Proposal for Mine Developments and Operations in Harmony with Environmental Protection

Jiro Yamatomi
Professor, Department of Geosystem Engineering, University of Tokyo

1. Summary

Mining industries usually produce useful and valuable materials by directly removing mineral resources from the earth, their adverse influence, however, on the environment is inevitable. Causes affecting environmental conditions by mine developments and operations include

(1) Disposals where waste and refuse of mineral processing are deposited,
(2) Mine water discharged from underground workings and/or tailings disposals, which is likely to be contaminated with heavy metals and other harmful substances, and
(3) Waste water and smoke from smelters and/or refineries.

This paper concerns environmental protections actually performed and being in process in Japan, where mining has a quite long history and, presumably, dates back to the 1st or 2nd century BC. Currently, Japan has small reserves of metaliferous minerals and her vigorous economic power mostly depends on the imported resources. Japan, however, used to be an exporter of gold, silver, and copper since the middle of the 16th century until some 100 years ago (nearly 100 year long history of hard rock mining in Japan is illustrated in Fig.2). Although only three major metallic mines are currently operated, it is estimated that Japan has over 7,000 suspended or abandoned mines and most of them have surface outcrops of the ore bodies. The other distinguishing feature of her old deposits is that the majority of them were small vein-type deposits, however, rich in a wide variety of valuable minerals (Table 1).

Figure 1 shows the locations of around 430 old mines that require some preventive measures for mine pollution. While approximately 290 mines of those having already received the environment protections from the Government, local autonomies, and mining companies, it is, nevertheless, still necessary to provide financial efforts to currently conduct pollution control measures for some 70 mines.

In order for Japan to contribute to minimize any adverse effects on the environment caused by mining developments and operations, we are proposing a conceptual program for promoting harmony between mining and environment in the APEC region. Moreover, we will recommend actions and measures that should be implemented prior to development and through development and operation as well as after mine closure. We will make a couple of the case studies on the environmental issues actually encountered in the Japanese mining

sectors (the locations of the selected mines for a present study are shown in Fig.3). And then, we will point out how to identify and solve the key issues concerning sustainable operations and mine developments that also should keep mutually cooperative relations with local communities. Finally, we will discuss the possibility of Japanese contribution and how to establish collaborative relations within the APEC region for harmonized mining with the environment.

2. Introduction

In Japan, it was around 1880 that the first mine pollution generated crucial problems on the environment and consequently attracted extensive public attention. Damages of fishery and agriculture were reported as the consequence of inflow of mine water into local rivers from the Ashio copper mine in Tochigi Prefecture. Moreover, in 1888, the pollution and subsequent influence to human bodies spread within the basin of the Tone River running through the Kanto Plain in which the Tokyo metropolitan area is located. The Ashio mine pollution is said to be the origin of the mine pollution issues in Japan.

In 1902, the Japanese Government ordered the Ashio copper mine to launch restoration and prevention works against the mine pollution, and it was the first practice in Japan to construct a mine drainage treatment facility in Ashio. Thereafter, anti-pollution measures were enhanced by the Government, which resulted in the 1939 amendment of the Japanese Mining Act enforced by incorporating the provisions on compensation for mine pollution. Furthermore, the Government politically and socio-economically supported to establish a variety of systems to prevent and regulate mine-related pollution as well as to develop technologies necessary to mitigate and remedy any unpleasant damages.

Since then, cooperation between the Government, local governments, and mining industries has been actively and continuously working for controlling environmental impacts caused by mining. Consequently, most of the environmental contamination caused by old mines have been removed, and MMAJ (the Metal Mining Agency of Japan, a semi-governmental organization under the jurisdiction of the Ministry of International Trade and Industry) have successfully developed improvement and innovation in technologies required for mine-related pollution control. However, we still have a large number of old mines discharging harmful water to be neutralized over a quite long period in the future, which could plausibly be a financially enormous burden for both of public and private sectors.

The present paper describes our studies, which are based on the mine pollution controls actually conducted in a couple of Japanese mines, and then we will refer to our concept of " Mine Developments and Operations in Harmony with Environmental Protection".

3. Case Studies on Pollution Control in Japanese Mines

3-1: Closed mines without causing environmental problems

< *Matsuki Mine* >

①Overview

The old Matsuki mine is located in Odate City, Akita Prefecture in the northern Honshu Island. The Matsuki deposit, classified as a Kuroko type deposit, was developed by Mitsubishi Metal Mining Corporation (currently succeeded to Mitsubishi Materials Corporation), after the official approval of the operation plan in 1969 with the conditions imposing 10 year long life and 10,000 tonne monthly production. The Matsuki mine came on stream 4 years later in 1973 and primarily produced copper until 1978, 5 years earlier than originally planned, because of extremely high rock pressure and mining difficulties largely caused by soft and weak ground condition and estimation error in the probable ore reserves as well.

②Regional condition

The Matsuki mine is located relatively close to (some 1.2 km from) the center of Odate City and covered by rice paddies. Thus, it was required from the beginning of the planning stage not to disturb the overlying rice fields by surface subsidence that is fairly known to be most likely induced by mining practice in Kuroko deposits. Top priority was, therefore, given to making a maximum effort not to produce any damage even after the inevitable mine closure.

③Characteristics of operation

As the Matsuki mine was designed to induce as little as possible surface damages to the agricultural activities and to complete operation within a relatively short limited life, the environmental measures implemented were as following.

1) Countermeasures against surface subsidence

It was generally predicted that surface subsidence would be possibly introduced by mining operations in a Kuroko-type deposit. The Matsuki mine, therefore, organized a subsidence control committee in which university professors and research groups participated and estimated the plausible subsidence as well as reviewed/discussed the engineering problems associated with mining in soft and weak ground.

Based on the prediction of surface subsidence made by the committee, the Matsuki mine clearly explained the possible impact caused by mining to the residents having their houses and lands within the area of influence. Furthermore, the mine negotiated with the residents concerned to take preventive action to purchase their houses and lands within the expected subsidence area or to exchange their lands with the other ones or to move their houses outside the area. As a consequence, there appeared none of problems related with the surface subsidence.

2) Countermeasures against mine water

At the design stage of the mine development, the mouth of the main shaft was selected at the highest elevation and then the shaft was excavated through a massive and competent rock mass free from pervious sand seams, in order to remarkably reduce efforts necessary for water drainage. The underground structure of the Matsuki mine is shown in Fig.4.

The discharged rate of mine water was substantially curtailed as was expected and, in addition, its quality was high enough only for requiring a settling pond to remove suspended solids for a limited period. Currently, the mine water from underground is untreated without sealing the main shaft.

3) Countermeasures against tailings

Since the scheduled life of the operation was comparatively short, it was designed at the planning stage not to construct a tailings disposal for the Matsuki mine but to use that of the Osarizawa mine, located some 20 km away, where the sediments after SS treatment was also sent.

④Harmony with the environment

None of significant pollution has occurred since the closure because of the effective countermeasures designed and carried out during the operation.

