Banded Iron Ore Deposits of An-shan and Other Districts

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1. An-shan iron ore deposits

A. Location and distribution

The An-shan iron ore deposits is a collective term used to designate the banded iron deposits and associated rich ore deposits widely distributed in an area between An-shan Station and Tang-kang-tzu Station to the south. They occur mainly on the east side of the main line of the South Manchuria Railway. Most of the ores are of low grade, yet these deposits rank as the largest iron deposits in the Far East in size and amount of reserves.

The principal localities of the ore deposits are as follows:

(1) Ying-tao-yuan—Wang-chia-pu-tzu—I-tan-shan area.
(2) Kuan-men-shan—Yen-chien-shan area.
(3) Ta-ku-shan area.
(4) Tung-an-shan—Hsi-an-shan area.
(5) Tieh-shih-shan area.
(6) Hsiao-ling-tzu area.

Of the above six areas, the poor ore (or banded iron ore) of Ta-ku-shan has been worked most widely, but the poor ores of Hsi-an-shan, Tung-an-shan and Yen-chien-shan have also been worked extensively. Rich ore has also been worked at Ying-tao-yuan, Wang-chia-pu-tzu, and Hsiao-ling-tzu.

B. Geology

The iron deposits occur in Pre-Cambrian beds, the larger portion of them in Proterozoic rocks. Since they closely resemble the Huronian iron deposits of the United States in mode of occurrence, age, and properties, they are thought to be Proterozoic at least.

The Proterozoic beds in the An-shan district can be roughly divided into two series; (1) the An-shan series consisting of slightly metamorphosed sedimentary rocks containing iron deposits and (2) the Sinian series resting unconformably upon the former.

The Sinian series has been renamed the Hsi-ho series by Rinji Saito. Its lowermost member, the Tiao-yu-tai quartzite, has been found in many places directly overlying the An-shan series with unconformity.

In addition to the sedimentary and metasedimentary rocks, the An-shan and the Hsi-ho series contain granite which was injected into them during two different periods of the Pre-Cambrian era. The older of these may be the oldest in Manchuria. At Tui-mien-shan of Hsi-an-shan, it is unconformably overlain by metamorphic rocks of the An-shan series and was named the Tui-mien-shan granite by R. Saito.

Since such a relationship exists, there is a strong possibility that the granite is of the same age as the Laurentian granite of North America.

The granite injected in the second period cuts through the An-shan series, and in many cases has captured or enclosed the An-shan beds in large blocks; the peneplain-like degraded surfaces of these rocks is covered by the Tiao-yu-tai quartzite of the Hsi-ho series.

This granite has been named the Kung-chang-ling granite and may be of the same age as the Killarney granite of North America.

(1) Tui-mien-shan granite

At Hsi-an-shan the Tui-mien-shan granite, a gray granite, is overlain unconformably by the An-shan series upon a plane of degradation. By an increase in sericite the granite here grades upwards into a sericite-rich, fine-grained metamorphic rock. This rock, about 10 m thick, is overlain by a thin conglomerate of the An-shan series, which consists mainly of rounded quartz pebbles. Above that, sericite phyllite is generally present. Such a transition of granite indicates that a weathered portion of the granite was metamorphosed. The quartz pebbles within the basal conglomerate consist mainly of vein quartz and may have been derived from the Tui-mien-shan granite itself.

The Tui-mien-shan granite is a grayish, leucocratic rock, a fairly large amount of which has a cataclastic structure. The component minerals are albite or oligoclase and quartz. Microcline is almost completely absent and no mafic minerals are present. It can be classed either as leuco-sodaclase-tonalite or leuco-granodiorite.

A crystalline schist is found within the Tui-mien-shan granite, indicating that there is a still older crystalline schist system. There are many unsolved problems concerning Archean rocks in Manchuria.

(2) An-shan series

The An-shan series is a group of crystalline schists containing a banded, or poor iron ore bed. An unconformity at its base can be observed in some parts and indicates that nearly complete peneplanation followed the large-scale granite injection of the Pre-Cambrian period. The conglomerate may also represent a regolith.

