Silver-Lead-Zinc Deposits in Manchuria

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I. Preface

In 1939 an elaborate report was published by Prof. T. Ogura of Ryojun College of Engineering, concerning the silver-lead-zinc deposits in Manchuria. Six years after, the development work on these deposits proceeded remarkably well, and, as was predicted by Prof. Ogura, as a result there now exist several mines with a twenty thousand-ton monthly treating capacity.

I have been asked by the Committee to submit a report on the subject, owing to a change in the scheduled program of the project. However, inasmuch as I actually inspected only two mines at the time, the Yang-chia-chang-tzu Mine and the Tien-pao-shan Mine, and as I had no chance to contact the authors of detailed reports on each mine, it might be presumptuous of me to write such a report. Nevertheless, I have managed to compile this report based on material previously published by Ogura, and with some supplementation of new findings from the data on hand.

Messrs. M. Yamashima and K. Murayama provided valuable opinions concerning the Huan-jen and Hsiu-yen mines, for which I would like to express my grateful acknowledgement here.

II. Distribution of the Ore Deposits

According to the Manshu Kobutsu Chosa Hokoku (Research Report on Manchurian Minerals, an annual publication of the South Manchuria Railway Company), 310 mineral deposits of silver-lead-zinc category were found in Manchuria, and ranked next to gold deposits in number. There were 102 in Feng-tien province, 96 in An-tung province, 27 in Je-hol province, 21 in Hsing-an province, 19 in Tung-hua province, 17 in Chin-chou province, 16 in Chi-lin province, 6 in Kuan-tung Leased Territory, and 6 in Chien-tao province. They were clustered in such areas as the Tung-pien-tao block, the Triangular area of Feng-tien province, the Hei-an block, etc., and their main distributions were limited to the region south of an east-west line passing through the Lake Hsing-kai in the east and the Lake Ta-li in the west, or the line nearly in accord with lat. 44°N. That is, their distribution was grouped with that of the other metallic deposits including gold deposits. This was attributed to conditions such as poor population, flatness of topography, thick soil covers, etc., in northern Manchuria, which have prevented the opportunity for outcrop findings.

III. The History of the Discovery of Mineral Deposits

No available data is known to exist on the discovery of mineral deposits in Manchuria. It is said that many old prospects, which were scattered through the vicinities of Yang-chia-chang-tzu, Sung-shu-wu, Tiehling, Hai-cheng and Ching-cheng-tzu, were operated several hundred years ago by the natives of Kao-li in their search for sulphide ores as the source of sulphur. In the Chin dynasty, gold and coal mines were operated by Chinese in a region centering around Feng-tien, but they were all closed in the 18th year of Tao-Kuang (1838) by government order.

According to written records, the Chinese government in the Chien-feng and Tung-chih periods altered their policy in order to alleviate financial strains caused by frequent civil wars and stimulated operation of the mining industry. In the 6th year of Chien-feng, the Cheng-ping silver mine of Je-hol province was opened and became the biggest silver mine in Manchuria. Thus, 16 to 17 mines were in operation during the 25 years from the end of Tung-chih (1850) to the 25th year of Kuang-chu (1899) in the territory north of Ho-peh. The Geological Section of the South Manchuria Railway Company was established at Ta-lien in 1907, and from 1912 the Japanese exhorted the operation of metallic mines scattered throughout remote localities for more than ten years, but without success. The fact indicates that the situation for the Japanese in Manchuria was extremely difficult.

During the "Manchurian Incident" in 1931 mining operations were more or less suspended, but reopening of mining and prospecting work were resumed and saw for a while an increase beginning in 1936. Of the 310 known localities, most of them are either of difficult access or are poor in grade and reserve, and so exploitation has been carried out on only a score of deposits.

IV. Production

Very few written records are available on the production of the metallic mines in Manchuria. The important data are shown next page.