⑤Conclusion

After the closure, the Matsuki mine has provoked neither impact nor disturbance on the environment so far, it can be, accordingly, regarded as a successful example of an abandoned mine in harmony with the environment owing to the preventive measures against anti-pollution during the operation.

< *Makimine Mine* >

①Overview

The Makimine mine is located in the middle of Miyazaki Prefecture on the southern Kyushu Island, approximately 20 ㎞ away from Nobeoka City. The Makimine deposit, principally rich in copper, can be classified as Kieslager and extends horizontally 2 km by

3 km and 900 m deep into the ground. The deposit, discovered in 1657, had been mined by a local feudal lord ruling the Nobeoka district from 1854 to 1889, when it was took over by the Mitsubishi Group, of which mining companies (currently succeeded to Mitsubishi Materials Corporation) carried on operation until its suspension in 1967. Later in 1983, the mining right was abandoned, the Makimine mine, however, produced 4.18 million tonne of crude ore in total with average Cu grade of 1.56%, from which 65,000 tonne of copper was recovered.

②Regional condition

The entire mine water discharged from underground flows into the Tsunanose River with high water quality running into the Gokase River, which is a regionally major fishing place of "*ayu*" or *sweetfish*, usually living in clean and clear water. Therefore, it is required to keep the quality of the mine water flowing out from the mine extremely high so as to protect the environment of the local rivers and the aquatic ecosystems.

③Characteristics of operation

1) Countermeasures against mine water during operations

After 1955 when a new deposit with relatively high grade of copper having been discovered, the mine continued operation in spite of the huge amount of flow up to 4.0 from a major fault. During the operation, the Makimine mine carried out grouting and systematically constructed a series of underground sumps/dams, as a consequence, leading to successful alleviation of the water drainage problems.

In 1962 a large volume of old stopes became available and allowed to be used as underground reservoirs. And thus, in 1963, another program of extensive construction of underground dams started with the aim of further reduction in the discharging rate down to 0.5 m^3/min, 1/8 of the previous one. The locations of the underground dams are shown in Fig.5.

2) Untreated discharge of mine water after closure

The quality of discharged water from underground after closure was found quite excellent; it was mainly due to the effective reduction in mine water during the operation and the selection of the main drainage adit at the uppermost level over the old workings.

Nevertheless, the mine water was discharged to the local river through a settling pond, where suspended solids (SS) made from ferrous sediments were removed because of the special attention to preserve the shelter of *sweetfish*. The level of SS gradually decreased year by year, and eventually it was 1990 that a final agreement with the Government and the local governments concerned as well as the fishermen's unions interested was made, and since then the mine water has been directly discharged without any treatment.

④Harmony with the environment

1) Because of the acceptable quality of the discharged water from underground, there is no adverse effects observed, especially on fishing, and hence the old Makimine mine is allowed to release its mine water without any treatment.
2) Once every month, the mine water is sampled and its pH level and Cu/Fe contents are regularly measured to examine the quality.

⑤Conclusion

After the closure, the Makimine mine has ever caused none of pollution and still remains harmless, so that the Makimine mine can be a typical example of an abandoned mine in harmony with the environment.

3-2: A closed mine required large-scale pollution control

< *Matsuo Mine* >

①Overview

The abandoned Matsuo mine is located in Iwate Prefecture of the Northeast Province and on a hillside of Hachimantai Mountains in the northwest of Mt. Iwate (2,038 m), about 1,000 m above sea level. The ore body extended about 1,500 m in east west and 1,500 m in north south with the thickness of 25 to 150 m, and it was said to be the largest sulfur mine in Asia. Fig.6 gives the location of the mine and Figs.7 to 21 also show the mine structure and other underground/surface facilities of the mine.

A big outcrop of native sulfur was discovered in 1882, and a full exploitation started in 1914. The Matsuo mine mined out about 28 million tonne of sulfur and sulfide ore with the total length of mining drifts and raises of 350 km, and 2.5 million tonne of refined sulfur were produced over approximately 60 years.

Around 1958, however, a serious recession started to cover the principal users of sulfur, such as chemical fiber industries, especially damaged by the trade liberalization, and thus sulfur mining gradually deteriorated. What was worse, moreover, along with the reinforcement of anti-pollution regulations in 1967, sulfur recovered from heavy oil at lower cost finally came into market. The Matsuo mine switched its operation by from underground to open pit mining to curtail the cost, however it could not avoid the fatal damages and eventually abandoned the mining right in 1972.

A large quantity of highly acid mine water discharged from underground flew into a local river, the Akagawa, which joins a regionally major river, the Kitagami. As a result, the river was quickly and severely polluted, which jeopardized the aquatic species and caused grave social impacts within the people living along the riverside. The Iwate Prefecture Government received the strong and extensive demands from the local communities along the river and sent a petition to request the restoration of the Kitagami River to the Government in 1971. Immediately, in order to discuss and prepare the necessary measures for contamination of the Kitagami River, the Government organized a conference, in which three Ministries (International Trade and Industry, Construction, and Home Affairs) and two Agencies (Environment and Forestry) were involved. The conference investigated the technologies to reduce the pollution and to restore the environment and discussed on the management system and financial expenditure for the possible countermeasures. In 1976, it was concluded to construct a neutralization plant at the mine site and to employ an innovative method combining "bacteria oxidation and calcium carbonate methods". After spending 4 years and 10 billion yens, the new neutralization plant and the sludge storage dam were completed in 1981.

The Iwate Prefecture entrusted the maintenance and operation of the plant to MMAJ since 1982, and soon later the Kitagami River restore its clean and clear water.

②Bacteria oxidation and calcium carbonate neutralization system

The thiobacillus ferrooxidans is a type of bacteria, which has been known to oxidize iron and investigated the possibility of an effective application to treatment of strong acid mine water in the Matsuo neutralization plant. And as a result, it is confirmed that the bacteria has a capability of oxidation of iron ions ($Fe^{2+} \Rightarrow Fe^{3+}$), especially predominant in a low pH region, and iron composites precipitate at pH 4.0. Consequently, it is concluded that the combined neutralization, in which first ferrous iron is oxidized into ferric iron by the bacteria in highly acid circumstance and then ferric iron reacts with $CaCo_3$, is sufficiently effective and economic.

③Construction works against the pollution source

In addition to the neutralization of acid drainage, a series of construction works have been conducted to prevent the collapse and washing out of the waste disposal as well as to prohibit surface water from infiltrating into the underground sulfur deposits and the tailings/waste disposals on surface. With the final aim of significantly reducing the drainage, the construction works actually carried out at the mine site are as follows.

(1) Reclamation of the former open pit and covering it by soil and vegetations

(2) Stabilization of the tailings and waste dumps

(3) Surface drainage channels

(4) The protection lining of the bed and banks of the Akagawa River

In addition to these measures, it was observed that the quality of the discharged water from the 3 m level adit, the lowest level, was quite poor, so that the adit was sealed by an underground plug. Consequently, the underground water level rose by 130 m and the quality of the discharged water was significantly improved. Currently, the acid mine water is drained through the permanent drainage tunnel installed at the 112 m level and sent to the neutralization plant.

