mines

fall of each one. At times the mine and its surroundings were under direct control of the bakufu [government]; at others it was directly managed by the government or the clan concerned or by contract.

Whichever method was adopted, the principle of public ownership of mines, established by Hideyoshi and continued by the Tokugawa regime, was adhered to throughout the period. And this not only gave control of all mineral products to the government, but it also provided the basis for the development of various mines.

Further, this principle meant, from the viewpoint of mining techniques, that political power secured control of conventional mining techniques which had been developed by the sixteenth century. The adoption of foreign techniques to raise the level of Japanese ones was thus made easy, and these new techniques were quickly disseminated to various mines throughout the country.

To elaborate on the first point above, Japanese mining techniques attained by the end of the sixteenth century comprised shaft driving in prospecting and mining, and cupellation and the western method of silver extraction. Generally, there were three mining methods invariably based on the premise that the vein had an outcrop: (1) the trench method (trenching from the outcrop along the vein); (2) vertical excavation (mining with a vertical shaft); and (3) the inclined shaft method (mining proceeding along the vein into the earth). Shaft mining

based on the driving of a shaft developed from what may be termed the outcrop mining method. There were actually two shaft mining methods, which may be regarded as having derived from the inclined shaft method.

Under one type, the existence of a vein was first detected from an outcrop, and was followed by the driving of a shaft towards the vein. A pit face was then provided for mining. The technique of detecting the ore deposits or the vein and that of driving a shaft in the right direction, expressed in terms of measurements, were of much importance in those days. However, it is after the middle of the seventeenth century that measuring appears as an occupation, and we must assume that the carpenter who was the foreman of the daiku [mining crew] or the kanako [master] had a knowledge of measuring techniques.

The second type of shaft mining involved the driving of a shaft for prospecting. Prospecting techniques thus formed an indispensable basis for shaft driving techniques. In those days the basic prospecting technique was still drift prospecting (a method for detecting the existence of mineral deposits by panning gravel in the gauge or from the gossan in the exposed section of the precipice or the gauge), which required many years' experience and good intuition. Prospecting was therefore carried out in the form of an appraisal of the features of the mountain concerned, and the person who had the necessary skill was known as the yamasaki, or prospector.

If shaft driving supported by measuring and prospecting techniques formed the technological basis for mining techniques up to the beginning of the seventeenth century, cupellation and the western method of silver extraction formed the technological basis for metallurgical techniques. In Japan, according to Netto, only smelting was known as a method for recovering metals from ores. The oldest record of the metallurgical techniques practiced in Japan refers to a type of oxidizing refining (processing of silver-bearing lead ores) practiced on the island of Tsushima.

Other methods known to have been used until the middle of the

seventeenth century include the western method for processing silver-bearing crude copper, the crushing method for gold ore, separation of gold and silver with salt, the Yamashita method for refining copper ore by deoxidization, and the amalgamation method for silver refining. Of these, the amalgamation method and the western method were clearly imported techniques. While the western method took root in Japan, the amalgamation method was abandoned after a short period due to the difficulty of obtaining mercury, though it was quickly adopted at the Sado silver mine.

It may be assumed, therefore, that there were three basic lines of metallurgical techniques employed at the beginning of the seventeenth century: the Yamashita method developed mainly at the copper mine of Nose, Settsu Province, and carried out at the mines in Kii, Ise, and their neighbouring areas; the cupellation method developed in 1533 at the Omori silver mine of Iwami and brought over to the Ikuno silver mine and others; and the western method which took root in the handicraft industry in such towns as Hakata and Osaka. The processing method employed at the Ani copper mine in Akita had been brought over from Kumano, Kii Province. Of 39 craftsmen engaged in metallurgy and known to have worked at the In'nai silver mine during its initial period, 11 were from Iwami, 6 from Osaka, and 2 each from Etchū, Bingo, Bizen, and Harima.

The metallurgical techniques of the above three lines were invariably used to obtain refined silver and copper; this is related to the fact that most of the major mines were functioning as silver and copper mines. Though these techniques of extracting silver, copper, and lead practiced at the beginning of the seventeenth century did not lead to a scientific system of processing, it may be said that they reached remarkably high levels within their limitations.

