ULTRABASIC ROCKS AND CHRYSOTILE ASBESTOS DEPOSITS
OF THE KAMUIKOTAN TECTONIC ZONE, HOKKAIDŌ.

Masayuki Saitō.

CONTENTS.
1. Ultrabasic rocks ................................................................. 1
   1.1. Introduction ............................................................... 1
   1.2. Structure of serpentinite mass and microscopic structure of serpentinite  3
   1.3. Serpentinization ......................................................... 8
2. Chrysotile asbestos deposits .................................................. 10
   2.1. Introduction .............................................................. 10
   2.2. Properties of chrysotile asbestos .................................... 14
   2.3. Place of chrysotile asbestos origination and shape of chrysotile asbestos vein  16
   2.4. Enrichment zone of chrysotile asbestos deposits .................... 19
   2.5. Serpentinization and formation of chrysotile asbestos .................. 23
   2.6. Consideration about the mechanism of chrysotile asbestos deposit formation.  32

1. ULTRABASIC ROCKS.

1.1. Introduction

In the Kamuikotan Tectonic Zone, ultrabasic rocks are found as the sporadic masses in the long extent of about 300 km from northern Toikanbetsu, Teshio province to southern Mitsuishi, Hidaka province (Fig. 1). However, these masses concentrate to several places (such as Toikanbetsu, Takadomari in Ishikari province, the catchment of the Mu River in Iburi province, that of the Saru River in Hidaka province and the environs of Mt. Perari in Hidaka province, etc.), where the ultrabasic rock masses occupy large extent. Many minor narrow masses distribute in the spaces of these large ones, and intermittently continue along the west side of the Central Range of Hokkaidō from north to south.

Many researchers agree with that the intrusions of ultrabasic rocks have occurred during the process of orogenic movement. The places of the ultrabasic rock intrusion are usually accordant with the tectonically weak zone in the orogenic zone. For instance, the vast ultrabasic rock mass at the south of the Kamuikotan Valley has intruded to the wide sheared zone where was intense shearing movement and much supply of materials; that zone has bordered the Cretaceous from Pre-Cretaceous, so-called Kamuikotan Metamorphic Rocks.

In the catchment of the Uihun River at the south of Asahikawa City, so-called Kamuikotan Metamorphic Rocks are found which contain various rocks from nearly
non-metamorphosed to fairly metamorphosed. They are divisible into four zones according to the rock characters. Remarkable intrusion of ultrabasic rock is restricted in the most recrystallized zone of green schist and black schist.* This fact suggests that crystalline schist zone experienced fairly intense metamorphism (namely the shearing movement and the injection of materials) and the intrusion of ultrabasic rock occurred with the thrust fault movement in the last stage of metamorphism.

Some of these ultrabasic rock masses such as the mass of Mt. Iwanai, Hidaka province, remain peridotite in part. Other masses contain microscopic relict crystals of olivine as in the following instances; the mass of Takadomari, Kamui, Yamabe and Mt. Byōbu in Ishikari province, Fukuyama (Yahata Chromite Mine) in Iburi province, Mitsuishi and Mt. Perari in Hidaka province, etc.. However, the peridotite relics are restricted to the only so small part, that the ultrabasic rocks are nearly perfectry altered to serpentine through throughout the whole area of the Kamuikotan Tectonic Zone. Concerning to the intrusion structure, joint system is reserved well, but no flow structure is recognized.** They also contain many chromite and chrysotile asbestos deposits.

On the contrary, the ultrabasic rock masses in the Hidaka Tectonic Zone, are the peridotite masses lacking chromite and chrysotile asbestos deposits, and presenting remarkable flow structure, and divisible into several facies (1) (15). Thus, the characters of ultrabasic rocks are different according to the tectonic zones.

In the Kamuikotan Tectonic Zone, there are local variations which are not so essential as in the differences against to the Hidaka Tectonic Zone.