V. Geology

The metallic mineral deposits in Manchuria showed denser distribution in the region south of lat. 44°N, and this region could be further divided by the plain of Liao-ho into the eastern and the western parts. The eastern part included the

Name of Mine	Location	Production
Cheng-ping silver mine	Cheng-te, Je-hol	Annual production of Ag, 1,730 kg, about 1904–1922 (closed)
Kang-chia-chang-tzu	Tieh-ling, Feng-tien	Lead ore, 19 tons, 1909
Hsiao-tien-tzu-kou	Kai-yuan, Feng-tien	Lead ore, 18 tons, about 1915–16
Hsuan-ling-hou	Pen-chi, Feng-tien	Lead ore, 10 tons, about 1915–16
Kuan-men-shan	Tieh-ling, Feng-tien	Lead ore, 65 tons, 1916–20
Tien-pao-shan	Yen-chi, Chien-tao	Cu-bearing lead-zinc ore, 8,020 tons, 1917; 11,275 tons, 1918; 7,089 tons, 1919; and 10,157 tons, 1920 (The mine was restored in 1935 and has been processing 150~300 t/d of mill feed)
Ching-cheng-tzu	Feng-cheng, Feng-tien	Lead ore, 340 tons, 1921; 1,000 tons, 1922; 500 tons, 1923; 2,640 tons, 1924; 2,823 tons, 1926; 462 tons, 1927; 366 tons, 1928; 1,450 tons, 1929. Lead metal, 3,500 tons, 1941; 7,500 tons, 1942; 5,500 tons, 1943; 5,500 tons, 1944. Milling capacity 15,000 t/m; mill feed grade was about Pb 9~13%
Yin-tzu-kou	Lin-chiang, Tung-hua	Lead ore, 280 tons, 1926
Kuei-tzu-ha-ta	Hsin-ching, Feng-tien	Silver, 20 kg, 1932
Yang-chia-chang-tzu	Chin-hsi, Chin-chou	Lead ore, 269 tons, 1934; 1,490 tons, 1935; 307 tons, 1938. Lead concentrate, 2,623 tons, 1941. Lead, 4,715 tons, 1942; 1,500 tons, 1943; no output in 1944. Milling capacity 25,000 t/m; Pb 3.5%, Zn 4.8%

Huan-jen	Huan-jen, An-tung	Pb 1,000 tons, Zn 2,500 tons, Cu 10 tons, 1943; Pb 2,500 tons, Zn 3,500 tons, Cu 100 tons, 1944. Milling capacity 3,000 t/m, Pb 9%, Zn 15%
Hsiu-yen	Hsiu-yen, An-tung	Pb conc. 121 tons, 1941; Pb 6,500 tons, Zn conc. 20,000 tons, 1943; Pb 4,500 tons, Zn conc. 22,000 tons, 1944. Milling capacity 10,000 t/m; Pb 2~3%, Zn 12~13%

Kuan-tung Leased Territory, the Triangular area of Feng-tien province, the Tung-pien-tao area, the Hsi-an area, and the Chien-tao area; and the western part was the Je-hol area in which the Chin-chou area was also included.

The geology of the eastern part consists of a Precambrian system, Paleozoic and Mesozoic formations, and such igneous rocks as granite, diorite, diabase, quartz porphyry, rhyolite, porphyrite, andesite and basalt. The Precambrian system consists of gneisses and Proterozoic (or Liao-ho system) sedimentary rocks, and is distributed widely through the Kuan-tung Leased Territory to the Triangular area. A remarkable characteristic of the Liao-ho system is the prevalence of limestone and dolomite. The Cambro-Ordovician formation stretches through Fu-chou, which is situated to the west of the Kuan-tung Leased Territory, to the vicinity of Tai-tzu-ho, and consists of a complex of limestone and shale. The Permo-Carboniferous formation in southern Manchuria covered the Ordovician formation and formed the upper Paleozoic coal-field regions through Fu-chou to the basin of the Tai-tzu-ho River. They consist mainly of shale, sandstone, and coal-bearing series. In northern Manchuria the Chi-lin formation (hornfels, breccia and limestone) exists in the vicinity of Chi-lin, and the Tu-man formation near the Korean border.

The Jurassic formation forms minor basins in various localities. It consists of conglomerate, tuff, and sandstone, and with occasional coal-bearing beds. The Cretaceous formation is developed only in the areas of Pen-chi-hu, Chi-lin, and Chien-tao. Of the igneous rocks, the largest in distribution is probably granite. The principal ones are: that which is distributed through the southern part of the Triangular area to the southern part of the Tung-pien-tao with a length of 250 km from the southwest to the northeast; a circular district in the Hsi-an area; and that which extends through Chi-lin with a length of about 120 km from the southwest to the northeast. Of the granite groups, some would belong to the older geological ages. But the majority of them have provided contact metamorphism upon the Ordovician and Permo-Carboniferous formations, have intruded into the Chi-lin formation, and are covered with the Jurassic formation; and they have been considered as the intrusives at the end of Paleozoic era, and have a very close relationship with the localization of mineral deposits. Diorite and gabbro intrude as a sheet into the Proterozoic formation, and they also intrude into the Ordovician formation. Quartz porphyry and rhyolite may probably belong to the end of Mesozoic, although some of them are found as dike rock in the older formations.