Owing to faulting or injections of the Kung-chang-ling granite, the An-shan series is generally distributed in segmental areas or blocks, so it is very hard to determine the horizons and sequences of the strata. Outcrops exclusively of iron ore are also found in many cases. Generally, they are either deposits associated with metasedimentary rocks or deposits consisting solely of iron ore within granite.

(a) Banded ore deposits associated with metasedimentary rocks:—Such deposits occur at Tung-an-shan, Hsi-an-shan, Ta-ku-shan, Yen-chien-shan, Ying-tao-yuan, and Wang-chia-pu-tzu. The metasedimentary rocks include sericite phyllite, graphite-sericite phyllite, and other such rocks. At Hsi-an-shan and Tung-an-shan, the western end of the distribution area, the deposit strikes approximately eastwest and dips 20°–40° or more to the north. To the east, at Ta-ku-shan, the strike is NW and the dip is about 60° NE. On the eastern fringe, from Ying-tao-yuan to I-tan-shan, the strike is NNW and the dip is more than 60° E. South of the above location, at Hsin-kuan-men-shan and Yen-chien-shan, the strike is nearly E-W and the dip is more than 30° N. From Hsi-an-shan to Yen-ch'ien-shan, alignment is nearly E-W and the dip is to the north. North of the eastern end of Yen-ch'ien-shan, between I-tan-shan and Ying-tao-yuan, the deposit strikes NNW. Thus the beds form a hook with the southern extension 25 km in length and with the eastern deposit fringe 15 km in length.

At Tung-an-shan and Hsi-an-shan, there are developments of sericite phyllite, chlorite phyllite, and graphite-sericite phyllite above and below the ore deposit; those below the deposit are smaller. The phyllites are fine-grained crystalline schists, the principal constituents of which are quartz, chlorite, graphite, sericite, and green mica. Under the microscope the rocks show many microscopic folds and reverse faults; pseudo-cleavage structure is also noticeable.

At Tung-an-shan, some chlorite schist of volcanic origin is found just below the ore deposit and a gritty chlorite phyllite of psammitic origin has also been found in the upper part of the ore deposit. The bedded iron deposit might be taken as one stratum, but detailed observations disclose that it consists of lenses of ore which do not necessarily lie in a single horizon.

At Ta-ku-shan only granite, presumably the Tui-mien-shan granite, appears to underlie the ore, and the phyllite group mentioned above overlies the ore.

At Hsin-kuan-men-shan and Yen-ch'ien-shan two ore beds have been found, of which the lower and principal deposit is underlain by granite, presumably the Kung-chang-ling.

The interval between the lower and upper deposits is occupied by a phyllite bed 200–300 m thick. Part of the phyllite contains an alternation of schistose grit, schistose and conglomeratic grit, and quartzite. The quartzite in some places includes fine-grained iron oxide minerals and iron chlorite. A thick phyllite bed containing schistose grit is found also above the upper ore bed.

Within the area from Ying-tao-yuan through Wang-chia-pu-tzu to I-tan-shan the deposit consists generally of one ore bed; and around Yang-erh-shan, east of Ying-tao-yuan, there is a second ore bed parallel to this bed. Of this area, the northern part has a large amount of injected granite and contains a poor residue of phyllite both above and below the ore bed; but to the south the ore bed is fairly thick. The iron deposit is continuous except for rare spots where it lenses out. Portions of it, however, vary greatly in thickness. Large developments of iron-chlorite schist, iron chlorite-bearing quartzite, and iron-chlorite grit are to be seen in this area just above and below the ore bed. This indicates that there is a genetic connection between the iron chlorite and the banded iron. Moreover, from this it can be inferred that a similar genetic relationship may exist where iron deposits formed after the An-shan series had been deposited.

As stated above, the greater part of the metamorphosed rocks of the An-shan series is metamorphosed pelitic sediment; the smaller part is metamorphosed psammitic sediment. The principal mineral components of the metamorphosed rocks are sericite, chlorite, quartz, and, in many cases, much graphite. The sedimentary facies resembles the Mesabi iron beds of the United States, and there is almost no volcanic material—a bed of the so-called prasinitic rock consisting of actinolite, epidote, and albite intercalated with the ore is found only around Wang-chia-pu-tzu. This material may have been derived from a basic volcanic rock.