④Conclusion

As described above, the Matsuo mine not only caused extensively adverse effects on the environment, but also required extremely enormous costs for the anti-pollution measures and restoration. So that, it can be said that the Matsuo mine closed and left a huge amount of “negative heritage” from socio-economic points of view, which should not be repeated any more. However, we have learned much from the restoration of the pollution related with the Matsuo mine. Namely, among others, it is notable that

(1)Discussion and consideration were made about the regional development of the old mine site and the surrounding area in order to create a new society and environment after the mine closure, and

(2)Remarkable progress was made in research and development for the innovative acid mine water treatment, such as the bacteria oxidation and calcium carbonate neutralization.

Furthermore, we have obtained valuable knowledge how to realize and keep the consistent harmony between mineral development and environmental protection through creation of new value of the region for post-mining stage, utilization of the regional rivers after restoration, and an ideal concept of the local society and its structure

3-3: Operating mines overcoming environmental issues

< *Toyoha Mine* >

①Overview

Toyoha mine produces mainly zinc. The main office, considered as the reference level of the mine, is located at an altitude of 550 m. Its deposit is of vein type comprising countless veins of various sizes that spreads out 3 km in east west direction, 2 km in north south direction and more than 600 m in depth. A high grade of silver content and the inclusion of rare metals such as indium characterize the deposit.

While it is not certain by whom and when the Toyoha mine had been discovered, the first mining right was established in 1895, namely, 102 years ago. Toyoha Mining Co., Ltd. was established by separating part of the then Nippon Mining Co., Ltd. in 1973, and now operates the mine as a wholly-owned subsidiary of the Nippon Mining & Metals Co., Ltd.

Annual production of crude ore is 480,000 tonne. Zinc being the main product and the indium being the byproducts, occupy approximately ten percent and one-third of the domestic demand, respectively.

②Regional condition

1) High-temperature rock area

The average ground temperature gradient in the vicinity of the mine is extremely high, specifically 20-30°C/100 m. The rock temperature around recently developed sites partly exceeds 100°C. Steam and hot water occasionally blow out at the drifting site.

2) Heavy snowfall area

The mine is located in the national forest adjacent to the national park, where snowfall in winter (November to April) exceeds 6 m, and the air temperature is low even in summer.

3) Proximity to a large city

The mine is located in the southwest part of Sapporo City (the population is approximately 1.8 million).

③Characteristics of operation

1) Utilization of river water

River water is induced to the underground mining site and utilized as cooling water to improve the working environment.

2) Highly efficient operation

The employed mining method is sublevel longhole stoping with a trackless principle. Raise boring machines are extensively used for construction of ventilation shaft or orepass, in addition, down-the-hole-drills for longhole production drilling and large-sized electric LHD are introduced to realize highly efficient operation.

In the cleaning stage of ore floatation process, column type floatation units are used in order to improve the recovery of the concentrate.

3) Mine water treatment method

Mine water is discharged through two independent discharge systems; namely, the site cooling water drainage and the underground infiltration water drainage. After heavy metal ions are removed by neutralization, the site cooling water is subjected to settling and clarification and then it is partly reused for mineral processing and the rest discharged into the Shirai River. The underground infiltration water containing a larger amount of heavy metals, on the other hand, is firstly subjected to neutralization and then transported to the tailings dam 8.7 km down and there discharged together with the floatation tailings. Fig.22 shows the flow routes of the water from underground, the processing plant, and the tailings dam.

4) Effluent water from the tailing dam

Effluent water is transported through a 17.5 km long pipeline and discharged further down the river beyond the potable water intake.

④Harmony with the environment

1) Coexistence with the natural environment

The abundant supply of cool water as a consequence of the snowfall as natural endowment along with low air temperature makes it possible to operate the mine by cooling off the rock, which is the hottest among rock surrounding any working stopes in the world.

2) Concluding an anti-pollution agreement with Sapporo municipality

According to the agreement with the Sapporo municipality, the standard imposed on the quality of the discharged water is more critical than the national standard and that of the Hokkaido Prefecture's ordinances.

3) Monitoring water quality

The sample of water is taken every day at each discharge outlet of treated mine water and the quality is examined. Principal control data (pH of water before and after the neutralization process and of the discharged water, amperage of the facilities and instruments, flow rate, etc.) are collected by remotely acquiring systems and sent to the central control room of the concentrating plant and then monitored there.

⑤Conclusion

The costs for mine water treatment and improvement of the underground environment, so as to control the environmental issues of the mine, occupy approximately 10 percent or more of the total operation cost. While the Toyoha mine making significant efforts to maintain its cost competitiveness by positively utilizing the endowment of natural environment, it also pays a special attention to preserve the natural environment around the mine and the water quality, which is the basis of the regional living environment. The Toyoha mine, moreover, endeavors as an environment friendly mine to concern itself with the development of the regional economy.

< Hishikari Mine >

①Overview

The Hishikari mine is the largest gold mine in the history of Japanese gold mining and its annual production is 155,000 tonne of silica ore containing 7.1 tonne of gold. The deposits are geologically characterized by the fact that the average grade of gold is exceptionally high, about 47 g/t, and high temperature hot water is spouting out from fractures opening in the veins. It was 1750 when the gold was first discovered in this region. The Sumitomo Metal Mining Co., Ltd. acquired the mining right of the Hishikari rigion in 1968 and continued exploration drilling until 1978 when MMAJ succeeded in detecting rich veins. By the MMAJ's structure drilling program for 1981, gold and silver veins were identified. Encouraged by the further promising results obtained by succeeding drilling, the Smitomo Metal Mining decided to develop the Hishikari mine and started driving a pair of declines as major access routes to underground.

Since then the Sumitomo Metal Mining has carried on the safe and efficient development and operation with a motto "the Hishikari mine should be a clean and bright underground factory", and also made efforts to preserve the natural environment and to promote friendly and prosperous interrelation with the residents.

②Geology and deposits

The mine comprises three deposits, namely, the Main, Yamada, and Sanjin deposits. The Main deposit consists of a number of veins and branched veins including Ryosen, Hosen, Zuisen, and Daisen. These veins are of a fissure-filling, epithermal gold-silver bearing quartz-adularia type and occur both in the Shimanto Supergroup and the Hishikari Lower andesites. These deposits were formed 780,000 to 1,040,000 years ago. Principal ores containing gold or silver include electrum, naumannite-aguilarite, pyrargyrite, and so on. The Yamada deposit is located in the west of the Main deposit and consists of Yusen vein and others extending in the Lower Hishikari andesites. The Sanjin deposit is formed with the Keisen and Shosen veins that have been developed nearly in the same direction as that of the Main deposit.

③Underground mining methods

The underground development and mining are based on the trackless mining system, since it has a higher flexibility and productivity.