Regarding the western part of southern Manchuria, the geology was found to be generally similar to the above-mentioned eastern part. But in the western part the development of the Mesozoic formations was regarded as more remarkable.

The Jurassic formation with important coal seams is found mainly in the northern districts of the western part. The Cretaceous formation is distributed through the southern half of Je-hol, and consists of remarkably developed pyroclastic sediments, and includes a complex of conglomerate, oil shale, green shale, etc. Igneous rocks are granite, diorite, rhyolite, andesite and porphyrite. The granite group intruded in two different ages, i.e., the Proterozoic and the intrusion at the end of Mesozoic due to the Yenshan crustal movement. The latter is deemed as having a close connection with the mineralization of the silver-lead-zinc deposits in Chin-chou province. Andesite and porphyrite were also erupted at the end of Mesozoic, and not infrequently they had connection with the formation of mineral deposits.

So far as it concernes the relation between the lithology and the mineralization of this category, of the deposits in about 75 localities 40 occur in limestone, 15 in gneiss and crystalline schist, 13 in granite and granite porphyry, 13 in quartzite and sandstone, and 4 in andesite and porphyrite. Namely, limestone is considered to have had a most important relation with the formation of ore deposits.

Although reports on the relation between the mineral deposit and the geological structure are not precise, they generally show a property of the fissure-filling veins in country rock. Frequently they exist metasomatically along the beddings of the strata, or sometimes occur as the metasomatic deposit at the intersection of the fissure systems. The direction of the fissure systems is not definite, but those found in the limestone should have a close relation with the intrusion of the igneous rock. A remarkable mineralization along faults is also seen frequently.

VI. The Ore Deposits

The silver-lead-zinc deposits are located mainly in the southern half of Manchuria, and the larger part belongs to the lead-zinc deposit of the world-type, but extremely big ones have not been found yet. Remarkably numerous ores were found in the limestone group and the deposits of vein type. At the time exploitation of only a few vein-type deposits had been started, and the ones being worked were predominantly of the contact-metasomatic deposit type. But, no deposit could have had more than 250,000 tons in ore reserve. In case of the contact-metasomatic deposit, there may have been an overlap of mineralization by not only pyrometasomatism but also by hydrothermal mineralization of the later stage, thereby resulting in variable deposit types with accompaniment of the metasomatic and vein deposits. With insufficient data on the research of the ore deposits, the ore minerals thus far determined were limited only to the easily recognizable ones. They were mainly of galena and sphalerite with the minor associations of pyrite, chalcopyrite, argentite, tetrahedrite, arsenopyrite, pyrrhotite, molybdenite, etc. The gangue minerals were dominantly calcite and quartz, with minor amounts of fluorite, barite, and siderite; and skarn minerals were found mainly in the contact-metasomatic deposits. The secondary minerals of lead and zinc ore, although they are rare in occurrence, were cerussite, anglesite, hemimorphite, and pyromorphite. Malachite and azurite were commonly found to be the secondary minerals of the copper ore. As the development of the oxidized zone was not so remarkable, mining operations were carried out in the primary ore zone.

A. Classification of Ore Deposits

From the origin and associated minerals, the deposits in Manchuria could be classified as follows. It is not certain, however, whether or not vein deposits contain a pegmatitic one. Some veins with a small amount of skarn minerals were provisionally put under contact-metasomatic deposits.

1. Contact-metasomatic deposits
2. Hydrothermal metasomatic deposits
3. Vein-type deposits (including fissure-filling and metasomatic veins)
    - (1) Quartz-calcite vein
        - (a) Lead-zinc-pyrite vein
        - (b) Lead-zinc vein
        - (c) Lead-pyrite vein
        - (d) Lead-copper vein
        - (e) Lead vein
        - (f) Silver-nickel-cobalt vein
        - (g) Silver vein
    - (2) Fluorite vein
        - (h) Lead-fluorite vein
    - (3) Barite vein
        - (i) Lead-barite vein

1. *Contact-Metasomatic Deposits*

Deposits of this type are found in the contact zone between the limestone-dolomite group and the intruding granite (or granite porphyry) or monzonite. Depending on the copper content the deposit may grade into a contact-metasomatic copper deposit. Even though the mineralization of lead and zinc minerals was poor, as in the case of the Yang-chia-chang-tzu Mine, the deposit was worked because of the minute but persistent existence of molybdenite in skarn zone. The deposit is accompanied by veins and metasomatic deposits of the later hydrothermal lead and zinc mineralization.