Aside from the banded iron ore intercalated within the metasedimentary rocks, some banded iron ore in Manchuria is found in metamorphosed rocks of volcanic origin such as plagioclase-amphibole schists. Generally the deposits in metasedimentary rocks are larger than those in meta-volcanic rocks, which is also true of the deposits in America.

The iron-bearing complex of An-shan is of one of the lowest grades of metamorphism among the iron-bearing formations in Manchuria. Despite this, it is somewhat more highly metamorphosed than the Mesabi beds; and, in general, Manchurian banded iron ore is more intensely metamorphosed than that of the Mesabi Range. Banded iron ore in Manchuria, other than that of An-shan, resembles banded iron ore of the Scandinavian type.

(b) Banded ore deposits in granite:—This type of banded iron ore is usually intruded by granite. Preservation of the other rocks, phyllites for example, indicates that they were shielded by the iron bed from a granite invasion. Where the action of the granite was extremely strong, the phyllites were entirely assimilated, leaving an iron deposit within the granite. At the same time, the deposit was separated into many massive ore bodies owing to the granite intrusion along fissures. The deposit of Hsiao-ling-tzu may be an example of this. Even in such cases the original orientation of the deposit, which appears to have been a vein, is well preserved. This indicates palingenesis, and it is possible that the resistive power to such action would be stronger in case of iron ore. Yang-erh-shan, Tieh-shih-shan near Tang-kang-tzu, and Hsiao-ling-tzu are examples of this. At Hsiao-ling-tzu, the ore is accompanied by metamorphosed rocks which had undergone various granitizations.

(3) Kung-chang-ling granite

This granite has been injected into the An-shan series and is unconformably overlain by the Tiao-yu-tai quartzite bed of the Hsi-ho series. In the Tieh-ling district, R. Saito divided this granite into Hsiang-lu-shan and Hsiao-li-kou granite. However, these two types of granite closely resemble each other, and it is difficult to make correlations between districts without additional special data.

The Kung-chang-ling granite is generally pale purple, leucocratic, and gneissic. A sample from Kung-chang-ling was found to contain 27.3 per cent quartz, 23.6 per cent albite, 6.5 per cent perthite, 41.4 per cent microcline, and 1.2 per cent sericite. It is thus a typical leucogranite; and its microcline is remarkably clear and shows a coarse lattice structure.

The banded iron bed is enclosed in and injected by this granite, but the degree of metamorphism is comparatively low. Locally the granite contains epidote, presumably of primary origin, and seems to resemble the so-called helsinkite. At Wang-chia-pu-tzu the iron ore near the contact has much tourmaline, containing in some instances a large amount of boron.

(4) Tiao-yu-tai quartzite

The rocks of the An-shan series, including the iron bed, and the Kung-chang-ling granite are unconformably overlain by the Tiao-yu-tai quartzite, which is the lowermost bed of the Hsi-ho series. In most places a basal conglomerate 2–3 m thick is present on the plane of unconformity; it is best exposed above the iron bed at An-shan. The basal conglomerate here consists chiefly of quartzite pebbles and banded iron ore, like that of the underlying ore bed. This indicates that the metamorphic action terminated before the conglomerate was deposited. Moreover, pebbles of rich ore are found in the conglomerate, so that the rich ore must also have been formed prior to the deposition of the Hsi-ho series.

The quartzite is a type of quartz sandstone consisting mainly of quartz sand. For the most part its cementing material also is quartz, but in many instances it is hematite; locally the rock is a payable iron ore. Most of the sand grains are round, especially those near the basement, but there are also many angular pebbles. In view of these features it is likely that this bed was formed under desert conditions.

C. Ore deposits

1. *Descriptions of the ore deposits*

(1) Tung-an-shan and Hsi-an -shan

These deposits lie about one km south of Chien-shan Station and form an east-trending range which the railway line crosses. The Hsi-an-shan deposit occurs in four separate mounds or hilltops, the most eastern of which is the longest—700 m. The beds in the eastern hill are about 40 m thick, strike N60°–70°W, and dip 40° N. The deposit in the western hilltop has a strike of N 30° W and a dip of 30° N; it is about 70 m thick and about 600 m long. Farther west at a location in the saddle, the deposit lies directly below the Tiao-yu-tai quartzite and is exposed for about 100 m. It strikes east and dips about 40° N.

