553.32 (521.12)

Geology and Manganese Deposits of the Kunohe Area, the North Kitakami Mountains

Morimasa Yoshii*

Abstract

The Triassic to Jurassic Iwaizumi Group composed of eugeosynclinal sediments accompanying mafic volcanics occur in the Kunohe area of the Iwaizumi belt, the North Kitakami Mountains. The Iwaizumi Group is divided into six formations: the Kisawahata Formation, the Magidai Formation, the Sawayamagawa Formation, the Akka Formation, the Seki Formation and the Kassemba Formation in ascending order. They are all conformable in the area.

The Magidai anticline lies at the central part of the area and trends north-northwest in parallel to the direction of the major structure of the Iwaizumi belt. Thickness of the formations is much more on the eastern limb of the anticline than on the western limb, with the exception of the Kassemba Formation distributed only on the western limb. Volume of the mafic volcanics is also much larger on the eastern limb of the anticline than on the western limb.

Bedded manganese deposits occur mostly in the Seki Formation which is characterized by the abundance of chert among the formations of the group. In most cases they occur conformably in chert beds. Massive chert is mostly found in the footwalls of manganese deposits and is rather rare in the hanging walls. Bedded chert, on the other hand, occurs in both the hanging walls and the footwalls, but occurs rather in the former than the latter.

The manganese deposits of the area are classified on the basis of the constituent ore minerals into three types: the braunite-ore deposits, the carbonate-ore deposits and the silicate-ore deposits.

The braunite-ore deposits occur mostly on the eastern limb of the Magidai anticline corresponding to abundance of mafic volcanics. The carbonate-ore deposits are distributed mostly on the western limb of the anticline where the mafic volcanics are rare. The silicate-ore deposits are situated within hornblende isograd of hornfels caused by early Cretaceous granitic intrusions.

Major manganese mineralization of the area is thought to have been mainly at the stage of sedimentation of the Jurassic Seki Formation. The braunite-ore deposits and the carbonate-ore deposits, especially the former, are thought to have been formed with genetic relation to mafic volcanism. In early Cretaceous some of the manganese deposits were thermally metamorphosed into the silicate-ore deposits by the granitic intrusions.

1. Introduction

Nearly one hundred bedded manganese deposits occur in the Kitakami Mountains, Iwate Prefecture, Northeast Japan. This area has been recognized one of the most important areas for manganese resources in Japan, together with such other areas as Hokkaido, Kwanto, Hida, Tamba and Shikoku. The production of manganese concentrates from the Kitakami Mountains up to 1971 was 840,000 tons with the average grade of 33 percent

* Mineral Deposits Department

Mn for metallic manganese and 44,000 tons with the average grade of 72 percent MnO_2 for manganese dioxides.

Most of the smaller manganese mines of this area have, however, been closed down during the past several years, and at the begining of 1977 only four mines are in operation: Noda-Tamagawa, Hijikuzu, Fujikura and Otaniyama.

Although the geology of the South Kitakami Mountains has been studied by many geologists since NAUMANN's (1881) discovery of the Triassic systems in this area, geology of the North Kitakami Mountains has remained unknown for a long time with the exceptions of the Cretaceous and the Paleogene systems near Kuji, Iwate Prefecture. A brief history of geological studies of the Kitakami Mountains after World War II may be summarized as follows.

MINATO (1950) showed the difference of lithology between the southern half and the northern half of the Kitakami Mountains. YAMASHITA (1957) noted the ultramafic rocks at the boundary of the southern half and the northern half of the area and named the boundary the Hayachine-Goyosan tectonic line, now called the Hayachine tectonic belt (Fig. 1). KANO (1958) showed the occurrence of the Mesozoic geosynclinal sediments along the northeastern end of the Kitakami Mountains and named the area the Kitakami marginal belt, now called the Taro belt.

In the Kamaishi area, between Kamaishi and Miyako of Iwate Prefecture, YOSHIDA (1961) and YOSHIDA and KATADA (1964) studied the lower Permian Kamaishi Formation in which many bedded manganese deposits occur. YOSHIDA (1968) divided the North Kitakami Mountains into three belts: the North Kitakami, the Iwaizumi, and the Taro belts.

SHIMAZU *et al.* (1970) studied the geology of the southern part of the Iwaizumi belt and named the eugeosynclinal sediments the Iwaizumi Formation. Afterward it was re-defined to be the Iwaizumi Group (Fig. 2). SUGIMOTO (1969; 1972; 1974) described the details of the Iwaizumi Group of the Iwaizumi belt and the Rikuchu Group of the Taro belt.

ONUKI (1956; 1969) reviewed the geology of the Kitakami Mountains. YOSHIDA (1975) reviewed the history of the development of the Paleozoic and Mesozoic geosyn-clines of Northeast Japan and redefined the division of the Kitakami Mountains as follows: the South Kitakami belt, the North Kitakami belt, the Iwaizumi belt and the Taro belt.

Descriptive studies on Japanese manganese deposits and manganese ore-minerals have been carried out by YOSHIMURA (1938; 1939; 1952; 1953; 1967; 1969; and others), LEE (1955), WATANABE (1957; 1959), HIROWATARI (1961; 1967; 1968; and others), HIRO-WATARI and TAKEDA (1962a; 1962b) and many other mineralogists and mining geologists.

On the manganese deposits in the Kitakami Mountains, M. NAMBU has been carring out a series of extensive descriptive studies since 1950's and published many excellent reports on the manganese deposits of the area. They were summarized by NAMBU, TANIDA and KUMAGAI (1969) and NAMBU *et al.* (1973). He carried out also minera-logical studies on the manganese ores and discovered several new manganese minerals (NAMBU and TANIDA, 1967; NAMBU, TANIDA and KITAMURA, 1969).

SUZUKI *et al.* (1962; 1963) studied the manganese deposits of the Kunohe area. OMORI *et al.* (1952) studied the mineralogy of the Himegamori deposit in the Kunohe area. TAKAHASHI (1961) studied the Otaniyama deposit of the North Kitakami belt.

The Noda-Tamagawa deposit which is the largest in the Kitakami Mountains was studied in detail (LEE, 1955; MIYAMOTO and ISHIDA, 1957; SATO *et al.*, 1957; WATANABE, 1959; WATANABE *et al.*, 1960; WATANABE *et al.*, 1961; WATANABE *et al.*, 1970b).

The geneses of the following bedded manganese deposits have been discussed in some detail: the Miocene deposits in Southwest Hokkaido (YOSHIMURA and SASA, 1935) and Inner Zone of Northeast Japan (MORITANI, 1963; 1964; 1967), and the "Paleozoic" deposits in the Ashio Massif of Central Japan (WATANABE, 1957; WATANABE *et al.*, 1957) and in the Tamba belt of the Inner Zone of Southwest Japan (IMOTO, 1966; RESEARCH GROUP OF THE TANBA BELT, 1969).

Geologic data are of prime importance in the genetic study of ore deposits. It was felt by the present author some years ago that the past knowledge on geology and manganese deposits in the Kitakami Mountains were insufficient to understand the geologic conditions pertaining to the mineralization of this important manganese ore field. A systematic study of geology and ore mineralogy of the Iwaizumi belt was thus planned, and the area vicinity of Kunohe was chosen, since nearly fifty bedded manganese deposits had been known to concentrate in the area. The area investigated comprises Karumai Town Ono, Yamagata and Kunohe Villages of Kunohe County, Iwate Prefecture. Geologically it is located at the northern end of the Iwaizumi belt.

The present paper summarizes the author's geological field work and underground survey of manganese deposits in the area and the mineralogical studies of collected specimens. Particular emphases will be given in discussion of the main stratigraphic horizon of the bedded manganese deposits and the geologic conditions for the manganese mineralization of the Kunohe area.

Acknowledgments

The author is most grateful to Dr. Fumitoshi HIROWATARI, Dr. Haruo SHIROZU and Dr. Kametoshi KANMERA of Kyushu University; Dr. Hitoshi MOMOI of Ehime University; Mr. Takashi YOSHIDA, Dr. Masato KATADA and Dr. Yoshihiko SHIMAZAKI of Geological Survey of Japan for much guidance and encouragement in the course of the study. Many thanks are due to Mr. Shoshiro OIKAWA and Mr. Susumu KUMAGAI of Iwate Prefecture for helping the author's field and underground work. Analytical work by Mr. Kenjiro MAEDA, Mr. Norio TONO and Mrs. Minako TERASHIMA and many thin sections prepared by Mr. Masaji ABE and Mr. Masaharu SATO, all in the Geological Survey of Japan, are gratefully acknowledged. Finally the author thanks very much again Dr. HIROWATARI and Dr. SHIMAZAKI for critically reading the manuscript and giving valuable suggestion, without whose kind guidance this work would not have taken this shape.

2. The General Geology and Manganese Deposits of the Kitakami Mountains

2. 1 Geology

The Kitakami Mountains are located near the northeastern end of Honshu. The area covers 11,000 km^2, being 250 km long in north-south direction and 80 km wide, and one fourth of it is occupied by early Cretaceous granitic intrusions. The rest of the area consists mainly of Silurian to lower Cretaceous sediments. Cenozoic system occurs in restricted parts.

Geologically the Kitakami Mountains are divided into four belts: the South Kitakami, the North Kitakami, the Iwaizumi, and the Taro belts (YOSHIDA, 1975). The Hayachine tectonic belt lies bounded by faults between the North Kitakami and the South Kitakami belts with maximum of 10 km in width (YOSHIDA and KATADA, 1964). The North Kitakami, the Iwaizumi, and the Taro belts are bounded by major faults named the Kuzumaki and the Taro tectonic lines (SHIMAZU *et al.*, 1970). These belts are shown in Fig. 1.

The South Kitakami belt consists mainly of Silurian to Permian geosynclinal sediments and Mesozoic neritic to littoral sediments. The Paleozoic formations consists of limestone, sandstone and slate, but have no chert. They generally show rather the marginal sedimentary facies in the Chichibu geosyncline. Volcanic rocks are rare except in the lower Devonian and lower Carboniferous formations. Manganese deposits are not found in this belt.

The Hayachine tectonic belt is made up largely of mafic volcanic rocks and sediments. The rocks in the tectonic belt are divided into the Carboniferous Kogawa Formation and the lower Permian Kuribayashi Formation in the Kamaishi area between Kamaishi and Miyako (YOSHIDA, 1961; YOSHIDA and KATADA, 1964).

The Kogawa Formation is composed mainly of mafic volcanic rocks intercalated with early Carboniferous limestone. It appears that the formation lies nearly between the North Kitakami and the South Kitakami belts as a barrier to the Permian geosynclines of both belts.

The Kuribayashi Formation is composed mainly of sandstone, tuffaceous sandstone, slate and thin lenticular chert. They show the marginal facies of the North Kitakami eugeosyncline (YOSHIDA, 1975).

The formations in the tectonic belt were intruded by ultramafic intrusions of various sizes. The formations are traceable along the trend as far as near Morioka from the Kamaishi area (YOSHIDA and KATADA, 1964).

The North Kitakami belt consists of lower to middle Permian eugeosynclinal sediments composed mainly of chert, slate and sandstone associated with small amounts of mafic volcanic rocks and limestone. The sediments show a typical sedimentary facies of the Chichibu geosyncline.

In the Kamaishi area the lower Permian Kamaishi Formation (YOSHIDA and KATADA, 1964) and the middle Permian Hanawa Formation (ONUKI and KUDO, 1954; KATADA and YOSHIDA, in preparation) occur. These formations consist of chert, slate and sandstone associated with limestone. Chert is abundant in the formations. Manganese deposits develop in this area, showing close association with chert.

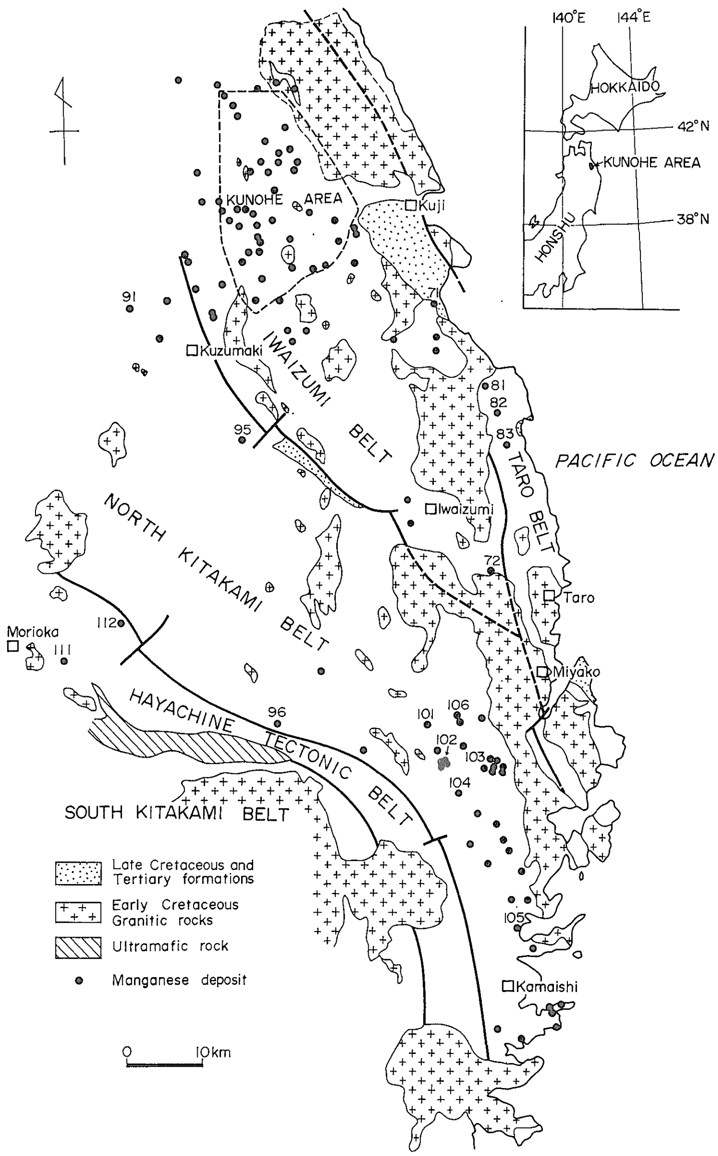
In the Kuzumaki area, 50 km northwest of the Kamaishi area, the Permian Kuzumaki Formation occurs (IWAI *et al.*, 1964). This formation is made up largely of phyllitic slate, slate, chert, lavas and tuff. Mafic volcanic rocks occur abundantly near the Fujikura manganese deposit, north of Kuzumaki.

The Iwaizumi belt consists mainly of Triassic to Jurassic eugeosynclinal sediments of the Iwaizumi Group (SHIMAZU *et al.*, 1970). The sediments of the group are rich in coarse materials compared with those in the North Kitakami belt. The group is composed mainly of slate, chert, sandstone, conglomerate, limestone and mafic volcanic rocks.

Limestone is well-developed forming the Akka limestone in the eastern part of the belt.

The Iwaizumi Group in the Kunohe area where many manganese deposits occur will be described in the following chapter (3. 1. 1).

The Taro belt consists mainly of the upper Jurassic to lower Cretaceous Rikuchu Group composed mainly of sandstone, slate and chert associated with andesite and dacite (SUGIMOTO, 1969; 1972). The Magisawa Formation is rich in chert and contains several manganese deposits.



71. Noda-Tamagawa 72. Hijikuzu 81. Mitsune 82. Akedo 83. Tanohata
91. Fujikura 95. Toyaba 96. Torii 101. Moichi 102. Toyomane
103. Daiichi-Fukushi 104. Otaniyama 105. Ozuchi 106. Hanawa
111. Tonaka 112. Kumanosawa

Fig. 1 Distribution of manganese deposits in the Kitakami Mountains.

Early Cretaceous granitic rocks intruded into the formations of each belt stated above. K-Ar age of the intrusions is 105–129 m.y. (KAWANO and UEDA, 1965; SHIBATA and MILLER, 1962). Lithologically they are trondhjemite, granodiorite and quartz diorite (KATADA, 1974). They caused thermal metamorphism of the formations in the belts.

2. 2 Manganese deposits

In the Kitakami Mountains manganese deposits occur in all of the belts except the South Kitakami belt. Distribution of the manganese deposits in the Kitakami Mountains is shown in Fig. 1. The manganiferous formations are shown in Table 1.

The manganese deposits are concentrated mostly in the lower Permian Kamaishi Formation of the Kamaishi area and the Jurassic Seki Formation of the Kunohe area: About thirty workable deposits have been known in the former, and nearly fifty in the latter.

Several deposits occur in the middle Permian Hanawa Formation of the Kamaishi area, the Permian Kuzumaki Formation of the Kuzumaki area and the upper Jurassic Magisawa Formation of the Taro belt. In the Hanawa Formation the Hanawa and several other deposits occur. In the Kuzumaki Formation the Fujikura, the Toyaba and several other small deposits are distributed sporadically (NAMBU, KONNO and KUMAGAI, 1967; NAMBU *et al.*, 1967a). In the Magisawa Formation the Tanohata, the Mitsune and the Akedo deposits occur (ABE and MURAMATSU, 1963; NAMBU, 1959; NAMBU *et*

Table 1 Manganese-bearing Formations in the Kitakami Mountains.

Age	Hayachine tectonic belt	North Kitakami belt		Iwaizumi belt (Kunohe area)	Taro belt
		Kamaishi area	Kuzumaki area		
Cretaceous					Rikuchu Group: Harachiyama F. Otomo F.
Jurassic				Iwaizumi Group: Kassemba F.* Seki F.** Akka F. Sawayamagawa F. ?	Rikuchu Group: Koshimeguri F. Magisawa F.*
Triassic				Iwaizumi Group: Magidai F.* Kisawahata F.*	
Permian	Kuribayashi F.*	Hanawa F.* Kamaishi F.**	Kuzumaki F.*		
Carbon-iferous	Kogawa F.*				

* Formations with several manganese deposits.
** Formations with abundant manganese deposits.

al., 1966).

A few deposits occur also in the Hayachine tectonic belt near Morioka. In the formation correlated to the carboniferous Kogawa Formation the Tonaka deposit occurs accompanied by many small bedded iron deposits whose constituent is hematite ore (TANIDA and SASAKI, 1965; NAMBU *et al.*, 1959; 1960; 1961; OKADA and KUMAGAI, 1960). In the formation correlated to the lower Permian Kuribayashi Formation, the Kumanosawa deposit is found (NAMBU and SASAKI, 1965).

In the Kitakami Mountains almost all of the manganese deposits are of bedded type. They are concentrated in chert-rich formations such as the Kamaishi Formation and the Seki Formation.

In this paper the manganese deposits are classified into three types on the basis of their major constituent ores: the braunite-ore deposits, the carbonate-ore deposits and

Table 2 Dimensions of Manganese Ore-bodies in the Kitakami Mountains.

	Length				Thickness		Number of ore body
	Strike side		Dip side				
	M.	S.	M.	S.	M.	S.	
North Kitakami belt							
Kamaishi area	50m	44m	57m	56m	1.7m	1.3m	31
Kuzumaki area	50	45	32	14	1.2	0.7	9
Iwaizumi belt							
Kunohe area	52	47	47	34	0.8	0.8	57
Taro belt	34	14	37	26	1.5	0.7	8
Kitakami Mountains	49	44	46	37	1.1	1.0	105

M: mean value, S: standard deviation.

Table 3 Production of Manganese Concentrates in the Kitakami Mountains.

	Metallic ore		Dioxide ore		Metal content	
	Quantity (m ton)	Grade (%)	Quantity (m ton)	Grade (%)	Quantity (m ton)	Ratio (%)
Hayachine tectonic belt	900	37	1,200	73	900	0
North Kitakami belt						
Kamaishi area	160,700	31	700	65	50,900	17
Kuzumaki area	37,000	30	300	73	11,300	4
Iwaizumi belt						
Kunohe area	114,200	38	41,400	73	63,200	21
Noda-Tamagawa mine*	475,300	34			160,300	54
Hijikuzu mine	41,200	16			6,500	2
Taro belt	14,200	33			4,600	2
Total	843,500	33	43,600	72	297,700	100

* Data were from Shin-Kogyokaihatsu Co. Ltd. Other data were derived from NAMBH, TANIDA and KUMAGAI (1969) and NAMBU *et al.* (1973).

the silicate-ore deposits. These types of the manganese deposits may correspond respectively to he "Tomisato-type", the "Manako-type" and the "Kaso-type" deposits of YOSHIMURA (1952). The former two types correspond to the "type-B" and the "type-A" deposits of WATANABE *et al.* (1970a). The details of these three types of deposits will be stated in the following chapter (3. 2. 3).

The statistics for the dimensions and the production of the manganese deposits in the Kitakami Mountains are shown in the following lines. The figures were derived mainly from the data by NAMBU, TANIDA and KUMAGAI (1969) and NAMBU *et al.* (1973).

The average dimensions of the manganese deposits in each area of the Kitakami Mountains are shown in Table 2. The average length of the deposits of the Kitakami Mountains is 49 m in strike direction and 46 m in dip direction. The average lengths in the both directions are thus nearly the same. The average thickness is 1.1 m.

Production of the manganese concentrates in each area is shown in Table 3. More than half of the production in the Kitakami Mountains is from the Noda-Tamagawa deposit. The Kunohe area comes next to it in the production.

3. Manganese Deposits of the Kunohe Area

3. 1 Geology

The studied area, named the Kunohe area in this paper, is located 70 km northeast of Morioka. The area extends 27 km long in north-south direction and 22 km wide and contains a number of manganese deposits.

Geologically, the area is situated in the northern part of the Iwaizumi belt. The major geologic units of the area are the Iwaizumi Group and early Cretaceous granitic intrusions. Neogene formations with mafic to intermediate intrusive rocks and Quaternary diluvial and alluvial sediments have limited extents. Quaternary volcanic ashes and falls derived from the Hakkoda and the Towada volcanoes cover the area widely.

The geology of the Kunohe area is shown in Fig. 2.

3. 1. 1 Iwaizumi Group

In the Kunohe area the Iwaizumi Group consists of the following six formations in ascending order: the Kisawahata, the Magidai, the Sawayamagawa, the Akka, the Seki and the Kassemba Formations. They are thought to be conformable with each other in the area (YOSHII and YOSHIDA, 1974), though in the south of the area an unconformity has been reported between the Magidai Formation and the Sawayamagawa Formation (SUGIMOTO and UDA, 1972). Several other formations belonging to the Iwaizumi Group, the Takayashiki, the Otori and the Osakamoto Formations, have not been found in the area.

The stratigraphic sequence of the area is shown in Table 4.

The Kisawahata Formation occurs along the axis of the Magidai anticline which lies at the central part of the area. This formation is made up largely of chert and slate at the southern part of the area and intercalates thin beds of chert, limestone, sandstone and mafic tuff in small amounts in the northern part, the north side of the Kawai fault.

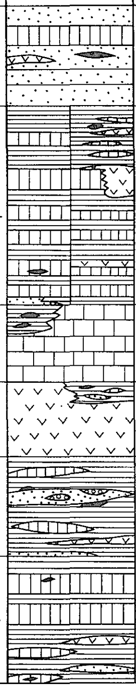
Slate is dark gray to black.

Numbers refer to manganese deposits: 1. Imoya, 2. Numabukuro, 3. Tsunagi, 4. Aratama, 11. Kohare, 12. Yamato, 13. Tengu, 14. Takamatsu, 15. Yanosawa, 19. Shimizugawa, 21. Kannon, 23. Takamine, 24. Kogarumai, 25. Taiho, 26. Otai, 27. Kotamagawa, 28. Ono, 29. Goto, 30. Funakozawa, 31. Tachikawa, 32. Hokushin, 37. Yamani, 38. Kunohe, 39. Ohata, 40. Yamagata, 41. Yokochi, 42. Kitakami, 43. Hokuei, 44. Hinosawa, 45. Kawai, 46. Daini-Asahi, 47. Takinosawa, 61. Kayatai.

Fig. 2 Geology of the Kunohe area.

Table 4 Stratigraphy of the Iwaizumi Group in the Kunohe Area.

Age	Formation	Thickness (m)	Column	Rock facies	Deposits
Jurassic	Kassemba	1000+		Coarse to medium sandstone with chert and slate.	Mn
Jurassic	Seki	2500+		Northeastern part: slate, chert, volcanics and red chert. Southwestern part: chert and slate with limestone.	Mn abundant
Jurassic	Akka	100–800		Limestone, partially with chert.	
Jurassic	Sawayamagawa	0–700		Mafic lavas, breccias and tuff with pillow lavas.	
Triassic	Magidai	250–1000		Slate, sandstone, conglomerate, volcanics, chert and limestone.	Mn
Triassic	Kisawahata	1500+		Slate and chert with volcanics, sandstone and limestone.	Mn



Chert is light gray to dark gray and bedded or massive. It grades into siliceous slate in some cases.

Sandstone is bluish gray and coarse- to fine-grained. It contains irregularly shaped black pelitic fragments of up to several centimeters long. The sand grains are mainly feldspar and quartz.

This formation is about 1,500 m thick in the area.

The Magidai Formation is distributed on both limbs of the Magidai anticline and conformably lies on the Kisawahata Formation.

The lithology is mainly sandstone, slate and small amounts of chert, conglomerate and limestone. Mafic tuff is abundant on the east limb of the anticline.

Sandstone is light gray to dark gray, coarse- to fine-grained and massive. It contains black pelitic fragments of up to 1 cm in diameter. In some cases sandstone beds alternate with slate showing graded bedding.

Chert is gray and bedded. It includes fossils of radiolaria in its unmetamorphosed parts.

Conglomerate occurs as lenses in the sandstone beds. It is 1–5 m thick. Pebbles of the conglomerate are chert, siliceous slate and limestone of up to 3 cm in diameter.

Limestone is gray to dark gray. The limestone beds are 2–3 cm thick. They contain late Triassic conodonts (MURATA and SUGIMOTO, 1971).

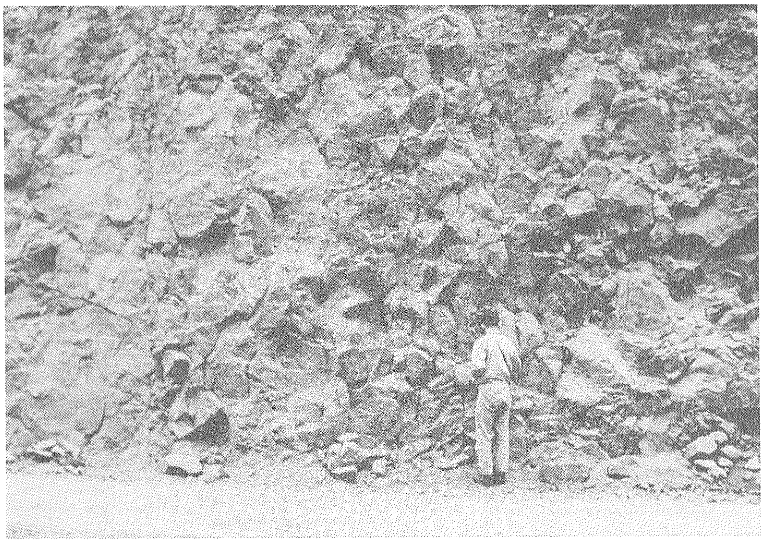


Fig. 3 A pillow lava of the Sawayamagawa Formation. At Kayamori along the Kuji river.

This formation is 1,000 m thick on the eastern limb of the Magidai anticline and 250 m thick on the western limb.

The Sawayamagawa Formation is underlain conformably by the Magidai Formation. This formation occurs on both limbs of the Magidai anticline and is well-developed at the south-eastern part of the area.