At the Yang-chia-chang-tzu Mine in Chin-hsi, Chin-chou province, the skarn zone contained magnetite, molybdenite, pyrite, fluorite, etc., and the country rock of limestone contained the lead and zinc deposits of hydrothermal metasomatism. A zonal arrangement of ore deposits from granite to the external part was seen there. The Sung-shu-wu Mine of the same area was also considered as a metasomatic vein with skarn minerals, and was considered as the extension of the Yang-chia-chang-tzu deposit.

The Tien-pao-shan Mine in Yen-chi, Chien-tao province, contained the contact-metasomatic deposit accompanied by hydrothermal disseminated deposits and veins. At the Huan-jen Mine in Huan-jen, An-tung province, banded and lens-like skarn ore bodies were found in the contact zone of monzonite.

The Ching-cheng-tzu Mine in Feng-cheng, An-tung province, was deemed a contact-metasomatic deposit, but the mine had comparatively poorly developed skarn ore deposits, and the later hydrothermal veins predominate.

The mineralized zone of the Yang-chia-chang-tzu Mine was the largest in size, with its length about 10 km from east to west, and the biggest part of the skarn zone had a length of over 1 km and a width of 100 m. The size of ore body in the Tien-pao-shan Mine, where the ore body forms a lenticular pipe, showed a length of 100 m and a maximum width of 20 m. The ore deposit at Ching-tsui-tzu, I-tung hsien, Chi-lin province, was said to be a contact-metasomatic deposit occurring between limestone and granite, accompanied by galena, fluorite, wollastonite and barite, but it required further investigation.

2. *Hydrothermal Metasomatic Deposits*

Hydrothermal metasomatic desposits are found mainly in limestone, forming irregular lenses or pipe-like masses.

At Kuan-ma-tsui-tzu, Pan-shih hsien, Chi-lin province, the deposit occurs along the bedding plane of limestone; at Yin-tzu-kou, Lin-chiang hsien, Tung-hua province, it was found to form lenticular bodies; and at Yang-chia-chang-tzu, Chin-hsi hsien, Chin-chou province, it formed spiral pipes at the intersecting points of the fissure system. So far as the size of ore body is concerned, the largest one was the above-mentioned pipe of the Yang-chia-chang-tzu, which had a diameter of 10 to 15 m, and its lower part was split into two platy bodies (each being 3 m wide and 30 m long). The ore consists mainly of galena, zincblende and pyrite, often with a small amount of chalcopyrite.

3. *Vein-Type Deposits*

There are two types of vein-type deposits; one is the fissure-filling type, and the other is the metasomatic type with a little gangue mineral and showing extreme swelling and pinching. Both are mesothermal or epithermal in character. The same mineralized zone would sometimes grade into a copper vein to form a copper deposit.

(1) Quartz-calcite vein. This is the most common type. Veins penetrating limestone are full of calcite. Veins of quartz, associated with siderite were found in the lead-zinc deposit of Hsuan-ling-hou, Pen-chi hsien, Feng-tien province. As for the mode of occurrence, some veins could be seen running parallel with the bedding plane or along the faults.

(a) *Lead-zinc-pyrite vein.* It is in many cases dominated by pyrite, and often contains chalcopyrite. The main localities are as follows:

Ching-cheng-tzu (Tien-nan-kou), Feng-cheng hsien, An-tung province.
Yang-chia-chang-tzu, Chin-hsi hsien, Chin-chou province.
Hsuan-ling-hou, Pen-chi hsien, Feng-tien province.
Kuang-tung-ling, Hsiu-yen hsien, An-tung province.

As for the size of the vein, the one at Yang-chia-chang-tzu was the biggest, with a maximum width of 6 m and a length of 150 m. The vein at Kuang-tung-ling was found in the granite and was often associated closely with acidic and basic dikes. At Hsuan-ling-hou, there was an auriferous quartz vein, with 5 to 10 gr/ton of gold. At the above-mentioned Kuang-tung-ling, the component minerals were chalcopyrite, specularite, quartz and chlorite, and were epithermal in character.