The techniques of extracting gold and silver, though immature in a sense, advanced a step further when the salt roasting method was devised around 1608 to separate gold and silver based on the cupellation method. This method of using salt, devised by gold- and

silversmiths such as Gotō Tokujō, who served the government, was of such an epoch-making nature that it was described later as the "beginning of chemical processing."

The principle of public ownership of mines inevitably led to the separation of mines from other industries and areas, to interchange between mines, and to a special distribution system for mine products.

The basic principle that mines must be special areas separated from other industries and areas, particularly from rural areas, led to the establishment of mid-mountain towns (san-chū), mining towns (kōzan-machi), and mining domains (kōzan-ryō). Though it is not necessary to go into details here, the direct objectives of the institution of mines as special areas were clearly: (1) to draw a distinction between mining labour and agrarian labour so that the organization of labour in each sector could be established, and (2) to negate the influence of the money economy used by miners, who relied on others for the supply of daily essentials, on the self-supporting agrarian economy. While designating mines as special areas brought about the separation of mining techniques from agricultural ones, it also produced a special social consciousness among farmers; they developed feelings of discrimination against miners, who in return developed a strong consciousness of themselves as a privileged class.

These mines classified as special areas were to develop interchanges among themselves; such interchanges became of crucial importance as the government strove to disseminate to the mines various techniques together with labour in its attempt to increase production. The shaft method and the metallurgical techniques already mentioned thus constituted the general technical level of Japanese mining in the seventeenth century.

Behind such developments towards interchange was the need to adhere to the principle that the supply of labour for increasing mining production should not affect agrarian labour; movement of the labour force thus became unavoidable. However, transfer of labour required

the granting of a special privilege. This privilege was given on the basis of the "53 Articles Concerning Mines Prescribed by Tokugawa Ieyasu," though the authenticity of this document was refuted later. Regardless of the authenticity of the document, however, the understanding that Ieyasu had granted a special privilege to miners prevailed in the seventeenth century; it actually took the form of a special permit for securing passage through barriers.

However, this privilege was more or less limited to mining workers. They enjoyed mobility because the techniques of shaft driving and mining were still undeveloped. Mining work using simple iron tools was largely dependent on the experience and physical strength of the miner himself. But the special privilege did not lead to a general practice of miners moving about on an individual basis; they were under a foreman or a master, who was in turn under a minebroker.

II. DEVELOPMENT OF TRADITIONAL TECHNIQUES

Japan's silver mines and copper mines flourished until the middle of the seventeenth century and the latter half of the same century, respectively; these periods were described as those of the "stagnant gold and silver mining and the growth of copper mining" in the latter half of the century. These mines, however, depended on the presence of good-grade ore near the surface. Accordingly, as long as prospecting techniques were limited, the development of mines was bound to reach its limit as well. It thus became necessary to mine and process low-grade ores deposited far below the surface. This was the problem which the silver mines of the mid-seventeenth century and the copper mines of the late seventeenth and early eighteenth centuries invariably began to confront, and the various efforts made to overcome this problem constitute the history of the development of mining techniques during the period from the seventeenth to the middle of the nineteenth centuries.

There was no development of mining techniques themselves. The scorching method — burning firewood in the pit which would be manually excavated for ore deposits after cooling — was generally practised from the end of the eighteenth century onward; this was the most rudimentary form of using fire. A more advanced mining method using explosives was not known until 1862, when Takatō Ōshima used them at the Yurappu lead mine in Hokkaido under the guidance of the American mining engineer Pumpelly. Extensive use of explosives at the Japanese mines is said to have been initiated by the importation of dynamite by the Morrison Company in 1878.

Prospecting techniques, which had been the concern of mine brokers, now

began to be taken over by prospectors. Even after 1868, manual mining continued to be firmly established in the Japanese mining industry. As the statistical table for 35 major mines clearly shows, as recently as around 1920 mining by rock drill exceeded manual mining. The main tools used in manual mining were the chisel, hammer, and mandrel. Manual mining was a special technique requiring experience and skill; but it was certainly energy consuming.