Several differences are recognized between the north and south areas of the Ishikari River in the environs of the Kamuikotan Valley. Almost of the leucocratic dyke rocks accompanied with the northern ultrabasic rock mass are dioritic aplite. Chromite deposits are placer and massive chromite deposits are scarecely known.*** This district is also the prominent zone of placer platinium deposit (40). On the other hand, almost of the leucocratic dyke rocks accompanied with the southern ultrabasic rock mass, are quartz-albitite. This district is the prominent area of massive chromite deposits, and many chromite mines are known. Here is no placer chromite deposit, but remarkable “Ryuko-type” deposit which is composed of the fragments of masive chromite. Also the placer platinium deposits are scarce except such poor ones as producing the mineral specimen only.

---

* After the survey of M. SUZUKI (unpublished Geological Map of Bie).

** Lately, gabbroic rock was reported from the environs of Fukuhara clearing of Wassamu, Teshio province. (Y. Igi et. al.) (16). Explanatory Text of the Horokanai Geological Map, 1958.

*** Lately, small ore body of massive chromite was found in the Eboizawa Serpentine Mass of Hamatonbetsu, Kitami province. Worked ores are known at the entrance of the abandoned gallery in the serpentine mass at the upper stream of the Osarunai stream, Horokanai, Ishikari province. (Y. Igi et. al.) (16). Explanatory Text of Horokanai Geological Map, 1958.
ULTRABASIC ROCKS AND CHRYSOTILE ASBESTOS DEPOSITS OF THE KAMUIKOTAN TECTONIC ZONE, HOKKAIDO.

Fig. 1 Index map showing distribution of ultrabasic rock masses and main chrysotile asbestos mines in Hokkaido.

The area of the Kamuikotan Tectonic Zone experienced the orogenic movement in large scale during Cretaceous to Tertiary. With the advance of the Hidaka Orogenic Movement, the ultrabasic rocks intruded during the latest Cretaceous to early Tertiary (24), and the shapes of intrusive masses were determined by the tectonic thrust movement. However, they were subjected to the effect of another later tectonic movement during Miocene to Pliocene and their shapes were dislocated and deformed by the many faults of slidings in various size. Usually, the foliated parts and the clayey parts of serpentinite are observed. Hitherto, these parts are generally known as "the part subjected to the remarkable serpentinization."

1.2. Structure of serpentinite mass and microscopic structure of serpentinite.

Althouth serpentinite is usually considered to be apt to exfoliate and be clayey, the structure of serpentinite mass and the structure of serpentinite have not been noticed. The appearances of so-called serpentinite in field are as follows; some are
massive and present clear joints (Fig. 2), some have lenticular massive relict in the foliated jointless mass (Fig. 3) and others are clayey. These various features are not local character but are commonly observed. In citing cases, these features in serpentinite are seen together in following places; Takadomari, the environs of the Kamnikotan Valley, Yamabe, Mt. Byōbu, the catchment of the Saru and Mu Rever and the upstream of the Kerimai River in Hidaka province, etc..

The joint system observed in serpentinite mass shows regular tendency which is one of the indication of the condition of intrusion. For instance, the mass in the Yahata Chromite Mine has two joint systems; one with the strike of N 20°-50° E and the steep
inclination to NW and SW, and other with the N 40°~70° W strike and NE dip. T. Kikuchi presented the Gefüge diagram of these joint systems as shown in Fig. 4 (20).

As above mentioned, massive serpentinites with joint system are recognized in many places. They present the peculiar serpentinite appearance of dark green to dark greyish green color, and the perfect serpentinization can be judged by naked eyes.