(b) *Lead-zinc vein.* It contains remarkably smaller amounts of pyrite than in the case of the above-mentioned (a). The main localities are as follows:

Kang-chia-chang-tzu, Hao-erh-shih and Kuan-men-shan, Tieh-ling hsien, Feng-tien province.
Chi-hsiang-yu, Pen-chi hsien, Feng-tien province.
Hsuan-ling-hou, Pen-chi hsien, Feng-tien province.
Hsiu-yen Mine (Chia-chia-pu-tzu), Hsiu-yen hsien, An-tung province.
Kuan-tung-ling, Hsiu-yen hsien, An-tung province.
Kuang-tung-kou, Chuang-ho hsien, An-tung province.
Cheng-ping Silver Mine (Yen-tung-shan), Cheng-te hsien, Je-hol province.

At the Cheng-ping Silver Mine, the ore veins were found in andesite area, and they contained galena and zincblende, with a small amount of chalcopyrite. There were 40 veins in all, of which the biggest one was 1.2 m in thickness and could attain 2.5 km in length. At the Hsiu-yen Mine, crystalline schists were country rocks in which the ore veins of a maximum thickness of 6 m and a length of several hundred meters were contained. They were metasomatic ore veins, filling the faults at the contacts of the porphyrite dike injected into the schists. The bonanza were connected by the veinlets of several centimeters thick.

(c) *Lead-pyrite vein.* It consists mainly of galena and pyrite. The main localities are as follows:

Ching-cheng-tzu (Ching-tzu-kou), San-tao-kou, Hsiao-pien-kou, Lan-chia-Kou, Miao-kou, Lu-chia-nan-kou and Ma-pao-kou in Feng-cheng hsien, An-tung province.
Tuan-piao, Fu hsien, Feng-tien province.
Tung-ta-kou, Hsin-ching hsien, Feng-tien province.

At the Ching-cheng-tzu Mine, the metasomatic ore veins, in association with several parallel veins, were found dominantly along with the dikes of diorite porphyrite and porphyrite, which were intruded into dolomite. The largest of the veins had a maximum thickness of 20 m and a length of 400 m, and often contained a small amount of pyrrhotite.

(d) *Lead-copper vein.* This type of vein contains a little more chalcopyrite than the above-mentioned (c). The main localities are as follows:

Su-tzu-ti-lu, Tieh-ling hsien, Feng-tien province.

Ching-cheng-tzu (San-tao-kou), Feng-cheng hsien, An-tung province.

The ore deposit at San-tao-kou was a stockwork deposit in dolomite. It showed a paragenesis of chalcopyrite-pyrite-galena-clacite, and seldom contained quartz as a gangue mineral.

(e) *Lead vein.* It consists mainly of galena, with a small amount of chalcopyrite. The localities are as follows:

Hsiao-tien-tzu-kou, Kai-yuan hsien, Feng-tien province.

Erh-tao-kou of Huang-pai-yu, Pen-chi hsien, Feng-tien province.

Ta-huang-pai-yu, Pen-chi hsien, Feng-tien province.

The deposit of Hsiao-tien-tzu-kou was a quartz vein in gneiss. The thickness of the vein was 1.3 m, and a length 350 m.

(f) *Silver-nickel-cobalt vein.* This type of vein was found only in the vicinity of Mu-chi, Hsin-ching hsien, Feng-tien province. It was a stockwork deposit in alaskite. The veinlet had a thickness of $0.5 \sim 1.3$ m and a length of 200 m. Ore minerals were löllingite, native silver, cobaltite, gersdorffite, erythrite, and arsenolite. A chemical analysis of the high grade ore showed Ag 26.14%, Ni 10.27%, Co 6.77%, As 18.67%, S 7.35% and Bi 0.42%.

A lead-zinc deposit was also found in the same locality, but it was not the same vein.

(g) *Silver vein.* It consists mainly of argenite and native silver, sometimes with a small amount of galena and chalcopyrite. The main localities are as follows:

Tien-pao-shan Mine (Tai-sheng vein), Yen-chi hsien, Chien-tao province.

Cheng-ping Silver Mine (Yen-tung-shan), Cheng-te hsien, Je-hol province.

Chi-lin-kou, Chi-chao-kou, Ta-hei-kou and Chi-jen-kou, Lan-ping hsien, Je-hol province.