In the Tung-an-shan deposit, the bed at the western end, which faces the An-shan River, strikes N 30° W and and dips 50°–80° NE. It is 1000 m long and 30–45 m thick; at the eastern hilltop the thickness is 100 m. East of that hill and beyond the saddle, the deposit strikes approximately east and extends for 400 m. After an interval the bed reappears and extends for about 300 m farther east, but the deposit becomes narrow and seems to taper out at the east end.

The deposits at the above two places are poor in magnetite. They are banded ore which consists mainly of hematite and quartz and which has a high iron content in comparison with other An-shan ore deposits. Hence both have been worked to obtain poor ore. The rich ore deposits at the boundary between the banded ore deposit and the underlying phyllite were worked during the initial stages of the An-shan Mine operation, but they have been almost entirely exhausted.

Production of the poor iron ore toward the end of the war was 800,000 tons (33% Fe) at Tung-an-shan and 200,000 tons (38% Fe) at Hsi-an-shan, a yearly total of 1,000,000 tons.

(2) Ta-ku-shan

Ta-ku-shan is located about 12 km southeast of the city of An-shan to which it is connected by a tramway for transportation of the ore. The stratigraphic succession, in descending order, is as follows:

		Thickness
	Tiao-yu-tai quartzite bed	
	unconformity	
An-shan Series	Coarse-banded, low grade iron bed ———	scores of meters
	Phyllite bed (mainly sericite phyllite) ——	about 300 m
	Phyllitic magnetite-grunerite schist ———	scores of meters
	Fine quality banded iron bed	200–250 m
	unconformity?	
	gray gneissose granite	

Only the iron bed of the lowest horizon is workable. It strikes northwest and dips more than 70° NE; it has a length of about 800 m and forms hills 170 m high. A northeast-trending granodiorite porphyry dike, about 60 m thick, traverses the ore bed at the central part and bisects it.

The ore from the northwestern half belongs to a type consisting primarily of hematite (mainly martite), magnetite, and quartz. The ore from the southeastern half consists mainly of magnetite and quartz but contains a considerable amount of cummingtonite-grunerite amphibole, and often actinolite and calcite. The ore can be readily split into flakes and may be easily crushed.

At Ta-ku-shan there were vein-like or bed-like rich ore bodies traversing the iron ore bed, but they have been exhausted. At present only open-pit mining of the poor ore is being carried on. During the war, 2,000,000 tons averaging 36 per cent iron was produced annually.

(3) Kuan-men-shan, Hsin-kuan-men-shan, and Yen-chien-shan

Kuan-men-shan is located about 7 km east of Ta-ku-shan and the iron deposit extends for about 5 km farther east. The ore beds strike approximately east and dip steeply to the north. The ore deposit consists of two main beds and minor lenses scattered within the interval between the two main beds. The stratigraphical succession, in descending order, is as follows:

	Tiao-yu-tai quartzite bed	Thickness
	unconformity	
An-shan Series	Green phyllite Schistose grit, and quartzite (several meters) Green phyllite, sericite phyllite	more than 30 m
	Coarse banded iron ore, and quartzite	
	Green phyllite, sericite phyllite with intercalated quartzite, and banded iron ore bed	200–300 m
	Narrow-banded fine quality iron bed	60–90 m
	unconformity	
	gneissose granite (injection?)	

Of the above, the lowest banded ore bed usually consists of quartz, hematite, and magnetite. However, at Yen-chien-shan this banded iron ore bed contains amphibole, iron chlorite, and ankerite and has been profitably worked because of a high iron content. The amphibole is grunerite or cummingtonite; the chief iron oxide mineral is magnetite.

Annual production of Yen-chien-shan during the war was 150,000 tons (35% Fe).