A pair of two declines were opened in the Honzan mine site and another pair in the Yamada mine site. These inclines give access to the main haulage drifts at levels of 100, 70, 40, and 10 MLs. The Honzan and Yamada districts are interconnected by the 40 ML drift for commuting. From each main drift, crosscuts are driven in the perpendicular direction to the vein for access. Once the crosscuts intersect the vein, exploration drifts are then extended to trace the vein along its strike. Mining methods employed are slice slitting, double slicing, and bench stoping that can be referred to as a smaller scale of sublevel open stoping, and selection is made depending on the geometrical characteristics the vein.

④Mineral processing

Excavated ores are hauled by trucks and dumped into the crusher for primary crushing on the surface, and then approximately 30 percent of the ores are rejected as waste by an ore sorter and handpicking. The sorted ores are transported by trucks to the ore storage and loading facilities in Kajiki harbor, some 40 km away from the Hishikari mine. Thereafter, the ores are shipped to the Toyo Plant of the Besshi Works of Sumitomo Metal Mining Co., Ltd. in Niihama City, Ehime Prefecture, where the ores are melted as flux for copper smelter, and the contained gold will be refined to 99.99% electric gold.

⑤Environmental control

1) Dewatering and treating hot water

One of the major obstacles in the mine was immense emergence of hot spring water at a temperature of 65°C. Implementation of meticulous plans, such as grouting into cracks and improving drainage facilities to prevent scales, made it possible to access the veins. At present, the hot water is dewatered from the pumping station situated at the 50 ML. The dewatered hot water is transported to the neighboring hot spas and welfare facilities through a 6 km long pipeline. The rest of hot water and the underground utility water are pumped up to a cooling tower where it is cooled from 65°C to 35°C, treated in the settling pond, pH adjustment tank, and thickener, and discharged to the Sendai River through a 6 km pipeline.

2) Environmental assessment and monitoring

Well-established monitoring technology has been applied in the Hishikari mine since the beginning of development activities, and maintained at a high level for preserving natural environment and the health of employees. Sumitomo Metal Mining Co., Ltd. decided to implement the assessment of the environmental conditions prior to developing the Hishikari mine and to monitor the conditions during the whole mine life. Items for monitoring include atmosphere, water quality, soil, hot water, fish, aquatic plants as the components of natural environment, as well as the elements of social life environment such as noise, vibration, dust, exhaust gas, traffic and the like. Results of the monitoring are used for the environment controls. The environmental measurement report is submitted twice a year and additional reports are produced as required.

3) Harmony with the local communities

The Hishkari mine employs 250 people including subcontractors' employees living in Hishikari Town with a population of 10,000. One of the policies of Sumitomo Metal Mining Co., Ltd. is to keep affirmative relations with the local communities. This is an essential act to maintain friendly relationships between the company and the local residents. The Hishikari mine can only exist as a member of the community by employing residents, giving education and training to them so as to foster them as important personnels of the mine.

3-4: Mines utilizing their facilities for post-mining stages

< *Kamioka Mine* >

①Overview

The Kamioka mine is located in Gifu Prefecture of the Central Province and at an elevation of 400 m in the heart of the high and massive mountain range called North Alps of Japan, approximately 60 km inland from the Japan Sea. The mine has a long history and dates back to around 720 AD, initially having opened as a gold, silver, and copper mine. However, the production of zinc and lead ore became predominant, and at last modernized lead and zinc smelters were constructed during the second half of 1800s. Currently, the mine excavates 2,510 tonne/day of Zn-Pb crude ores with the average grades of 4.18% Zn, 0.23% Pb, and 18 g/t Ag, from which 42,400 tonne/year of zinc concentrates and 1,700 tonnes of lead concentrates are processed as well.

The Kamioka mine, which is operated by Kamioka Mining and Smelting Co., Ltd., 100% subsidiary of Mitsui Mining and Smelting Co., Ltd., installed new business; utilization of underground spaces as laboratories/testing sites and restructuring of its lead smelter for scraped battery recycling.

②Underground space business

In 1990, the Kamioka mine launched the Underground Utilization Division in order to promote to positively utilize its excellent technologies and useful infrastructures for hard rock mining and to create new value, other than by mining, to be added to excavated underground spaces. To date, the following projects came on stream.

1) The Kamiokande (KAMIOKA Nucleon Decay Experiment) project

The Kamiokande is a scientific research project, in the fields of neutrino astronomy and particle physics, to detect cosmic-origin neutrinos to clarify their intrinsic properties. The project was organized by the Institute for Cosmic Ray Research, University of Tokyo, who ordered the Kamioka mine to excavate a large underground space at a depth of 1,000m. Selection of the site in deep underground is due to its natural isolation to avoid any contamination and disturbance caused by cosmic ray usually pouring down to the surface. A huge tank of pure water, equipped with a numerous number of photoelectron detectors, has a diameter of 15.5m, a height of 16m, and the capacity of 3,000 tonne.

The excavation started in 1982 and the installation was completed in 1983; the first direct detection of cosmic neutrinos was made in 1987, when the supernova of the Large Magellanic Cloud was burst. In 1988, solar neutrinos were observed adding to the advancements in neutrino astronomy.

2) The Super-Kamiokande project

The Super-Kamiokande is the second generation of the scientific program organized by the Institute for Cosmic Ray Research, University of Tokyo. The cavern of the Super-Kamiokande was designed to be able to accommodate a 50,000 tonne water tank with a diameter of 40 m and a height of 57.6 m in order to improve the accuracy of observation ten times higher than that of the first generation. It is similarly located at a depth of 1,000 m below the surface and 150 m away from the former one. The excavation was initiated in late 1991 and finished in the middle of 1994, and finally having been in operation since 1996.

3) CAES (Compressed Air Energy Storage Experiment) project

An unlined storage chamber with a dimension of 5.5 m in wide by 4.5 m in height by 9.0 m in length was excavated to examine the feasibility of the CAES, which utilizes redundant power at night to compress air and store it in a storage cavern and release the compressed air to generate power at peak demand during daytime. The Kamioka mine has an experience to have stored highly compressed air in underground spaces in order to operate rock drills more effectively, which might be one of technological backgrounds to invite the CAES project.

4) Decompression chamber project

An experimental gymnastic training facility has a capacity of 280 m^3, a floor area of 90 m^2, and a height of 2.6 to 3.8 m. It was excavated and sealed within a tight rock mass to artificially create the highland training effects, by decompressing the air in the chamber, which can be specifically regulated to generate simulated highland atmosphere at an elevation of up to approximately 4,000 m.

5) Explosives performance testing project

A large water pool with a diameter of 20 m and a depth of 10 m was constructed in a dome shaped opening in underground, for the research and testing purposes by explosives manufactures. They are using the underground pool for investigating underwater blasting and also conducting experiments to evaluate the performance of explosives by employing another underground excavation as well.

In the future, the Kamioka mine will more insistently and more extensively promote its underground spaces to be utilized as underground warehouses, underground factories for precision machine and biotechnological manufacturing, underground dams and power stations, and sports/recreational facilities. These future applications of underground excavations are based on the favorite and advantageous characteristics of hard rock mass, for instance, capabilities of hermetic sealing, isolation, earthquake resistance, and long-term stability, as well as availability of relatively constant underground climate.