Ya-pa-tien, Lung-hua hsien, Je-hol province.

Niu-chuan-tzu, Feng-ning hsien, Je-hol province.

At the Tien-pao-shan Mine, the Tai-sheng vein had a maximum thickness of 5 m and a length of 55 m, and a large amount of native silver, in thin folia, had been found within the oxidized zone which extended from the outcrop to a depth of 70 m below. As stated above, the Cheng-ping Silver Mine had been the largest silver producer of Manchuria. The ore veins in Je-hol were generally narrow fissure-filling veins in granite or gneiss area, of which the biggest one showed a thickness of 3 m and a length of 130 m.

(2) Fluorite vein. As the vein material, it contains fluorite, and a small amount of quartz.

(h) *Lead-fluorite vain.* It is a fluorite vein in granite-gneiss, and is located mainly in the district of Hai-cheng hsien and Kai-ping hsien of Feng-tien province. The main localities are as follows:

Lao-mu-kou, Hai-cheng hsien, Feng-tien province.
Pei-ssu-tao-kou, Kai-ping hsien, Feng-tien province.
Hsiu-yen Mine (Hsi-shan deposit), Hsiu-yen hsien, Feng-tien province.

The deposit of Pei-ssu-tao-kou contained a small amount of chalcopyrite and pyrite. The Hsi-shan deposit of the Hsiu-yen Mine had a width of 2–5 m and a length of over 1 km. The bonanza had a thickness of 5 m, and contained 35–40% fluorite and 2% Pb.

(3) Barite vein.

(i) *Lead-barite vein.* The vein material consists mainly of barite. The main localities are as follows:

Wang-chia-chuang, Chang-ling-ssu-hui, Kuan-tung Leased Territory.
Chien-hsien-shih, Chang-shan-ssu-hui, Kuan-tung Leased Territory.
Kuang-tung-tzu, Chi-an hsien, Tung-hua province.
Wan-pao-kai-tzu, Kuan-tien hsien, An-tung province.

The ore vein at Wan-pao-kai-tzu was found along the contact zone between quartz porphyry and porphyrite. The ore consists of galena, with a little chalcopyrite, pyrite and quartz. The mine was once exploited for copper. The deposit at Kuang-tung-tzu is a lenticular vein in limestone. The vein had a maximum thickness of 12 m and a length of 60 m. The ore consists mainly of galena and barite, accompanied by some chalcopyrite, bornite and zincblende.

Classification can be done according to the above-mentioned method. Meanwhile, Prof. OGURA made classifications of deposits at 75 localities in Manchuria according to the kind of country rocks, in which he separated out the overlapped mineralizations into each individual mineralization type. According to him, the contact-metasomatic deposits were found in 6 localities, the vein-type deposits in limestone in 31 localities, in granite or granite porphyry in 13 localities, in gneiss in 10 localities, in schist in 5 localities, and in the other rocks (quartzite, effusive rocks, etc.) in 12 localities.

B. Mode of Occurrence of the Minerals

Since only a few important deposits were investigated, the minerals described were not so numerous. Descriptions of the ore-forming minerals will be given here under the headings of the ore mineral, the skarn mineral, and the secondary mineral.

1. *The Ore Minerals*

(a) *Galena.* Galena is the principal ore mineral and it ranges in size from a minute granular to a coarse crystal sometimes attaining about 3 cm in diameter.

The so-called schistose galena was often found in the Hsiu-yen Mine. It showed a somewhat reddish luster and is said to have had a high silver content. Gelena from Manchuria was generally considered to be especially higher in silver content in fine grains than in coarser ones, but sometimes fine crystals of argentiferous tetrahedrite were found to constitute a close mixture with galena. The silver content of galena was in proportion to the lead content. Therefore, OGURA (1939), upon inspection of the analysis of 77 samples from various parts of Manchuria, made conversion of the lead content of samples into a lead content of 86.6% or an equivalent to galena, and the silver content was allocated by similar procedure, for comparison with each other. According to this study, the highest figure was shown by the galena from the Tien-pao-shan Mine with 33% Ag, while the majority of cases were between 0.10% and 0.29%.