(4) Ying-tao-yuan, Wang-chia-pu-tzu, Hu-chia-pu-tzu, and I-tan-shan

From I-tan-shan, which is about 3 km north of Kuan-men-shan, to Ying-tao-yuan, which is about 12 km northeast of An-shan Station—a distance of about 12 km—the iron deposit is in continuous exposure. It consists of one iron bed.

At Ying-tao-yuan and Wang-chia-pu-tzu, massive, or bedded, rich iron ore is enclosed within the ore bed or within the iron-chlorite bearing rock close to the ore bed. The iron formation strikes roughly north-northwest, and dips steeply to the east or west. The rocks other than the iron bed are primarily green phyllite and sericite phyllite. East of the iron bed there are numerous quartzite beds, and one or two quartzite beds are found to the west.

The iron formation, both in the east and west, is in contact with the Kung-chang-ling granite, by which it was injected. The granite at the contact becomes gneissose, with jointing generally parallel to the schistosity of the iron formation.

East of Ying-tao-yuan at Yang-erh-shan, there is an isolated banded-iron deposit not associated with phyllite but enclosed in granite. The deposit has a fairly long extension.

The iron ore usually consists of hematite, magnetite, and quartz. The thickness of the ore deposit varies greatly. At Wang-chia-pu-tzu the thickness ranges from 140 to 170 m, which is the prevailing thickness range of the thicker iron deposits of other localities. However, these beds, like those at Ying-tao-yuan, may in part be duplicated by thrust faults.

The iron bed is accompanied by iron-chlorite bearing rock above and below, and at Ying-tao-yuan it is associated with thuringite schist.

The rich ore is being worked mainly at Ying-tao-yuan and Wang-chia-pu-tzu. The rich ore of Ying-tao-yuan forms small lenticular ore bodies within thuringite schist and consists mainly of massive magnetite or martite.

At Wang-chia-pu-tzu the rich ore occurs as a bed-like deposit along the boundary between the banded iron ore and the iron-chlorite bearing rock. The rich ore consists of iron-chlorite, magnetite, quartz, ankerite, etc. According to mineral composition, it is analogous with the banded iron ore of Yen-chien-shan. In some portions, it contains a large amount of schörlite. The thickness of the rich iron deposit ranges between 0.3 and 0.4 m.

A portion of the rich ore at I-tan-shan is a brecciated ore vein which obliquely cuts the banded ore deposit. This may be caused by the leaching of silica by hydrothermal action along the fault zone.

(5) Tieh-shih-shan

At Tieh-shih-shan 1.5 km west of Tang-kang-tzu Station, the iron ore deposit is found within the gneissose granite in a nearly bed-like form. The deposit strikes northeast, and dips from 50° NW to an almost vertical position. The ore bed has a thickness of 15 m and length of about 300 m. The banded iron ore of the bed consists of hematite, magnetite, and quartz. A rich hematite ore occurs sporadically.

(6) Hsiao-ling-tzu

The ore bed of Hsiao-ling-tzu is located 4–6 km southeast of Tang-kang-tzu Station. The ore deposit, of nearly bedded form, is found within the Kung-chang-ling granite. According to underground observations, this granite was injected along the fissures of the ore deposit. However, the Cretaceous Chien-shan granite may have been injected in part along the same course. The ore bed strikes east, and dips 40°–50° N.

The blocks of the separated ore bed are arranged in a series of low hills about 100 m high. West to east these are Ti-tan-shan, Ting-chia-shan, Ta-wai-tzu-shan, Shuang-ling-tzu, Tsai-chia-fen, and Chang-kang-shan. The total length of the bed is 2,600 m and the thickness is 5–30 m. In addition, several other ore beds have been confirmed by prospecting by means of trenches and drill tests.

The ore deposit has been intensively affected by granitization. Above and below the deposit there is friable plagioclase-blue green hornblende-fels. Migmatitic granite is also found in quantity.

In addition to magnetite, hematite, and quartz, the iron ore generally contains blue-green hornblende and actinolite. The composition of ore varies greatly and diopside, or salite, calcite, spinel and other minerals are present in some sections. At Chang-kang-shan there are ores which are in various stages of transition from banded to rich ore (with about 50% Fe), and scattered occurrences of rich ore. The rich ore, other than magnetite, consists predominantly of diopside, iron-rich olivine, and spinel, and some portions contain anthophyllite. It may be considered the thermal metamorphic rock of a rich ore of the Wang-chia-pu-tzu type.