TABLE 5. Manual and Mechanical Mining

Year	Production (t)		Total man days	Total workers	Production per worker (t)
1907	A	934,470	1,447,065	2,089	0.645
	B	18,485	26,076	110	0.709
1912	A	1,125,516	1,432,902	2,691	0.785
	B	215,641	75,515	302	2.855
1917	A	1,923,246	1,862,819	4,174	1.032
	B	896,982	151,705	583	5.910
1922	A	923,647	785,407	2,986	1.042
	B	1,184,653	219,423	789	5.400
1927	A	1,083,432	852,397	3,392	1.555
	B	2,016,981	416,378	1,516	4.840

A = Manual Mining B = Mechanical Mining

Fire was used in a supplementary mining technique, the scorching method, at the Besshi copper mine; this special technique was gradually incorporated into the system of mine management. These techniques of mine management and prospecting were passed on by various books on mining compiled at the end of the seventeenth century; these included the Kōzan Shihō Yōroku [Summary of important mines] of 1691 compiled by Motoshige Kurosawa (Fuboku) of the Akita fief, who held the position of mining administrator. It was based on data obtained from the Innai silver mine of Akita.

Initially, foremen and masters were skilled in shaft maintenance. However, with the extension of the shaft, the responsibility for shaft maintenance gradually fell to maintenance carpenters, and the techniques of maintenance became more diversified in response to different shaft conditions based on the timber used and the method of timbering employed.

Shaft driving led to new problems: drainage and smoke extraction. These problems necessitated the driving of drainage shafts and smoke ducts. Attempts had already been made from about 1605 to drill drainage shafts at the Ikuno and Innai silver mines, and the drilling of a smoke duct is said to have been carried out at the Aikawa silver mine of Sado in 1633. Smoke ducts were not made specifically but were installed by extending a ventilation shaft from the surface or from an old shaft or by using a companion shaft driven at the same time as the prospecting shaft.

Accordingly, as far as shaft driving was concerned, drainage work rather than smoke extraction was the main concern; builders were thus organized for drainage work. Needless to say, the drainage shaft was not the only means of drainage. As the major cause of damage to mines was inundation of the shaft due to seeping water, the drainage problem was handled in various ways; the most rudimentary method was the well-bucket. The Sado Shimin Fūzoku Tsuika [Customs of the four classes of Sado: additions], compiled in 1840, describes this as follows:

> Though various devices such as the bamboo pump, Archimedean pump, and plunger were tried out until recently, as the shaft became deeper, handiworks frequently broke down and water could not be extracted satisfactorily. It seems that a well-bucket with a pulley is the best method of pumping water, as it gives little trouble and is also economical.

In other words, the well-bucket provided the principal means of water pumping even after the introduction of new types of drainage equipment at the Aikawa silver mine of Sado, and the renowned mizugae-ninsoku [pumping labourers] were employed for pumping water. At the Ikuno silver mine and the Besshi copper mine, bamboo and wooden conduits formed the main drainage equipment. In 1880, such pumpjng equipment began to be replaced by power equipment when the steam-driven Cornish pump was adopted at Sado. Pumping equipment prior to that was all manually operated with low pumping efficiency; the most effective method of drainage was the driving of a drainage shaft.

In connection with gas explosions, shaft driving caused problems in

respect of ventilation, the most important working condition sought by mine workers. The problem of ventilation is closely related to shaft lighting as well as to the generation of gas and dust in the shaft. During the seventeenth century, rape-oil lamps and torches provided shaft lighting. Lighting in the shaft was provided by rape-oil lamps and bamboo branches until the 1890s. These were replaced by metal hand lamps. Towards the end of the Meiji period, acetylene lamps began to be used.

Other ventilation methods were devised besides the smoke ducts described above. One of the methods employed was to place wind boxes or funnels in a row along the shaft with air sent in through the mouth by minnow. However, this method had serious limitations, resulting in a large number of miners suffering from the Kedae [respiratory] disease at various mines.