The formation is composed mainly of basalt flows with pillow lavas, auto-brecciated lavas, tuff and volcanic conglomerate. The pillow lava is shown in Fig. 3.

This formation is 700 m thick on the eastern limb of the Magidai anticline and 100 m on the western limb.

The Akka Formation is underlain conformably by the Sawayamagawa Formation. This formation occurs on both limbs of the Magidai anticline.

The formation consists mainly of limestone which is well-developed on the eastern limb of the anticline. This limestone is northern extention of the Akka limestone. On the western limb the limestone thins out on the north side of the Kawai fault and is associated with slate and chert at the northern end. The limestone beds alternate with chert in some places.

Limestone is white, gray and dark gray with bluish tint. It is more or less recrystallized by thermal metamorphism. The unmetamorphosed part is dark colored and rarely includes fossils of hexacoral, sponge and calcareous algae. At Izurumachi *Thecosmilia*? sp. and *Solenopora* sp. occur in the lenticular limestone (YOSHII and YOSHIDA, 1974).

This formation is 800 m thick on the eastern limb of the Magidai anticline and 0–100 m thick on the western limb.

The Seki Formation is underlain conformably by the Akka Formation. It occurs also on both limbs of the Magidai anticline. This formation is characterized by exclusively dominant chert among the Iwaizumi Group. Lithology of the formation differs on both limbs of the anticline.

On the eastern limb of the anticline, lower part of the formation consists mainly of slate, chert and mafic volcanic rocks. The upper part of the formation comprises alternation of slate, sandstone, chert and mafic tuff.

Chert is red, gray and dark gray. It is bedded or massive. Tuffaceous films of several millimeters thick are intercalated in the bedded chert every 3–15 cm. Red chert is abundant in this part of the area and encloses manganese deposits in many cases. Several well-developed chert beds containing the major manganese deposits are traceable for several kilometers and are interfingered with mafic volcanics at the northern end of the area.

Slate is dark gray to black and in some cases purple red and greenish gray. In many cases it is phyllitic. A dark-colored slate bed whose whethered color is notably light greenish-brown is traceable for several kilometers as a key bed.

Sandstone is dark gray to gray, coarse- to medium-grained and massive. It is composed mainly of quartz and feldspar in various ratios, and contains small pelitic fragments. Each sandstone bed is up to 30 m thick.

Limestone is gray to light gray with bluish tint. It is more or less recrystallized by thermal metamorphism. No fossils have been found in it. It occurs as lenses of up to 20 m thick.

Mafic volcanic rocks are composed mainly of basalt lavas and tuff. They are greenish gray to dark green and purple. In many cases they are up to 20 m thick and usually alternate or interfinger with chert and slate. The tuff beds are traceable for several kilometers in some cases.

The mafic volcanic rocks are well-developed at the northern end of the area and is thought to have a close relation with the manganese mineralization in this formation.

On the western limb of the anticline the formation is made up largely of chert and slate associated with small amounts of sandstone, limestone and mafic tuff.

Chert is gray to dark gray. Red chert is rare. The chert is bedded to massive and grades into siliceous slate in many cases.

Slate is dark gray to black. It is siliceous in many cases and is rarely phyllitic.

Sandstone is dark gray to gray, medium-grained and massive. It is composed mainly of quartz and feldspar. It occurs near Kawai.

Mafic tuff is rare and mafic lava is not found. It occurs near the Yamagata deposit at Hinosawa. It is greenish gray.

Thickness of this formation is 2,500 m on the western limb of the Magidai anticline and seems to be thicker on the eastern limb than on the western limb, though the exact thickness is unknown on the eastern limb.

The Kassemba Formation is underlain conformably by the Seki Formation. This formation occurs at the southwestern end of the area on the western limb of the Magidai anticline.

The formation consists mainly of sandstone associated with small amounts of chert, slate, limestone and mafic tuff.

Sandstone is gray to bluish gray, coarse- to medium-grained and massive. It is composed mainly of quartz and feldspar, and it contains pelitic fragments.

Chert is gray to light gray. Chert beds occur at the southwestern end of the area and enclose the Kayatai deposit.

Limestone is gray. It occurs as thin beds overlain by the chert beds.

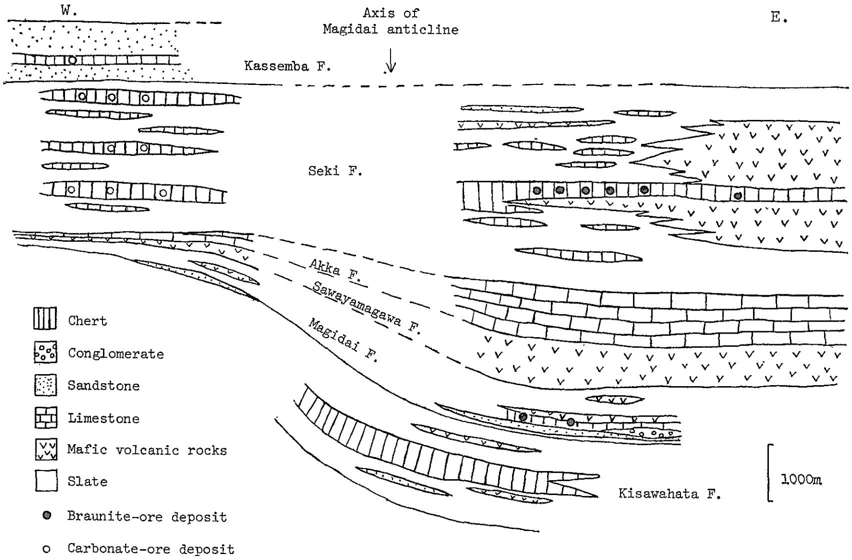


Fig. 4 Schematic cross-section of the Iwaizumi Group in the Kunohe area.

This formation is at least 1,000 m thick though the exact thickness is unknown in the area.

A schematic cross-section of the Iwaizumi Group in east-west direction is shown in Fig. 4. It shows that the approximate thickness of these formations excluding the Kassemba is much more on the eastern limb of the Magidai anticline, and the volcanics are abundant also on the eastern limb.

3.1.2 Intrusive rocks

Early Cretaceous granitic rocks intruded in the Kunohe area. They are called the Hashikami, the Numabukuro, the Heromachi, the Ushigasawa, the Okubo and the Hiraniwa intrusive bodies (Yoshii and Katada, 1974).

The Hashikami body is the largest in the area. It crops out 20 km long in north-south direction and 12 km wide at the northeastern end of the area. Lithologically it is granodiorite to trondhjemite containing idiomorphic hornblende and biotite with porphyritic texture.

The Hiraniwa body is the second in size. It crops out for a length of 14 km in north-south direction and 2 km in width at the southwestern end of the area. It intruded at the southwestern end of the area. It is granodiorite associated with monzonitic diorite and monzonitic gabbro, and the rock facies varies considerably.

Other intrusive bodies are small, 1–3 km in north-south direction and 0.5–1 km east-west direction, and occur sporadically in the area. The lithology of the Numabukuro body is quartz diorite and granodiorite. The Okubo body consists of gabbro and allied rocks with layered texture.

These igneous activity caused a contact metamorphism on the Iwaizumi Group. Biotite isograd of the hornfels lies about 5 km from the Hashikami body and 1–3 km from other intrusions. Hornblende isograd lies near 2 km from the intrusions. These intrusions were also responsible for the pyrometasomatism of the manganese deposits, which will be discussed later.

Small intrusive bodies of basalt and andesite occur at several localities in the area. Some of them are arranged linearly along a fault in the southwestern part of the area. They crop out as much as 500 m or less in diameter. The lithology of the intrusions varies considerably: augite-hypersthene andesite, hypersthene-augite quartz porphyrite and pyroxene-olivine basalt. It is probable that they were formed by the Neogene volcanic activity prevailing outside the area.

3. 1. 3 Geologic structure

The general strike of the formation of the Iwaizumi Group is N.15°–60°W. in the area. The apparent structure is monoclinic, but it is quite complicated by folding and faulting as shown in Fig. 5. Two outstanding foldings were distinguished. They are the Magidai anticline and the Mawatari syncline. Their axes trend north-northwest and plunge southward at low angles.

Major strike faults in the area are the Oitai fault and Kogarumai fault. The Oitai fault is an anticlinal fault along the Magidai anticline. The Kogarumai fault is a synclinal

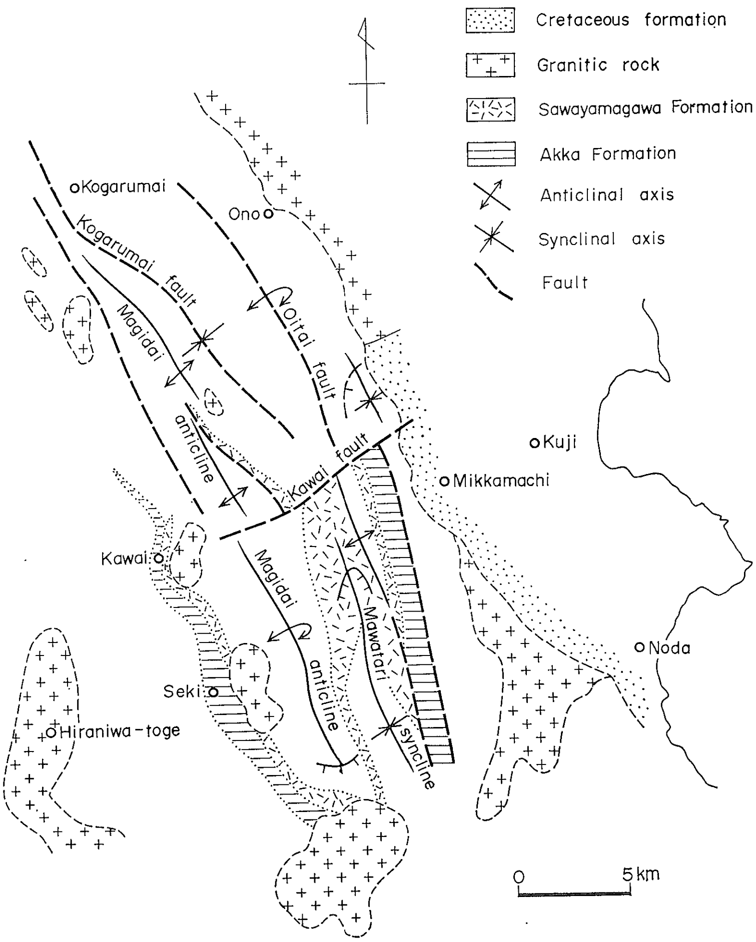


Fig. 5 Geologic structure of the Kunohe area.

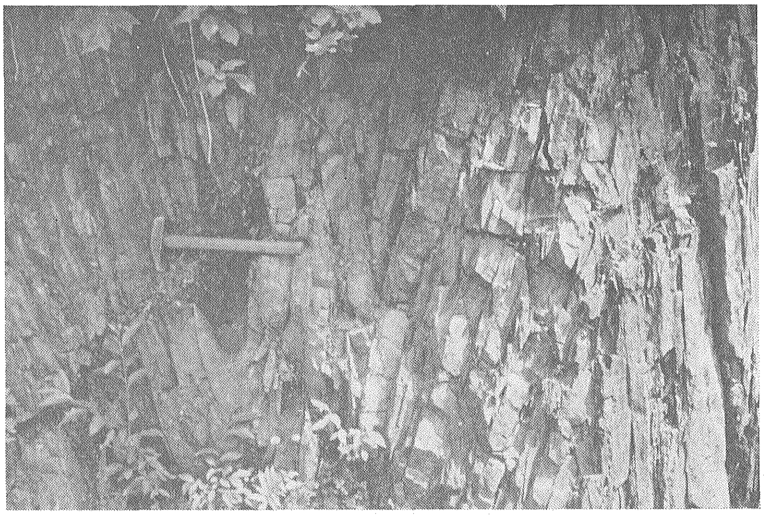


Fig. 6 Bedded chert with minor folding.

fault along the Mawatari syncline. The Kawai and the Nemori faults are major dip faults.

The formations are overturned on the east side of the Sawayamagawa fault near Sawayama and between the Magidai anticline and the Takanarizawa fault near Tengu in view of the structure of pillow lavas and grading of sandstone beds. These faults are shown in Fig. 2.

Minor foldings are observed in chert beds in many places and rarely in slate beds. They have wavy or zig-zag forms turning every several meters as shown in Fig. 6. Axes of the minor foldings trend generally northwest-southeast direction and plunge southward on the eastern limb of the Magidai anticline, while they trend east-west direction and plunge westward on the western limb. Plunge of the minor folding ranges from 5° to 70° with the average of 30°.

3. 2 Manganese Deposits

Nearly fifty manganese deposits have been known in the Kunohe area. Distribution of the deposits is shown in Fig. 7. Dimensions of the deposits are shown in Table 5. Stratigraphic horizons, productions and types of the deposits are shown in the following sections.

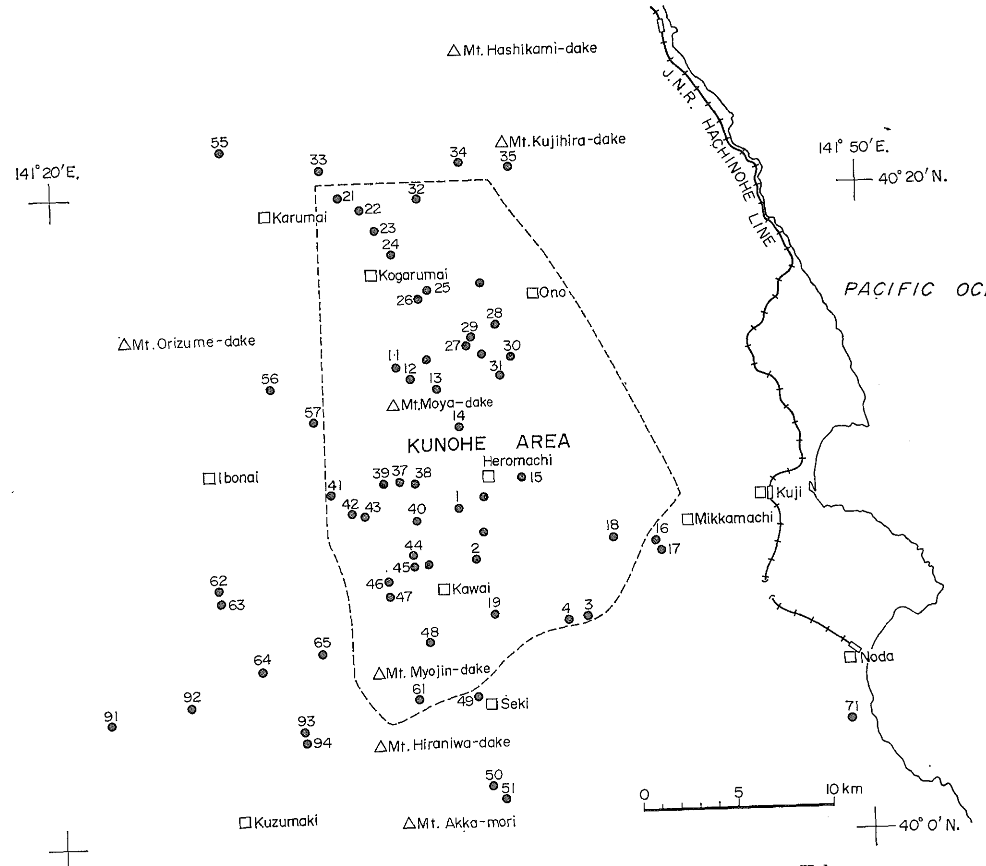
3. 2. 1 Stratigraphic horizons

In the Kunohe area manganese deposits occur in the Kisawahata, the Magidai, the Seki and the Kassemba Formations of the Iwaizumi Group.

In the Kisawahata Formation several small deposits occur: Imoya, Numabukuro, Aratama and Tsunagi.

In the Magidai Formation there occur Kohare, Tengu, Yamato, Takamatsu, Yanosawa, Mikkamachi, Makado, Tsuboana and Shimizugawa. Major deposits are Takamatsu and Yanosawa. The deposits except Shimizugawa occur on the eastern limb of the Magidai anticline. Kohare and Tengu are in the same chert bed.

Many deposits occur in the Seki Formation. On the eastern limb of the Magidai anticline they are Kannon, Takamine, Kogarumai, Taiho, Otai, Kotamagawa, Ono,



1. Imoya 2. Numabukuro 3. Tsunagi 4. Aratama 11. Kohare
12. Yamato 13. Tengu 14. Takamatsu 15. Yanosawa 16. Mikkamachi
17. Makado 18. Tsuboana 19. Shimizugawa 21. Kannon 22. Omaki
23. Takamine 24. Kogarumai 25. Taiho 26. Otai 27. Kotamagawa
28. Ono 29. Goto 30. Funakozawa 31. Tachikawa 32. Hokushin
33. Nagakura 34. Himegamori 35. Kujihira 37. Yamani 38. Kunohe
39. Ohata 40. Yamagata 41. Yokochi 42. Kitakami 43. Hokuei
44. Hinosawa 45. Kawai 46. Daini-Asahi 47. Takinosawa 48. Misawa
49. Seki 50. Oguni 51. Toyokuchi 55. Myoho 56. Hosoya
57. Oyukiya 61. Kayatai 62. Sainokami 63. Kurano 64. Okami
65. Taki 71. Noda-Tamagawa 91. Fujikura 92. Itamachiya 93. Nabekura
94. Unagisawa

Fig. 7 Distribution of manganese deposits in the Kunohe area.

Funakozawa, Tachikawa, Hokushin and Nagakura. Major deposits are Kotamagawa and Funakozawa. Several deposits are in the same chert beds: Kogarumai, Taiho and Goto; and Otai, Kotamagawa and Tachikawa.

On the western limb of the anticline there occur Yamani, Kunohe, Ohata, Yamagata, Yokochi, Kitakami, Hinosawa, Kawai, Daini-Asahi, Takinosawa, Misawa, Oguni, Toyokuchi, Hosoya and Oyukiya. Major deposits are Yokochi, Hinosawa, Kawai and Oguni. Several deposits are in the same chert beds: Yamani and Kunohe; Ohata and Yamagata, Hinosawa and Kawai; Kitakami and Hokuei; and Daini-Asahi and Takinosawa.

Several deposits occur in the Kassemba Formation. They are Kayatai, Sainokami, Kurano, Okami and Taki. Sainokami and Kurano are in the northwestern extention of the formation outside the area.

Table 5 Dimensions and Wall Rocks of the Manganese Ore-bodies in the Kunohe Area.

Deposit	Length (m) Strike	Dip	Thickness (m)	Footwall	Hanging wall
Kisawahata Formation					
Imoya	5—23		0.1—0.4	bd-ch	bd-ch
Numabukuro	5—45		0.2	bd-ch	bd-ch
Tsunagi	20?		0.2—0.3	ms-ch	sl
Magidai Formation					
Kohare	40		0.2—1	ms-ch	slt-tf
Yamato	5—10		1	ms-ch	bd-ch
Tengu	40—50		0.1	ms-ch	ms-ch
Takamatsu	170	70	0.4—1.5	ms-ch	pr-bd-ch
Yanosawa	30	44	1	sl, ms-ch	r-bd-ch
Mikkamachi	15			bd-ch	bd-ch, ms-ch
Makado	20		0.4	r-ms-ch	bd-ch
Tsuboana	10		1>	bd-ch	bd-ch
Shimizugawa	20	20	0.3—2.5	bd-ch	bd-ch
Seki Formation (northeastern part)					
Kannon	60		0.1—0.5	r-ms-ch	r-ms-ch
Omaki	20		0.7—1	bd-ch	bd-ch
Takamine	100	60	0.5—1	r-bd-ch	r-bd-ch
Kogarumai	80	60	0.3	r-bd-ch	r-bd-ch
Taiho	20		0.5—0.8	r-ms-ch	bd-ch
Otai	50—60	20—30	0.3—0.4	bd-ch	bd-ch
Kotamagawa	50—100	100	0.5—1	r-bd-ch, ms-ch	r-bd-ch
Ono	30?	20?	1	r-bd-ch	r-bd-ch
Goto	60		0.3	r-bd-ch	r-bd-ch
Funakozawa	200	130	0.5—1	r-ms-ch	tfc-bd-ch
Tachikawa	30	90	0.5—1.5	bd-ch, r-sl	bd-ch, r-sl
Nagakura	3—8		0.1	r-bd-ch	r-bd-ch
Himegamori			1	ch	ch
Seki Formation (southwestern part)					
Yamani	10—15		0.7>	bd-ch	bd-ch
Kunohe	6		0.4—1	bd-ch	bd-ch
Ohata	60—90	60	0.3—0.6	bd-ch, ms-ch	bd-ch
Yamagata	90		0.1—1	pr-bd-ch	pr-bd-ch
Yokochi	220	80	2	bd-ch, ms-ch	bd-ch
Kitakami	35	30	0.1—2	ms-ch	bd-ch
Hokuei	10>		0.1>	bd-ch	sl
Hinosawa	70—90	40—60	1.2	pr-ms-ch	bd-ch, ms-ch
Kawai	100	110	2	pr-bd-ch	bd-ch
Daini-Asahi	16		0.1—0.5	bd-ch, ms-ch	bd-ch, ms-ch
Takinosawa	20—30		0.4—0.7	ms-ch, bd-ch	bd-ch
Misawa	40		0.3—0.7	bd-ch	bd-ch
Oguni	90	90	0.1—2	bd-ch, ms-ch	ms-ch
Toyokuchi	40—70	80	0.1—1.5	bd-ch	bd-ch
Oyukiya	40		1	ms-ch	ms-ch
Kassemba Formation					
Kayatai	100?		1.5	bd-ch	bd-ch
Sainokami	70—120	100	1>	bd-ch, ms-ch	bd-ch
Kurano	60	30		bd-ch, ms-ch	bd-ch, ms-ch
Okami	30	90	0.5	bd-ch, ms-ch	bd-ch
Taki	70—100	40	0.3—0.6	bd-ch	sl, bd-ch, ms-ch

ch: chert, sl: slate, tf: tuff, slt: silty, tfc: tuffaceous, bd: bedded, ms: massive, r: red, pr: partly red.

3.2.2 Productions

Productions of the manganese concentrates from the Kunohe area are shown in Table 6. The statistics for the productions were derived from the data by NAMBU, TANIDA and KUMAGAI (1969).

Table 6 Production of Manganese ores from the Kunohe Area.

a) Production of ore concentrates from deposits in each formation.

Deposit	Metallic ore		Dioxide ore		Period of working
	Quantity (ton)	Average grade for Mn (%)	Quantity (ton)	Average grade for MnO_2 (%)	
Kisawahata Formation					
Numabukuro	250	?			1942—1945
Tsunagi	100	?			1941—1942
Total	350	?			
Magidai Formation					
Kohare	1,350	38	200	74	1943—1967
Tengu			2,000	?	1937—1945
Takamatsu	16,200	36			1938—1962
Yanosawa	800	40			1955—1958
Mikkamachi	300	30			1955—1958
Makado	350?	?			?
Tsuboana	2,000?	?			1940?
Shimizugawa	2,300	27			1964—1966
Total	23,300	35	2,200	74	
Seki Formation (northeastern part)					
Kannon	400*	?	1,000**	73	* ? —1945 **1964—1967
Takamine	350	48	1,050	70	1938—1962
Kogarumai	700	49	350	80	1943—1960
Otai	300	29	350	75	1961—1966
Kotamagawa	7,900	45			1935—1968
Ono	1,750	46	200	75	1939—1945
Funakozawa	9,700	41			1957—1968
Tachikawa	4,700	41	1,800	78	1937—1968
Sub-total	25,800	43	4,750	75	
Seki Formation (southwestern part)					
Kunohe	500?	?			?
Ohata	3,200	41			1939—1953
Yamagata	200	31	400	68	1958—1963
Yokochi	12,400	33	1,500	76	1952—1963
Kitakami	50	33	100	66	1959—1962
Hinosawa	17,450	42	2,300	76	1933—1967
Kawai			23,900	71	1940—1961
Takinosawa	1,150	44	5,200	75	1937—1961
Misawa	500?	?			1937— ?
Oguni	9,700	38			1937—1962
Toyokuchi	3,000 800	? 35			1940—1950 1958—1960
Hosoya	1,000?	?			1939?
Oyukiya	6,000?	?			? —1945
Sub-total	55,950	38	33,400	72	
Total	81,750	40	38,150	73	
Kassemba Formation					
Sainokami	2,650	37			1956—1962
Kurano	200*	42	200**	80	*1943—1945 **1962—1966
OKami	850	31	600	70	1958—1962
Taki	5,050	35	250	72	1944—1967
Total	8,750	35	1,050	72	

The data were derived from NAMBU, TANIDA and KUMAGAI (1969).

Table 6 (Continued).
b) Ratios of manganese metal produced from each formation.

Formation	Quantity (ton)	Ratio (%)
Kisawahata	100	0
Magidai	9,200	14
Seki	50,300	80
Kassemba	3,500	6
Total	63,200	100

The total manganese concentrates produced from the area by 1971 were 114,000 tons of metallic ore with the average grade of 38 percent Mn and 41,000 tons of oxide ore with the average grade of 73 percent MnO_2. The metal content is 63,000 tons. The production is 21 percent of the total output from the Kitakami Mountains.

In the area the manganese ores were produced mostly from the Seki Formation. By 1971 the manganese concentrates from this formation were 82,000 tons with the average grade of 40 percent Mn and 38,000 tons with the average grade of 73 percent MnO_2, being equivalent to 80 percent of the total manganese metal produced from the area.

From the Magidai Formation 23,000 tons (average 35 percent Mn) and 2,000 tons (average 74 percent MnO_2) were produced. They are 14 percent of total manganese metal from the area.

From the Kassemba Formation 9,000 tons (average 35 percent Mn) and 1,000 tons (average 72 percent MnO_2) were produced, being 6 percent of the production from the area.

3.2.3 The braunite-ore deposits

The manganese deposits of the Kunohe area and the vicinity are classified into three types on the basis of the major constituent ore: the braunite-ore deposits, the carbonate-ore deposits and the silicate-ore deposits.

The braunite-ore deposits are distributed mostly on the eastern limb of the Magidai anticline. Takamatsu and Yanosawa (all in the Magidai Formation), Kannon, Omaki, Takamine, Kogarumai, Taiho, Otai, Kotamagawa, Ono, Goto, Funakozawa and Tachikawa (all in the Seki Formation) belong to this type. On the western limb of the anticline only Yamagata is of this type.

Distribution of the braunite-ore deposits coincides with that of mafic volcanics. On the eastern limb of the Magidai anticline the mafic volcanics occur in abundance as shown in Figs. 2 and 4. Though they are rare on the western limb of the anticline, the Yamagata deposit is accompanied exceptionally by mafic tuff.

The deposits of this type consist mainly of braunite ore. Several deposits, Takamatsu, Yanosawa and Yamagata, contain varying amount of carbonate ore in addition to the main braunite ore.

The braunite ore is iron black with submetallic luster and very fine-grained. It usually forms bands with red chert (Plate 12–1, 2).

The deposits are characteristically accompanied by red chert which contains fine-grained hematite. The thickness of each red chert is usually about 2 m and in some cases up to 10 m. In the Kotamagawa deposit it shows especially bright red within 2 m from

Table 7 Manganese and Iron Contents of Chert.

Sample	Average (%)		Number
	MnO	Fe_2O_3	
a) Red chert in the braunite ore deposits*			
In ore bodies	2.846	1.331	10
Within 1 m from ore bodies	0.678	2.147	31
Over 1 m from ore bodies	0.196	0.978	34
Having no ore bodies	0.233	1.227	6
b) Chert outside of manganese deposits			
White chert	0.026	0.41	12
Red chert	0.124	1.43	8
Black chert	0.121	1.74	20

Analyst: Norio TONO. * Kannon, Taiho, Otai, Funakozawa and Tachikawa.