③Scraped battery recycling

The lead smelter of the Kamioka mine had relied on lead concentrates both from its own and imported ores for over 100 years until 1994, when the smelter started to produce lead bullion exclusively from battery scraps (B/S). It was partly due to the decrease of the concentrates available from the Kamioka mine, and partly owing to the reduction in the company's profitability as an inland customer smelter.

The recycling rate of B/S in Japan, having been maintained at nearly 100 % until 1985, was gradually declining because of the depression in the market and at last dropped to 70 % in 1993; a large number of batteries were not recovered and just abandoned.

In order to cope with the emerging environmental issues, the lead smelting industry and battery manufacturers cooperatively organized a B/S recovery and processing system under the guidance of the Ministry of International Trade and Industry. Because of the partial assistance provided by the battery manufacturers for recovering the used batteries, the recycling rate have been restored to the current level of approximately 100%.

The Kamioka lead smelter redesigned and modified the furnace, originally having accepted lead concentrates, into a B/S processing furnace. As a preprocessing, B/S crushers were introduced in place of the sintering kilns for the lead concentrates. The existing treatment facility for waste water has a sufficient capacity to process the released waste acid.

The B/S processing furnace can produce approximately 30,000 tonne/year of lead bullion, from which pure metal lead with a quality of 99.99 % is recovered by electrolytic refining.

< Inarizawa pit of Hanaoka Mine >

①Overview

Hanaoka Mining Co., Ltd., having operated a couple of Kuroko mines in the suburb of Odate City, Akita Prefecture, was separated from Dowa Mining Co., Ltd. as a subsidiary in November 1986, when the economic environment became crucial for the mining industry. However, the influence of the mining company on regional economy was still significant, so that the Inarizawa open-pit mine was developed, after the separation, and planned to subsequently utilize the space of the pit after excavation as a repository for industrial wastes. The location of the Inrizawa pit is shown in Fig.23 and a schematic illustration of the pit is given in Fig.24, as well.

The following three factors should be noted as the key concepts behind the project.

1) Conformity to the company's philosophy

One of the basic concepts of Dowa Mining Co., Ltd. about development of new projects is the promotion of local economy. The development of the Inarizawa pit was also regarded as a vital approach for growing up the regional economy. In addition to the direct effects caused by the mining alone, it was quite significant for the local economy after the inevitable mine closure to use the company's capabilities and infrastructures for the treatment of industrial wastes, causing crucial environmental problems in various part of the country.

2) Independence from overseas market conditions

The Inarizawa project is developing new business that makes the administrative constitution of the company immune from the fluctuations of metal prices as well as foreign exchange rates.

3) Application of existing administrative resources

At the time of planning the Inarizawa project, Dowa Mining Co., Ltd. operated a couple of Kuroko mines in the Hanaoka-Odate region, so that there remained both of experienced persons and facilities that could afford to operate open pit mining and treat mine water as well as control pollution. Making use of these human resources as well as the utilities and facilities available in the region, the Inarizawa open pit started production and the consequent final treatment facilities of industrial waste disposal is operating. In addition to Hanaoka Mining Co., Ltd., Dowa Clean Technical Service Co., Ltd. was established to operate industrial waste treatment business mainly constituted of the incineration of waste solvents and oily sludge as well as neutralization of waste acids and alkalis. Since the nearby repository, the Inarizawa pit, can accept the final waste generated from the intermediary processes at Dowa Clean Technical Service, the cooperative and complementary relations between Hanaoka Mining and Dowa Clean Technical Service also strengthen the competitiveness in collecting industrial waste, in spite of their remote location away from the major industrial regions in Japan.

②Characteristics of operation

1) Planning stage

The Inarizawa deposit had a high stripping ratio of approximately 500,000 m^3 of overburden against approximately 70,000 tonne of ore, it seemed difficult to be developed at the beginning of planning. Accordingly, the following two schemes were reviewed in the stage of making the master plan:

- To store the overburden soil stripped in the course of development, and after the operation, then to use it as covering materials for reclamation to prevent mine-related pollution.
- To start a business utilizing the evacuated space of the open pit with a volume of approximately 350,000 m^3 available after the operation as an industrial waste disposal site.

In other words, these schemes are based on the policy that we can convert the costs of stripping and mine closure into the positive profit by utilizing the stripped overburden and space as the solution of other environmental problems. Obtaining the positive results of the feasibility study, the development was started in October 1984.

2) Operation stage

As indicated in Table 2, the Inarizawa pit had produced approximately 70,000 tonne of ore in total and mined out in February 1986. After the exhaustion of the ore, the company started the negotiation to obtain an approval of the Government as planned, and initiated the industrial waste disposal operation in June 1987. Later an expansion of the pit was carried out to provide the final site with a total reclamation capacity of approximately 1,080,000 m^3.

③Public recognition of environmental problems

While in the Kanto Province involving the Tokyo metropolitan area, the shortage of the site for industrial waste disposal has already become a serious problem, in Akita Prefecture, the collection of industrial waste is still difficult because of the uncertainty of demand increase. The capacity of present disposal site is, however, already far less than the estimated capacity for the final disposal of the current quantity of the industrial waste in this region as well. Therefore, in the near future the acquisition of another sites for final waste disposal is supposed to become more important as the public recognition improves and the adequate waste disposal prevails.

④Conclusion

In the concept of "mining in harmony with environmental preservation", the mine closure plan should be included in the feasibility study stage, regarding environmental preservation during development and operation stages as a matter of course. The Inarizawa open pit mine was most probably impossible to develop without the concept of converting the costs of stripping and mine closure into positive profits by utilizing the stripped overburden and space as the solution of other environmental issues. In other words, it is a valuable example in which the concept of "mine development and operation in consideration of environmental preservation is less expensive as a whole", has been enhanced to the concept " mine development becomes feasible when environmental preservation is taken into consideration."

On concluding the case study on the Inarizawa pit, however, it is first and foremost essential that the mining company should have an enterprise philosophy on the environment and society. Secondly, it was one of successful factors that the mine had advantageous resources for environmental preservation. What is more important is that the public recognition for environmental problems should be sufficiently high.

4. Concluding Remarks for the Case Studies

From the preceding case studies on the mine pollution ever experienced and pollution control measures ever carried out in Japan, it can be concluded that the following actions are really essential and effective, especially for preventing any contamination caused by water drainage from tailings disposal and underground. Our recommendations were itemized as follows according to the mine development and operation stages.