On the other hand, the relicts of original rocks such as peridotite or pyroxenite are seen at the Mt. Iwanai, Mt. Asaba in Takadomari, and the environs of border mountains between Ishikari and Teshio province, etc. In these masses, peripheral part of joints alters to dark green serpentine. Consequently, it suggests that the serpentinization of ultrabasic rock starts from parts along joints to inside. Microscopic examination of these serpentinites from Takadomari indicate the alternation of peridotitic part and serpentinitic part (30). This is caused from the serpentinization along the joint and parallel fissures. In peridotitic part, olivine crystal near to the margin or fissure, alters slightly to serpentine. In serpentinized part, the structure of original rock remains, but olivine alters perfectly to serpentine of mesh structure (Fig. 17).
On the other hand, common dark green to greyish green massive serpentinite which is perfectly altered, shows microscopically very complex structure. In addition to above mentioned mesh structure, flame-like serpentine, blade-like antigorite (Fig. 5) or amorphous serpentine (Fig. 18), etc. are recognized. Former three are commonly seen in dark green massive serpentinite in many places. The massive serpentinite composed of amorphous serpentine is yellowish green to yellowish brown in general, but some is dark green in color. The following yellowish green serpentinites, the mother rocks of disseminated chromite ore, are composed of amorphous serpentine; the mass in the upper stream of the Nukabira River, a tributary of the Saru River (Hattannukabira Chromite Mine), and in the Mt. Byōbu (Byōbu Chromtite Mine) (30) (31).

![Fig. 5 Photomicrography of thin section of massive serpentinite from Kamui, showing flame-like serpentine. Ordinary crossed nicols, x80.](image)

Such successive alteration process is well observed in the massive serpentinite of the Yamabe Asbestos Mine of which the author will describe in detail in the chapter of chrysotile asbestos deposits. The outline of the process is as follows; ① Serpentine with relict structure of peridotite→② Serpentine with mesh structure→③ Serpentine with amorphous of flame-like serpentine or blade-like antigorite. The formation of chrysotile asbestos vein starts in stage ②, and becomes most active in stage ③.

Chromite ore keeps original form before stage ②, but begins to lose original form gradually in stage ③. Namely, fissures grow out, the outline of crystal breaks from margin and fine black and opaque minerals separate. Most of these minerals are magnetite which is separated in the course of the alteration from olivine to serpentine and of the decomposition of chromite, but some of them are chromite grains.

The serpentinization until this stage advances according to the joint system in ultrabasic rock; it begins from the joint plane or numerous microfissures parallel to the
joint, and spreads gradually to whole rock mass. This alteration process is assumed to be carried out without any addition of exotic materials, so that it is proper to term the autometamorphism of ultrabasic rock.

In the cases of foliated serpentinite or clayey one, mesh structure representing the relict of original rock is perfectly lost and the almost of the amorphous serpentine or blade-like antigorite recrystallize to the felt-like aggregation of fine and flaky antigorite (Fig. 6) or the fibrous and fine antigorite grains grow to make the direction as flowing. In this case, chromite grains are intensely broken and corroded to lose their original form and change to granular form moreover, the separated opaque minerals increase in volume and are scattered entirely in the serpentinite. Besides, their sizes become large and they aggregate to fine bands filling the fissures in serpentinite or fibrous asbestos. In this case, the vein or sac-shaped chamber of aragonite or calcite (Yamabe, Usappu, etc.) and talc (Yamabe, Usappu, Mitsuishi, etc.) grow, and chrysotile asbestos are filled interspaces in fibres with those minerals and the fibres are lastly replaced by talc.

Fig. 6  Photomicrography of thin section of foliated serpeninite from Kamui, showing fine-grained, felt-like antigolite in clusters of ordinary flaky antigolite. Ordinary closed nicols. × 80.