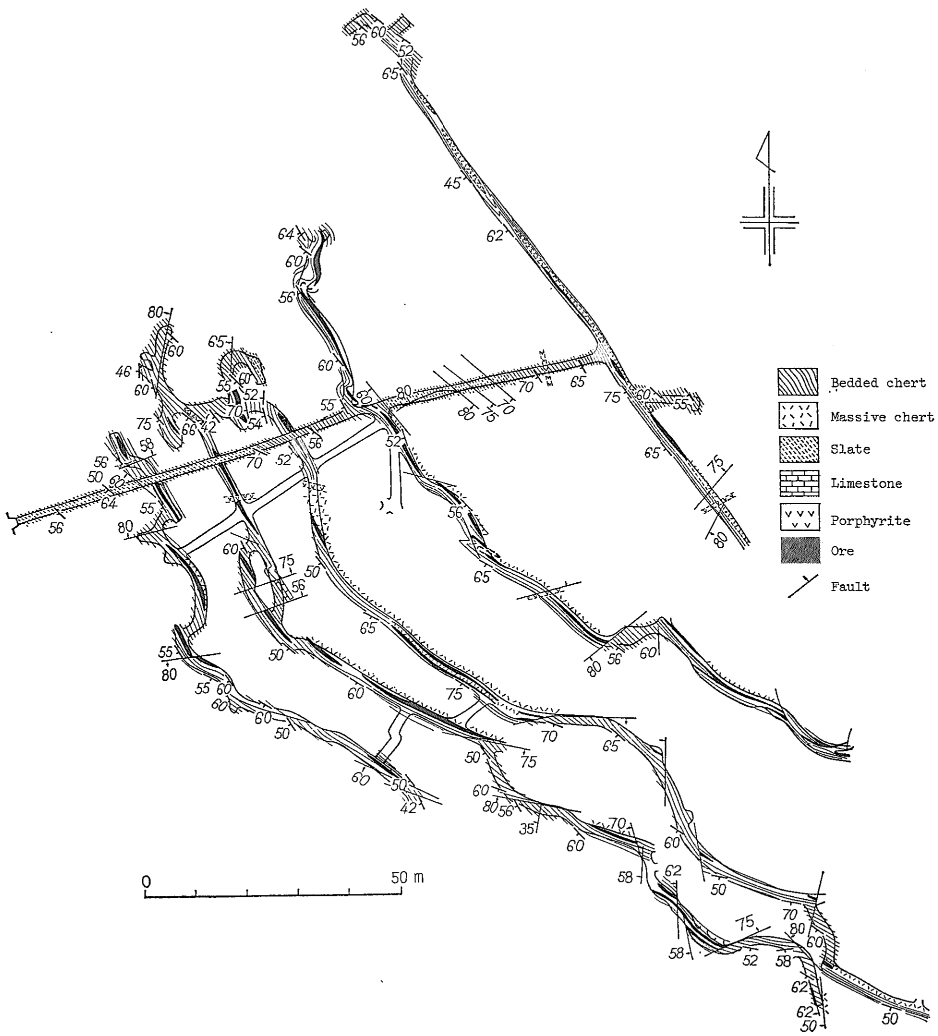


Fig. 8 Underground geologic map of the Funakozawa deposit.
From SUZUKI *et al.* (1963).

the ore body.

Manganese and iron contents of several kinds of chert are shown in Table 7. It is seen that the iron content of red chert is higher in the portions within 1 m from the manganese ore bodies (2.1 percent Fe_2O_3) than in the ore bodies (1.3 percent Fe_2O_3).

As an example of the braunite-ore deposit the Funakozawa deposit is described in the following paragraphs:

Funakozawa is located at Matsunokitai of Ono Village, 4 km south-southwest of Ono.

This deposit is 200 m long in strike direction, 130 m long in dip direction and 0.5–1 m thick. The underground geologic map is shown in Fig. 8. The ore body is conformable to the wall rocks. It is folded, and the axis of the minor folding trends N.70°–90°E. and plunges northward at 45°–55°.

The primary ore is braunite ore associated with small amounts of tephroite, rhodochrosite, spessartine, hausmannite and jacobsite. The braunite ore usually forms a banded ore alternating with chert every several millimeters to several centimeters (Plate 12–2). A schematic section of the ore body is shown in Fig. 9. The ore is cut by veinlets of rhodonite and nambulite. Piedmontite was found in the ore (NAMBU, 1958).

The chemical analysis of the braunite ore is shown in Table 8. The ore contains 31.75 percent MnO, 48.77 percent MnO_2 and 0.76 percent Fe_2O_3. The ore is poor in iron component.

The oxidized ore occurs at the uppermost part of the ore body. This ore is composed mainly of cryptomelane and pyrolusite associated with small amounts of nsutite and hollandite (NAMBU, 1958).

The footwall of the ore body consists of red massive chert. It is about 0.5 m thick, and swells and pinches in accordance with the ore body. The iron content of the red chert is 2.71 percent Fe_2O_3 and is much more than that of the braunite ore. The chemical analysis of the red chert is shown in Table 8.

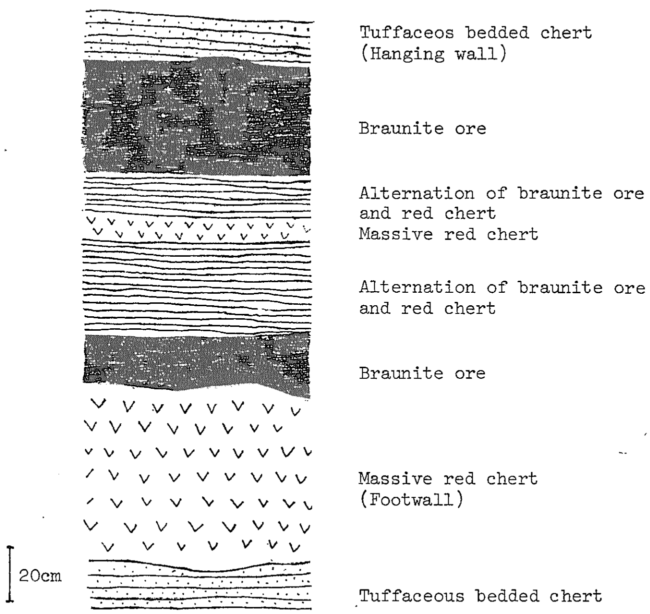


Fig. 9 Schematic columnar-section of the Funakozawa deposit.

The hanging wall is dark-purple tuffaceous bedded chert and tuffaceous slate.

The production of the ore concentrate from the deposit from 1957 to 1968 was about 9,700 tons with the average grade of 41 percent Mn (NAMBU, TANIDA and KUMAGAI, 1969).

Table 8 Chemical Analyses of the Braunite Ore and Red Chert in the Funakozawa Deposit.

	Braunite ore	Red chert
MnO_2	48.77	0.00
SiO_2	9.55	95.56
TiO_2	0.11	0.03
Al_2O_3	1.07	0.69
Fe_2O_3	0.76	2.71
FeO	0.00	0.00
MnO	31.75	0.07
MgO	1.66	0.09
CaO	1.43	0.01
Na_2O	0.29	0.04
K_2O	0.33	0.08
P_2O_5	0.09	0.04
H_2O^+	1.18	0.05
H_2O^-	0.24	0.12
CO_2	0.09	0.03
Total	97.34	99.52

Analyst: Kikumatsu OTA.

3.2.4 The carbonate-ore deposits

Manganese deposits of this type are distributed on the western limb of the Magidai anticline. The major deposits are Kunohe, Ohata, Yokochi, Kitakami, Hinosawa, Kawai, Daini-Asahi, Takinosawa, Oguni, Toyokuchi (all in the Seki Formation), Kayatai, Sainokami, Kurano and Okami (all in the Kassemba Formation).

Distribution of the deposits of this type coincides with the part of the mafic volcanics being poor as shown in Figs. 2 and 4.

The carbonate-ore consists mainly of fine-grained rhodochrosite associated with hausmannite, tephroite and rhodonite in various amounts. In some cases the ore contains also small amounts of jacobsite, braunite, bementite, pyrophanite, galaxite, alleghanyite, manganese micas, dannemorite and neotocite. Identification of these minerals is generally hard because they are very fine-grained and are mixed with each other.

Color of the ore varies from dark brown to light brown, brownish gray, bluish gray,

Table 9 Chemical Analyses of the Carbonate Ore from the Kunohe Area.

Deposit	Color	Total Mn	MnO_2	SiO_2	Fe	P
1. Kohare	Brown	48.52	0.56	14.84	0.43	0.026
2. Takamatsu	Brown	42.04	0.00	16.76	1.56	0.061
3. Shimizugawa	Black	45.75	—	18.52	2.02	0.070
4. Shimizugawa	Gray	42.83	—	20.40	2.36	0.048
5. Shimizugawa	Brown	44.13	—	17.29	3.07	0.070
6. Shimizugawa	Pink	35.92	—	28.53	2.35	0.070
7. Kunohe	Brown	36.12	—	22.27	1.50	0.057
8. Kunohe	Brown	26.76	—	41.04	3.09	0.061
9. Hinosawa	Chocolate	48.28	59.27	11.31	0.58	0.035
10. Hinosawa	Brown	31.77	49.27	16.41	0.63	0.048
11. Takinosawa	Brown	49.65	—	18.09	0.92	0.271
12. Takinosawa	Brown	51.19	—	14.99	0.50	0.170
13. Takinosawa	Brown	44.80	—	10.00	0.50	0.140
14. Takinosawa	Brown	37.42	—	7.51	1.12	0.166

Analysts: Minako TERASHIMA (nos. 3–8 and 11–14), Kikumatsu OTA (nos. 1–2 and 9–10).

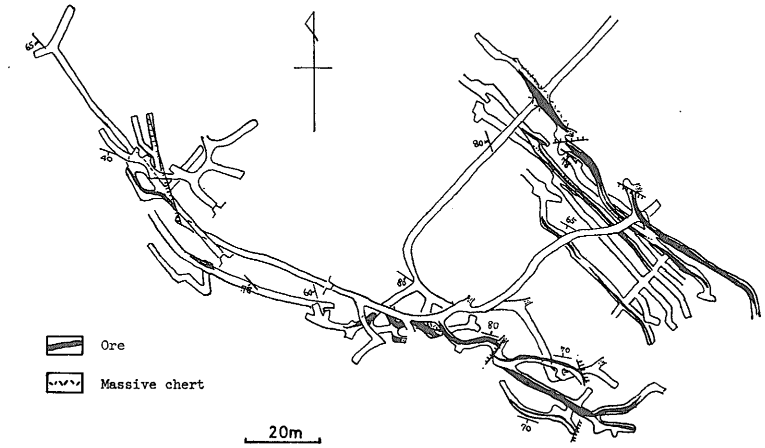


Fig. 10 Underground map of the Hinosawa deposit.
From SUZUKI *et al.* (1962).

dark gray to light gray and pink. Dark-brown ore is so-called Chocolate ore (YOSHIMURA, 1952). It contains high content of hausmannite and is high-grade ore with about 50 percent Mn. Gray ore is composed mainly of rhodochrosite. Bluish ore contains tephroite abundantly. Pink ore is composed of coarse-grained rhodochrosite or a mixture of fine-grained rhodonite and quartz.

The carbonate ore shows a banded texture in many cases as shown in Plates 13–3 and 14–1. The minerals are arranged in parallel to the bedding of the wall rocks. The grain size of the minerals is usually around 0.02 mm in diameter.

Chemical analyses of several carbonate ores from the area are shown in Table 9. The ores contain average 42 percent Mn, 18.4 percent SiO_2, 1.5 percent Fe and 0.09 percent P.

As an example of the carbonate-ore deposits, the Hinosawa deposit is described in the following paragraphs:

Hinosawa is located at Hinosawa of Yamagata Village, 3 km northwest of Kawai.

This deposit is 70–80 m long in strike direction, 40–60 m long in dip direction and about 1.2 m thick in average. The ore body is much folded, and the axis of the minor folding trends N.50°W. and plunges northward at 50°. The underground map of the deposit is shown in Fig. 10.

The primary ore of the deposit consists mainly of the Chocolate ore and brownish carbonate ore. The Chocolate ore is composed mainly of hausmannite and rhodochrosite, and the brownish ore is composed of rhodo-

Table 10 Chemical Analysis of Chocolate Ore from the Hinosawa Deposit.

MnO_2	17.13
SiO_2	11.31
TiO_2	0.06
Al_2O_3	0.63
Fe_2O_3	0.84
FeO	0.00
MnO	59.27
MgO	1.04
CaO	0.56
Na_2O	0.06
K_2O	0.06
P_2O_5	0.08
CO_2	4.71
H_2O+	3.73
H_2O-	0.70
Total	100.18

Analyst: Kikumatsu OTA.

chrosite, hausmannite, rhodonite, tephroite and jacobsite with various amounts.

The chemical analysis of the Chocolate ore from the deposit is shown in Table 10.

The oxidized ore of the uppermost part of the ore body is composed of nsutite and cryptomelane.

The footwall of the ore body is gray massive chert. The hanging wall is bedded chert and massive chert.

The production of the ore concentrates from the deposit from 1933 to 1967 was 17,450 tons with the average grade of 42 percent Mn and 2,300 tons with the average grade of 76 percent MnO_2 (NAMBU, TANIDA and KUMAGAI, 1969).

3. 2. 5 The silicate-ore deposits

Manganese deposits of this type occur within 2 km or in the roof pendants of early Cretaceous granitic intrusions. In the Kunohe area the deposits are Shimizugawa, Himegamori, Kujihira and Taki. Shimizugawa is located 1 km east from the Numabukuro body. Himegamori and Kujihira are in the roof pendant of the Hashikami body. Taki is about 2 km west of the Hiraniwa body. Outside of the area, there occur Noda-Tamagawa, Tanohata, Hijikuzu and others. Noda-Tamagawa and Tanohata are located near the Tanohata body. Hijikuzu is near the Miyako body.

The Iwaizumi Group and other formations containing the deposits of this type were thermally metamorphosed by the intrusions to the grade of, at least, hornblende-hornfels facies.

The silicate ore consists mainly of coarse-grained rhodonite and tephroite associated with spessartine, manganese amphiboles, manganese micas, rhodochrosite, hausmannite, pyrophanite and other high-temperature minerals. Grains of the minerals vary from 0.2 mm to more than 2 mm in diameter and are more than ten times as much as those of the carbonate ore in the diameter.

Rhodonite and tephroite ores are constituent in the silicate ore. The rhodonite ore contains about 35 percent Mn, 0.6–2 percent Fe, about 46 percent SiO_2 and about 0.04 percent P. The tephroite ore is composed mainly of tephroite associated with hausmannite and manganese micas in various amounts. This ore contains 46–52 percent Mn, 0.2–4 percent Fe, about 30 percent SiO_2 and 0.01–0.1 percent P.

Boundary between the rhodonite ore and the tephroite ore is sharp. At the boundary there occur several minerals: bementite (Shimizugawa), spessartine (Himegamori and Noda-Tamagawa), bustamite (Noda-Tamagawa; Plate 16–2) and rhodochrosite (Taki; Plate 16–3). Coarse-grained rhodonite occurs as veinlets along the contact (Taki; Plate 16–3). In many cases the grains of the minerals decrease in size (less than 0.1 mm) within 1–5 mm from the boundary.

As a typical silicate-ore deposit, the Noda-Tamagawa deposit will be shown in the following paragraphs, although this deposit is located outside of the Kunohe area.

Noda-Tamagawa is located at Tamagawa of Noda Village 16 km southeast of Kuji.

The deposit occurs in a formation of undefined Iwaizumi Group at the eastern end of the Iwaizumi belt. The formation was highly metamorphosed by the intrusion of the Tanohata granitic body, forming such metamorphic minerals as sillimanite, andalusite and cordierite in the host rocks of the deposit.

This deposit is the largest among the manganese deposits in the Kitakami Moun-

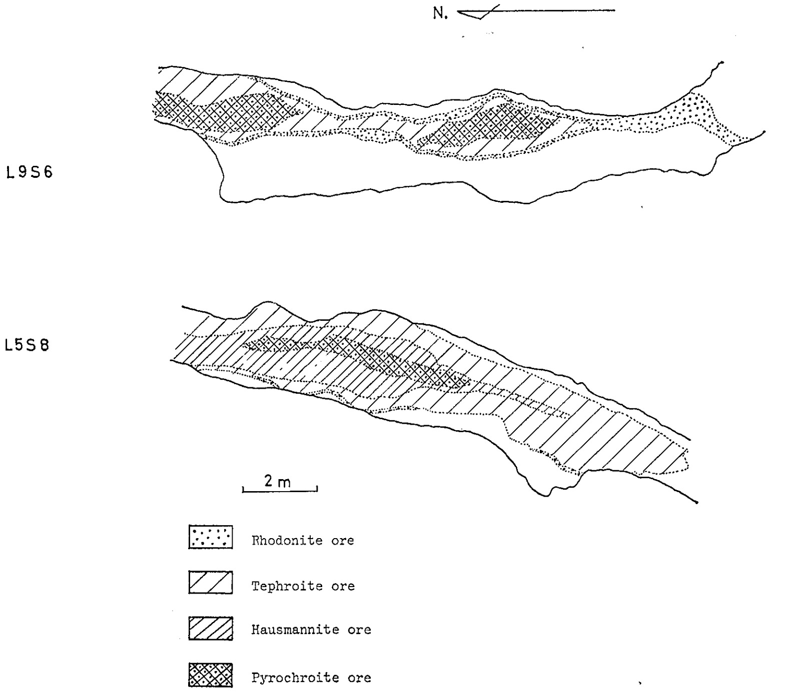


Fig. 11 Zonations of ores in the Noda-Tamagawa deposit.
The data obtained by Shin-Kogyokaihatsu Co., Ltd.

tains. It is made up of several ore bodies: Misago, Kirihata and Maida.

The largest Misago ore body is 1,200 m long in strike direction, 500 m long in dip direction and 0.5–2 m thick. The ore body strikes N.10°–20°E. and dips westerly at very high angles or vertically. It plunges southwestward at 45° in parallel to the axis of the minor folding.

The primary ores are mainly rhodonite ore, tephroite ore, hausmannite ore and pyrochroite ore. The rhodonite ore is associated with a small amount of spessartine. The tephroite ore is associated with manganobarian phlogopite and hausmannite. The hausmannite ore is associated with tephroite, manganobarian phlogopite and kinoshitalite. The pyrochroite ore is associated with rhodochrosite.

The ores are arranged with a symmetrical zoning from both walls to the central part of the ore body as shown in Fig. 11. The silica content of the ores decreases from about 40 percent to about 5 percent toward the central part of the ore body. The silica component was introduced from the siliceous walls into the ores in the course of the pyrometasomatism (WATANABE, 1959).

The Misago ore body is intersected by a granitic intrusion. The contact is seen at a working face of N7 of 8th level, −220 m from the adit level. A reaction rim of about 1 cm wide develops along the boundary between the ore body and the intrusion. The rim is composed mainly of dannemorite, potassium feldspar and quartz as shown in Plate 14–2 (YOSHII and KOMURA, 1971).

The footwall of the ore body is hornfels of bedded chert. The hanging wall is hornfels of massive chert.

Table 11 Manganese Ore-Minerals in the Kunohe Area.

Ore mineral / Deposit	Primary ore																			Oxidized ore							
	Jacobsite	Braunite	Hausmannite	Rhodochrosite	Mangancalcite	Alleghanyite	Tephroite	Rhodonite	Pyroxmangite	Dannemorite	Stilpnomelane	Mn-phlogopite	Piedmontite	Spessartine	Bementite	Neotocite	Galaxite	Pyrophanite	Alabandite	Crypotmelane	Hollandite	Pyrolusite	Nsutite	Birnessite	Manjiroie	Todorokite	Manganite
Imoya	—	—	C	B	—	—	—	C	C	—	—	—	—	C	C	—	—	—	—	—	—	B	B	—	—	—	—
Tsunagi	C	—	—	—	—	—	C	C	—	—	—	—	—	—	—	C	—	—	—	—	—	B	—	—	—	—	—
Kohare	C	—	—	C	—	—	B	B	C	—	—	—	—	C	—	C	—	—	—	B	—	B	B	B	B	—	—
Takamatsu	—	A	—	A	—	—	B	B	C	C	—	—	—	C	C	C	—	—	C	B	—	B	B	—	—	—	—
Yanosawa	—	A	—	C	—	—	A	A	C	—	—	C	—	—	—	—	—	—	—	—	—	B	C	—	—	—	—
Mikkamachi	—	—	—	—	—	—	B	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	—	—	—
Makado	—	—	—	—	—	—	B	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	—	—	—
Tsuboana	—	—	—	—	—	—	—	B	—	—	—	—	—	—	—	—	—	—	—	—	—	B	B	—	—	—	—
Shimizugawa	C	—	—	A	—	C	B	A	—	C	—	—	—	C	C	C	C	C	—	C	—	B	C	—	—	—	—
Kannon	—	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	B	B	—	—	—	—
Takamine	—	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	C	C	—	—	—	C
Kogarumai	—	A	—	C	—	—	C	C	—	—	—	—	—	—	—	C	—	—	—	B	—	B	—	—	—	—	—
Taiho	—	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	B	—	—	—	—	—
Kotamagawa	—	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	B	B	—	B	B	—
Ono	—	A	—	—	—	—	—	—	—	—	—	—	—	C	—	—	—	—	—	B	—	—	B	—	—	—	—
Goto	—	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	—	—	—	—	C	—
Funakozawa	C	A	C	C	—	—	C	C	—	—	—	C	C	C	C	C	—	—	—	B	C	B	C	—	—	—	—
Tachikawa	—	A	—	C	—	—	C	C	—	—	—	—	—	C	—	C	—	—	—	B	—	B	B	—	B	C	—
Nagakura	—	A	—	—	—	—	—	—	—	—	—	—	—	C	—	—	—	—	—	B	—	—	C	—	—	—	—
Himegamori	—	—	C	—	—	—	A	A	—	—	—	—	—	C	C	—	—	C	—	—	—	—	—	—	—	—	—
Kujihira	—	—	—	—	—	—	A	—	—	—	—	—	—	C	—	—	—	—	—	B	—	—	—	—	—	C	—
Kunohe	—	—	B	A	—	—	—	A	C	—	—	—	—	C	—	C	—	—	—	—	—	B	B	—	—	—	—
Ohata	—	—	—	C	—	—	C	A	—	—	—	—	—	—	—	—	—	—	—	—	—	B	B	—	—	—	—
Yamagata	—	A	C	A	—	—	B	A	—	C	C	C	—	C	C	—	—	C	—	C	—	C	B	—	—	—	C
Yokochi	C	C	C	C	—	—	A	A	—	—	—	—	—	—	—	C	—	—	—	B	—	B	—	—	—	—	C
Kitakami	C	—	C	C	—	—	B	B	—	—	—	—	—	—	—	C	—	—	—	B	—	—	B	—	—	—	—
Hinosawa	C	—	A	A	C	—	C	C	—	—	—	—	—	—	—	C	—	—	—	B	—	—	B	—	—	—	—
Kawai	—	—	—	—	—	—	—	C	—	—	—	—	—	—	—	—	—	—	—	A	—	—	B	—	C	—	—
Daini-Asahi	—	—	—	—	—	—	B	B	—	—	—	—	—	—	—	—	—	—	—	—	—	B	B	—	—	—	—
Takinosawa	—	C	A	A	—	—	—	—	—	—	—	—	—	—	C	—	—	—	—	B	—	B	B	—	—	—	—
Misawa	—	—	—	—	—	—	B	B	—	—	—	—	—	—	—	—	—	—	—	—	—	B	—	—	—	—	—
Oguni	—	B	—	B	C	—	B	A	—	C	—	—	—	—	—	C	—	—	—	B	—	—	B	—	—	—	—
Toyokuchi	—	B	C	A	C	—	B	B	—	—	—	—	—	—	—	C	—	—	—	B	—	B	B	B	—	—	—
Oyukiya	—	—	—	—	—	—	B	B	—	—	—	—	—	—	—	—	—	—	—	B	—	B	—	—	—	—	—
Kayatai	—	—	—	C	—	C	C	A	—	C	C	C	—	C	—	—	—	—	—	—	—	B	—	—	—	—	—
Sainokami	—	—	A	A	C	C	B	B	—	—	—	—	—	C	C	C	C	—	—	C	—	—	A	C	—	—	—
Kurano	B	—	—	B	—	—	—	B	—	—	—	—	—	—	—	—	—	—	—	A	—	A	A	—	—	—	—
Okami	—	—	—	A	—	—	B	B	—	—	—	—	—	—	—	C	—	—	—	C	—	B	B	—	—	—	—
Taki	C	—	C	C	—	—	A	A	C	—	—	—	—	C	C	C	—	—	—	B	—	B	B	C	—	—	—

A: dominant, B: major, C: accessory

Table 12 X-ray Powder Data of Tephroite.

No.	5–1426T	11–31303T	7–706T	
Locality	Himegamori	Taki	Noda-Tamagawa	
hkl	d (Å)			I
020	5.29	5.28	5.29	25
021	4.03	4.03	4.03	45
101	3.84	3.84	3.84	13
111	3.61	3.61	3.61	45
120	3.59	3.58	3.59	10
002	3.12	3.12	3.11	22
130	2.86	2.86	2.86	72
022	2.69	2.69	2.68	20
040	2.65	2.66	2.65	5
131	2.60	2.60	2.60	100
112	2.55	2.55	2.55	72
041	2.44	2.44	2.44	15
210	2.38	2.38	2.37	18
122	—	2.35	2.35	22
140	2.33	2.33	2.32	25
211	2.228	2.222	2.223	10
132	2.112	2.109	2.106	2
150	1.946	1.943	1.942	10
113	—	1.884	1.880	8
151	1.858	1.854	1.854	2
222	1.811	1.807	1.805	72
240	1.798	1.795	1.793	10
241	1.728	1.724	1.723	18
061	1.700	1.697	1.697	10
	1.685	1.681	1.680	18
	1.652	1.649	1.648	10
	1.638	1.636	1.634	3
	1.562	1.559	1.558	18
	1.538	1.536	1.537	20
	1.447	1.445	1.446	15
	1.442	—	—	2
	1.433	1.430	—	2
	1.395	1.391	1.392	2

Conditions: Mn filtered Fe radiation (λ=1.9360Å for Kα_1) at 30kV and 10mA; slits 1°, 0.15mm, 1°; 2θ 0.25°/min.; 800cpm., time constant 2 sec.; goniometer radius 150mm.

The production of the ore concentrate from 1942 to 1973 was 475,300 tons with the average grade of 34 percent Mn. This is 54 percent of the total manganese metal produced from the Kitakami Mountains (Table 3).

3.2.6 Ore mineralogy

Manganese ore minerals from the area are listed in Table 11. Major ore minerals are described in the following paragraphs:

Table 13 Chemical Analyses of Tephroite.