(1) Prior to mine development

- Environmental baseline survey is indispensable for a quantitative assessment of the natural condition and the extent of background contamination before disturbance brought by mining activities. Particularly in Japan, the baseline survey is quite important, since it is used for defining the enterprise liability for environmental preservation, resulting in the amount of the expenditure for restoration that must be paid by the company responsible for environmental contamination. Once again, the significance of the baseline survey must be repeated; it is also employed to assess the target of restoration of the natural environment after mine closure.
- Mine planning should not be merely based on the cost effectiveness and profitability, anymore. It is recommended to embody pollution control measures after mine closure and a reuse plan of mine utilities and facilities to be contributed to the local communities; for these purposes, the cost, fund, and term required for pollution control and redevelopment must be clearly stated in documents at mine

planning.

(2) During development and operation

- Continuous monitoring of the environment from the initial development until the final closure should be conducted and the results of the monitoring and analysis must be opened to anyone concerned.
- The agreement on prevention of mine pollution must be made with the local communities and, in addition, periodical meetings and/or opportunities of exchanging view and information with the local residents might effectively encourage the cooperative relation.

(3) After mine closure

- Successful redevelopment and restructuring of the mine facilities and infrastructures will create new values after closure for the communities. The utilization of underground spaces and recycling of used batteries at the Kamioka mine and industrial waste treatment business at the Inarizawa open pit are the typical examples. Although opening of a new mine producing positive effects on neighboring communities, closure of a mine usually depresses employment and economy of an area, which lead local governments and residents to view mineral development with considerable mixed emotions. Therefore, the redevelopment planning after mine closure should not be regarded as insignificant.

In other words, we can summarize the key issues for mine pollution control as follows.

(1) Information disclosure and communication with local residents

We have learned much about mining pollution control for last 130 years, the era of modernization of Japan. For example, positive disclosing of information concerning mine development and operation as well as keeping sound relations between a mine operator and local residents make remarkable progress on resolving unexpected troubles, minimizing unpredictable damages, and stabilizing operation itself. Building a good correlation also deserves consideration, since a relatively longer term and stronger interdependence with neighboring communities than other industrial sectors are usually accompanied with mining operation.

(2) Innovation in technologies for mine water treatment

Because of steep and mountainous topography as well as substantial precipitation, how effectively acid mine water contaminated with heavy metal can be neutralized is a matter of the most critical concern among the mine pollution problems in Japan. Therefore, we have practiced, since an earlier time of our modern mining, a couple of countermeasures for reducing mine water required to be treated, by reclamation/revegitation of old surface pits and caved areas, construction of open channels overlying deposits and underground sealing plugs, grouting, backfilling, and so on. In addition, hydrological researches on regional water balance and behaviors have proved quite effective for reasonable arrangement and installation of controlling measures. Furthermore, surface and underground neutralization facilities, if necessary, have been installed. As a consequence, we can get a lot of encouraging results showing slow but steady improvement in water quality and reduction in discharge rate.

(3) Advanced planning of reuse of mine utilities and facilities after mine closure

Prediction of the plausible mine pollution as accurately and as early as possible prior to the inevitable suspension of operation is apparently of vital importance both for reasonable estimation of fund and term required for anti-pollution measures and reclamation, and for an appropriate design of post-mining utilization of mine lands. An advanced planning also enables for us to have enough time to prepare the most suitable measures and modify them as well as to sufficiently examine/discuss the proposed plan.

As typically shown by the Inarizawa pit, working as an environmentally acceptable repository for industrial wastes, a well-designed advanced planning for a post-mining business can also increase opportunities of success of operation. Even though conditions and circumstances are too unfavorable to allow operation, there could still remain significant chance of operation, if accompanying sub-business after closure can be properly prepared at the time of making a master plan. The used facilities and utilities of a suspended mine can be regarded as great resources equipped with useful hardware and software to initiate a new business. Hence, we should more positively evaluate the potentiality of a well-designed plan comprehensively involving development, operation, and post-mining redevelopment stages, since such a plan can be expected to increase chance of success of mining as well as to promote environmentally friendly or self-sustainable mineral development. It can be said that investment and cost to be spent for improving the environment might produce another possibility of an innovative mine in harmony with global sustainability.

5. Proposal for the Future

It is generally getting recognized that, for realizing the sustainable mineral developments within the APEC region, we have to overcome mine-related environmental issues which have potential to cause a lot of difficulties and obstacles for mining industries in near future.

In order to optimize mining activities at a reasonable level, *i.e.* assuring stable economic development within the APEC region, our experience and knowledge obtained from the history of mine pollution in Japan could fairly be instructive. Namely, we can not disregard the importance of clearly defining the impeding environmental agendas followed by analysis and investigation, which must be in conjunction with quick and effective countermeasures against induced pollution. Although it is true that our present recommendations might cost a heavy burden for mineral development, they can be expected to notably reduce possible introduction of a more crucial and prolonged damage on the environment and consequently lead to shortening of term and saving of total cost required for restoration.

In addition, it is also significant to construct a database in which our experience and knowledge concerning mine pollution and technologies for pollution control including treatment of mine water will be stored. And then the database will be built in an information network easily available/accessible from anywhere within the APEC region. We will further increase the opportunities to transfer our technologies as well as making an effort to establish a cooperative institute to investigate technological innovations necessary for the APEC sustainable development.

Finally, it should be stated that, as one of leading countries, Japan is positive and ready for contributing our plenty of experience/knowledge/technologies stored and developed in Japan towards founding a collaborative and interactively supporting system for research about treatment of polluted mine water. In addition to universities, research institutes, and mining companies in Japan, MMAJ's Matsuo facilities and Technology Research Center at Kosaka, Akita Prefecture, can be incorporated into a program for mineral development in harmony with environmental protection that is one of key issues for the sustainable growth of the APEC region.