These phenomena suggest that the massive serpentinite with joint system alters gradually under the circumstance of stress and supply of exotic materials. Accordingly, this alteration is considered to be subjected to the strong influence of geological environment in which the ultrabasic rock occurred. There are rich in foliated serpentinites in following places where the ultrabasic rock experienced strong stress after their intrusions; the environs of the Kamuikotan Valley and the Nittō Chromite Mine in the catchment of the Saru River. On the other hand, foliated serpentinites are rare in Takadomari near to Uryu River area where is considered to experience
less stress. Then, it is probable to say in general that there are places of foliated or nonfoliated serpentine. But the foliation of serpentineite is the results of secondary disturbance of tectonic movement. Accordingly, there is massive relict in the place of intense foliation. On the contrary, fairly foliated ones in local are found in the area of weak foliation. The serpentinization in such stage has been carried out especially to the peculiar part in the serpentineite mass and it has not been done homogeneously to whole mass.

1.3. Serpentinization

The serpentinization which is carried out under the addition of water and silica or sometimes oxygen with them,* is the most common and wide metamorphism reaction on peridotite.

T. Du Rietz researched in detail on the ultrabasic rock at Jämtland, north of West Sweden. He indicated that the serpentinization started along the cracks in olivine when the ultrabasic rock intruded in which olivine crystals had commenced to crystallize or been crystallizing. The alteration in this stage is simple hydration to olivine. Subsequently, the whole of olivine convert to amorphous serpentine, and in later, amorphous serpentine recrystallizes partly to flame-like serpentine and iron oxide recrystallizes to magnetite. Besides, antigorite usually grows as the last product of serpentinization.

On the latter stage of alteration, he concluded that the hydrothermal solution necessary to the serpentinization was derived from not peridotite magma but acidic intrusive such as granite or pegmatite because of following fact: (1) The serpentinization in small peridotite mass is more intense than that in large one, (2) The serpentinization around the margin is more intense than in the center of mass, and (3) Serpentinization becomes more violent towards the area of phyllitic rocks. Concerning to the genesis of antigorite, he considered as follows: the strong pressure of the folding movement was important.

As described, T. Du Rietz distinguished two stages in the serpentinization according to its degree. The first stage is serpentinization by the aqueous solution derived from the intrusion of ultrabasic rock, and the second stage is that by the intrusion of acidic igneous rock and the hydrothermal solution derived from it. Similar consideration had been expressed by H. H. Hess (1933) (14). H. C. Cooke (1936) (4) explained similar one in later. They distinguished definitely two stages; the first stage is defined as the autometamorphism caused by the post igneous activity of ultrabasic rock intrusion, and the second stage as hydrothermal alteration by the intrusion of acidic igneous rocks. Against T. Du Rietz considered the serpentinization

---

* P. Haapola

\[3 \text{Mg}_2\text{Si}_3\text{O}_4 + 4 \text{H}_2\text{O} + \text{SiO}_2 \rightarrow 2 \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9\]

\[3 \text{MgSiO}_3 + 2 \text{H}_2\text{O} \rightarrow \text{H}_4\text{Mg}_3\text{Si}_2\text{O}_8 + \text{SiO}_2\]

T. Du Rietz

\[23 \text{Mg}_{11}\text{FeSi}_8\text{O}_{34} + 176 \text{H}_2\text{O} + 38 \text{SiO}_2 + 4 \text{O} = 11 \text{H}_4\text{Mg}_2\text{FeSi}_{16}\text{O}_{22} + 4 \text{Fe}_3\text{O}_4\]
in early stage was carried out partially. H. C. Cooke expressed as follows. The
serpentinization in early stage is done to the whole of ultrabasic rock and the 40~60
% of whole rock mass alters to serpentinite. The serpentinization next stage is
partial alteration by the removing solution along cracks, because it is remarkable
especially along the sheared zone, fault plane or joint. On the contrary, P. Haapola
(1936) who has researched on the serpentinite in North Karelia, Finland, defined as
all serpentinization was the autometamorphism of ultrabasic rock, according to the
following reasons; (1) Serpentinite found in the crystalline schist area lacking granite,
is perfectly serpentinized, (2) The relation between the distribution of granite and the
degree of serpentinization is obscure, and (3) the alteration found at the contact zone
between granitic vein and serpentinite is restricted to only the formation of the layers
of biotite, chlorite, talc or carbonate minerals, namely serpentinization has finished
before granite intrusion (12).