No.	5-1426T	11-31303T	7-706T
Locality	Himegamori	Taki	Noda-Tamagawa
SiO_2	29.68	29.85	30.17
TiO_2	0.02	0.02	0.02
Al_2O_3	0.19	0.26	0.32
Fe_2O_3	0.58	0.20	0.23
FeO	0.78	0.07	1.25
MnO	66.92	65.07	63.71
MgO	0.59	3.41	3.73
CaO	0.30	0.32	0.13
Na_2O	0.01	0.01	0.02
K_2O	0.01	0.01	0.01
P_2O_5	0.02	0.22	0.05
H_2O^+	0.20	0.22	0.13
H_2O^-	0.16	0.18	0.15
Total	99.46	99.84	99.92

Numbers of Ions on the Basis of 4 Oxygens

	5-1426T		11-31303T		7-706T	
Si	0.998		1.002		0.989	1.001 (Si+Al)
Al	0.008	1.995 (Al–P)	0.010	2.051 (Al–P)	0.012	
Ti	0.001		0.001		0.000	1.992 (Ti–P)
Fe^{3+}	0.015		0.005		0.006	
Fe^{2+}	0.022		0.002		0.034	
Mn	1.906		1.851		2.006	
Mg	0.030		0.171		0.182	
Ca	0.011		0.004		0.000	
Na	0.001		0.001		0.001	
K	0.000		0.000		0.000	
P	0.001		0.006		0.000	

Refractive Indices

	5-1426T	11-31303T	7-706T
α	1.780	1.770	1.773
γ	1.810	1.780	1.782

Analyst: Kenjiro MAEDA.

Rhodochrosite is the major consituent of the carbonate ore. It occurs also as veinlets cutting the ores and as pseudomorphs replacing other minerals in many cases.

In the carbonate ore this mineral has granular and anhedral forms of 0.04–0.2 mm in size. In some cases it occurs as spherulitic (Sainokami) or foliated (Takamatsu) aggregates up to 1 mm. Coarse-grained pink crystals of more than 1 mm occur in Shimizugawa.

Hausmannite occurs both in the carbonate ore and the silicate ore.

In the carbonate ore this mineral is a constituent of the high-grade ore, especially Chocolate ore, and is mixed with rhodochrosite in various ratios. This mineral occurs as aggregates of fine-grained (about 0.02 mm) granular crystals. The aggregates have layered

Table 14 X-ray Powder Data of Rhodonite.

No.	1	2	3	4	5	6	
hkl	d (Å)						I
$\bar{1}10$	7.11	7.14	7.14	7.14	7.07	7.09	35
001	6.67	6.70	6.67	6.71	6.64	6.64	5
$1\bar{1}1$, 101	4.77	4.78	4.78	4.78	4.75	4.75	8
$1\bar{2}1$	—	4.14	4.12	4.13	4.11	4.11	5
030, $\bar{1}30$	3.82	3.82	3.83	3.82	3.79	3.81	2
200	3.67	—	—	—	3.68	3.68	2
$\bar{2}20$	3.56	3.56	3.57	3.57	3.54	3.55	100
$\bar{2}11$	—	—	3.42	3.42	—	3.41	0.5
$1\bar{3}1$, 002, 121	3.35	3.34	3.34	3.34	3.33	3.33	30
$\bar{1}31$	3.26	3.28	3.26	3.26	3.25	3.27	5
012, $\bar{1}02$, 201	3.14	3.15	3.14	3.14	3.13	3.13	25
$\bar{2}21$, 130, $\bar{2}30$	3.08	3.09	3.09	3.09	3.08	3.08	35
$1\bar{1}2$, $0\bar{2}2$	2.97	2.97	2.98	2.98	2.96	2.97	50
$\bar{1}40$	2.93	2.94	2.93	2.94	2.93	2.92	12
$\bar{1}22$	—	2.81	2.81	2.81	2.81	2.82	5
$2\bar{3}1$	2.78	2.79	2.79	2.79	2.78	2.78	5
112	2.76	2.77	2.77	2.76	2.75	2.75	10
$\bar{1}41$	—	2.65	—	2.66	2.65	2.65	1
$\bar{2}12$, $0\bar{3}2$	2.60	2.60	2.60	2.60	2.59	2.59	10
$1\bar{3}2$	—	2.54	2.55	—	—	2.54	0.5
221	2.51	2.51	2.52	2.52	2.50	2.51	15
	2.46	2.46	—	—	—	2.45	0.5
	2.37	2.37	2.38	2.38	2.36	2.37	8
	2.314	2.317	2.325	—	—	2.320	0.5
	2.284	—	—	2.279	—	2.271	0.5
	2.223	2.227	2.226	2.226	2.220	2.223	5
	2.179	2.183	2.180	2.182	2.178	2.177	10
	—	2.158	—	2.158	—	2.154	1
	2.117	2.119	—	2.119	2.114	2.113	2
	—	—	—	—	2.083	2.092	2
	2.067	2.070	2.070	2.070	2.062	2.063	2
	1.895	1.895	—	1.899	1.891	1.895	2
	1.860	—	1.870	1.870	1.860	1.864	1
	1.818	—	1.825	—	—	—	0.5
	1.777	—	1.784	—	—	1.779	10
	1.696	1.697	1.697	—	1.694	1.694	2
	—	1.690	—	1.691	1.687	1.687	2
	1.665	1.667	1.666	1.666	1.663	1.663	5
	—	—	—	—	1.632	1.638	0.5
	1.586	—	—	—	1.587	1.588	0.5
	—	1.547	—	1.549	1.545	1.545	20

Locality (specimen number): 1. Shimizugawa (7–9051R), 2. Funakozawa (7–9018R), 3. Himegamori (5–1426R), 4. Kayatai (11–902R), 5. Noda-Tamagawa (7–706R), 6. Noda-Tamagawa (8–601R).
Conditions: Mn filtered Fe radiation (λ=1.9360Å for $K\alpha_1$) at 30kV and 10mA; slits 1°, 0.3mm, 1°; 2θ 1°/min., 400–800 cps., time constant 1–2 sec. goniometer radius 150mm.

Table 15 Refractive Indices of Rhodonite, Pyroxmangite and Nambulite.

Mineral and Sample no.	Locality	α	β	γ
Rhodonite				
7-9051R	Shimizugawa	1.725	1.730	1.739
11-31303R	Taki	1.721	1.726	1.732
5-1426R	Himegamori	1.717	1.722	1.728
7-710R	Noda-Tamagawa (Kirihata)	1.720	1.724	1.731
7-706R	Noda-Tamagawa (L9-S2)	1.720	1.725	1.732
8-601R	Noda-Tamagawa (L8-N1)	1.721	1.727	1.733
9-9518R	Tanohata	1.722	1.728	1.735
7-9018	Funakozawa	1.724	1.728	1.736
Pyroxmangite				
11-15303P	Kohare	1.731	1.738	1.748
9-120P	Taki	1.723	1.728	1.738
11-52001P	Hijikuzu	1.739	1.743	1.756
Nambulite				
7-9013	Funakozawa	1.707	1.710	1.730

or oolitic texture with association of rhodochrosite and tephroite. The mineral is dark brown in hand specimens and dark reddish brown to almost opaque in thin section.

In the silicate ore this mineral is coarse-grained (0.2–0.4 mm). It is brownish black with brown streak in hand specimens and dark reddish brown and pleochroic in thin section. In the Noda-Tamagawa deposit it occurs inner part of the ore bodies and is associated with tephroite, manganese micas and rhodochrosite (Plate 15–1; Plate 18–3; Plate 19–1 and 2).

Braunite is the constituent of the braunite ore. This mineral is iron black with submetallic luster and black streak in hand specimens. Grain size is very fine. In some cases the mineral is associated with such oxidized minerals as pyrolusite and cryptomelane in the ore (Kannon, Kotamagawa and Yamagata).

Tephroite occurs in both the carbonate ore and the silicate ore.

In the carbonate ore this mineral occurs as granular forms in grain sizes of 0.01–0.02 mm. It is associated with rhodochrosite and hausmannite.

In the silicate ore this mineral is the most important constituent forming the tephroite ore. The mineral is associated with manganese micas and hausmannite. The mineral usually has anhedral form (Plate 14–3) and in some cases colloded form (Plate 15–1). The grain sizes are 1 mm to more than 2 mm. The mineral is dark gray in some cases with greenish tint in hand specimens. It is colorless and little pleochroic and occasionally shows wavy extinction in thin section (Plate 15–2).

The X-ray powder data are shown in Table 12. The chemical analyses and the refractive indices are shown in Table 13.

Rhodonite occurs in both the carbonate ore and the silicate ore. In many cases it occurs as veinlets in the ores (Funakozawa, Imoya and others).

In the carbonate ore this mineral occurs in comparatively low-grade ore. It is mixed with quartz in various ratios. The grain size is around 0.05 mm, and in some cases it is hard to distinguish the mineral from tephroite in thin section.

Table 16 Chemical Analyses of Rhodonite and Nambulite.

Mineral	Rhodonite			Nambulite
No.	7-706R	8-601R	7-9018	7-9013
Locality	Noda-Tamagawa		Funakozawa	
SiO_2	45.82	45.73	46.70	49.23
TiO_2	0.02	0.02	0.01	0.01
Al_2O_3	0.91	0.50	0.15	0.37
Fe_2O_3	0.64	1.00	0.47	0.40
FeO	0.18	1.58	—	—
MnO	45.48	43.30	45.87	42.00
MgO	2.82	1.45	1.54	1.32
CaO	3.24	4.88	4.57	0.81
Li_2O	—	—	—	1.31
Na_2O	0.01	0.01	0.01	2.20
K_2O	0.01	0.01	0.01	0.04
P_2O_5	0.07	0.10	—	0.02
H_2O^+	0.37	0.66	0.18	1.63
H_2O^-	0.20	0.38	0.11	0.26
CO_2	0.00	0.28	—	0.19
Total	99.77	99.90	99.62	100.10

Numbers of Ions on the Basis of 15 (O, OH).

Ion	7-706R		8-601R		7-9018		7-9013	
Si	4.891	5.006	4.944	5.008	4.956		4.981	5.000
Al	0.115		0.064		0.019	5.000	0.019 0.026	
Ti	0.002		0.002		0.001		0.001	
Fe^{3+}	0.051		0.081		0.024 0.013		0.031	
Fe^{2+}	0.016		0.143		—		—	3.857
Mn	4.112		3.924		4.123		3.600	
Mg	0.449	5.010	0.234	4.962	0.244		0.199	
Ca	0.371		0.565		0.520	4.905	0.088	
Li	—		—		—		0.533	
Na	0.002		0.002		0.003		0.432	1.060
K	0.001		0.001		0.002		0.005	
P	0.006		0.010		0.000		0.002	

Analyst: Kenjiro MAEDA.

In the silicate ore this mineral is one of the constituents. It is rose pink to brownish red in hand specimens. It is colorless and little pleochroic in thin section. The mineral usually has granular form (Plate 15–3) and also has prismatic form (Plate 16–1). The grain sizes are 0.15 mm to more than 2 mm.

The X-ray powder data are shown in Table 14. The refractive indices are shown in Table 15. The chemical analyses are shown in Table 16.

Pyroxmangite occurs as veinlets in the carbonate ore (Imoya, Takamatsu, Yanosawa, Kohare and Kunohe) and the silicate ore (Taki). This mineral occurs also as one of the constituents of the silicate ore in the Hijikuzu deposit.

This mineral is pink in hand specimens. It is colorless and little pleochroic in thin section. The crystals from the veinlets have prismatic form (Plate 17–1 and 2) and those from Hijikuzu have granular form. The grain sizes are 0.3–1 mm in length for the former and up to 5 mm for the latter. The refractive indices of the mineral are shown in Table 15. The X-ray powder data and the chemical analysis for the specimen from Hijikuzu are shown in Tables 17 and 18, respectively.

Nambulite occurs as veinlets in the braunite ore of the Funakozawa deposit. It is associated with rhodochrosite, neotocite and albite. This mineral is reddish brown with orange tint in hand specimens. It is colorless and little pleochroic in thin section. It has prismatic form (Plate 17–3). The grain size is up to 8 mm. The mineral is similar to rhodonite in thin section and is distinguished from the latter by lower optical axial angle (2Vz = 30°) and X-ray powder patterns (YOSHII *et al.*, 1972). The X-ray powder data

Table 17 X-ray Powder Data of Pyroxmangite from the Hijikuzu Deposit.

hkl	d (Å)	I
$\bar{1}10$	6.89	5
001	6.58	6
$1\bar{1}1$	4.70	13
$\bar{2}10$	3.69	5
$0\bar{4}1$	3.53	8
$\bar{2}20$	3.45	100
220	3.34	4
$\bar{2}\bar{1}1$	3.31	8
041	3.27	2
$\bar{1}\bar{4}1$	3.21	4
201	3.17	2
$\bar{2}\bar{3}0$	3.12	25
$\bar{1}41$	3.08	3
211	3.07	3
$2\bar{3}0$	3.02	20
$2\bar{2}1$	3.00	2
141	2.94	40
—	2.93	3
$\bar{2}\bar{3}1$	2.86	3
	2.82	5
	2.80	2
	2.75	3
	2.67	10
	2.63	12
	2.49	8
	2.46	3
	2.30	20
	2.202	10
	2.178	5
	2.060	10
	2.042	3
	1.716	2
	1.570	1
	1.484	1
	1.415	5

Conditions: Mn filtered Fe radiation (λ = 1.9360Å for $K\alpha_1$) at 30kV and 10mA; sslits 1°, 0.15mm, 1°; 2θ 0.25°/min.; 800cpm, time constant 2sec.; goniometer radius 150mm.

Table 18 Chemical Analysis of Pyroxmangite from the Hijikuzu Deposit.

a		b		
SiO_2	46.01	Si	6.936	7.000
TiO_2	0.04	Al	0.034	
Al_2O_3	0.19	Ti	0.005	
Fe_2O_3	1.03	Fe^{3+}	0.025 / 0.092	
FeO	9.82	Fe^{2+}	1.238	6.981
MnO	39.32	Mn	5.021	
MgO	1.43	Mg	0.321	
CaO	1.86	Ca	0.300	
Na_2O	0.01	Na	0.003	
K_2O	0.01	K	0.002	
P_2O_5	0.03	P	0.004	
H_2O^+	0.20			
H_2O^-	0.06			
Total	100.10			

a: Weight Percentage.
b: Numbers of Ions on the Basis of 21 Oxygens.

Table 19 X-ray Powder Data of Nambulite.

hkl	d (Å)	I	hkl	d (Å)	I
$\bar{1}10$	7.11	25	$\bar{2}22$, $\bar{3}20$	2.51	15
001	6.70	25	$\bar{1}32$	2.49	30
020	5.62	10	122	2.41	10
$\bar{1}01$	5.21	15	$\bar{3}30$	2.38	5
$1\bar{1}1$	4.75	15	$2\bar{2}2$	2.37	10
021, $\bar{1}21$, $1\bar{2}1$	4.13	10		2.246	15
120	3.92	10		2.241	20
$\bar{2}20$	3.56	20		2.221	30
$12\bar{1}$	3.54	35		2.198	45
$1\bar{3}1$, 002, $20\bar{1}$	3.34	40		2.177	10
$0\bar{1}2$	3.27	10		2.166	10
$\bar{1}02$, 031	3.17	65		2.071	10
012	3.14	45		2.041	10
$\bar{1}12$	3.09	55		1.996	15
$2\bar{2}1$	3.07	60		1.847	35
201	3.05	10		1.814	5
$11\bar{2}$	3.01	30		1.698	25
$0\bar{2}2$	2.97	80		1.695	25
$1\bar{1}2$	2.96	100		1.675	20
$\bar{1}40$, 102	2.92	70		1.670	35
$1\bar{2}2$	2.81	10		1.637	10
112, 220	2.71	35		1.592	15
$22\bar{1}$	2.62	40		1.577	15
				1.547	5
				1.460	10
				1.417	10
				1.414	25
				1.409	15
				1.406	15

Conditions: Mn filtered Fe radiation (λ=1.9360Å for $KK\alpha_1$) at 30kV and 10mA; slits 1°, 1°, 0.1mm.; 2θ 0.25°/min.; 800cps.; time constant 4 sec, goniometer radius 185mm.

are shown in Table 19. Structurally this mineral is more similar to babingtonite rather than rhodonite (NARITA *et al.*, 1975). The refractive indices are shown in Table 15. The chemical analysis is shown in Table 16.

Dannemorite occurs in both the carbonate ore (Takamatsu, Yanosawa and Yamagata) and the silicate ore (Kayatai and Noda-Tamagawa). This mineral is associated with rhodonite, spessartine, manganese micas, quartz and rhodochrosite. The mineral is gray with brownish tint in hand specimens. It is almost colorless and little pleochroic in thin section. It has fibrous form. The grain size is 0.1–0.4 mm long (Plate 18–1). In the Noda-Tamagawa deposit this mineral occurs at the contact of the rhodonite ore and a granitic intrusion (Plate 14–2).

Stilpnomelane occurs as veinlets in the silicate ore of the Kayatai deposit. This mineral is brown in hand specimens. It is yellow to brown and is strongly pleochroic in thin section. The mineral has tabular to fibrous form. The grain size is around 0.3 mm (Plate 18–2).

Manganoan phlogopite occurs in the braunite ore (Yanosawa, Funakozawa and Yamagata) and the silicate ore (Kayatai). This mineral is brown in hand specimens. It is very pale brown and weakly pleochroic in thin section. The grain size is 0.03–0.2 mm long.

Table 20 X-ray Powder Data of Manganobarian Phlogopite and Kinoshitalite from the Noda-Tamagawa Deposit.

No.	1		2		3		4		5		6	
hkl	d (Å)	I	d	I	d	I	d	I	d	I	d	I
001	10.11	1,400	10.05	860	10.10	850	10.10	670	10.05	410	10.11	90
002	5.07	16	5.04	6	5.04	25	5.05	16	5.04	50	5.05	95
111	—		—		—		3.95	2	3.95	2	3.96	3
$11\bar{2}$	—		3.67	4	3.68	3	3.69	5	3.68	5	3.68	5
003	3.38	620	3.36	460	3.37	510	3.37	390	3.36	320	3.37	190
013, 112	3.17	5	3.16	8	3.17	10	3.17	15	3.16	12	3.16	10
$11\bar{3}$	2.94	6	2.93	8	2.94	12	2.94	13	2.93	10	2.93	10
122, 023	2.73	5	2.72	8	2.72	5	2.72	10	2.72	7	2.72	8
200	2.63	3	2.62	3	2.64	5	2.63	7	2.63	5	2.63	5
004	2.53	92	2.52	75	2.53	110	2.53	85	2.52	90	2.52	100
201	—		2.44	3	2.45	3	2.45	3	2.45	2	—	
211	—		—		—		—		—		2.37	2
202	2.194	2	2.181	3	2.189	5	2.187	7	2.184	5	2.183	5
005	2.029	100	2.018	100	2.023	100	2.021	100	2.020	100	2.020	100
006	1.691	30	1.682	20	1.686	27	1.685	20	1.684	24	1.684	30
060	1.551	5	1.543	5	1.548	8	1.546	12	1.546	7	1.546	7
007	1.449	20	1.442	13	1.446	12	1.445	9	1.444	7	1.442	4
$20\bar{7}$	1.376	5	1.369	6	1.373	7	1.371	10	1.371	4	1.371	3

Nos. 1–5: manganobarian phlogopite, no. 6: kinoshitalite.
Conditions: Ni filtered Cu radiation (λ=1.5405Å for $K\alpha_1$) at 20–30kV and 6–10mA; slits (1/6)°–1°, 0.3mm, (1/6)°–1°; 2θ 0.25°/min., 400–1000cps.; time constant 1–2 sec, Goniometer radius 150mm.

Manganobarian phlogopite occurs in the Noda-Tamagawa deposit. This mineral is associated with tephroite and hausmannite (Plate 18–3; Plate 19–1).

In hand specimens this mineral is brown. It is also dark brown with purple tint for manganese-rich specimens and light yellowish-brown for barium-rich specimens. In thin section it is very pale brown to pale brown and weakly pleochroic with the absorption of $X < Y \fallingdotseq Z$. The specimens with abundant manganese and trivalent iron components show "reverse pleochroism" with the absorption of $X > Y \fallingdotseq Z$ (YOSHII and MAEDA, 1975). The mineral is tabular. The grain size is up to 2 mm.

The X-ray powder data are shown in Table 20. The cell parameters and the physical and optical properties are shown in Table 21. Chemical analyses are shown in Table 22.

Kinoshitalite occurs in the Noda-Tamagawa deposit. This mineral is associated with tephroite and hausmannite in one case and is associated also with celcian, quartz, rhodonite, chalcopyrite and pyrrhotite in another case. The mineral is yellowish brown in hand specimen. It is very pale brown to pale brown and weakly pleochroic with the absorption of $X < Y \fallingdotseq Z$ in thin section (Plate 19–2). The mineral is tabular and brittle. The grain size is up to 1 mm.

This mineral is much similar to manganobarian phlogopite both in hand specimens and in thin section and is distinguished from the latter by the lower birefringence and

Table 21 Cell Parameters and Physical and Optical Properties of Manganobarian Phlogopite and Kinoshitalite from the Noda-Tamagawa Deposit.

No.	1	2	3	4	5	6
Cell parameters						
a_0 (Å)	5.350	5.326	5.355	5.349	5.334	5.345
b_0	9.307	9.257	9.288	9.274	9.274	9.250
c_0	10.30	10.25	10.27	10.27	10.26	10.26
β	100°0′	100°0′	99°58′	99°55′	99°55′	99°59′
Specific gravity						
Calc.	3.03	3.01	3.09	3.07	3.18	3.32
Obs.	3.03	3.00	3.07	3.06	3.17	3.30
Optical properties						
α	1.599	1.575	1.596	1.589	1.621	1.619
β	1.645	1.608	1.634	1.624	1.639	1.633
γ	1.646	1.612	1.635	1.624	1.641	1.635
$\gamma-\alpha$	0.047	0.037	0.039	0.035	0.020	0.016
2Vx	38°	53°	13°	30°	25°	23°
Absorption	X>Y≒Z	X<Y≒Z	X>Y≒Z	X<Y≒Z	X<Y≒Z	X<Y≒Z

Nos. 1–5: manganobarian phlogopite, no. 6: kinoshitalite.

weak 001 and strong 002 reflections on the X-ray diffraction (Yoshii *et al.*, 1973; Yoshii, Togashi and Maeda, 1973; Yoshii and Maeda, 1975). The data of this mineral are compared with manganobarian phlogopite in Tables 20, 21 and 22.

Spessartine occurs in both the carbonate and the silicate ores. This mineral is associated with rhodochrosite, tephroite, rhodonite and manganese micas. The mineral is honey yellow to gray in hand specimens. It is colorless in thin section. It has euhedral and granular form. The grain size is 0.02–0.08 mm in the carbonate ore and 0.2–0.4 mm in the silicate ore.

In the Taki deposit a "spessartine rock" occurs. It is gray in hand specimens and is composed mainly of spessartine associated intergranularly with bementite in thin section (Plate 19–3).

Bementite occurs as veinlets and pools in the carbonate ore (Takamatsu, Shimizugawa and Kunohe) and in the silicate ore (Kayatai and Taki). This mineral is brown in hand specimens and colorless to very pale brown in thin section. It is fibrous. The grain size is 0.01–0.06 mm.

Alleghanyite occurs in the carbonate ore. This mineral is associated with rhodochrosite and galaxite (Shimizugawa, Kayatai and Sainokami). The mineral is reddish brown in hand specimens. It is colorless in thin section. The crystals are hemihedral and prismatic and are usually twinned. The grain size is 0.15–0.4 mm (Plate 20–1).

Galaxite occurs in the carbonate ore (Shimizugawa, Sainokami and others). This mineral is golden yellowish brown, euhedral and granular in thin section. The grain size is about 0.02 mm (Plate 20–2).

Pyrophanite occurs in the silicate ore. This mineral is associated with tephroite and rhodonite (Shimizugawa, Himegamori and Noda-Tamagawa). This mineral is brown to

Table 22a Chemical Analyses of Manganobarian Phlogopite and Kinoshitalite from the Noda-Tamagawa Deposit.

No.	1	2	3	4	5	6
SiO_2	35.65	37.86	34.10	33.69	29.12	24.58
TiO_2	0.44	0.36	0.71	0.33	0.16	0.16
Al_2O_3	12.70	12.06	13.89	15.58	21.19	22.06
Fe_2O_3	2.35	1.34	1.76	0.95	0.69	0.71
Mn_2O_3	3.11	3.54	3.19	3.44	3.55	3.24
FeO	0.04	0.04	0.04	0.04	0.04	0.04
MnO	14.61	7.59	11.85	8.76	7.60	7.38
MgO	15.15	20.15	16.59	19.23	17.56	16.60
CaO	0.05	0.04	0.05	0.03	0.05	0.05
BaO	1.93	3.56	6.03	6.79	11.05	17.85
Na_2O	1.25	2.16	0.58	0.49	0.56	0.68
K_2O	8.60	7.62	7.39	7.24	5.63	3.30
F	0.15	0.39	0.14	0.33	0.27	0.21
H_2O^+	3.69	3.12	3.27	2.96	2.20	2.90
H_2O^-	0.18	0.20	0.15	0.18	0.18	0.20
Total	100.90	100.03	99.76	100.04	99.85	99.96
$-(F_2=0)$	0.06	0.16	0.06	0.14	0.11	0.09
Total	99.84	99.87	99.70	99.90	99.74	99.87

Nos. 1–5: manganobarian phlogopite, no. 6: kinoshitalite.
Analysts: Kenjiro MAEDA (except F), Minoru YOSHIDA (F in nos. 1–5) and Kozo NAGASHIMA (F in no. 6).

Table 22b Numbers of Ions of Manganobarian Phlogopite and Kinoshitalite on the Basis of 12 (O, OH, F)

No.	1		2		3		4		5		6	
Si	2.748		2.857		2.673		2.613	4.000	2.334	4.000	2.052	4.000
Al	1.154	4.000	1.073	4.000	1.284	4.000	1.387 / 0.037		1.666 / 0.336		1.948 / 0.223	
Ti	0.025		0.020		0.042		0.019		0.010		0.010	
Fe^{3+}	0.073 / 0.063		0.050 / 0.026		0.001 / 0.103		0.055		0.041		0.045	
Mn^{3+}	0.183		0.203		0.190		0.203	3.115	0.217	3.221	0.206	3.074
Fe^{2+}	0.003	2.943	0.003	2.983	0.003	3.021	0.003		0.003		0.003	
Mn^{2+}	0.954		0.485		0.787		0.576		0.516		0.522	
Mg	1.740		2.266		1.938		2.222		2.098		2.065	
Ca	0.004		0.003		0.004		0.002		0.004		0.005	
Ba	0.058	1.095	0.105	1.158	0.185	1.016	0.206	0.998	0.347	1.014	0.584	1.051
Na	0.187		0.316		0.088		0.074		0.087		0.110	
K	0.846		0.734		0.739		0.716		0.576		0.352	
OH	1.897	1.934	1.570	1.663	1.709	1.744	1.531	1.612	1.176	1.244	1.615	1.670
F	0.037		0.093		0.035		0.081		0.068		0.055	

reddish brown and short prismatic in thin section. The grain size is about 0.02 mm (Plate 20–3).

3. 2. 7 Wall rocks

A striking feature of the Paleozoic and Mesozoic bedded manganese deposits in Japan is their association with chert. Most of the wall rocks of the manganese deposits in the Kunohe area are also chert. It occurs in both the footwall and the hanging wall of 46 out of 48 deposits in the area. Twenty three deposits have massive chert in their footwall, and 10 deposits have massive chert in the hanging wall. Bedded chert forms the hanging wall of 38 deposits and the footwall of 30 deposits. In some deposits mafic tuff and tuffaceous slate form the hanging wall (Funakozawa, Kohare and others). The wall rocks of the deposits in the area are shown in Table 5.