The galena from the Ching-cheng-tzu Mine was also high in silver content, and so T. TATSUMI (1942) inspected the mode of occurrence of silver in the ore. The result showed that the silver content was fairly proportional to the lead content, or roughly 24.1 gr/ton toward 1% Pb. The ore contained mainly galena and tetrahedrite, and tetrahedrite was found encrusted with galena. TATSUMI calculated that the silver content in galena was equivalent to 16 gr/ton toward 1% Pb, and the silver content in tetrahedrite was estimated as about one-tenth of the copper amount. The results indicated that the galena from Ching-cheng-tzu was about two times higher than that of the preceding results, but there was a still pending problem as to the form and the mode of occurrence of silver in galena.

(b) *Zincblende.* This is also a principal ore mineral, and found in a larger amount than galena. Larger crystals of zincblende were as much as 2 cm in diameter, and they were dominantly of the black variety and rare in the brown variety. (Zincblende from the Kuang-tung-kou Mine in Chuang-ho hsien, Antung province, was brownish in color and transparent.) Drop-like inclusions of chalcopyrite, with a diameter of less than 0.01 mm, are frequently found in the crystal of zincblende. The author found zincblende, in association with greenockite, at the outcrop of the Yang-chia-chang-tzu Mine.

(c) *Pyrite.* Pyrite, often in association with the above two minerals, was found in a larger amount. No information was obtained at the time for the variety belonging to marcasite.

(d) *Chalcopyrite.* This has often been found as an associated mineral with the ore. Irregular and massive chalcopyrite is scattering within the pyrite and galena ore.

(e) *Argentite.* This mineral is very rare in occurrence, and was found only at the Tien-pao-shan Mine of Chien-tao province, and at several spots in Lan-ping hsien, Je-hol province, but we have no reliable written information as to its nature.

(f) *Molybdenite.* Molybdenite was found at the Yang-chia-chang-tzu Mine and the Ching cheng-tzu Mine, as disseminated minute flakes in the skarn minerals. Molybdenite within the fissure was frequently found as dark-colored clayey film. Mill feed grade at the Yang-chia-chang-tzu Mine was about 0.5% MoS_2.

(g) *Arsenopyrite.* It is rare in occurrence. At the Yang-chia-chang-tzu Mine it was found as prismatic crystals 2–3 mm in size, forming stringer or dissemination within limestone. At the Ching-cheng-tzu Mine, the lead-pyrite veins were found to contain argentite and this mineral.

(h) *Pyrrhotite.* Sometimes this was found in the veins, and often also in the contact-metasomatic deposits. The examples are the mines of Yang-chia-chang-tzu, Huan-jen and Ching-cheng-tzu.

(i) *Magnetite.* It has been exclusively found in the contact-metasomatic deposits, but with small amounts. The localities are the Yang-chia-chang-tzu and the Huan-jen Mines.

(j) *Hematite.* Some of the lead-zinc-pyrite veins of the Kuang-tung-ling in Hsiu-yen hsien, An-tung province, contained quartz, chlorite and specularite. If it were micaceous hematite, they would have been considered as similar in nature to the gold- and silver-bearing chlorite-hematite veins in the vicinity of Osarizawa, Akita prefecture, Japan; the latter indicates special characteristics of the Tertiary mineralization in Japan.

2. *Skarn minerals*

Reddish brown garnet, hedenbergite, diopside, epidote, zoisite, tremolite and vesuvianite are the principal contact minerals. At the Ching-chang-tzu Mine, diopside, tremolite, forsterite and phlogopite were found in the country rock of dolomite; and cordierite was found in thermally metamorphosed schist. At the Ching-tsui-tzu Mine in I-tung hsien, Chi-lin province, wollastonite was formed in limestone.

3. *Gangue minerals*

The gangue minerals, of the ore deposits other than the contact-metasomatic deposits, are generally quartz and calcite. Calcite would be especially prominent if the country rock were limestone, and quartz would be the major one if the country rock were other than limestone.

Fluorite and barite are found often as the gangue mineral in association with quartz. Fluorite is violet or green in color, and often forms an octahedron of about 3 cm in diameter. Barite is white and prismatic, showing a fibrous structure. Siderite, in association with quartz, constitutes the gangue of the Hsuan-ling-hou Mine.

4. *Secondary minerals*

The oxidized zone of ore deposit would produce the following minerals.

(a) *Native silver.* Thin foil-like native silver was found in large amounts in the Ta-sheng vein of the Tien-pao-shan Mine, Chien-tao province.

(b) *Cerussite.* The prismatic crystals of about 1 mm in length were found at the Yang-chia-chang-tzu Mine.

(c) *Anglesite.* It was rarely found in the Yang-chia-chang-tzu Mine.