The author think that serpentinization is divided two stage, and the first stage is
the alteration by autometamorphism which covers generally on the ultrabasic rock
mass. However, the thinking which the partial serpentinization in the next stage is
the result of acidic rock intrusion is somewhat doubtful. As before mentioned, it is
important that P. Haapola indicated no definite relation between the distribution of
granite and the degree of serpentinization.

One of the Pre-Cretaceous formation in the Kamuiktan Tectonic Zone contains
"Torifun" Formation, which is the very crushed schalstein containing network of
calcite veinlets, and sandstone or slate, and which have been considered to represent
one horizon in the Pre-Cretaceous(23). However, the author recognized similar rock
in the lower Cretaceous at Kanayama in Ishikari province where is the type locality
of the "Torifun" Formation. The rock is found at the shearing zone in the shape
of the lower Cretaceous and the film of black manganese covers shear plane. Therefore,
the "Torifun" Formation does not represent particular horizon in Pre-Cretaceous, but
probably means the tectonically weak zone formed by the supply of exotic materials
during the process of the Hidaka Orogenic Movement.

The author found gold bearing quartz vein at Shinjo in Ishikari province, and
iron sulphide vein at the upper stream of the Hobetsu River in Iburi province. In
the environs of Kamui in the Kamuiktan Valley, there are many pyrite bearing
quartz veinlets forming network in the sheared zone in so-called black schist. The
indication of mercury deposits are seen in the sheared zone of the schalstein of Pre-
Cretaceous at the environs of Yamabe in Ishikari province. Lately, cupriferous iron
sulphide deposits were discovered in the Naegawa Chert Formation of Pre-Cretaceous
in the middle stream of Umanai Rever, Furano Town in Ishikari province.

S. Sako (33) reported as follows; so-called Naegawa Chert Formation, the mother
rock of the ore deposit, is hornfels one of which contains relict of the original shale
correlated to the Shimanooshita Shale of the lower Cretaceous. Many dykes of
trondhjemite in this district intrude to the shale of middle Cretaceous and are bearing the trace of mineralization.

Accordingly, the age of this cupriferous iron sulphide deposit formation is fairly young; from latest Cretaceous to early Tertiary in age Besides, if these mercury deposits in the environs of Yamabe are correlated to the numerous mercury deposits found in the Central to Northeast part of Hokkaido, the age of deposit formation is post Miocene. Another copper deposits in the amphibolite found in Onnabetsu, westward of Shibetsu City to the environs of Soeushinai northward of Onnabetsu, are also considered to the result of the mineralization after serpentinite intrusion (10).

Followings are well known; the Hidaka Orogenic Movement in the Kamuikotan Tectonic Zone had originated from early to latest Cretaceous in age, the influence of it acted until post Miocen to the western Ishikari Coal Field and decided the geological structure of the Field (7) (8) (24).

However, from above mentioned facts, the author consider as follows. The influence of the Hidaka Orogenic Movement in Tertiary is not only the folding or fault movement in the Ishikari Coal Field, but also there has occurred the active tectonic movement in the Kamuikotan Tectonic Zone such as the formation of sheared zone accompanying the supply and removal of materials. The igneous intrusions, metamorphism or formation of ore deposits must be treated as the serial phenomena in the history of the tectonic movement.

As conclusion, the author wants to consider that the second stage of serpentinization is one of the tectonic movement in orogenic zone rather than the metamorphism by peculiar igneous rock. Then, the degree of serpentinization is various according to the differences of geological environment where the rock mass placed, after the intrusion of ultrabasic rock. In this way, the complex process of serpentinization observed in present may be explained more profitable.