Bedded chert of the wall rocks is light gray, dark gray, red, purple, brown and green. Red chert is common in the braunite-ore deposits occurring within 2 to 10 m from the ore bodies. The bedded chert contains intercalations of silty or tuffaceous matter of 1–5 mm thick alternating every 3–15 cm. The chert is composed mainly of very fine-grained quartz with various amounts of clay minerals, hematite (in case of red chert) and clastic fragments. Occasionally the chert grades into silty, tuffaceous or limy chert.

Massive chert is mainly gray and red. Red massive chert is accompanied mostly by the braunite-ore deposits. The massive chert is 0.5–2 m thick in most cases. It swells and pinches in accordance with the thickness of the accompanied manganese ore body. The massive chert is composed mainly of quartz. The red massive chert contains also hematite. The ferric content of the red massive chert is higher than that of the braunite ore (Table 8).

The bedded manganese ore bodies are usually conformable to the wall rocks. In some cases the boundary between the ore body and the footwall is found to be undulated with intervals of several meters, even when the ore body itself is not so much folded (Takamatsu, Kotamagawa, Oguni and Sainokami).

Minor foldings are commonly observed in the wall rocks. In the northeastern part of the area (on the eastern limb of the Magidai anticline) the axes of the minor foldings generally trend N.10°–50°W. and plunge southward at 20°–70°. Several deposits have other axes which trend N.40°–90°W. (or E.) and plunge northward at 43°–65°. In the southwestern part of the area (on the western limb of the anticline) they trend N.40°–80°W. (or E.) and plunge northward at 5°–50°. The shoots of the manganese ore bodies in the area are generally in parallel to the plunge of the axes of the minor folding. This feature is observed also in the similar type manganese deposits of other area (Hirowatari, 1966).

4. Discussion

It has been revealed in this study that the bedded manganese deposits of the Kunohe area are concentrated in the Jurassic Seki Formation which is most abundant in chert among the formations of the Iwaizumi Group.

The fact that the bedded manganese deposits are concentrated in specific chert-rich formations in sedimentary basins has also been known in several other areas: the North

Kitakami belt (YOSHIDA and KATADA, 1964), the Ashio massif of Central Japan (WATANABE, 1957; WATANABE *et al.*, 1957; FUJIMOTO, 1961; WATANABE *et al.*, 1970a), and the Tamba belt, Inner zone of Southwest Japan (SAKAGUCHI, 1961; IMOTO, 1966). The manganese deposits of the Kunohe area as well as the areas cited above are accompanied conformably by chert in most cases. They are underlain mostly by massive chert (YOSHIMURA, 1952; WATANABE, 1957; HIROWATARI and TAKEDA, 1962b; IMOTO, 1966; 1967). Dimensions of the manganese deposits seem to have some correlation with the volume of the accompanying chert (YOSHIMURA, 1952; IMOTO, 1967). Therefore the chert is believed to have genetic relation to the bedded manganese deposit.

In general, siliceous matter is hardly precipitated in inorganic processes from normal sea-water because it is undersaturated with silica (KRAUSKOPF, 1956b). Bedded chert contains many fossils and is assumed to be formed in organic processes (NAKAO, 1969; IMOTO and TAKAHASHI, 1972; IMOTO and SAITO, 1973; IMOTO and FUKUTOMI, 1975). Organisms with silica crust are known to flourish where the amount of volcanic matter is increased in sea-water (KANMERA, 1968). Therefore the deposition of bedded chert may indicate the prevalence of submarine volcanism in the sedimentary basin concerned.

Massive chert intercalating the manganese deposits is seen to swell and pinch in accordance with the thickness of ore body. The massive chert contains few fossils (IMOTO and TAKAHASHI, 1972) and is assumed to be formed by submarine hydrothermal processes caused by mafic volcanism (IWAO, 1962; 1970) with rapid precipitation (WATANABE *et al.*, 1970b). Miocene bedded manganese deposits related to intermediate to mafic volcanism in the Green-tuff areas of Inner zone of Northeast Japan are also accompanied by siliceous rock (YOSHIMURA, 1952; MORITANI, 1963), and the dimensions of the deposits vary roughly with the extent of this rock (YOSHIMURA and SASA, 1935; DOI and HARIYA, 1966; MORITANI, 1967), like the above manganese deposits.

Distribution of the braunite-ore deposits of the Kunohe area is in accordance with that of the mafic volcanics. It is seen that several chert beds of the Seki Formation containing the major braunite-ore deposits are interfingered with mafic volcanics developed at the northern end of the area. Therefore it may be said that the mafic volcanism have close relation to the manganese mineralization of this area. Although the carbonate-ore deposits seem to have little direct connection to the mafic volcanics, their genetic relation may be inferred from the close association between ore bodies and conformable chert beds. In the Tamba belt, Western Honshu, the carbonate-ore type deposits of presumably submarine hydrothermal origin occur concentrated in the area with little volcanics (IMOTO, 1966).

It appears therefore that the bedded manganese deposits of the Kunohe area, which are accompanied conformably by siliceous rocks and have occasionally spatial relationship with mafic volcanic rocks, are formed by submarine hydrothermal activity related to mafic volcanism as in the case of similar bedded manganese deposits from other areas in the world (TALIAFERRO and HUDSON, 1943; WATANABE, 1957; HEWETT, 1966; 1972).

The sedimentary basin of the Iwaizumi Group in this area is thought to have been comparatively shallow and not so large because the sediments contain coarse materials with heterogeneous mineral composition. These geologic conditions may suggest the area to have been in mildly oxidizing environment. Taking account of the physicochemical conditions for stability of manganese compounds (ZOBELL, 1946; KRUMBEIN and GARRELS,

1952; KRAUSKOPF, 1957; 1967; SOKOLOVA, 1962; GARRELS and CHRIST, 1965; ROY, 1968; STASHCHUK, 1968; CRERAR and BARNES, 1974), it is inferred that the conditions of the sedimentary basin of this area may have generally suited for forming many bedded manganese deposits. Difference of the physicochemical conditions in the area may have resulted in forming two types of deposits, the braunite-ore deposits and the carbonate-ore deposits. The braunite-ore deposits may have been formed under comparatively oxidizing conditions with abundant silica component, and the carbonate-ore deposits under less oxidizing conditions (KRAUSKOPF, 1957; 1967).

Manganese is mixed with iron in hydrothermal solutions coming from the depth and is separated from iron in the processes of deposition according to the difference of physicochemical properties between manganese and iron (KRAUSKOPF, 1956a; 1957; BISCHOFF, 1969; BORCHERT, 1970; BONATTI *et al.*, 1972). Manganese ores from the Kunohe area contain iron with only small amount (average 1.5 percent and maximum 3 percent of Fe).

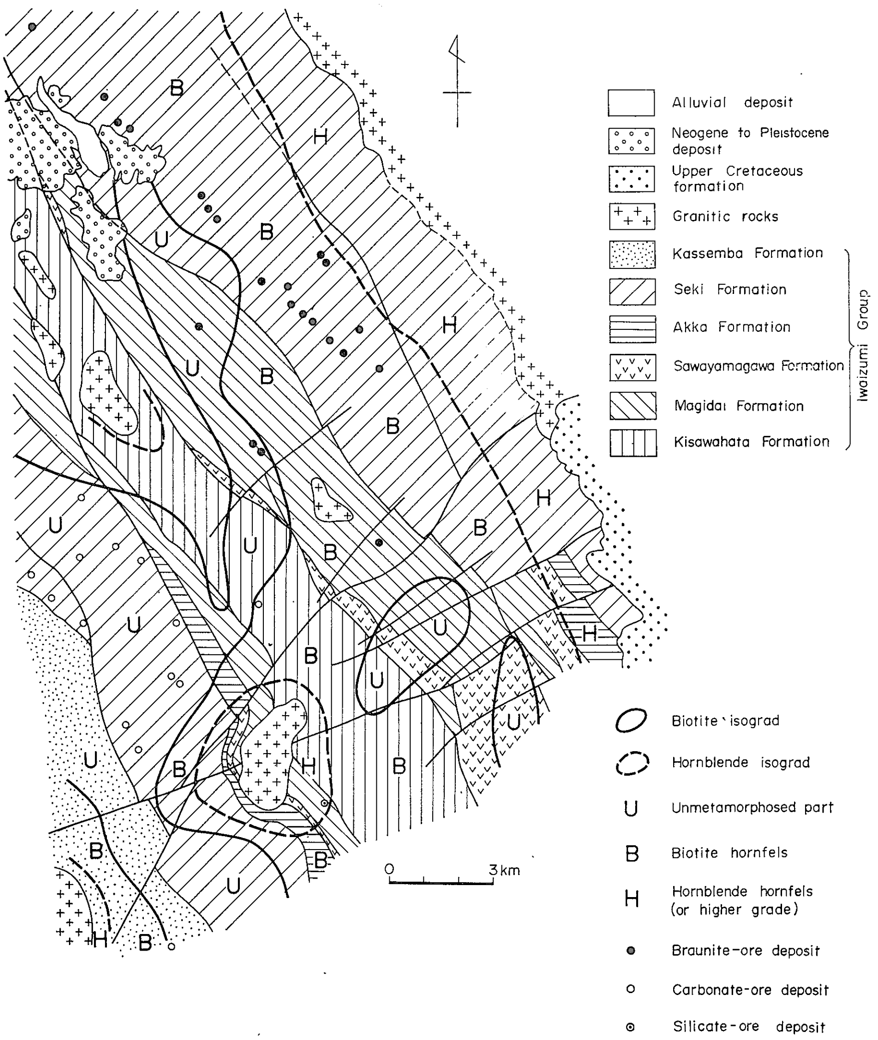


Fig. 12 Relation between geology and types of manganese deposits in the Kunohe area.

The Iwaizumi Group of the Kunohe area were more or less thermally metamorphosed by early Cretaceous granitic intrusions except the western part of the area as shown in Fig 12. In the isograd of biotite hornfels metamorphism of the manganese ores is not so apparent, but such minerals as spessartine, manganese micas, stilpnomelane, dannemorite, galaxite and alleghanyite are found as the metamorphic minerals. It is common that the ores are cut by veinlets of rhodochrosite, mangancalcite, rhodonite and pyroxmangite.

The silicate-ore deposits occur in the hornblende isograd of hornfels or much more highly metamorphosed part. In some cases ores show a symmetrical arrangement of minerals, and the silica content of the minerals decreases from the walls to the central part of the ore bodies. From these the silicate-ore deposits are believed to have been formed by introduction of silica component from the siliceous walls into the ores in the course of the pyrometasomatism (WATANABE, 1957; WATANABE *et al.*, 1970b).

In some cases the silicate-ore deposit contains a relic of the carbonate ore composed of recrystallized rhodochrosite (Shimizugawa and others), indicating that the ores had been originally the carbonate ores. However, it is unclear whether or not the braunite ore in the area was also changed into the silicate ore by the thermal metamorphism. The braunite ore seems to be more stable than the carbonate ore at high temperature, and the braunite-ore type deposits are known to occur in both thermally and regionally metamorphosed areas outside the Kitakami Mountains (YOSHIMURA, 1952; 1958; MIYAHISA, 1969; HIROWATARI, 1971).

The formation of the bedded manganese deposits of the Kunohe area will be concluded as follows: Major manganese mineralization of the area was at the stage of the Jurassic Seki Formation and was related to mafic volcanism, same as the bedded manganese deposits from other areas in the world (WATANABE, 1957; TALIAFERRO and HUDSON, 1943 and others). Two types of deposits, the braunite-ore deposits and the carbonate-ore deposits, were resulted from different geologic conditions of the sedimentary basin in the area. The deposits were then thermally metamorphosed into the silicate-ore deposits by early Cretaceous granitic intrusions.

5. Summary

The study on the geology and the manganese deposits in the Kunohe area of the North Kitakami Mountains is summarized in the followings.

1) The Triassic to Jurassic Iwaizumi Group in the Kunohe area consists of the Kisawahata Formation, the Magidai Formation, the Sawayamagawa Formation, the Akka Formation, the Seki Formation and the Kassemba Formation. They are all conformable in the area. Thickness of the formations is much larger on the eastern limb of the Magidai anticline with the exception of the Kassemba Formation which occurs only on the western limb. Mafic volcanics are abundant also on the eastern limb of the anticline but is rare on the western limb.

2) Bedded manganese deposits in the Kunohe area are concentrated mostly (more than 80 percent) in the Seki Formation. Several deposits occur in the Kisawahata Formation, the Magidai Formation and the Kassemba Formation. The Seki Formation is characterized as the most chert-rich formation of the Iwaizumi Group.

3) The manganese deposits in the area are conformable to the wall rocks which comprise mostly chert. Massive chert is mostly found in the footwalls of the deposits and is rather rare in the hanging walls. Bedded chert occurs in both the hanging walls and the footwalls, but it occurs rather in the former than the latter.

4) The manganese deposits in the area are classified on the basis of constituent ore minerals into three types: the braunite-ore deposits, the carbonate-ore deposits and the silicate-ore deposits.

5) The braunite-ore deposits consist mainly of braunite ore and are accompanied characteristically by red chert. The deposits of this type are distributed mostly on the eastern limb of the Magidai anticline in accordance with abundance of mafic volcanics. The deposits may have been originated by the mafic volcanism developed at the northern end of the area.

6) The carbonate-ore deposits consist mainly of fine-grained rhodochrosite with various amounts of hausmannite, tephroite and rhodonite. The deposits of this type occur mostly on the western limb of the Magidai anticline with little apparent relation to the mafic volcanism. However they may have also genetic relation to the mafic volcanism because their mode of occurrence is much similar to the braunite-ore deposits with the exception of having no red chert.

7) The silicate-ore deposits consist mainly of coarse-grained manganese silicate ores such as rhodonite ore and tephroite ore. The deposits of this type are products of thermal metamorphism resulted by early Cretaceous granitic intrusions.

References

Abe, H. and Muramatsu, N. (1963) Manganese deposits in Fudai district. *Domestic Iron Resource Survey*, MITI, no. 2, p. 178–183 (in Japanese).

Bischoff, J. L. (1969) Red sea geothermal brine deposits: their mineralogy, chemistry and genesis, in Degens, E. T. and Ross, D. A., ed., *Hot Brines and Recent Heavy Metal Deposits in the Red Sea*, Springer-Verlag, p. 368–401.

Bonatti, E., Fisher, D. E., Joensuu, O., Rydell, H. S. and Beyth, M. (1972) Iron-manganese-barium deposit from the northern Afar Rift (Ethiopia). *Econ. Geol.*, vol. 67, p. 717–730.

Borchert, H. (1970) On the ore-deposition and geochemistry of manganese. *Miner. Dep.* (Berl.), vol. 5, p. 300–314.

Crerar, D. A. and Barnes, H. L. (1974) Deposition of deep-sea manganese nodules. *Geochim. Cosmochim. Acta*, vol. 38, p. 279–300.

Doi, S. and Hariya, Y. (1966) Pirika-type manganese deposits and their exploration. *Exploration of manganese deposits*, Soc. Mining Geol. Japan, p. 1–7 (in Japanese).

Fujimoto, H. (1961) *The geological sheet map "Tochigi", scale 1:50,000, and its explanatory text*. 62p., Geol. Surv. Japan (in Japanese with English abstract 6p.).

Garrels, R. M. and Christ, C. L. (1965) *Solutions, minerals, and equilibria*. 450p., Harper and Row, New York.

Hewett, D. F. (1966) Stratified deposits of the oxides and carbonates of manganese. *Econ. Geol.*, vol. 61, p. 431–461.

———— (1972) Manganite, hausmannite, braunite: features, modes of origin. *Econ. Geol.*, vol. 67, p. 83–102.

Hirowatari, F. (1961) Minerals and their paragenetic relations of the manganese deposits of Fukumaki mine, Yamaguchi Prefecture. *Bull. Geol. Surv. Japan*, vol. 12, p. 565–572 (in Japanese with English abstract).

———— (1967) Forms and dimensions of manganese deposits in the Paleozoic formations. *Exploration of manganese deposits*, Soc. Mining Geol. Japan, p. 11–15 (in Japanese).

———— (1968) Distribution of the manganese ore deposits in Paleozoic formations of Japan. *Mem. Geol. Soc. Japan,* no. 1, p. 33–40 (in Japanese with English abstract).
———— (1971) The manganese ore deposits in the metamorphic zones of Japan. *Mem. Geol. Soc. Japan,* no. 6, p. 203–204 (in Japanese with English abstract).
———— and Takeda, H. (1962a) On the manganese ore deposits in the Watarase river district, Gumma Prefecture. *Bull. Geol. Surv. Japan,* vol. 13, p. 437–452 (in Japanese with English abstract).
———— and ———— (1962b) On the manganese ore deposits in the Kaso, Hikoma and Hishimura districts, Tochigi Prefecture. *Bull. Geol. Surv. Japan,* vol. 13, p. 683–708 (in Japanese with English abstract).
Imoto, N. (1966) Manganese ore deposits in the central part of the Tamba district. *Mem. Kyoto Univ. Edu.,* Ser. B, no. 29, p. 19–30 (in Japanese with English abstract).
———— (1967) Genesis of Paleozoic manganese deposits in the Tamba belt. *Problems on Sedimentology,* Joint Symp. (Nagoya), Geol. Soc. Japan etc., p. 72–76 (in Japanese).
———— and Fukutomi, M. (1975) Genesis of bedded cherts in the Tamba belt, Southwest Japan. *Problems on Geosynclines in Japan,* Monogr. no. 19, Organ. Commit. Symp. 1974, Assoc. Geol. Collab. Japan, p. 35–42 (in Japanese with English abstract).
———— and Saito, Y. (1973) Scanning electron microscopy of chert. *Bull. Nat. Sci. Mus. Japan,* vol. 16, p. 397–400.
———— and Takahashi, A. (1972) The micro-texture of cherts. *Jour. Marine Geol.,* vol. 8, p. 12–17 (in Japanese with English abstract).
Iwai, J., Murata, M., Hase, K. and Omura, K. (1964) On the Paleozoic formations in the vicinity of Kuzumaki, North Kitakami Mountains. *Jour. Geol. Soc. Japan,* vol. 70, p. 382–383 (in Japanese).
Iwao, S. (1962) Geology of the silica deposits in the Tamba district, Japan. *Mining Geol. (Tokyo),* vol. 12, p. 334–345 (in Japanese with English abstract).
———— (1970) Clay and silica deposits of volcanic affinity in Japan, in Tatsumi, T., ed., *Volcanism and Ore Genesis,* Univ. Tokyo, p. 267–284.
Kanmera, K. (1968) On some sedimentary rocks associated with geosynclinal volcanic rocks. *Mem. Geol. Soc. Japan,* no. 1, p. 23–32 (in Japanese with English abstract).
Kano, H. (1958) Geological consideration on the Cretaceous metallogenetic provinces of Kieslager in the outer geosynclinal zones of Honshu, Japan. *Mining Geol. (Tokyo),* vol. 8, p. 319–327 (in Japanese with English abstract).
Katada, M. (1974) Cretaceous granitic rocks in the Kitakami Mountains, I: Introductory remarks, *Rept. Geol. Surv. Japan,* no. 251, p 1–7 (in Japanese with English abstract).
———— and Yoshida, T. (in preparation) *Geology of the Miyako district.* Quadrangle Series, scale 1:50,000, Geol. Surv. Japan (in Japanese with English abstract).
Kawano, Y. and Ueda, Y. (1965) K–A dating on the igneous rocks in Japan (II). *Jour. Japan Assoc. Min. Petr. Econ.,* vol. 53, p. 143–154 (in Japanese with English abstract).
Krauskopf, K. B. (1956a) Separation of manganese from iron in the formation of manganese deposits in volcanic associations. *Internat. Geol. Cong., 20th, Mexico City, Symp. Manganese,* vol. 1, p. 119–131.
———— (1956b) Dissolution and precipitation of silica at low temperatures. *Geochim. Cosmochim. Acta,* vol. 10, p. 1–26.
———— (1957) Separation of manganese from iron in sedimentary processes. *Geochim. Cosmochim. Acta,* vol. 12, p. 61–84.
———— (1967) *Introduction to geochemistry.* 698p., McGraw-Hill, New York.
Krumbein, W. C. and Garrels, R. M. (1952) Origin and classification of chemical sediments in term of pH and oxidation-reduction potentials. *Jour. Geol.,* vol. 60, p. 1–33.
Lee, D. E. (1955) *Mineralogy of some Japanese manganese ores.* 64p., Stanford Univ.
Minato, M. (1950) Geology of the Kitakami Mountains. *Assoc. Geol. Collab. Japan,* Monogr. no. 5, p. 1–20 (in Japanese).
Miyahisa, M. (1969) Geological problems on the manganese ore deposits of Sambagawa metamorphic zone, Southwest Japan. *Sci. Rept. Fac. Sci. Kyushu Univ.,* Geol., vol. 9, p. 29–37 (in Japanese with English abstract).
Miyamoto, H. and Ishida, Y. (1957) Report on the manganese deposits of Nodatamagawa mine, Iwate Prefecture. *Bull. Geol. Surv. Japan,* vol. 8, p. 77–102 (in Japanese with

English abstract).
MORITANI, T. (1963) On the Neogene Tertiary in the Fukaura district, Aomori Prefecture, with special reference to the manganese ore deposits. *Mem. Hiroshima Univ.*, no. 12, p. 131–147 (in Japanese with English abstract).
———— (1964) Stratigraphic horizon of the Miocene bedded manganese ore deposits in Japan. *Earth Sci. (Tokyo)*, no. 72, p. 17–23 (in Japanese with English abstract).
———— (1967) Bedded manganese deposits and related deposits in the Green-tuff areas and their sedimentologic environments. *Problems on Sedimentology*, Joint Symp. (Nagoya), Geol. Soc. Japan etc., p. 64–71 (in Japanese).
MURATA, M. and SUGIMOTO, M. (1971) Late Triassic conodonts from the northern part of the Kitakami massif, Northeast Japan. *Bull. Geol. Soc. Japan*, vol. 77, p. 393–394 (in Japanese).
NAKAO, S. (1969) Chert in the Konosé Group of the Sambosan belt, Southern Kyushu. *Sci. Rept., Fac. Sci. Kyushu Univ.*, Geol., vol. 10, p. 11–24 (in Japanese with English abstract).
NAMBU, M. (1958) *Report on the several manganese deposits in the Kitakami Mountains.* 37p., Iwate Prefecture (in Japanese).
———— (1959) *On the ore minerals of several manganese deposits in the Kitakami Mountains.* 33p., Iwate Prefecture (in Japanese).
———— (1960) *Manganese deposits and ore minerals of the Hongo, the Yamagata, the Fujikura, the Yokochi, the Takamine and the Otaniyama mines, in the Kitakami Mountains.* 32p., Iwate Prefecture (in Japanese).
————, CHIBA, Y. and KUMAGAI, S. (1965) Manganese deposits in Kannon district. *Domestic Iron Resource Survey*, MITI, no. 4, p. 44–45 (in Japanese).
————, ————, SATO, S. and SASAKI, S. (1967a) Manganese deposits in the Fujikura mine. *Domestic Iron Resource Survey*, MITI, no. 6, p. 44–47 (in Japanese).
————, ————, ———— and ———— (1967b) Manganese deposits in the Taki mine. *Domestic Iron Resource Survey*, MITI, no. 6, p. 49–52 (in Japanese).
————, KANO, S., CHIBA, Y. and KUMAGAI, S. (1965a) Manganese deposits in Takamine district. *Domestic Iron Resource Survey*, MITI, no. 4, p. 42–44 (in Japanese).
————, KOMAGATA, S. and KUMAGAI, S. (1967) Manganese deposits in the Goto mine. *Domestic Iron Resource Survey*, MITI, no. 6, p. 52–54 (in Japanese).
————, KONNO, Y. and KUMAGAI, S. (1967) Manganese deposit in the Toyaba mine. *Domestic Iron Resource Survey*, MITI, no. 6, p. 47–49 (in Japanese).
————, OHIRA, Y., NAKUI, T. and MURAMATSU, N. (1965b) Manganese deposits in Toyomane (Daiichi–Fukushi) district. *Domestic Iron Resource Survey*, MITI, no. 4, p. 53–55 (in Japanese).
————, ————, OIKAWA, S., NAKUI, T. and MURAMATSU, N. (1965c) Manganese deposits in Toyomane (Otaniyama) district. *Domestic Iron Resource Survey*, MITI, no. 4, p. 55–57 (in Japanese).
————, OKADA, K., TANIDA, K., ISHIHARA, T., KUNUI, T., TANNO, H., SATO, S., NAKUI, T. and SASAKI, S. (1961) Iron deposits in Morioka district. *Unutilized Iron Resources of Japan*, MITI, no. 9, p. 88–97 (in Japanese).
————, ————, ————, ONUMA, Z., TAKAHASHI, Y., SATO, S. and NAKUI, T. (1959) Iron deposits in the eastern part of Morioka City. *Unutilized Iron Resources of Japan*, MITI, no. 7, p. 94–100 (in Japanese).
———— and SASAKI, S. (1965) Manganese deposits in the Kumanosawa mine. *Domestic Iron Resource Survey*, MITI, no. 4, p. 63–65 (in Japanese).
NAMBU, M. and TANIDA, K. (1961) On the progressive alteration of manganese dioxide minerals in the Toyoguchi mine, Iwate Prefecture. *Jour. Japan. Assoc. Min. Petr. Econ.*, vol. 45, p. 39–48 (in Japanese with English abstract).
———— and ———— (1964) Oxidation of the manganese ore deposits of Taki mine, Iwate Prefecture with special reference to the formation of amorphous dioxide mineral. *Jour. Japan. Min. Petr. Econ.*, vol. 51, p. 223–232 (in Japanese with English abstract).
———— and ———— (1967) Manjirōite, a new manganese dioxide mineral, from Kohare mine, Iwate Prefecture, Japan. *Jour. Japan. Assoc. Min. Petr. Econ.*, vol. 58,

p. 39–54 (in Japanese with English abstract).
———, ———, ARAI, K., IBE, Y., SATO, S. KUMAGAI, S. and SASAKI, S. (1960) Iron deposits in Morioka City. *Unutilized Iron Resources of Japan,* MITI, no. 8, p. 91–95 (in Japanese).
———, ———, KANO, S., KITAMURA, T., OHIRA, Y., SAITO, K., SAHARA, Y. and KUMAGAI, S. (1965d) Manganese deposits in the Kunohe and Yamagata districts. *Domestic Iron Resource Survey,* MITI, no. 4, p. 45–53 (in Japanese).
———, ——— and KITAMURA, T. (1969) Kôzulite, a new alkali amphibole, from Tanohata mine, Iwate Prefecture, Japan. *Jour. Japan. Assoc. Min. Petr. Econ.,* vol. 62, p. 311–328 (in Japanese with English abstract).
———, ——— and ——— (1970a) Manganoan wollastonite from Hijikuzu mine, Iwate Prefecture., *Bull. Res. Inst. Min. Dress. Met.,* vol. 26, p. 11–21 (in Japanese with English abstract).
———, ——— and ——— (1970b) Manganiferous hedenbergite from Hijikuzu mine, Iwate Prefecture. *Bull. Res. Inst. Dress. Met.,* vol. 26, p. 123–132 (in Japanese with English abstract).
———, ———, ———, NAKAGAWA, I., KOMAGATA, S. and KUMAGAI, S. (1966) Manganese deposits in the Tanohata and the Fudai districts. *Domestic Iron Resource Survey,* MITI, no. 5, p. 47–50 (in Japanese).
———, ——— and KUMAGAI, S. (1969) *Manganese deposits in the Kitakami Mountains I.* 155p., Iwate Prefecture (in Japanese).
———, ———, OIKAWA, S., KUMAGAI, S. and NASUKAWA, S. (1973) *Manganese deposits in the Kitakami Mountains II.* 85p., Iwate Prefecture (in Japanese).
———, TOMIMURA, H. and KUMAGAI, S. (1966) Manganese deposits in Okawame district. *Domestic Iron Resource Survey,* MITI, no. 5, p. 42–46 (in Japanese).
NARITA, H., KOTO, K., MORIMOTO, N. and YOSHII, M. (1975) The crystal structure of nambulite (Li, Na) $Mn_4Si_5O_{14}(OH)$. *Acta Cryst.,* vol. B31, p. 2422–2426.
NAUMANN, E. (1881) Über das vorkommen von Triasbildungen im nordlichen Japan. *Kaiserliche Kgl. Geol. Reischsanst (Wien) Jahrlb.,* vol. 31, p. 519–528.
OKADA, K. and KUMAGAI, S. (1960) Iron deposits in eastern Morioka City. *Unutilized Iron Resources of Japan,* MITI, no. 8, p. 95–100 (in Japanese).
OMORI, K., HASEGAWA, S. and OTOMO, J. (1952) A new occurrence of hausmannite and tephroite from a manganese deposit at Himegamori, Iwate Prefecture. *Jour. Japan. Assoc. Min. Petr. Econ.,* vol. 36, p. 65–72 (in Japanese with English abstract).
ONUKI, Y. (1956) *Geology of the Kitakami massif.* Explanatory text of the geological map, scale 1:100,000, of Iwate Prefecture II, Iwate Prefecture, p. 1–189 (in Japanese).
——— (1969) Geology of the Kitakami massif, Northeast Japan. *Contr. Inst. Geol. Pal. Tohoku Univ.,* no. 69, p. 1–239 (in Japanese with English abstract).
——— and KUDO, H. (1954) Finding of the Permian system in the North Kitakami Mountains. *Jour. Geol. Soc. Japan,* vol. 60, p. 360–362 (in Japanese).
RESEARCH GROUP OF THE TANBA BELT (1969) The Paleozoic system in the Tanba belt (part 1). *Earth Sci. (Tokyo),* vol. 23, p. 187–193 (in Japanese with English abstract).
ROY, S. (1968) Mineralogy of the different genetic types of manganese deposits. *Econ. Geol.,* vol. 63, p. 760–786.
SAKAGUCHI, S. (1961) Stratigraphy and paleontology of the South Tamba district. *Mem. Osaka Gakugei Univ.,* B, no. 10, p. 35–76.
SATO, A., FUKUDA, K. and WADA, T. (1957) On the manganese deposit and its prospecting of Nodatamagawa mine, Iwate Prefecture. *Mining Geol. (Tokyo),* vol. 7, p. 98–103 (in Japanese).
SHIBATA, K. and MILLER, J. A. (1962) Potassium-argon ages of granitic rocks from the Kitakami highlands. *Bull. Geol. Surv. Japan,* vol. 13, p. 709–711.
SHIMAZU, M. TANAKA, K. and YOSHIDA, T. (1970) *Geology of the Taro district.* 54p., Quadrangle Series, scale 1:50,000, Geol. Surv. Japan (in Japanese with English abstract 6p.).
SOKOLOVA, E. I. (1962) *Physicochemical investigations of sedimentary iron and manganese ores and associated rocks.* Acad. Sci. U.S.S.R. (in Russian), English translation, Israel Prog. Sci. Transl. (1964), 220p.