Important measures for shaft ventilation were tested at the Ōmori silver mine in Iwami Province from 1856 through 1858: the medicated steam method and the mask method were devised by Miyatabashira Masayuki from Kasaoka in Bicchū Province. The mask method devised by Miyatabashira involved wearing a mask to which plum skins were attached. In the medicated steam method, a mixture of vinegar dilluted with water and containing various herbs was boiled and sent through the wind boxes mentioned above. To develop these methods, Miyatabashira also conducted an analysis of mine pollution. These events were epoch-making in that the chemical analysis of the air in the shaft and pharmacological remedies were considered for the first time.

The size of the shaft is related to the way ore is removed to the surface. As is well-known, extraction was carried out by juvenile male workers and in some case by female workers. Carrying ore out in baskets was the prevailing haulage method during the Edo period. This aspect of mining was the first to be improved in the Meiji period. It began with the laying of a track and the installation of a hoist by Coignet in 1868 at Sado.

This was followed by the adoption of mine cars at various mines in 1884-1885; the kind of power used also shifted from manual to horse-driven and then to electricity at the turn of the century. The change in haulage method also required that the form of the shaft be improved.

Dressing was carried out in most cases by female workers supervised by a foreman or master; they also carried out crushing. These female workers possessed the screening skill necessary for dressing. Dressing labour emerged in the process of the development of metallurgy from crushing with stone and cupellation to the hatakimonohaku method.

Crushing labour was provided by hand. One exception was the adoption of a water wheel at the Aikawa silver mine at Sado in 1626; but this did not take root. It was revived in 1794, but it was not until the 1820s that it became widely used at Sado. The spread of crushing by water wheel corresponded to the development in cupellation techniques for powdered ore at Sado. While manual crushing with stone is said to have been discontinued at Sado, the extent to which crushing by water wheel spread to other mines is not known. It may be estimated that general changes in dressing techniques in Japan were made mainly by hand until 1889 when dressing plants using the German method were established for copper at Sado and for silver and lead at Hosokura.

It is not possible to identify changes in ore-burning techniques. There appeared to be some change in the size of the burner for copper ore; stool, reverberatory, revolving, and mechanical furnaces began to be used during the Meiji period. However, with the successful refining of crude ore in 1900 at Kosaka, their technological significance in metallurgy began to diminish rapidly.

III. METALLURGICAL TECHNIQUES FROM THE MID-SEVENTEENTH CENTURY TO THE MID-NINETEENTH CENTURY

The development of metallurgical techniques may be classified into two categories. One was to bring about a reduction in cost with increased efficiency in refining by increasing the processing capacity of each blowing unit; this not only involved the expansion of the size of the unit but also required improvement of the bellows. The other was to upgrade the product's purity through repeated refining of scrap ore produced during the process of refining. This brought about a diversification of products. However, the technical improvement in these two directions was carried out within the framework of cupellation and the old western silver-extracting techniques.

These cupellation and silver-extracting techniques were quickly undermined by various western techniques which were introduced into Japan from the beginning of the Meiji period. Of the adopted techniques, the cyanide process for gold and silver and the fire refining of crude copper ore, both of which spread during the first decade of the present century, and the general adoption of converter copper refining between 1910 and 1920, finally led to the abandonment of traditional techniques.

An example of the level of Japanese metallurgical techniques reached by this time may be seen in the table prepared by Yonehachi Takashima concerning the Ani copper mine. Yonehachi explains the basic process of copper refining in ten stages which may roughly be divided into three main steps: the production of crude copper and silver contraction; the production of refined copper; and the production of silver copper.