(d) *Hemimorphite.* At the Yang-chia-chang-tzu Mine, it formed white botryoidal aggregates within the veins.

(e) *Pyromorphite.* It has been exclusively found (as the pyromorphite vein in quartzite) in the Kuang-tung-shan area of Hua-tung-kou, Feng-tien province.

(f) *Malachite.*

(g) *Azurite.* Azurite, together with malachite, was encrusted on the surface of chalcopyrite, or found as stringers.

(h) *Gypsum.* It was often found in the deposits in limestone.

C. Succession of Minerals

Although there were no sufficient data as to the succession of ore and gangue minerals, Ogura (1939) summarized the studies that had been made on the deposits of several localities. According to this study, the succession of minerals, from early to later stages, should be as follows:

(1) Pyrite—sphalerite—galena—chalcopyrite—quartz—calcite.
(2) Pyrite—chalcopyrite—sphalerite—galena—quartz—calcite.
(3) Galena—fluorite—quartz.
(4) Barite—galena—quartz and barite (graphic intergrowth).

D. Distribution of the Oxidized Zone

The oxidized zones are poorly developed in general. They are accompanied by only a few secondary minerals. At Yang-chia-chang-tzu, the depth of the oxidized zone was less than 20 m. In the case of Tien-pao-shan, the depth of the oxidized zone within the contact-metasomatic deposit was less than 30 m; in some part of the vein-type deposit it may be as deep as 70 m from the outcrop. Mining of the oxidized zone had never been attempted.

E. Geological and Structural Control of Ore Deposits

In the case of the contact-metasomatic deposit, the development of the skarn zone is controlled by the shape of intrusives, and the high grade part is found as irregular veins or lenses within the skarn zone. In the case of the hydrothermal metasomatic deposit, the metasomatic action might have penetrated sometimes along the bedding plane of limestone, but the deposits appear mainly as pipe-like bodies at the intersection of the fissure systems.

Such deposits are also very irregular in shape, and some of the shapes are hardly explained either by the fissure system or by the structure of country rock, as exemplified well by the spiral pipe-like ore body at the Yang-chia-chang-tzu Mine. Generally speaking, the veins are developed chiefly along the dike-like intrusives, and they generally become metasomatic veins with very little gangue mineral and a remarkably lenticular shape, when they are found within the limestone group. The Ching-cheng-tzu Mine, which was studied by Tatsumi (1942) offered a good example showing abrupt changes for vein development by the nature of country rocks. Namely, the veins were swollen within the dolomite area, but they were sharply pinched upon entering into the schist area, and the galena content was also decreased. In some extreme cases, even the mineral association would be changed sharply; for instance, the lead and zinc vein would be changed into a pyrite-quartz vein or quartz-calcite vein, or might completely disappear. A similar relation is known where the veins have entered from dolomite into dike rocks.

F. Metallogenic Epoch

Plutonic intrusives such as granite or diorite are found frequently within the country rocks of the silver-lead-zinc deposits of Manchuria. Even though there may be no plutonic intrusives within the mining area, a close inspection through the area might often lead to the discovery of some minor intrusives differentiated from them. The acidic plutonic rocks are considered to have the closest relation to the localization of ore deposit. In the eastern area of the southern half of Manchuria, the principal age of the granite intrusions is considered to be the end of Paleozoic, or they might have intruded the Permo-Carboniferous formations and are covered with the Jurassic formation. While, in the western area of the southern half, the ore deposits have been found in schist, quartzite, and andesite; and the igneous activity, with a close relation to the formation of mineral deposit, is considered to be the Yenshan crustal movement of Cretaceous period.

VII. Summary

Silver-lead-zinc deposits in Manchuria show a denser distribution in the region south of the lat. 44°N, and the deposits exploited at the time were dominantly contact-metasomatic deposits. The vein-type deposits occupied nearly 90% of the total known localities, but they were small in scale. Generally the country rocks were dominantly limestone, and sometimes the mineral association showed a sharp change in its character, owing to the change in the nature of country rocks.

Among the silver ore veins, we can find an example of the silver-cobalt-nickel type. Regarding the silver content the galena at the Ching-cheng-tzu Mine showed about two times as much of any known result of the previous studies in Manchuria. The metallogenic age may be around the end of the Paleozoic in the eastern area of the southern half of Manchuria, whereas in the western area the age may be some time at the end of the Mesozoic, although further investigations are still necessary.

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