2. CHRYSOTILE ASBESTOS DEPOSITS.

2.1. Introduction.

Mineralogically, asbestos are divisible to chrysotile asbestos and amphibole asbestos. The latter one found in Japan is no valuable for practical use. The mother rocks of chrysotile asbestos are serpentinite and magnesian limestone in general. Almost chrysotile asbestos in Japan belongs to the former. The latter is the ore deposit in the serpentinized part by the contact metamorphism of intrusive rock to magnesian limestone. These cases are rich in Manchuria and Korea (34), but poor in Japan except one instance of "mountain leather" at the Sennin Mine, Iwate prefecture.

Although the productions of chrysotile asbestos in Japan are known in Hokkaido, Nigata, Tottori and Kumamoto prefecture, almost of them come from Hokkaido. In Hokkaido, the working mines during pre World War II to War time were about ten, and the production exceeded 8,000 tons per year in the most prosperous age in 1944.
However, almost of these mines except two, the Nozawa and Yamabe Mine in Yamabe area, Ishikari province, were exhausted and the production decreased to 1,000 tons per year, because of the planless working and no prospecting in the war time. But another causes were the low grade of ore (asbestos content 2~4 %), shortness of fibre less than 6 class and the lack of basic knowledges for the management of mine among the owners who were importer of asbestos or processor of asbestos.

The chrysotile asbestos deposits in Hokkaidō are accompanied with the serpentine masses at many places in the Kamuiokotan Tectonic Zone, especially there are concentrated in the Yamabe area in Ishikari province, Usappu and Mitsuishi area in Hidaka province (Fig. 7).

The working and closed mines of chrysotile asbestos and the places of chrysotile asbestos production in Hokkaidō are shown in Tabe 1.

The fibres of chrysotile asbestos from Hokkaidō are shorter than that from Canada, but their properties are nearly same. Jun Suzuki compared the refractive indices of the chrysotile asbestos from Queveque, Camada with that of the representative asbestos mines in Hokkaidō such as Nunobe, Asahi-usappu anb Tobetsu mine. And concluded that both are nearly equal. He also compared the chemical composition of the chrysotile asbestos from Queveque with that from Nozawa mine, and indicated that both are very similar except that the latter is slightly rich in alumina and some of the latter is rich in lime (37).

Yamabe area in Ishikari province, is the place producing chrysotile asbestos with the longest fibre among Japan. The longest fibre attains to about 2.5 cm, which is very short comparing to that of Canadian chrysotile asbestos fibre of 7~8 cm in length. Most of the chrysotile asbestos fibres in Yamabe area are less than 0.5 cm and that of about 1 cm in length are usually treated as long fibre. However, the chrysotile asbestos fibres from Usappu, Mitsuishi and Shizunai in Hidaka province, are shorter than that from Yamabe. They are commonly 0.2~0.3 cm and scarcely over than 1 cm in length. Even such fibres are longer than the chrysotile asbestos fibres from Shizuoka, Shimane or Kumamoto prefecture.

The occurrence of the chrysotile asbestos deposits in Hokkaidō has been considered as follows; the layered, lenticular or banded enrichment zones of chrysotile asbestos conentrate to the places of remarkable serpentinization such as small serpentine mass or the margin of large mass (37). Accordingly, chrysotile asbestos has been usually assumed to originate after the completion or nearly completion of serpentinization, at the very cracky part along the margin of ultrabasic rock mass. Moreover, there are so many leucocratic and melanocratic dykes in the serpentine mass that the formation of chrysotile has been considered to be in close relaton to these dykes intruded as the post igneous activity of ultrabasic rock intrusion (16) (36) (37). However, the formation of chrysotile asbestos does not restricted only in such places.