Gold and silver extraction was not yet being practised at Sado during

TABLE 6. Refining at the Ani Copper Mine

Division		Stage	Raw material		No. of blowings	No. of hours	Production	
A	I	Crushing, dressing						
	II	Ore burning (extraction of sulphur content)	Dressing	750.00 kan	18 days		Roasted ore	600.00 kan
			Charcoal	1.50 kan				
			Grass	100.00 kan				
			Firewood	10 tsubo				
	III	Crude copper cuppellation (extraction of impurities)	Roasted ore	600.00 kan	2	13	Crude copper	247.00 kan
			Charcoal	185.20 kan			Sulfidized copper	90.00 kan
			Sulfidized copper	90.00 kan				
			Firewood	2 logs				
B	IV	Mixed cupellation	Crude copper	31.80 kan	3	6	Alloyed copper	35.00 kan
			Lead	6.00 kan				
			Charcoal	42.00 kan				
	V	Namban cupellation (extraction of silver lead)	Alloyed copper	41.76 kan		10	Contracted silver	31.00 kan
			Charcoal	18.00 kan			Refined silver	7.00 kan
							Sludge	2.00 kan
	VI	Komarugata cupellation (extraction of impurities)	Contracted copper	100.00 kan	3	7.5	Komarugata copper	
			Kaisō (catalyst)	9.00 kan				
			Charcoal	42.00 kan				
	VII	Chōdō cupellation (refining)	Komarugata copper	81.00 kan		7	Refined copper	80.00 kan
			Kaisō (catalyst)	7.00 kan				
			Charcoal	47.00 kan				
C	VIII	Cupellation (extraction of silver lead)	(From V)					
			Refined lead	20.00 kan		7.5	Silver	12.40 momme
			Charcoal	5.50 kan			Sludge	23.00 kan
	IX	Refining	Silver					
	X	Sludge	(From VIII)					
			Sludge	174.00 kan		5	Lead	125.00 kan
			Charcoal	52.00 kan			Kaisō (catalyst)	67.00 kan

the period from 1818 to 1830. That is, salt roasting at Sado was mainly intended to increase the lustre of gold by steaming or washing in roasted salt; it was different both in method and in purpose from the salt roasting practiced by silversmiths. Salt roasting as a method for extracting gold and silver was still monopolized by silversmiths.

In practice, metallurgical techniques for gold, silver, copper, and lead were devised by individual mines, thus leading to technical differentiation as can be seen in the case of copper mines. However, after the middle of the seventeenth century, it became increasingly difficult for individual improvements to spread to other mines. This is because while the dissemination of techniques before the middle of the seventeenth century concerned the principles of metallurgy and their specific applications, improvements and methods devised thereafter were further advances, indicating that they were applications of the same principles but adapted to the conditions of particular mines. Unlike the time prior to the seventeenth century, mines were already in decline, and this accentuated the individual character of these techniques.

Metallurgical techniques took root according to the conditions of individual mines. Accordingly, it became quite difficult for the government or the clans to transfer techniques by moving craftsmen; the craftsmen in fact assumed the role of those who adopted techniques. This was closely related to the fact that they were becoming increasingly independent of mine officials and mine brokers. The result was the independent character of improvement made and methods devised; even when they were transmitted to other regions they showed individual and particular characteristics. These conditions led to technical differences among various mines. Nevertheless, metallurgical techniques developed through new devices, improvements, and the partial transmission of techniques.

From the viewpoint of the history of technology, our attention is drawn to the so-called ōshu method of metallurgy adopted at Ani in 1816, which most appropriately corresponded by sulfidization to the method

of reducing copper smelting. This method was to become the main metallurgical method used at the Ani copper mine. Further, the method for extracting silver adopted at the Hosokura lead mine in 1818 was a technical improvement of great significance. The method was, however, labour-intensive for carpenters and bellow hands on the blowing floor. The fact that profits increased, though by a small margin, even after the adoption of such a labour-intensive method, points to the low wages of these workers.

Small mines at the end of the Edo period are also worthy of note. In view of the fact that large mines were more or less on the decline towards the end of the Edo period (e.g., the Besshi copper mine was closed down for three months), it may well be that mining techniques were picked up and carried on at these small mines at this time.

It is clear that the highest level of metallurgical standards was maintained throughout the Edo period by privileged city craftsmen; but it is not clear what technical development was made by goldsmiths in respect to gold and silver and by copper refiners in respect to copper.

As far as we know, the most advanced improvement in metallurgical techniques was made at local silver-extracting works. Kagoyama in Akita and Takayama in Higo are notable in this area. Kagoyama was established early. The metallurgical process employed there, as shown in the table, represents the highest technical level attained by the middle of the nineteenth century in Japan.