STASHCHUK, M. F. (1968) *The oxidation-reduction potential in geology*. Nedra, Moscow (in Russian), English translation, Consultants Bureaus, New York, Div. Plunum Publ. Corp. (1972), 121p.

SUGIMOTO, M. 1969) Geology of the Omoto-Tanohata district, outer Kitakami belt, Northeast Japan. *Contr. Inst. Geol. Pal., Tohoku Univ.*, no. 70, p. 1–22 (in Japanese with English abstract).

——— (1972) On the Kuzumaki tectonic line and the Tarō tectonic line, northern Kitakami massif, Northeast Honshu, Japan. *Prof. Jun-ichi Iwai Mem. Vol.*, p. 97–109 (in Japanese with English abstract).

——— (1974) Stratigraphical study in the outer belt of the Kitakami massif, Northeast Japan. *Contr. Inst. Geol. Pal., Tohoku Univ.*, no. 74, p 1–48 (in Japanese with English abstract).

——— and UDA, S. (1972) On the unconformity at the base of the Sawayamagawa Formation, northern Kitakami massif, Northeast Honshū, Japan. *Mem. Fac. Edu. Kanazawa Univ.*, no. 21, p. 83–91 (in Japanese with English abstract).

SUZUKI, T., TAKAHASHI, Y., SHIMIZU, M. and NAKUI, T. (1962) Manganese deposits in Yamagata district. *Domestic Iron Resource Survey*, MITI, no. 1, p. 219–229 (in Japanese).

———, ———, ———, YOSHII, M., SASAKI, S. and KUMAGAI, S. (1963) Manganese deposits in Ono and Karumai districts. *Domestic Iron Resource Survey*, MITI, no. 2, p. 168–178 (in Japanese).

TAKAHASHI, I. (1961) Geology and manganese ore deposit of the Ōtaniyama mine, Iwate Prefecture. *Jour. Japan. Assoc. Min. Petr. Econ.*, vol. 45, p. 137–148 (in Japanese with English abstract).

TALIAFERRO, N. L. (1943) Manganese deposits of the Sierra Nevada, their genesis and metamorphism. *Calif. Div. Min. Bull.*, no. 125, p. 277–332.

——— and HUDSON, F. S. (1943) Genesis of the manganese deposits of the Coast Ranges of California. *Calif. Div. Min. Bull.*, no. 125, p. 217–275.

TANIDA, K. and SASAKI, S. (1965) Manganese deposits in Tonakayama district. *Domestic Iron Resource Survey*, MITI, no. 4, p. 61–63 (in Japanese).

WATANABE, T. (1957) Genesis of bedded manganese deposits and cupriferous pyrite deposits in Japan. *Mining Geol.* (*Tokyo*), vol. 7, p. 87–97 (in Japanese with English abstract).

——— (1959) The minerals of Noda-Tamagawa mine, Iwaté Prefecture, Japan. I, Note on geology and paragenesis of minerals. *Miner. Jour.*, vol. 2, p. 408–421.

———, KATO, A. and ITO, J. (1960) The minerals of the Noda-Tamagawa mine, Iwaté Prefecture, Japan. II, pyrochroite ore (Kimiman-kō) and its origin. *Miner. Jour.*, vol. 3, p. 30–41.

———, MUKAIYAMA, H., KANEHIRA, K. and HAMADA, T. (1957) *Explanatory text of the geological map of Ashio massif*. 40p., Tochigi Prefecture (in Japanese).

——— TAKÉUCHI, Y. and ITO, J. (1961) The minerals of the Noda-Tamagawa mine, Iwate Prefecture, Japan. III, yoshimuraite, a new barium-titanium-manganese silicate mineral. *Miner Jour.*, vol. 3, p. 156–167.

———, YUI, S. and KATO, A. (1970a) Bedded manganese deposits in Japan, a review, in TATSUMI, T., ed., *Volcanism and Ore Genesis*, Univ. Tokyo, p. 119–142.

———, ——— and ——— (1970b) Metamorphosed bedded manganese deposits of the Noda-Tamagawa mine, in TATSUMI, T., ed., *Volcanism and Ore Genesis*, Univ. Tokyo, p. 143–152.

YAMASHITA, N. (1957) *The Mesozoic, part II*. 94p., Assoc. Geol. Collab. Japan (in Japanese).

YOSHIDA, T. (1961) *The geological sheet map "Kamaishi", scale 1:50,000, and its explanatory text*. 26p., Geol. Surv. Japan (in Japanese with English abstract 5p.).

——— (1968) The tectonic division of the Paleozoic and Mesozoic formations of the northern Kitakami Mountains. *Jour. Geol. Soc. Japan*, vol. 74, p. 139 (in Japanese).

——— (1975) Development of Northeast Japan geosyncline in the Paleozoic and the Mesozoic. *Problems on Geosyncline in Japan*, Monogr. no. 19, Organ, Commit. Symp. 1974, Assoc. Geol. Collab. Japan, p. 103–114 (in Japanese with English abstract).

———— and KATADA, M. (1964) *The geological sheet map "Otsuchi and Karodake", scale 1:50,000, and its explanatory text.* 30p., Geol. Surv. Japan (in Japanese with English abstract 6p.).

YOSHII, M., AOKI, Y. and MAEDA, K. (1972) Nambulite, a new lithium- and sodium-bearing manganese silicate from the Funakozawa mine, northeastern Japan. *Miner. Jour.*, vol. 7, p. 29–44.

———— and KATADA, M. (1974) Cretaceous granitic rocks in the Kitakami Mountains, II: Granitic rocks in the Kitakami Mountains. *Rept. Geol. Japan,* no. 251, p. 8–22 (in Japanese with English abstract).

———— and KOMURA, T. (1971) Zonal arrangement of minerals at the granitic contact of the manganese ore deposit in Noda-Tamagawa mine, Iwate Prefecture, northern Japan. *Soc. Mining Geol. Japan,* Spec. Is., no. 3, p. 449–453.

———— and MAEDA, K. (1975) Relation between barium content and the physical and optical properties in the manganoan phlogopite-kinoshitalite series. *Miner. Jour.*, vol. 8, p. 58–65.

————, ————, WATANABE, T., YUI, S., KATO, A. and NAGASHIMA, K. (1973) Kinoshitalite, a new mineral from the Noda-Tamagawa mine. *Geosci. Mag. (Kyoto)*, vol. 24, p. 181–188 (in Japanese with English abstract).

———— TOGASHI, Y. and MAEDA, K. (1973) On the intensity changes of basal reflections with relation to barium content in manganoan phlogopite and kinoshitalite. *Bull. Geol. Surv. Japan,* vol. 24, p. 543–550.

———— and YOSHIDA, M. (1974) Geology of the manganese-ore area in the northern end of the Kitakami Mountains. *Bull. Geol. Surv. Japan,* vol. 25, p. 147–156 (in Japanese with English abstract).

YOSHIMURA, T. (1938): Geology and ore deposit of Kaso mine, Totigi Prefecture, with special reference to mineral paragenesis. *Jour. Geol. Soc. Japan,* vol. 45, Supple. no. 532, p. 1–91 (in Japanese).

———— (1939) Studies on the minerals from the manganese deposit of the Kaso mine, Japan. *Jour. Fac. Sci., Hokkaido Univ.,* vol. 4, p. 316–451.

———— (1952) *Manganese ore deposits of Japan.* 567p., Mangan Kenkyukai, Kyushu Univ., Fukuoka (in Japanese).

———— (1953) Types of manganese deposits in Japan. *Proc. 7th Pacific Sci. Congr.,* vol. 2, p. 216–217.

———— (1958) The Muramatsu-type manganese deposits. *Prof. Jun Suzuki's Sixtieth Birthday Mem. Vol.,* p. 371–378 (in Japanese).

———— (1967) Supplement to "Manganese ore deposits of Japan" part I, manganese mineralization, minerals and ores. *Sci. Rept. Fac. Sci., Kyushu Univ., Geol.,* vol. 9, Spec. Is., no. 1, p. 1–485 (in Japanese with English abstract).

———— (1969) Supplement to "Manganese ore deposits of Japan" part II, manganese mines of Japan. *Sci. Rept. Fac. Sci., Kyushu Univ., Geol.* vol. 9, Spec. Is., no. 2, p. 487–1004 (in Japanese).

———— and SASA, Y. (1935) A type of manganese ore deposits in Oshima peninsula, Hokkaido. *Jour. Geol. Soc. Japan,* vol. 42, p. 615–633 (in Japanese).

ZOBELL, C. E. (1946) Studies on redox potential of marine sediments. *Amer. Assoc. Petroleum Geol. Bull.,* vol. 30, p. 477–512.

Appendix

The brief descriptions of the manganese deposits in this paper are listed in the followings. The data came mainly from NAMBU, TANIDA and KUMAGAI (1969) and NAMBU *et al.* (1973) in addition to the data from this study. References by other authors are at the last line of each description.

Deposit numbers in Appendix and Figs. 1, 2 and 7 are given in the following manner:

1–70: Deposits in the Iwaizumi Group of the Kunohe area and the vicinity.
- 1–10: Deposits in the Kisawahata Formation.
- 11–20: Deposits in the Magidai Formation.
- 21–60: Deposits in the Seki Formation.
- 61–70: Deposits in the Kassemba Formation.

71–80: Deposits in undefined Iwaizumi Group.
81–90: Deposits in the Taro belt.
91–100: Deposits in the Kuzumaki area and the vicinity of the North Kitakami belt.
101–110: Deposits in the Kamaishi area of the North Kitakami belt.
111– : Deposits in the Hayachine tectonic belt.

Deposits in the Kisawahata Formation

1. *Imoya*

This deposit is located at Matsuzaka of Yamagata Village, 4 km north of Kawai.

The deposit consists of two ore bodies. They are 5–23 m long in strike direction and 0.1–0.3 m thick.

The primary ore of the deposit is the carbonate ore composed mainly of rhodochrosite, hausmannite, rhodonite and small amount of spessartine. Pyroxmangite occurs as veinlets in the ore. The oxidized ore is composed of pyrolusite and nsutite.

The wall rock of the deposit is bedded chert.

The production of the ores is unknown.

Reference: NAMBU *et al.* (1965d).

2. *Numabukuro*

This deposit is located at Numabukuro of Yamagata Village, 2.5 km northeast of Kawai.

The deposit is 5–45 m long in strike direction and up to 0.2 m thick.

The ore of the deposit is the oxidized ore composed of pyrolusite and nsutite.

The wall rock of the deposit is bedded chert.

The production of the ore from 1942 to 1945 was 250 tons with unknown grade.

3. *Tsunagi*

This deposit is located at Tsunagi of Yamagata Village, 7 km east of Kawai.

The deposit is several ten meters long in strike direction and 0.2–0.3 m thick. The ore body is much folded, and the exact dimension is unknown.

The ore of the deposit is mainly the oxidized ore composed mainly of pyrolusite. The primary ore occurs in small amount. It is composed mainly of rhodonite, tephroite, jacobsite and neotocite.

The footwall of the deposit is massive chert. The hanging wall is slate.

The production of the ores from 1941 to 1942 was about 100 tons with unknown grade.

Deposits in the Magidai Formation

11. *Kohare*

This deposit is located at Aozawa of Karumai Town, 5.5 km southeast of Kogarumai.

The deposit is up to 40 m long in strike direction and 0.2–1 m thick.

The ore of the deposit is mostly the oxidized ore composed of cryptomelane, manjirōite, pyrolusite, nsutite and birnessite. At the bottom of the deposit the primary ore occurs in small amount. It is the carbonate ore composed mainly of rhodonite, tephroite and rhodochrosite associated with small amounts of spessartine, jacobsite and neotocite. Pyroxmangite occurs as veinlets in the ore (Plate 17–1; Table 15). The chemical analysis of the carbonate ore is in Table 9.

The footwall of the deposit is massive chert. The hanging wall is silty tuff.

The production of the ore concentrates from the deposit from 1943 to 1967 was 1,350 tons with the average grade of 38 percent Mn and 200 tons with the average grade of 74 percent MnO_2.

Reference: SUZUKI *et al.* (1963).

12. *Yamato*

This deposit is located at Nakamura of Karumai Town, 6 km south-southeast of Kogarumai.

The deposit is 4.5–9.5 m long in strike direction and 1 m thick.

The ore of the deposit is the oxidized ore composed mainly of cryptomelane associated with small amount of spessartine.

The wall rock of the deposit is bedded chert and massive chert.

The production of the ore is unknown.

13. *Tengu*

This deposit is located at Tengu of Karumai Town, 7 km southeast of Kogarumai.

The deposit is 40–50 m long in strike direction and up to 0.1 m thick. The ore of the deposit is the oxidized ore composed of cryptomelane and small amount of nsutite.

The wall rock of the deposit is massive chert.

The production of the oxidized ore concentrate from the deposit from 1937 to 1945 was about 2,000 tons with unknown grade.

14. *Takamatsu*

This deposit is located at Takamatsuzawa of Yamagata Village, 3 km north-northwest of Heromachi.

Several outcrops of the deposit are traceable for 2 km in strike direction. Each ore body is up to 170 m long in strike direction, 83 m long in dip direction and 0.4–1.5 m thick.

The primary ore of the deposit is made up of the braunite ore and the carbonate ore. The carbonate ore is composed mainly of rhodochrosite associated with tephroite, rhodonite and small amounts of spessartine, dannemorite, bementite and alabandite. The chemical analysis of the carbonate ore is shown in Table 9. The oxidized ore is composed mainly of nsutite, cryptomelane and pyrolusite.

The footwall of the deposit is gray massive chert. The boundary between the footwall and the ore body undulates more than that between the hanging wall and the ore body. The hanging wall is gray bedded chert and red bedded chert.

The production of the manganese concentrates from the deposit from 1938 to 1962 was 16,200 tons with the average grade of 36 percent Mn.

Reference: NAMBU (1958).

15. *Yanosawa*

This deposit is located at Yanosawa of Yamagata Village, 2 km east of Heromachi.

Five ore bodies occur in the deposit. The principal ore body is 30 m long in strike direction, 44 m long in dip direction and about 1 m thick.

The primary ore of the deposit consists mainly of the braunite ore associated with the carbonate ore composed mainly of rhodochrosite, tephroite and rhodonite. Pyroxmangite occurs as veinlets cutting the ore. The oxidized ore is composed mainly of pyrolusite associated with nsutite in small amount.

The footwall of the deposit is slate (0.2 m thick) and massive chert (1.5 m thick). The hanging wall is red bedded chert (1 m thick).

The production of the manganese concentrates from 1955 to 1958 was known to be 800 tons with the average grade of 40 percent Mn.

Reference: NAMBU (1958).

16. *Mikkamachi*

This deposit is located at Makado of Kuji City, 6 km west of Kuji.

The deposit is 15 m long in strike direction. Length in dip direction and thickness are unknown.

The primary ore of the deposit is composed of rhodonite and tephroite accompanied by quartz. The oxidized ore is nsutite.

The footwall of the deposit is bedded chert. The hanging wall is bedded chert and massive chert.

The production of the ore concentrate from the deposit from 1955 to 1958 was about 300 tons with the average grade of 30 percent Mn.

Reference: NAMBU, TOMIMURA and KUMAGAI (1966).

17. *Makado*

This deposit is located at Makado of Kuji City, 6 km west of Kuji.

The deposit is 20 m long in strike direction and up to 0.35 m thick.

The primary ore of the deposit is composed of rhodonite and tephroite accompanied by small amount of quartz. The oxidized ore is mainly nsutite.

The footwall of the deposit is red massive chert. The hanging wall is bedded chert.

The production of ore is said to be 350 tons with unknown grade.

18. *Tsuboana*

This deposit is located at Tsuboana of Kuji City, 9 km west of Kuji.

The deposit is about 10 m long in strike direction and up to 1 m thick.

The primary ore of the deposit is composed mainly of rhodonite. The oxidized ore is mainly nsutite and pyrolusite.

The wall rock of the deposit is bedded chert.

The production of the ore was about 2,000 tons around 1940 with unknown grade.

Reference: NAMBU, TOMIMURA and KUMAGAI (1966).

19. *Shimizugawa*

This deposit is located at Shimizugawa of Yamagata Village, 3 km east-southeast of Kawai.

The deposit consists of several ore bodies. They are about 20 m long in strike direction, about 20 m long in dip direction and 0.3–2.5 m thick.

The primary ore consists mainly of the silicate ore associated with the carbonate ore. The silicate ore is composed mainly of rhodonite associated with tephroite. This ore is a product of thermal metamorphism caused by the Numabukuro intrusive body located about 1.5 km from the deposit. So-called Bakappi, a low-grade silicate ore of several meters thick, occurs in part of the deposit. This ore is thought to have been formed by introduction of manganese component from the ore to the siliceous walls in the course of the pyrometasomatism. The carbonate ore is composed mainly of rhodochrosite associated with small amounts of jacobsite, spessartine, dannemorite, alleghanyite, galaxite, pyrophanite, bementite and neotocite. The chemical analysis of the carbonate ore is listed in Table 9. The oxidized ore is mainly pyrolusite associated with cryptomelane and nsutite.

The wall rock of the deposit is bedded chert.

The production of the ore concentrates from the deposit from 1964 to 1966 was 2,300 tons with the average grade of 27 percent Mn.

Reference: NAMBU *et al.* (1965d).

Deposits in the Seki Formation

21. *Kannon*

This deposit is located at Tokusanai of Karumai Town, 5 km north-northwest of Kogarumai.

The deposit is 60 m long in strike direction and 0.1–0.5 m thick. The deposit is folded, and an axis of minor folding trends N.10°E. and plunges Southward at 70°, and another axis trends N.50°W. and plunges northward at 65°.

The primary ore of the deposit is braunite. The oxidized ore is composed of cryptomelane, pyrolusite and nsutite.

The footwall of the deposit is red massive chert (10 m in thickness) and bedded chert. The hanging wall is red massive chert.

The production of the ore was 400 tons with unknown grade by 1945 and 1,000 tons with the grade of 70–75 percent MnO_2 since 1964.

Reference: NAMBU, CHIBA and KUMAGAI (1965).

22. *Omaki*

This deposit is located at Tokusanai of Karumai Town, 4 km north of Kogarumai.

The deposit is 20 m long in strike direction and 0.7–1 m thick.

The ore of the deposit is mainly the oxidized ore composed of cryptomelane, pyrolusite, nsutite and small amount of todorokite.

The wall rock of the deposit is bedded chert.

The production of the ore is unknown.

23. *Takamine*

This deposit is located at Matsunowaki of Karumai Town, 2 km north of Kogarumai.

The deposit is about 100 m long in strike direction, 60 m long in dip direction and 0.5–1 m (maximum 3 m) thick. The ore body is folded, and the axis of the minor folding trends N.40°–50°W. and plunges southward at 20°.

The primary ore of the deposit is composed of braunite. The oxidized ore is mainly cryptomelane associated with small amount of todorokite.

The wall rock of the deposit is red bedded chert with 5–10 m in thickness.

The production of the ore concentrates from the deposit from 1938 to 1962 was 350 tons with the average grade of 48 percent Mn and 1,050 tons with the average grade of 70 percent MnO_2.

References: NAMBU (1960); NAMBU *et al.* (1965a).

24. *Kogarumai*

This deposit is located at Matsunowaki of Karumai Town, 1.5 km northeast of Kogarumai.

The deposit is 80 m long in strike direction, 60 m long in dip direction and about 0.3 m thick. The ore body is folded, and an axis of the minor folding trends N.10°W. and plunges southward at 70°, and another axis trends N.40°W. and plunges northward at 43°.

The primary ore of the deposit is the braunite ore. It forms bands with small amounts of tephroite, rhodonite and rhodochrosite. The oxidized ore is composed of cryptomelane and pyrolusite.

The wall rock of the deposit is red bedded chert.

The production of the ore concentrates from the deposit from 1943 to 1960 was 700 tons with the average grade of 49 percent Mn and 350 tons with the average grade of 80 percent MnO_2.

Reference: NAMBU (1958).

25. *Taiho*

This deposit is located at Otai of Karumai Town, 3.5 km east-southeast of Kogarumai.

The deposit consists of several ore bodies. Each of them is up to 20 m long in strike direction and 0.5–0.8 m thick. The ore bodies are folded, and the axis of the minor folding trends N.30°W. and plunges southward at 50°.

The primary ore of the deposit is the braunite ore. It forms bands with chert every 1 cm thick. The oxidized ore is composed of cryptomelane and pyrolusite.

The footwall is red massive chert. The hanging wall is gray bedded chert.

The production of the ore is unknown.

26. *Otai*

This deposit is located at Otai of Karumai Town, 3 km east-southeast of Kogarumai.

The deposit consists of several ore bodies. They are 50–60 m long in strike direction, 20–30 m long in dip direction and 0.3–0.4 m (maximum 1.5 m) thick.

The ore of the deposit is oxidized ore composed mainly of cryptomelane and nsutite.

The wall rock of the deposit is bedded chert.

The production of the ore concentrates from the deposit from 1961 to 1966 was 300 tons with the average grade of 29 percent Mn and 350 tons with the average grade of 75 percent MnO_2.

Reference: Suzuki *et al.* (1963).

27. *Kotamagawa*

This deposit is located at Tamagawa of Karumai Town, 4.5 km southwest of Ono.

The deposit consists of several ore bodies cropping out for more than 3 km in strike direction. Each ore body is 50–100 m long in the strike direction, 100 m long in dip direction and 0.5–1 m (maximum 3 m) thick. The ore bodies are folded, and the axis of the minor folding trends N.10°–40°W. and plunges southward at 25°–34°.

The primary ore of the deposit is mainly the braunite ore. It alternates with red chert every 1–2 cm thick as shown in Plate 12–1. The oxidized ore is composed of cryptomelane, manganosite, nsutite, pyrolusite and todorokite.

The footwall of the ore bodies is red bedded chert and red massive chert. The hanging wall is red bedded chert. Films of tuffaceous matter are intercalated in the red bedded chert every 2–3 cm. The boundary between the footwall and the ore bodies undulates more distinctly than that between the hanging wall and the ore bodies does. Color of the red chert is especially bright red within 2 m from the ore bodies.

The production of the ore from the deposit from 1935 to 1968 was 7,900 tons with the average grade of 45 percent Mn.

Reference: Suzuki *et al.* (1963).

28. *Ono*

This deposit is located at Genda of Ono Village, 3 km southwest of Ono.

The deposit consists of two ore bodies. They are about 30 m long in strike direction, about 20 m long in dip direction and up to 1 m thick.

The primary ore of the deposit is the braunite ore associated with small amount of spessartine. The oxidized ore is composed mainly of cryptomelane and nsutite.

The wall rock of the deposit is red bedded chert.

The production of the ore concentrates from the deposit was 700 tons during the 1910's, and 1,750 tons with the average grade of 46 percent Mn and 200 tons with the average grade of 75 percent MnO_2 from 1939 to 1945.

29. *Goto*

This deposit is located at Tamagawa of Kogarumai Town, 4 km southwest of Ono.

The deposit consists of several ore bodies. The largest ore body is 60 m long in strike direction and 0.3 m thick.

The ore of the deposit consists of the braunite ore. The oxidized ore is composed mainly of cryptomelane associated with small amount of todorokite.

The wall rock of the deposit is red bedded chert.

The production of the ore from the deposit is unknown.

Reference: NAMBU, KOMAGATA and KUMAGAI (1967).

30. *Funakozawa*

The description of this deposit is in 3. 2. 3 in the text.

31. *Tachikawa*

This deposit is located at Kogarumai of Karumai Town, 4.5 km south-southwest of Ono.

The deposit is 30 m long in strike direction, 90 m long in dip direction and 0.5–1 m thick. The ore body is strongly folded. It extends toward the depth along the axis of the minor folding which trends N.15°–40°W. and plunges southward at 20°–30°.

The primary ore occurs in small amount. It consists mainly of the braunite ore associated with small amount of the carbonate ore composed of rhodonite, tephroite, spessartine, neotocite and rhodochrosite.

The oxidized ore occupies the major part of the deposit. It is composed of cryptomelane, manjirōite, nsutite and small amount of todorokite.

The wall rock of the deposit is red bedded chert and red tuffaceous slate.

The production of the ore concentrates from the deposit from 1937 to 1968 was 4,700 tons with the average grade of 41 percent Mn and 1,800 tons with the average grade of 78 percent MnO_2.

Reference: SUZUKI *et al.* (1963).

33. *Nagakura*

This deposit is located at Tokusanai of Karumai Town, 7 km northwest of Kogarumai.

The deposit consists of three ore bodies arranged in strike direction. They are 3–8 m long in the strike direction and 0.1 m thick.