Because of the transportation factor, only rich ore in this deposit was worked extensively. The average grade for annual production was an iron content of 50 per cent, and the reserves of rich ore were said to be about 50,000 tons.

2. *Descriptions of ores*

Like other banded iron ore deposits in Manchuria, the ore of the An-shan deposits can be divided into "poor" and "rich" ores.

The poor ore is an ordinary banded iron ore, generally 20–40 per cent iron, which makes up the larger part of the ore deposit. Characteristically its banding is well-developed, like similar ores in other countries.

Macroscopically, the structure can be classified into various types, and the distribution of the ores can also be separated into zones in accordance with the classification.

First, a classification by the coarseness of the banded structure can be made. An iron ore with hardly any banded structure, or an ore which appears a nearly homogeneous steel-gray, was once named hornfels-like ore by the author. This type is often seen in ores consisting solely of hematite and quartz, and the grain of the iron oxide minerals is fine. However, some banding can be observed under the microscope.

Then there are some finely and regularly banded iron ores, with each thin layer varying in thickness from 0.5 to 2.0 mm. The author named this type finely-banded ore. At Tung-an-shan there is a bed-like deposit of ore about 10 m thick which consists only of this type; the ore shows an unbroken alternation of bands of quartz laminae, and bands of hematite and quartz laminae. However at Ta-ku-shan and, to some extent, at Yen-chien-shan there are variegated alternations of laminae of magnetite, hematite, and quartz; laminae of iron oxide minerals, grunerite and quartz; and laminae of iron oxide minerals together with intercalations of quartz laminae. Such ore is especially predominant in the high grade banded iron ore. In addition, a banded ore formed of an alternation of iron oxide mineral and iron chlorite laminae, quartz laminae and quartz and iron oxide laminae has been found at Ho-shan-chuang-tzu.

The author named banded iron ore with bands as thick as 0.2–1.0 cm, or sometimes 2.0 cm, coarse banded ore. In such ore, most of the quartz laminae are considerably thicker than the laminae of quartz and iron-oxide mineral. Accordingly the grade of iron should be about 21–22 per cent. Banded ore of this type is usually found as a thick bed, either above or below the fine banded ore, or as a single ore bed. Tung-an-shan and Hsi-an-shan are fine examples of the former, and Hsin-kuan-men-shan (or La-tzu-shan) of the latter.

In view of the value of ore, working banded ore which contains amphibole, or cummingtonite-grunerite, should be the most profitable because this ore is easily milled, is of high grade, and has a high magnetite content. Ta-ku-shan and Yen-chien-shan contain ore of this type.

Next in value is the fine-banded ore consisting of hematite and quartz. This has a grade ranging from 33 to 38 per cent iron in contrast to the ore just discussed which contains about 36 per cent iron; the high percentage of hematite makes it necessary to use a reductive roasting process. It has the objectionable quality of stiffness. The poor ore from Tung-an-shan and Hsi-an-shan is an example of this type.

The banded iron ore is a crystalline schist showing stable mineral facies which vary according to the degree of metamorphism. In the An-shan district the degree of metamorphism is generally low and most of the amphibole found there is either fibrous cummingtonite-grunerite or tremolite-actinolite. Iron chlorite and ankerite are also found in it. Among the iron-oxide minerals, ore with amphibole and iron chlorite is high in magnetite content. It has been assumed through petrographic studies that the larger part of magnetite is derived from siderite. If we leave aside the question of origin, the An-shan ore may be analogous to the Mesabi ore because of the degree of metamorphism. However, it contains more calcium oxide and aluminum oxide than the Mesabi ore and the existence of primary grunerite has not been proved. The granular structure common in Mesabi ore was noted in tailings from Yang-erh-shan, near Ying-tao-yuan.