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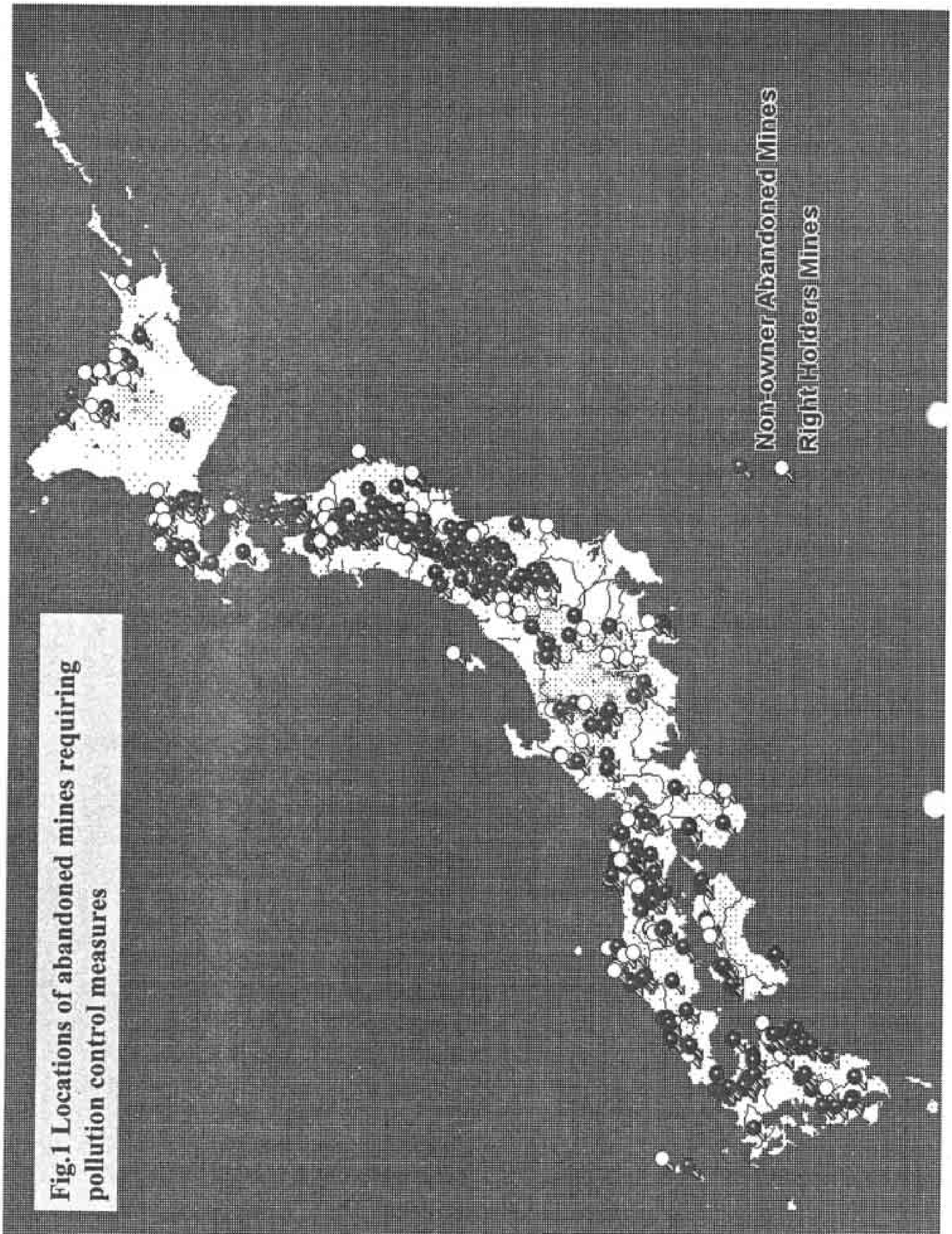

Fig.1 Locations of abandoned mines requiring pollution control measures

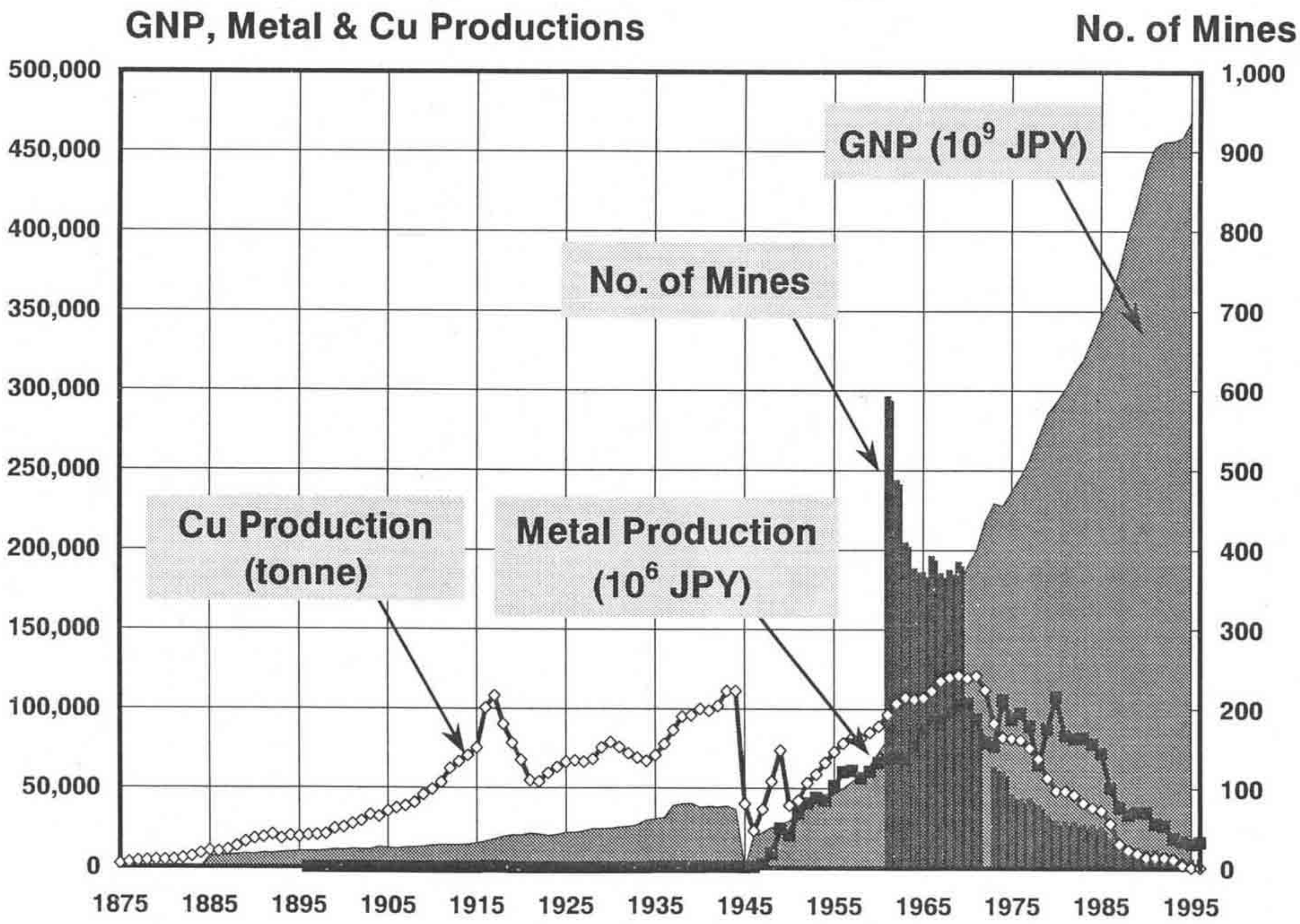

Fig.2 Metal Production in Japan (1875-1995)