The primary ore of the deposit is mainly the braunite ore associated with small amount of spessartine. The oxidized ore is composed of cryptomelane and small amount of nsutite.

The wall rock of the deposit is red bedded chert.

The production of the ore since 1949 was several hundred tons with unknown grade.

34. *Himegamori*

This deposit is located at Himegamori of Karumai Town, 8 km northeast of Kogarumai.

The deposit is situated in a roof pendant of the Hashikami intrusive body.

The thickness of the deposit is about 1 m; but the length of it is unknown.

The primary ore of the deposit consists of the silicate ore composed mainly of coarse-grained rhodonite and tephroite associated with small amounts of spessartine and hausmannite. A photomicrograph of the tephroite is shown in Plate 15–2. The X-ray powder data and the chemical analysis of the tephroite are shown in Tables 12 and 13, respectively.

The wall rock of the deposit is chert hornfels.

The production of the ore is unknown.

Reference: OMORI, HASEGAWA and OTOMO (1952).

35. *Kujihira*

This deposit is located at Sambongiyama of Ono Village, 6 km north of Ono.

The deposit is situated in a roof pendant of the Hashikami intrusive body.

The details of the dimensions of the deposit are unknown.

The primary ore of the deposit consists of the silicate ore composed mainly of tephroite with small amount of spessartine. The oxidized ore is cryptomelane associated with todorokite.

The production of the ore is unknown.

37. *Yamani*

This deposit is located at Izurumachi of Yamagata Village, 6.5 km northwest of Kawai.

The deposit is 10–15 m long in strike direction and up to 0.7 m thick.

The ore of the deposit is amorphous dioxide.

The wall rock of the deposit is gray bedded chert.

The production of the ore is less than 20 tons with unknown grade.

38. *Kunohe*

This deposit is located at Izurumachi of Yamagata Village, 6 km north-northwest of Kawai.

The deposit is 6 m long in strike direction and 0.4–1 m thick. Minor folding is observed in the deposit. An axis of the minor folding trends N.40°W. and plunges northward at 40°, and another one trends N.20°E. and plunges southward at 10°.

The primary ore of the deposit is the carbonate ore composed mainly of rhodochrosite and rhodonite associated with small amounts of spessartine and neotocite. Pyroxmangite occurs as veinlets in the ore. A photomicrograph of the pyroxmangite is shown in Plate 17–2. The chemical analyses of the carbonate ore are shown in Table 9. The oxidized ore is composed mainly of pyrolusite and nsutite.

The wall rock of the deposit is gray bedded chert.

The production of the ores was about 500 tons with unknown grade.

39. *Ohata*

This deposit is located at Ohata of Yamagata Village, 7 km northwest of Kawai.

The deposit consists of several ore bodies. They are 60–90 m long in strike direction, 60 m long in dip direction and 0.3–0.6 m (in maximum more than 1 m) thick.

The primary ore of the deposit is the carbonate ore composed mainly of rhodonite, tephroite and rhodochrosite. The oxidized ore is composed of pyrolusite and nsutite.

The footwall is gray bedded chert and gray massive chert. The hanging wall is gray bedded chert.

The production of the ore concentrates from the deposit from 1939 to 1953 was 3,200 tons with the average grade of 41 percent Mn.

40. *Yamagata*

This deposit is located at Hinosawa of Yamagata Village, 4 km north-northwest of Kawai.

The deposit is 90 m long in strike direction and 0.1–1 m (maximum 2.5 m) thick.

The primary ore of the deposit consists of the braunite ore and the carbonate ore. The braunite ore forms bands with chert. A photomicrograph of the ore is shown in Plate 13–1. The carbonate ore is composed of rhodonite associated with various amounts of tephroite, rhodochrosite and small amounts of hausmannite, spessartine, dannemorite, stilpnomelane, bementite and pyrophanite. The oxidized ore is composed mainly of nsutite associated with small amounts of cryptomelane, pyrolusite and manganite.

The wall rock of the deposit is gray bedded chert and red bedded chert.

The production of the ore concentrates from the deposit from 1958 to 1963 was 200 tons with the average grade of 31 percent Mn and 400 tons with the average grade of 68 percent MnO_2.

References: NAMBU (1960); SUZUKI *et al.* (1962).

41. *Yokochi*

This deposit is located at Yokochi of Yamagata Village, 7.5 km northwest of Kawai.

The deposit consists of several ore bodies traceable for 2 km in strike direction. The largest ore body is 220 m long in strike direction, 80 m long in dip direction and in average 2 m thick.

The primary ore of the deposit is the carbonate ore composed of rhodonite and tephroite associated with small amounts of braunite, jacobsite, hausmannite, rhodochrosite and neotocite. The oxidized ore is composed mainly of cryptomelane and pyrolusite associated with small amount of manganite.

The footwall of the deposit is gray bedded chert and gray massive chert. The hanging wall is gray bedded chert.

The production of the ore concentrates from the deposit from 1952 to 1963 was 12,400 tons with the average grade of 33 percent Mn and 1,500 tons with the average grade of 76 percent MnO_2.

References: NAMBU (1960); SUZUKI *et al.* (1962).

42. *Kitakami*

This deposit is located at Kitoko of Yamagata Village, 6.5 km northwest of Kawai.

The deposit is 35 m long in strike direction, 30 m long in dip direction and 0.1–2 m thick.

The primary ore of the deposit consists of the carbonate ore composed mainly of rhodonite and tephroite associated with small amounts of jacobsite, hausmannite, rhodochrosite and neotocite. The oxidized ore is composed mainly of cryptomelane and nsutite.

The footwall of the deposit is gray massive chert. The hanging wall is gray bedded chert.

The production of the ore concentrates from the deposit from 1959 to 1962 was 50 tons with the average grade of 33 percent Mn and 100 tons with the average grade of 66 percent MnO_2.

43. *Hokuei*

This deposit is located at Yaba of Yamagata Village, 6 km northwest of Kawai.

The deposit consists of several ore bodies. They are up to 10 m long in strike direction and up to 0.1 m thick.

The ore of the deposit is mainly the oxidized ore composed mainly of pyrolusite and nsutite.

The footwall of the deposit is gray bedded chert. The hanging wall is slate.

The production of the ore from the deposit is unknown.

44. *Hinosawa*

The description of this deposit is in 3. 2. 4 in the text.

45. *Kawai*

This deposit is located at Hinosawa of Yamagata Village, 2.5 km northwest of Kawai.

The deposit is 100 m long in strike direction, 110 m long in dip direction and 2 m (maximum 10 m) thick.

The ore of the deposit consists mainly of the oxidized ore composed mainly of cryptomelane and nsutite associated with small amount of manjirōite. The oxidized zone of the deposit extends as deep as 120 m from the outcrop.

The footwall is gray bedded chert and also red bedded chert in part. The hanging wall is gray bedded chert.

The production of the ore concentrates from the deposit from 1940 to 1961 was 23,900 tons with the average grade of 71 percent MnO_2. This deposit is the most important producer of the dioxide ore in the Kitakami Mountains.

Reference: NAMBU *et al.* (1965d).

46. *Daini-Asahi*

This deposit is located at Kamiinose of Yamagata Village, 3 km west of Kawai.

The deposit is 16 m long in strike direction and 0.1–0.5 m (maximum 1.5 m) thick.

The primary ore of the deposit is the carbonate ore composed mainly of rhodonite and tephroite. The oxidized ore is composed mainly of pyrolusite and nsutite.

The wall rock of the deposit is gray bedded chert and gray massive chert.

The production of the ore concentrates was 15 tons in 1965 with the grade of 25 percent Mn and 17 tons in 1963 with the grade of 75 percent MnO_2.

Reference: NAMBU *et al.* (1965d).

47. *Takinosawa*

This deposit is located at Takinosawa of Yamagata Village, 2.5 km west of Kawai.

The deposit consists of several ore bodies. They are 20–30 m long in strike direction and 0.4–0.7 m (maximum 3 m) thick.

The primary ore of the deposit consists of the carbonate ore composed mainly of rhodochrosite and hausmannite associated with small amount of braunite. So-called Chocolate ore occurs. The chemical analysis data of the ore are shown in Table 9. The oxidized ore is composed of cryptomelane, pyrolusite and nsutite.

The footwall is gray massive chert and gray bedded chert. The hanging wall is gray bedded chert.

The production of the ore concentrates from the deposit from 1937 to 1961 was 1,150 tons with the average grade of 44 percent Mn and 5,200 tons with the average grade of 75 percent MnO_2.

Reference: SUZUKI *et al.* (1962).

48. *Misawa*

This deposit is located at Kawai of Yamagata Village.

The deposit is 40 m long in strike direction and 0.3–0.7 m thick.

The primary ore of the deposit is the carbonate ore composed mainly of rhodonite and tephroite. The oxidized ore is mainly pyrolusite.

The wall rock is gray bedded chert.

The production of the ore concentrates from the deposit from 1937 to 1941 was 500 tons with unknown grade.

50. *Oguni*

This deposit is located at Oguni of Yamagata Village, 10 km south-southeast of Kawai.

The deposit consists of several ore bodies. The major ore bodies are about 90 m long in strike direction, 90 m long in dip direction and 0.1–2 m (maximum 4 m) thick.

The primary ore of the deposit is the carbonate ore composed of rhodonite associated with various amounts of tephroite, rhodochrosite, braunite and small amounts of mangancalcite, dannemorite and neotocite. The oxidized ore is composed of nsutite and cryptomelane.

The footwall of the deposit is gray bedded chert and gray massive chert. The hanging wall is gray massive chert. The boundary between the footwall and the ore body undulates more distincly than that between the hanging wall and the ore body does.

The production of the ore concentrates from the deposit from 1937 to 1962 was 9,700 tons with the average of 38 percent Mn.

Reference: NAMBU (1959).

51. *Toyokuchi*

This deposit is located at Oguni of Yamagata Village, 11 km south-southeast of Kawai.

The deposit is 40–70 m long in strike direction, 80 m long in dip direction and 0.1–1.5 m thick.

The primary ore of the deposit consists of the carbonate ore composed mainly of rhodochrosite associated with rhodonite, tephroite, braunite and small amounts of hausmannite, neotocite and mangancalcite. The oxidized ore is composed of cryptomelane, pyrolusite, nsutite and birnessite.

The wall rock is gray bedded chert.

The production of the ore concentrates from the deposit was 3,000 tons from 1940 to 1950 with unknown grade, and 800 tons from 1958 to 1960 with the average grade of 35 percent Mn.

References: NAMBU (1959); NAMBU and TANIDA (1961).

57. *Oyukiya*

This deposit is located at Oyukiya of Kunohe Village, 7 km east of Ibonai.

The deposit is 40 m long in strike direction and 1 m thick.

The primary ore of the deposit is composed of rhodonite and tephroite. The oxidized ore is composed of cryptomelane and pyrolusite.

The wall rock of the deposit is massive chert.

The production of the ore from the deposit by 1945 was 6,000–7,000 tons with unknown grade.

Deposits in the Kassemba Formation

61. *Kayatai*

This deposit is located at Kayatai of Yamagata Village, 6 km south of Kawai.

The deposit is about 100 m long in strike direction and 1.5 m thick.

The primary ore of the deposit consists mainly of the silicate ore composed mainly of rhodonite associated with tephroite and small amounts of rhodochrosite, alleghanyite, dannemorite, stilpnomelane, manganoan phlogopite and spessartine. A photomicrograph of the stilpnomelane is shown in Plate 18–2. The oxidized ore is mainly pyrolusite.

The wall rock of the deposit is bedded chert.

The production of the ore from the deposit is unknown.

Reference: NAMBU *et al.* (1965d).

62. *Sainokami*

This deposit is located at Sainokami of Kunohe Village, 6 km south of Ibonai.

The deposit extends 70–120 m at each working level, and the total length is 270 m in strike direction, and 100 m in dip direction. The thickness is up to 1 m. The deposit plunges in parallel to the axis of the minor folding which trends N.10°–20°E. and plunges northward at 35°.

The primary ore of the deposit consists of the carbonate ore composed mainly of rhodochrosite, tephroite, rhodonite and hausmannite associated with small amounts of galaxite, alleghanyite and spessartine. Pyroxmangite, bementite and neotocite occur as veinlets in the ore. A photomicrograph of the ore is shown in Plate 14–1. The oxidized ore is composed mainly of nsutite associated with birnessite and cryptomelane.

The footwall of the deposit is gray bedded chert and gray massive chert. The hanging wall is gray bedded chert. The boundary between the footwall and the ore body undulates more distinctly than that between the hanging wall and the ore body does.

The production of the ore concentrates from the deposit from 1956 to 1962 was 2,650 tons with the average grade of 37 percent Mn.

Reference: NAMBU (1959).

63. *Kurano*

This deposit is located at Kurano of Kunohe Village, 6.5 km south of Ibonai.

The deposit consists of two ore bodies. They are about 60 m long in strike direction, 30 m long in dip direction. The thickness of the deposit is unknown.

The ore of the deposit is mainly the oxidized ore composed of cryptomelane, pyrolusite and nsutite. The primary ore occurs in small amount. It consists of the carbonate ore composed mainly of rhodonite, jacobsite and rhodochrosite.

The wall rock of the deposit is massive chert and bedded chert.

The production of the ore concentrates from the deposit from 1943 to 1945 was 200 tons with the average grade of 42 percent Mn and from 1962 to 1966 was 200 tons with the average grade of 80 percent MnO_2.

Reference: NAMBU *et al.* (1965d).

64. *Okami*

This deposit is located at Shibahiki of Kunohe Village, 10 km southwest of Kawai.

The deposit is 30 m long at each working level and extends 150 m in strike direction and 90 m in dip direction with the average thickness of 0.5 m. The ore body plunges northward at 30°.

The primary ore of the deposit is the carbonate ore composed mainly of rhodochrosite, rhodonite and tephroite. Neotocite occurs as veinlets in the ore. The oxidized ore is composed mainly of nsutite and pyrolusite associated with small amounts of cryptomelane and manganite.

The footwall of the deposit is bedded chert and massive chert. The hanging wall is bedded chert.

The production of the ore concentrates from the deposit from 1958 to 1962 was 850 tons with the average grade of 31 percent Mn and 600 tons with the average grade of 70 percent MnO_2.

Reference: NAMBU (1958).

65. *Taki*

This deposit is located at Rainai of Yamagata Village, 7 km southeast of Kawai.

This deposit consists of two ore bodies. They are 70–100 m long in strike direction, about 40 m long in dip direction and 0.3–0.6 m thick. The deposit is folded, and the axis of the minor folding trends N.60°E. and plunges northward at 25°.

The ore bodies were thermally metamorphosed by the Hiraniwa intrusive body, forming the silicate ore composed mainly of rhodonite and tephroite associated with small amounts of rhodochrosite, spessartine, jacobsite and hausmannite. Neotocite and pyroxmangite occur as veinlets in the ore. The chemical analysis of the tephroite is shown in Table 13. A photomicrograph of the boundary of the rhodonite ore and the tephroite ore is shown in Plate 16–3. The oxidized ore is composed mainly of cryptomelane, pyrolusite and nsutite associated with small amount of birnessite.

The footwall of the deposit is gray bedded chert. The hanging wall is gray siliceous slate and bedded chert associated with massive chert.

The production of the ore concentrates from the deposit from 1944 to 1967 was 5,050 tons with the average grade of 35 percent Mn and 250 tons with the average grade of 72 percent MnO_2.

References: NAMBU and TANIDA (1964); NAMBU *et al.* (1967b).

Deposits in undefined Iwaizumi Group outside of the Kunohe area

71. *Noda-Tamagawa*

The description of this deposit is in 3. 2. 5 in the text.

72. *Hijikuzu*

This deposit is located at Hijikuzu of Iwaizumi Town, 8 km west-southwest of Taro.

The deposit is 150 m long in strike direction, 84 m long in dip direction and 2.5 m thick.

The deposit suffered strongly a thermal metamorphism by the Miyako intrusive body, forming the silicate ore composed mainly of pyroxmangite, rhodonite, tephroite and braunite associated with several skarn minerals. The refractive indices, the X-ray powder data and the chemical analysis of the pyroxmangite are shown in Tables 15, 17 and 18, respectively.

The wall rock is the hornfels of massive chert and bedded chert.

The production of the ore concentrates from 1967 to 1972 was 41,200 tons with the average grade of 16 percent Mn.

References: NAMBU, TANIDA and KITAMURA (1970a; 1970b).

地名および鉱床名

Akedo	明戸
Akka (-mori)	安家（森）
Aozawa	青沢
Ashio	足尾
Daiichi-Fukushi	第一福士
Daini-Asahi	第二旭
Fujikura	藤倉
Funakozawa	舟子沢
Genda	源田
Goto	午当
Goyosan	五葉山
Hakkoda	八甲田
Hanawa	花輪
Hashikami (-dake)	階上（岳）
Hayachine	早池峰
Heromachi	戸呂町
Hida	飛驒
Hijikuzu	肘葛
Himegamori	姫ヶ森
Hinosawa	日野沢
Hiraniwa (-dake)	平庭（岳）
Hokkaido	北海道
Hokuei	北栄
Hokushin	北辰
Honshu	本州
Hosoya	細屋
Ibonai	伊保内
Imoya	伊茂屋
Itamachiya	板待屋
Iwaizumi	岩泉
Iwate	岩手
Izurumachi	出ル町
Kagamiiwa	鏡岩
Kamaishi	釜石
Kamiinose	上猪瀬
Kannon	観音
Karumai	軽米
Kassemba	合戦場
Kawai	川井
Kayamori	茅森
Kayatai	茅平
Kirihata	桐畑
Kisawahata	木沢畑
Kitakami	北上
Kitoko	木藤古
Kogarumai	小軽米
Kogawa	小川
Kohare	小晴
Kotamagawa	小玉川
Kuji	久慈
Kujihira (-dake)	久慈平（岳）
Kumanosawa	熊ノ沢
Kunohe	九戸
Kurano	倉野
Kuribayashi	栗林
Kuromori	黒森
Kuzumaki	葛巻
Kwanto	関東
Magidai	間木平
Magisawa	槙木沢
Maida	米田
Makado	真門
Matsunokitai	松ノ木平
Matsunowaki	松ノ脇
Matsuzaka	松坂
Mawatari	馬渡
Mikkamachi	三日町
Misago	ミサゴ
Misawa	身沢
Mitsune	三根
Miyako	宮古
Mizusawa	水沢
Moichi	茂市
Morioka	盛岡
Moya-dake	霧岳
Myoho	明峰
Myojin (-dake)	明神（岳）
Nabekura	鍋倉
Nagakura	永倉
Nakamura	中村
Nemori	根森
Noda-Tamagawa	野田玉川
Numabukuro	沼袋
Ochiyasu	落安
Oguni	小国
Ohata	大畑
Oitai	生平
Okami	大神
Okubo	大久保
Omaki	大巻
Ono	大野
Osakamoto	大坂本
Otai	大平
Otaniyama	大谷山
Otori	大鳥
Oyukiya	大雪屋
Ozuchi	大槌
Rainai	来内
Rikuchu	陸中
Sainokami	妻ノ神
Sambongiyama	三本木山
Sawayama	沢山
Sawayamagawa	沢山川
Seki	関
Shibahiki	芝引
Shikoku	四国
Shimizugawa	清水川
Tachikawa	立川
Taiho	大豊
Takamatsu	高松
Takamatsuzawa	高松沢
Takamine	高峰
Takanarizawa	高成沢
Takayashiki	高屋敷
Taki	滝
Takinosawa	滝ノ沢
Tamagawa	玉川
Tamba	丹波
Tanohata	田野畑
Taro	田老
Tengu	天狗
Tokusanai	戸草内
Tonaka	戸中
Torii	鳥井
Towada	十和田
Toyaba	遠矢場
Toyokuchi	豊口
Toyomane	豊間根
Tsuboana	坪穴
Tsunagi	繋
Unagisawa	鰻沢
Ushigasawa	牛ヶ沢
Yaba	野場
Yamagata	山形
Yamani	やまに
Yamato	大和
Yanosawa	矢ノ沢
Yokochi	横地

地 質 調 査 所 月 報（第 29 巻 第 5 号）

北部北上山地九戸地域の地質およびマンガン鉱床

吉井 守正

要　旨

北部北上山地北端部の九戸地域，すなわち岩手県九戸郡軽米町・大野村・山形村および九戸村の一帯には，層状マンガン鉱床が密集している．この地域は，岩泉帯に属し，三畳紀からジュラ紀にかけての優地向斜堆積物からなる岩泉層群によって主として構成されている．この地域の地層は，下位から木沢畑層・間木平層・沢山川層・安家層・関層および合戦場層が，それぞれ整合関係をもって累重している．地域の中央部には，ほぼ南北方向の軸をもつ間木平背斜があり，地域西端部にだけ分布する合戦場層を除く各層は，この背斜の両翼に分布する．各層の層厚は一般に背斜の東翼で厚く，苦鉄質火山岩類も東翼で発達する．

地域内のマンガン鉱床は，チャートに富む関層中に集中して胚胎されている．鉱床の母岩もほとんどの場合チャートからなり，下盤は塊状チャートであることが多い．これらの鉱床は，主要鉱石によってブラウン鉱鉱床・炭酸塩鉱床および珪酸塩鉱床に区分される．ブラウン鉱鉱床は，おもに間木平背斜の東翼に分布する．炭酸塩鉱床は同背斜の西翼に分布する．珪酸塩鉱床は，前期白亜紀の花崗岩類によってホルンフェルス化して角閃石を生じた範囲内に分布する．

この地域でのマンガン鉱化作用の主要な時期は，ジュラ紀の関層堆積時であり，ブラウン鉱鉱床と炭酸塩鉱床は当時の苦鉄質火山活動と関係して生成したものと考えられる．とくに前者は密接な関係をもっていたであろう．その後，前期白亜紀になり，鉱床のいくつかは花崗岩類の貫入によって熱変成作用を受けて，珪酸塩鉱床に変化した．

（受付：1977年10月11日；受理：1977年10月31日）

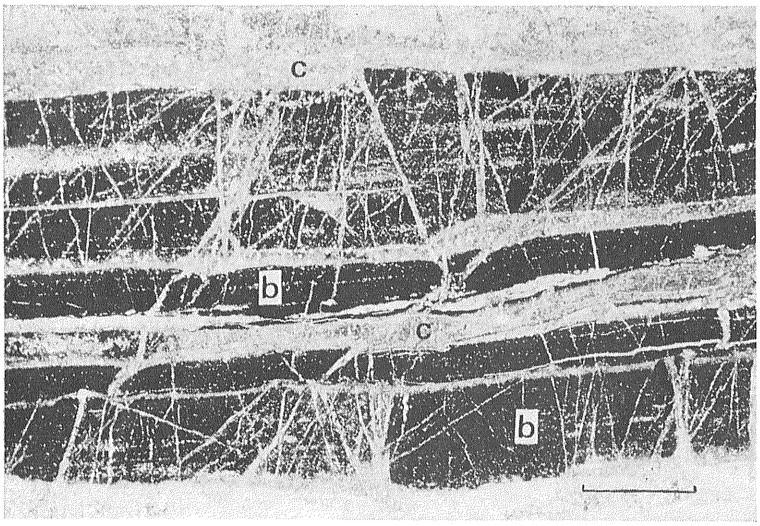
PLATES

(with 12–20)

1. The braunite ore from the Kotamagawa deposit.
The ore alternates with red chert forming a banded ore.

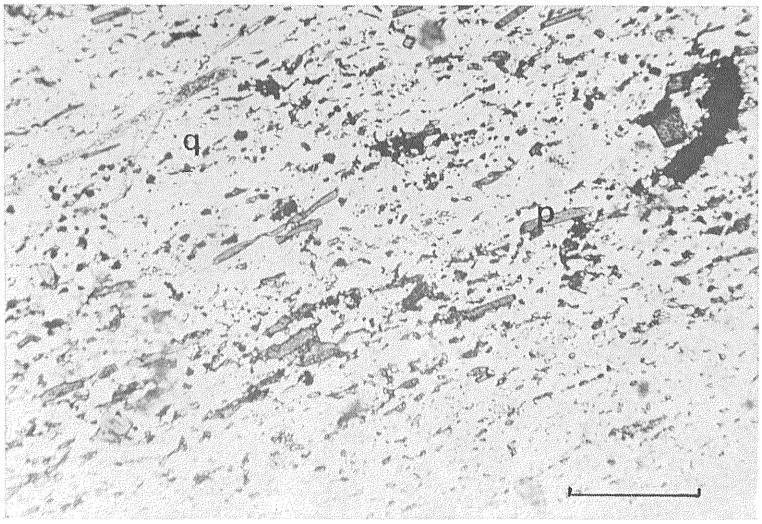
2. The braunite ore from the Funakozawa deposit.

3. Red massive chert of the footwall of the Funakozawa deposit.



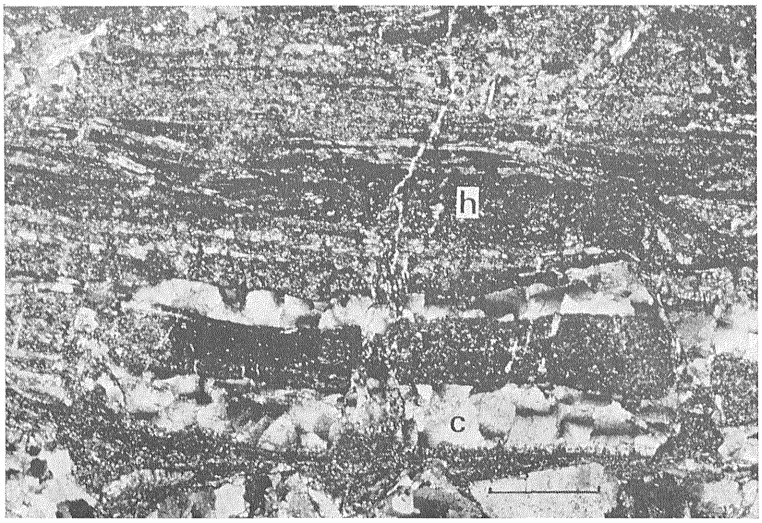
1. Photomicrograph of the braunite ore from the Yamagata deposit in thin section.

b: braunite, c: rhodochrosite and quartz. Plane light. Scale 2mm.



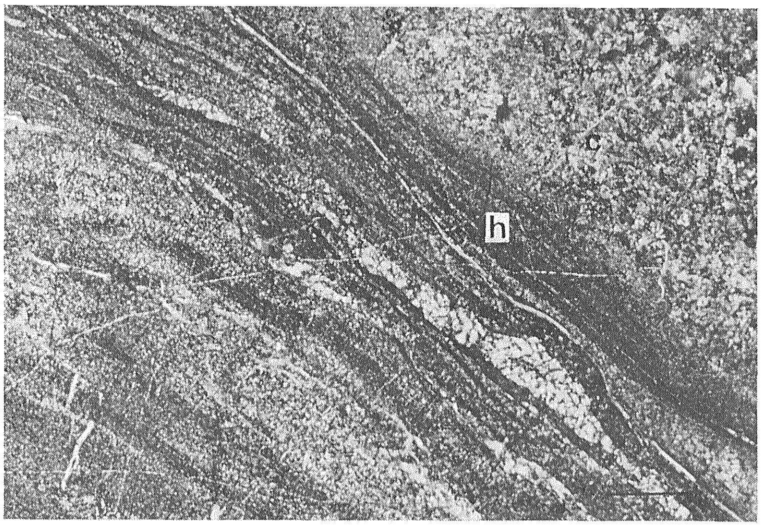
2. Photomicrograph of chert of the Funakozawa deposit in thin section.

p: piedmontite, q: quartz. Plane light. Scale 0.2mm.