The rich ore may have been derived from various sources. It is worked mainly at Ying-tao-yuan and Wang-chia-pu-tzu; at both of these places the ore reserves are at the one million ton level. The ore is obtained by underground mining. Annual production at the end of the war was 50,000 tons (60% Fe) from Ying-tao-yuan and 50,000 tons (50% Fe) from Wang-chia-pu-tzu.

The rich ore of Ying-tao-yuan is found as lenses and masses within the thuringite schist, which is intercalated between the beds of banded iron ore. The ore consists of either magnetite or martite. Due to the presence of Kung-chang-ling granite, the thuringite schist contains tourmaline and phengite-like muscovite. Nevertheless, the forerunner of granitization by granitic magma should be the presence of silica, alumina, and alkali minerals, and its end phase should be the formation of blue-green hornblende-plagioclase-fels, as in the cases of Hsiao-ling-tzu and Ying-tao-yuan, from the iron ore and thüringite-schist. Neither local migration of iron, nor local leaching of silica can be taken as the origin of the rich ore. The rich ore should be interpreted as an altered form of the lenticular ore bodies of either siderite or ankerite which were primary deposits in the thüringite-schist.

The rich ore of Wang-chia-pu-tzu occurs as a bedded deposit with an iron content of 50 per cent within the iron chlorite-bearing banded iron ore lying at the eastern margin of the banded iron bed. It consists mainly of ore containing ankerite, iron chlorite, magnetite, quartz, and considerable tourmaline. The iron content, 50 per cent, corresponds to that of the black iron-bearing laminae which are found in the banded iron ore, and the mineral composition is also the same as that of some of the black iron-bearing laminae. Therefore, if we assume that such portions could only have been deposited separately, we can possibly explain its origin.

The appearance of tourmaline in the ore should be an indication that the boron of magmatic origin became fixed under a chemical condition most favorable for the combination. The rich ore of Hsiao-ling-tzu could be considered a metamorphosed rock of the type of the rich ore of Wang-chia-pu-tzu.

The rich ores that have been formed at the lower part, or within the iron ore bed at Hsi-an-shan and Tung-an-shan, are probably of secondary origin. They occur as massive deposits in veins and, in some places, are brecciated. The origin of these ores might be attributed to partial migration of iron content, resedimentation, or leaching of silica. These ores are already almost exhausted.

3. *The grade of ore and the ore reserves*

According to an estimate made about 1940, the ore reserves (positive) and the average grade of ore were as follows:

Name of deposit	Positive ore reserves (t)	Average grade of ore (Fe %)	Number of samples
Ta-ku-shan	84,900,000	36.45	440
Tung-an-shan	148,200,000	32.10	799
Hsi-an-shan	46,700,000	26.62	426
Ying-tao-yuan	37,900,000	31.34	453
Wang-chia-pu-tzu	118,200,000	25.74	1,077
Pai-chia-pu-tzu	66,400,000	24.50	1,348
I-tan-shan	93,300,000	25.92	944
Kuan-men-shan	19,500,000	32.32	379
Hsin-kuan-men-shan	30,000,000	30.00	-
Hsiao-ling-tzu	500,000	-	-
Tieh-shih-shan	300,000	-	-
Total:	646,000,000		

Magnetic prospecting has confirmed the supposition that banded iron ore should continue to a considerable depth under the valley level. If an estimate of ore reserves were extended to 50 m below the valley level, the positive and probable ore reserves would be increased at least three times. Because of transportation costs and restrictions on mining, the ores with 35–36 per cent iron and those located above the valley level have been worked primarily. On the other hand, some fairly high grade ores, like those of Ta-ku-shan and Yen-chien-shan, have shown a considerable loss of iron into the tailings. This may be due to the effect of ferrous silicates such as thüringite in the ore; a study of the effective iron in the ore should be carried out in the future.

2. Banded iron deposits of other districts

We have given a detailed description of the iron deposits of An-shan, which we selected as representative of the banded iron deposits in Manchuria. They form one of the largest iron ore deposits in the Far East. There are many similar deposits of various sizes, e.g. Wai-tou-shan, Kung-chang-ling, Miao-erh-kou, Chiao-tou, and Li-shu-shan; but because of transportation and mining costs, only the iron ores of the An-shan deposits are being worked.