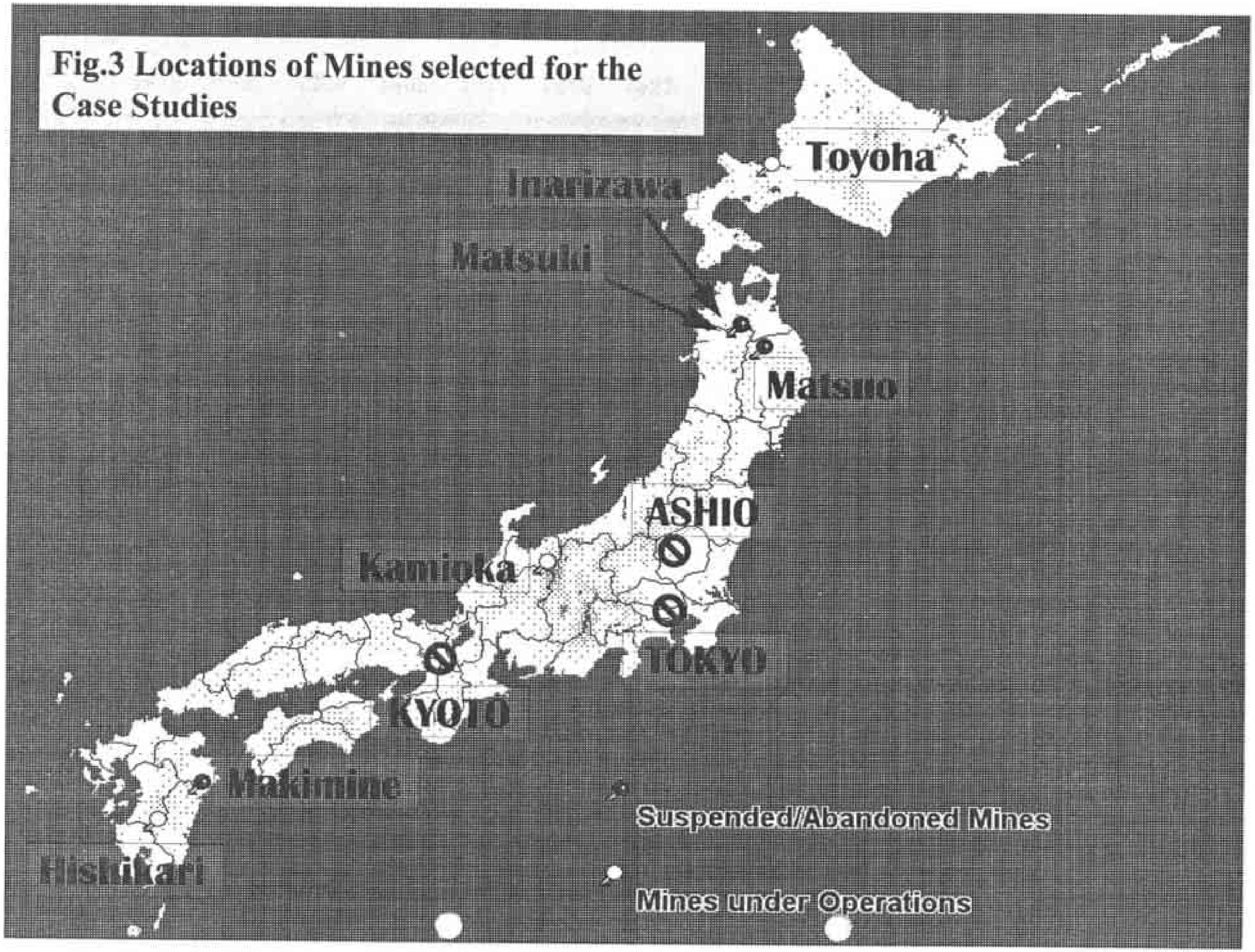

Fig.3 Locations of Mines selected for the Case Studies

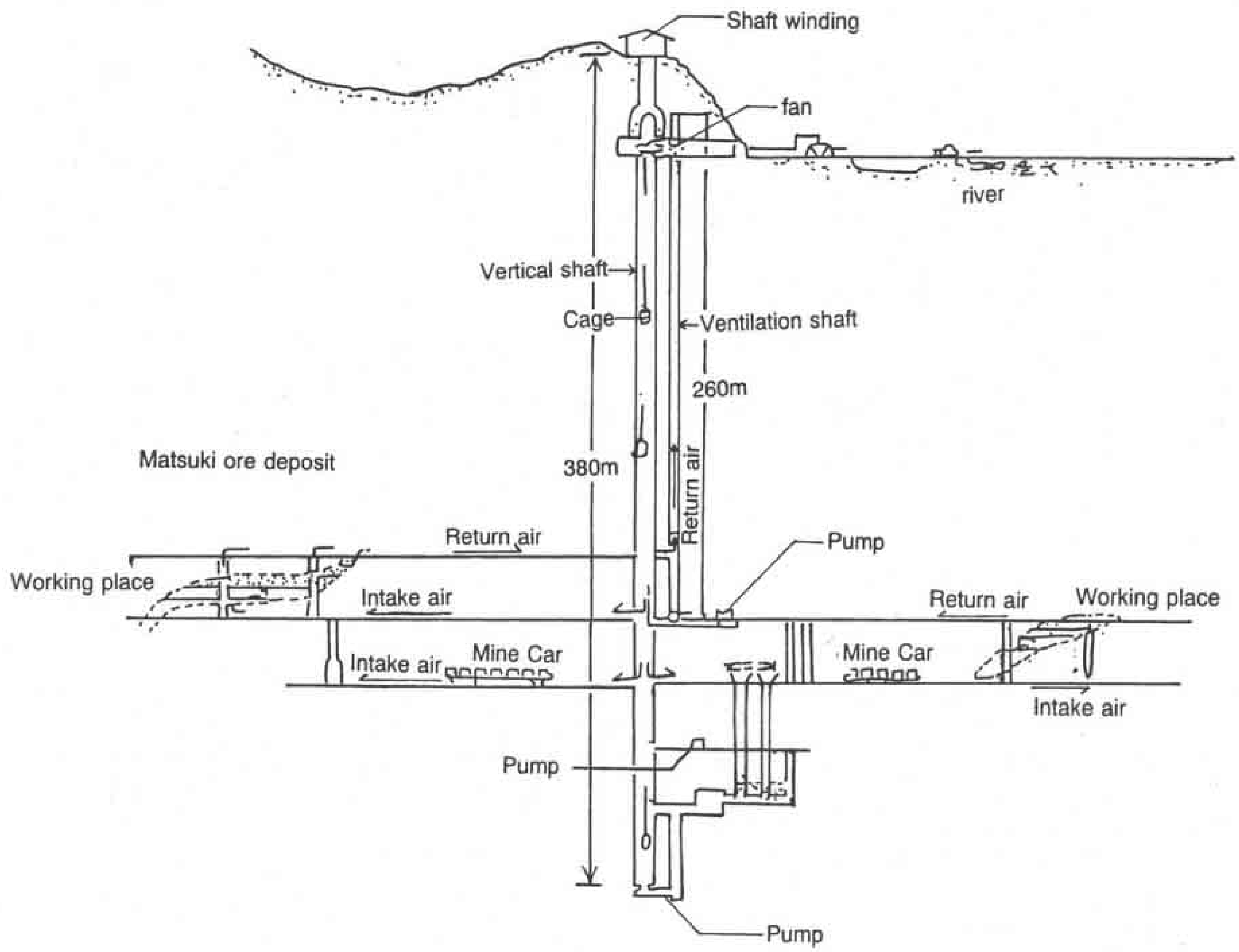

Figure 4 Matsuki Mine