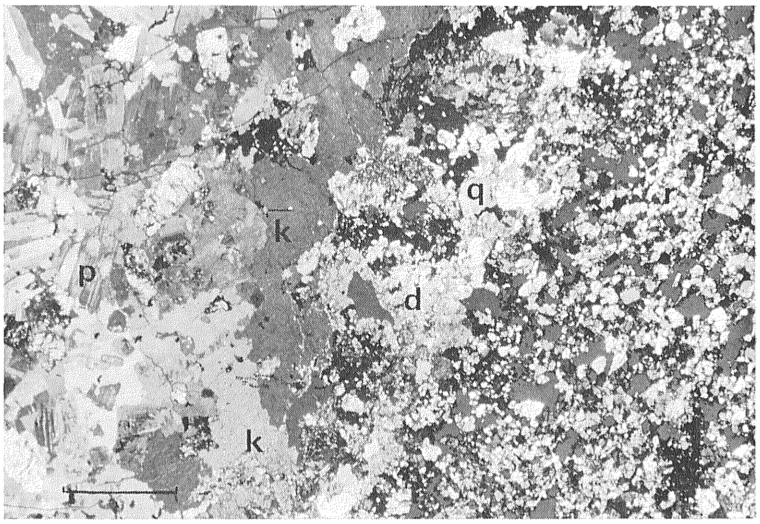
3. Photomicrograph of the carbonate ore from the Yokochi deposit in thin section.

c: rhodochrosite, h: hausmannite. Crossed-nicols. Scale 2mm.



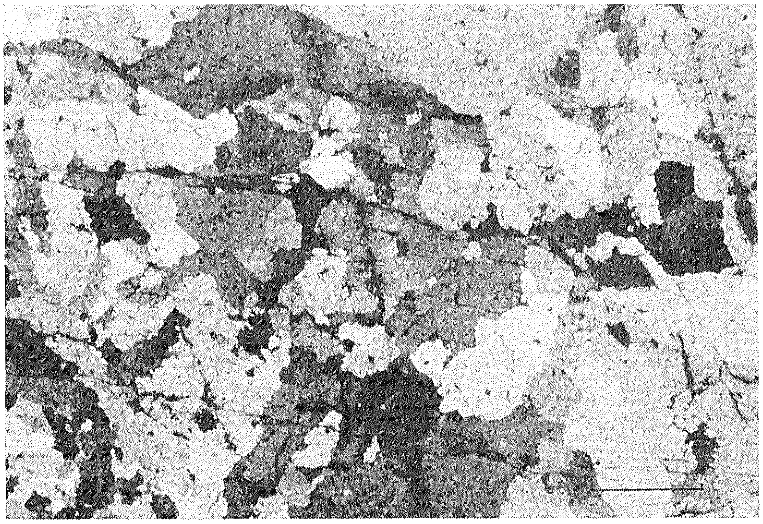
1. Photomicrograph of the carbonate ore from the Sainokami deposit in thin section.

c: rhodochrosite, h: hausmannite. Crossed nicols. Scale 2mm.



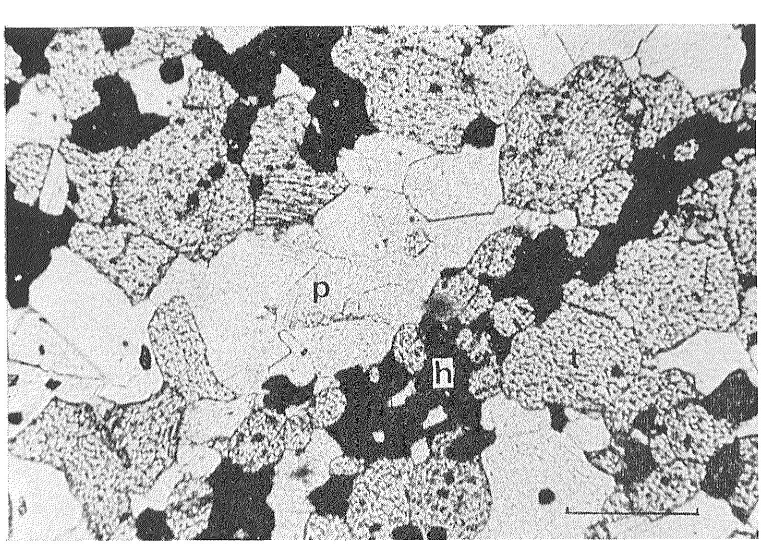
2. Photomicrograph of a boundary between granitic intrusion (left) and rhodonite ore (right) in the Noda-Tamagawa deposit in thin section.

d: dannemorite, k: potassium feldspar, p: plagioclase, q: quartz, r: rhodonite. Crossed nicols. Scale 2mm.



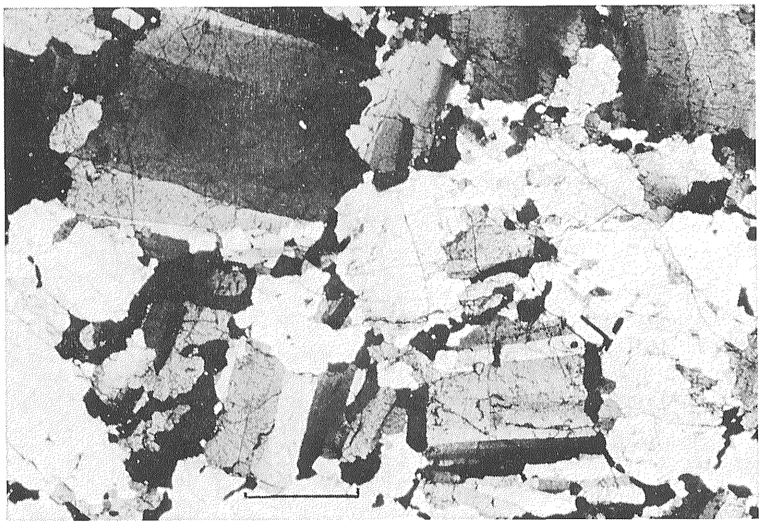
3. Photomicrograph of tephroite ore from the Taki deposit in thin section.

Crossed nicols. Scale 2mm.



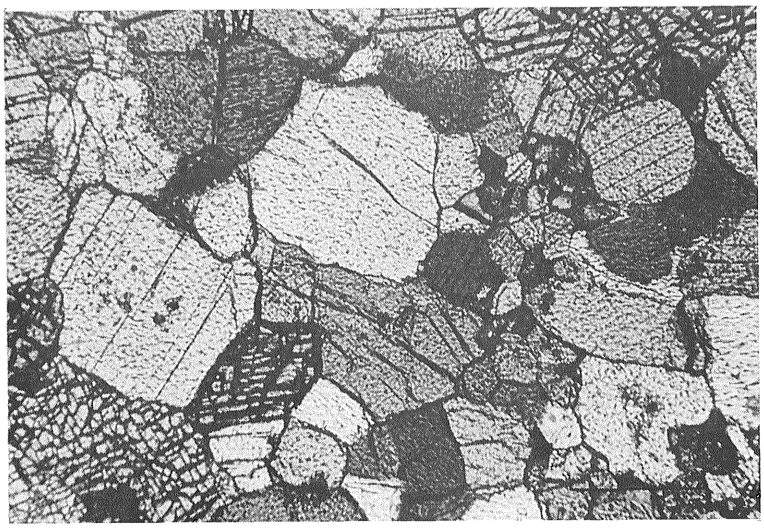
1. Photomicrograph of tephroite-manganobarian phlogopite-hausmannite ore from the Noda-Tamagawa deposit in thin section.

h: hausmannite, p: manganobarian phlogopite, t: tephroite. Plane light. Scale 0.2mm.



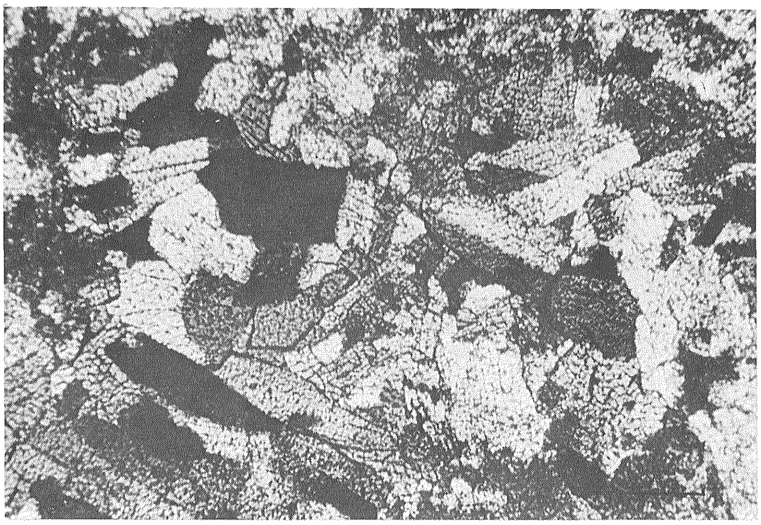
2. Photomicrograph of tephroite ore from the Himegamori deposit in thin section.

Crossed nicols. Scale 0.2mm.



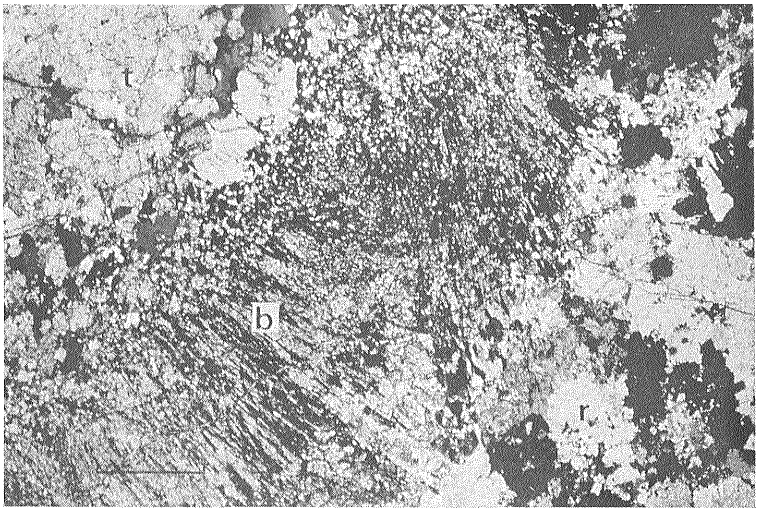
3. Photomicrograph of rhodonite ore from the Noda-Tamagawa deposit in thin section.

Crossed nicols. Scale 0.2mm.



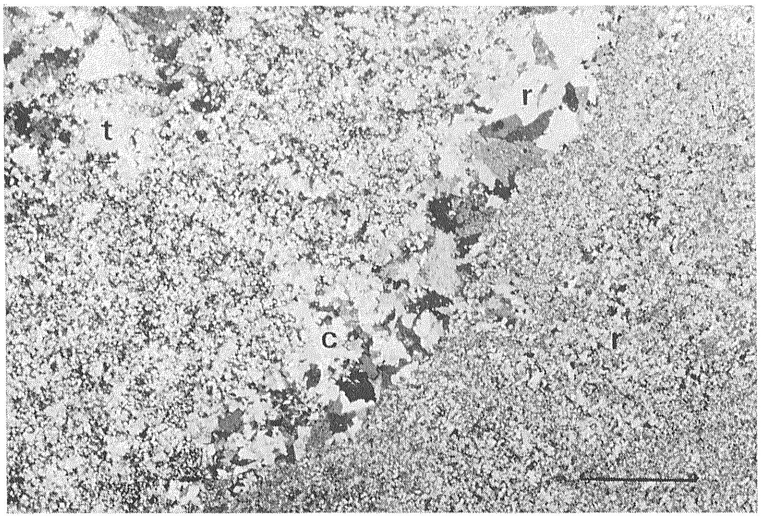
1. Photomicrograph of rhodonite ore from the Taki deposit in thin section.

Crossed nicols. Scale 0.2mm.



2. Photomicrograph of a boundary between tephroite ore (left) and rhodonite ore (right) in the Noda-Tamagawa deposit in thin section.

b: bustamite, r: rhodonite, t: tephroite. Crossed nicols. Scale 2mm.

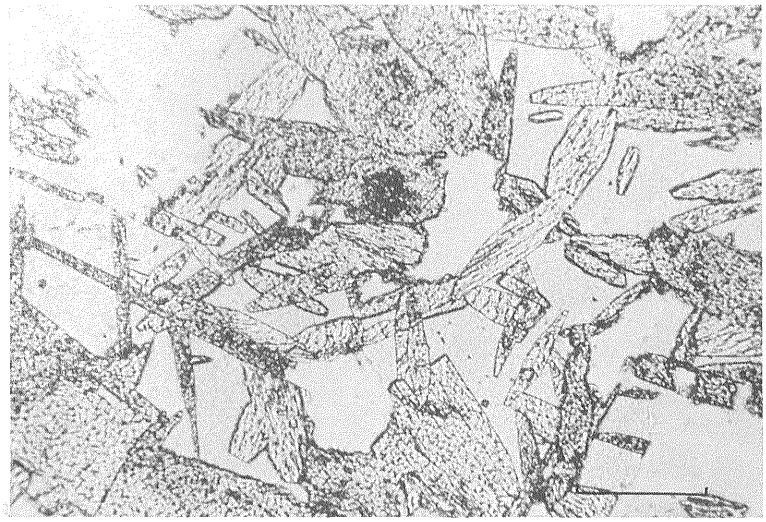


3. Photomicrograph of a boundary between tephroite ore (left) and rhodonite ore (right) in the Taki deposit in thin section.

c: rhodochrosite, r: rhodonite, t: tephroite. Crossed nicols. Scale 2mm.

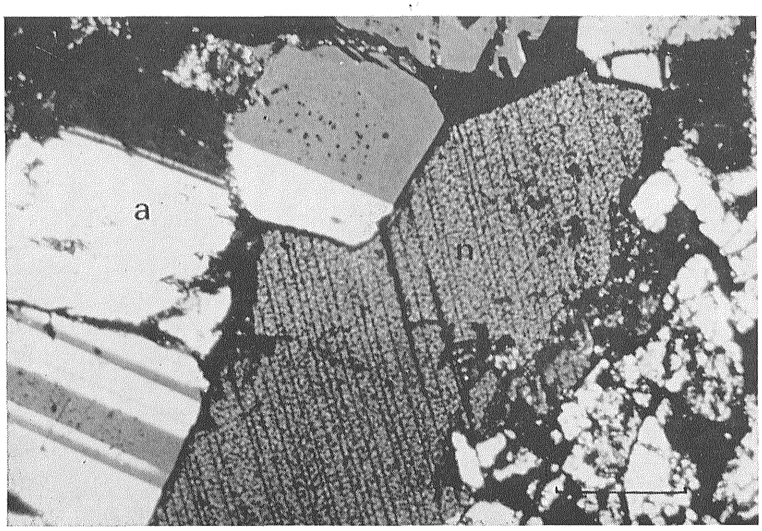
1. Photomicrograph of pyroxmangite in veinlets of the Kohare deposit in thin section.

Plane light. Scale 0.2mm.



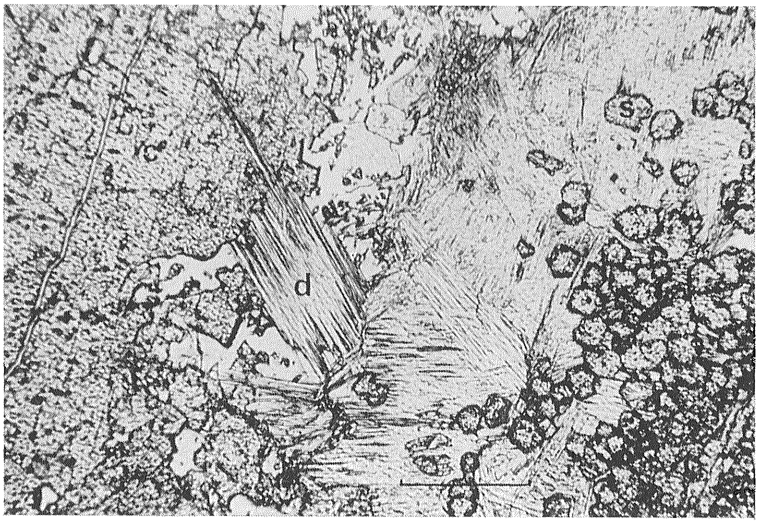
2. Photomicrograph of pyroxmangite in veinlets of the Kunohe deposit in thin section.

Plane light. Scale 0.2mm.



3. Photomicrograph of nambulite in veinlets of the Funakozawa deposit in thin section.

a: albite, n: nambulite. Crossed nicols. Scale 0.2mm.

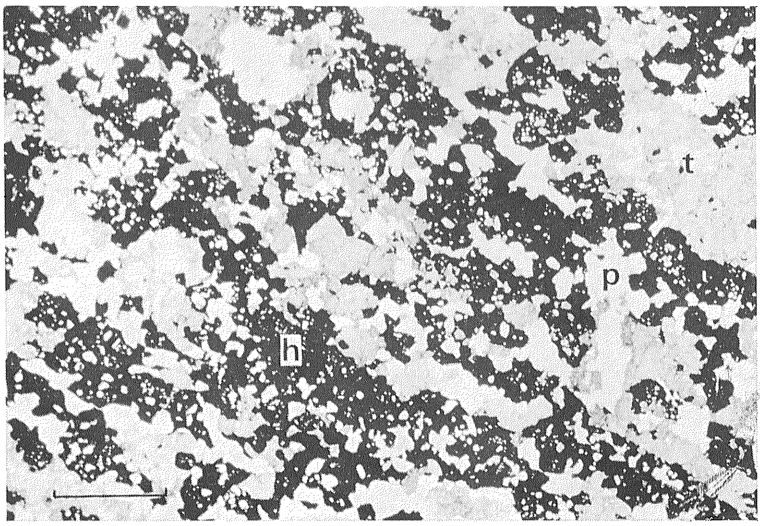


1. Photomicrograph of dannemorite in the carbonate ore from the Shimizugawa deposit in thin section.

c: rhodochrosite, d: dannemorite, s: spessartine. Plane light. Scale 0.2mm.

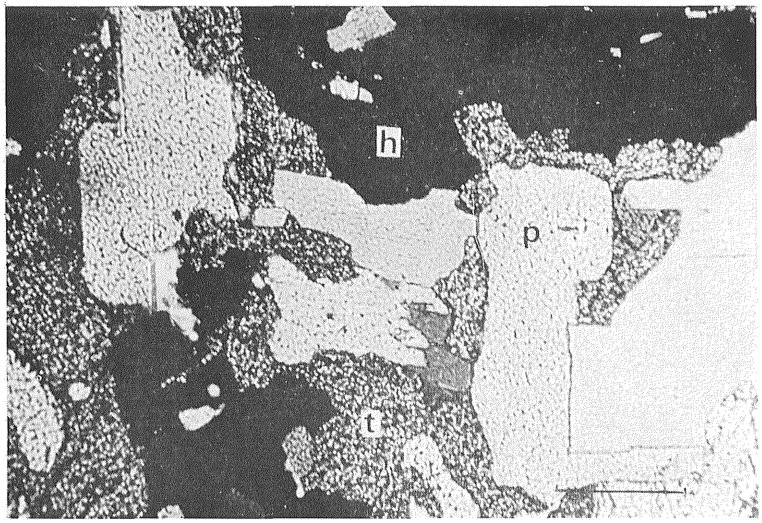
2. Photomicrograph of stilpnomelane in the carbonate ore from the Kayatai deposit in thin section.

s: stilpnomelane. Plane light. Scale 0.2mm.



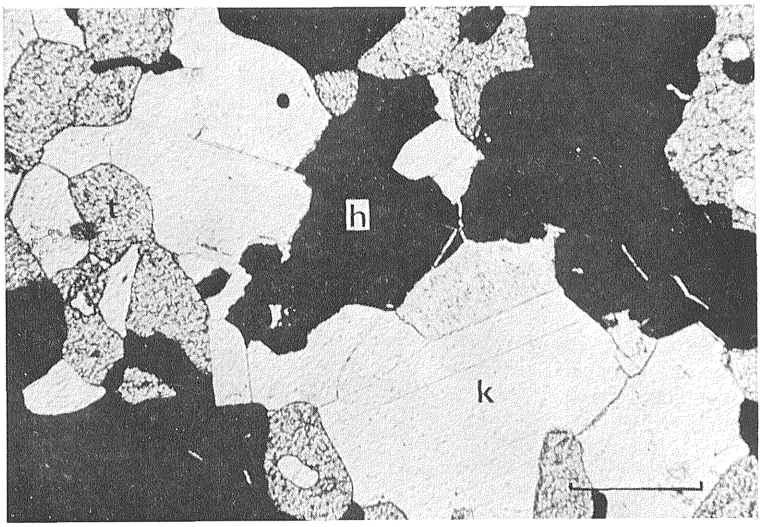
3. Photomicrograph of hausmannite-tephroite-manganobarian phlogopite ore from the Noda-Tamagawa deposit in thin section.

h: hausmannite, p: manganobarian phlogopite, t: tephroite. Plane light. Scale 0.2mm.



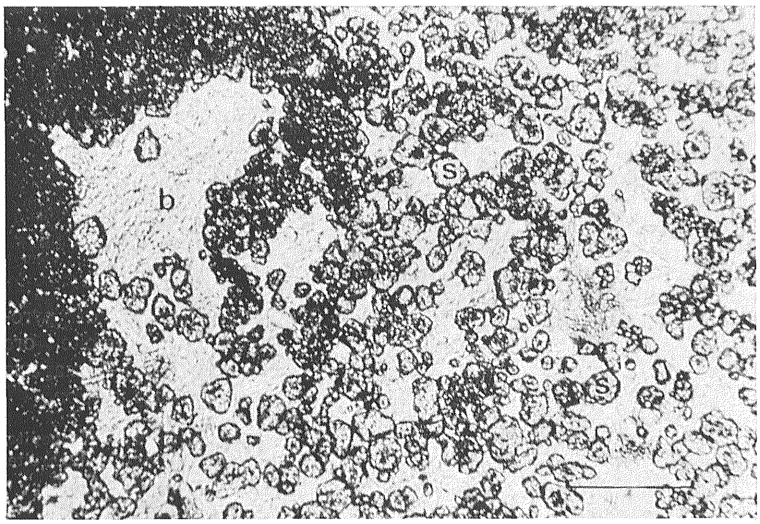
1. Photomicrograph of manganobarian phlogopite from the Noda-Tamagawa deposit in thin section.

h: hausmannite, p: manganobarian phlogopite, t: tephroite. Plane light. Scale 0.2mm.



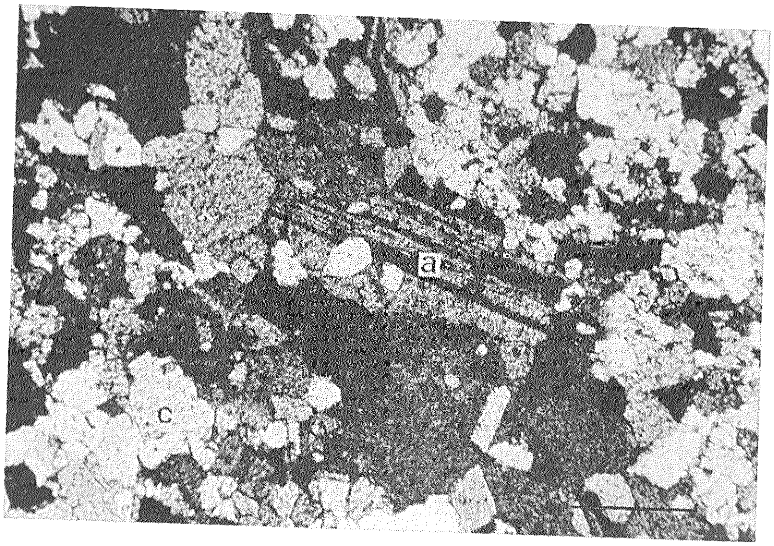
2. Photomicrograph of kinoshitalite from the Noda-Tamagawa deposit in thin section.

h: hausmannite, k: kinoshitalite, t: tephroite. Plane light. Scale 0.2mm.



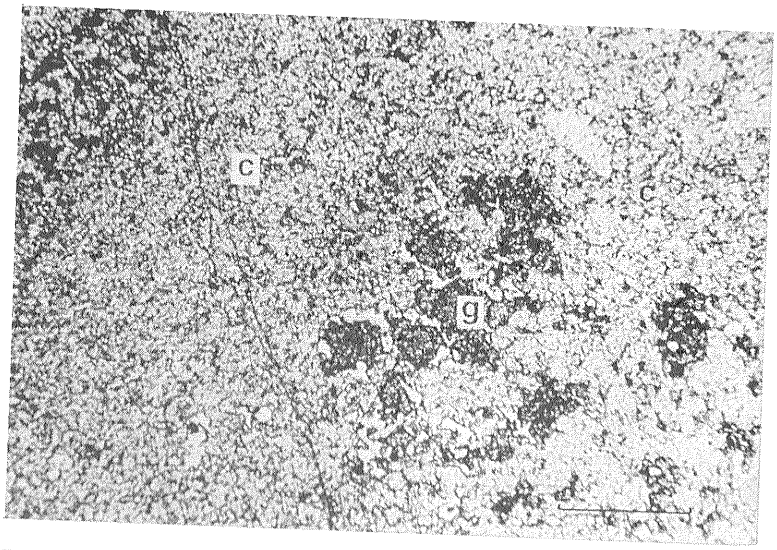
3. Photomicrograph of "spessartine rock" from the Taki deposit in thin section.

b: bementite, s: spessartine. Plane light. Scale 0.2mm.



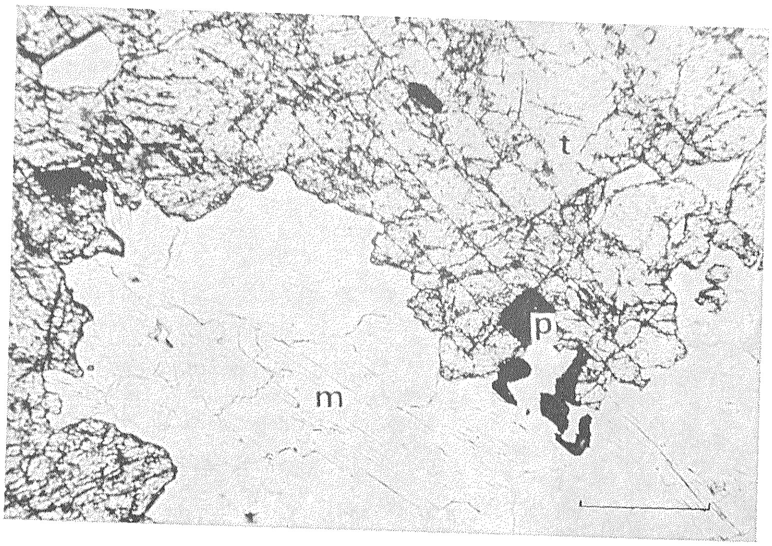
1. Photomicrograph of alleghanyite in the carbonate ore from the Shimizugawa deposit in thin section.

a: alleghanyite, c: rhodochrosite. Crossed nicols. Scale 0.2mm.



2. Photomicrograph of galaxite in the carbonate ore from the Shimizugawa deposit in thin section.

c: rhodochrosite, g: galaxite. Plane light. Scale 0.2mm.



3. Photomicrograph of pyrophanite in tephroite ore from the Noda-Tamagawa deposit in thin section.

m: manganobarian phlogopite, p: pyrophanite, t: tephroite. Plane light. Scale 0.2mm.