Banded iron ore is a crystalline schist, but the ores in other locations are more highly metamorphosed than the An-shan ore. The banded iron ores are classified according to mineral composition and the degree of metamorphism.

They may be divided into two groups according to mineral composition. Group

A consists mainly of quartz and iron oxides like hematite and magnetite. It is found either in association with group B, or grading into B, or as an independent bed; but in all cases, due to the low degree of metamorphism, mineralogical changes are almost lacking.

Group B is found to contain various minerals in addition to those of group A. The majority are iron-rich silicate minerals. Moreover, because of the degree of alteration, the variations of mineral combinations are great, a factor similar to that existing in metamorphosed basic rocks.

The four facies into which banded ores can be classified according to degree of metamorphism are as follows:

Type No. 1 *Iron chlorite banded iron ore.* This facies contains either carbonate minerals or iron chlorite or both. In addition fibrous cummingtonite, or grunerite, is also contained in much of the rock, according to the composition and mode of occurrence. This may be the banded iron ore with the lowest degree of metamorphism in Manchuria, and the grains of the iron oxide minerals are the smallest in size. The ores of Ta-ku-shan and Yen-chien-shan are excellent examples.

Type No. 2 *Amphibole banded ore.* This type ore consists chiefly of quartz, iron oxide minerals, and amphiboles. The amphiboles are not fibrous. The iron-bearing silicates are limited almost entirely to the amphiboles. Some portions of the rock consist entirely of amphiboles. Of the amphiboles, three varieties—the cummingtonite-grunerite system, diopside-actinolite system, and blue-green hornblende—are the most prevalent.

In addition, glaucophanic amphibole and pargasite are found in some parts. Ore of this type can be correlated with the so-called amphibolite facies, comparatively high in degree of metamorphism and found in many localities, e.g. Wai-tou-shan, Li-shu-shan, Kung-chang-ling, and Chiao-tou.

Type No. 3 *Pyroxene banded iron ore.* This type of iron ore consists chiefly of quartz, iron oxide minerals, and pyroxenes. The country rock is the migmatitic gneiss. The pyroxenes include hedenbergite and rhombic pyroxenes. The latter ranges in composition from iron-hypersthene to orthoferrosilite, but the pyroxene with about 90 per cent $FeSiO_3$, eulite, is most common. Generally both varieties of pyroxenes are found in association, but it is not known in what ratio the varieties occur. Occurrences of ore of this type are not common. Ma-ho-ssu in the vicinity of Fu-shun is the best example of this facies.

Type No. 4 *Eulysite.* This type generally shows a chemical composition similar to that of the banded iron ore, but it frequently lacks iron oxide minerals. The principal components are fayalite, iron-hypersthene-orthoferrosilite, and hedenbergite. Minute amounts of quartz are present in some portions. This ore is sometimes found in pyroxene-banded iron ore, and is likely to be enclosed within migmatitic gneiss as small masses. Generally it has a high aluminum oxide content, and feldspar is often found with it. It is formed where the effect of granitization is strong. With greater granitization, fayalite and hedenbergite disappear and almandite appears. In the opinion of the author, eulysite may thus be changed into almandite-eulysite and with further granitization may become lepidomelane-fels. This type is rarely found in Manchuria. The deposits of Ma-ho-ssu, Wang-chang-tzu of Jehol, and Yu-hsi-kou of Antung are among the best examples.

There is no great difference between the genetic condition of the rich ore deposits and that of An-shan.

Important rich deposits are those at Kung-chang-ling, and Miao-erh-kou.

The deposit at Kung-chang-ling is the largest in Manchuria. It is a lenticular deposit found in iron-chlorite schist and forms a shoot of considerable extent along the ore course. The estimated positive ore reserves are about 40,000,000 tons, and the sum of probable and possible reserves may be as much as 170,000,000 tons.

The rich ore deposit of Miao-erh-kou is a lenticular ore bed in the amphibole-banded iron ore. It contains cummingtonite and has a rather low degree of metamorphism. It is a magnetite ore with carbonate minerals, iron chlorite, anthophyllite, mica, and other minerals. The ore reserves have been estimated at more than 2,000,000 tons.