On the occasion of the survey of Takadomari sepentinite mass in 1949, the author
Fig. 7  Index map showing location of chrysoberyl axesites mines in Hokkaido
9 Urawa deposit of Tohoku Mine
10 Tahara Mine
11 Shinohara deposit of Tohoku Mine
12 Inami deposit Mine
13 Inami deposit of Tohoku Mine
14 Honkiri Mine
15 Kurihara Mine
1 Nukabe Mine
2 Nozawa Mine
3 Yanaka Mine
4 Shinohara deposit of Tohoku Mine
5 Asohia deposit of Tohoku Mine
6 Naka Mine
7 Misano Mine
8 Nishikawa Mine
<table>
<thead>
<tr>
<th>Working mines</th>
<th>Places of chrysotile asbestos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozawa Mine.</td>
<td>Upper stream of the Toikanbetsu river, Horonobe village, Teshio province.</td>
</tr>
<tr>
<td>Yamabe Mine.</td>
<td>Pankenai, Nakagama village, Teshio province.</td>
</tr>
<tr>
<td>Closed mines</td>
<td>Westward of Sakkuru, Tokiwa village, Teshio province.</td>
</tr>
<tr>
<td>Nunobe Mine.</td>
<td>Inushibetsu, Shibetsu city, Teshio province.</td>
</tr>
<tr>
<td>Nishikawa Mine.</td>
<td>Middle stream of the Upun river, Asahikawa city, Ishikari province.</td>
</tr>
<tr>
<td>Urawa deposit of Tōbetsu Mine.</td>
<td>Westside-boot of Mt. Ashibetsu, Furano town, Ishikari province.</td>
</tr>
<tr>
<td>Nishihata deposit of Tōbetsu Mine.</td>
<td>Surroundings of Mt. Byobu, Minamifurano village, Ishikari province.</td>
</tr>
<tr>
<td>Sekie Mine.</td>
<td>Fukuyama, Hobetsu village, Ishikari province.</td>
</tr>
<tr>
<td>Nishihôrai deposit of Tōbetsu Mine.</td>
<td>Yahata chromite mine, Hobetsu village, Ishikari province.</td>
</tr>
<tr>
<td>Honkiri deposit of Tōbetsu Mine.</td>
<td>Middle stream of the Iwanai river, Biratori town, Hidaka Province.</td>
</tr>
<tr>
<td></td>
<td>Middle stream of Niseu river, Biratori town, Hidaka province.</td>
</tr>
<tr>
<td></td>
<td>Daiwa pit of Nittō chromite mine, Biratori town, Hidaka province.</td>
</tr>
<tr>
<td></td>
<td>Nukabira chromite mine, Biratori town, Hidaka province.</td>
</tr>
<tr>
<td></td>
<td>Environs of Mt. Perari, Shizunai town, Hidaka province.</td>
</tr>
<tr>
<td></td>
<td>Aneichi, Mitsuishi town, Hidaka province.</td>
</tr>
<tr>
<td></td>
<td>Ibetsu-sawa a tributary of Shibechari river, Shizunai town, Hidaka province.</td>
</tr>
</tbody>
</table>
found the chrysotile asbestos veinlet at the central part of the mass where is subjected to so weak serpentinization that there remains the structure of original rock. Similar features have been recognized in other serpentine masses of various places. Even in the ultrabasic rock mass in the Hidaka Tectonic Zone such as the Tottabetsu peridotite mass in the Central Hidaka Mountains, chrysotile asbestos veinlet is known from the narrow serpentinized part along crack.* Concerning to the leucocratic or melanocratic dykes which have been considered to have some relations to the chrysotile asbestos formation, following two instances are known. Such dykes as dioritic aplite in the Takadomari and Inushibetsu Serpentinite Masses had intruded clearly before the formation of chrysotile asbestose and they had proposed suitable places for the chrysotile asbestos formation. On the contrary, there are such dykes intruded after the formation of chrysotile asbestose and altered it, as the trondhjemite in the Yamabe Serpentinite Mass.

These phenomena above mentioned suggest the close relation between the serpentinization and the formation of chrysotile asbestose. At the same time, it suggests the necessity of investigation for old hypothesis.

The relation between the serpentinization and the formation of chrysotile asbestos, has not been researched with cantion and it has been understood obscurely. However, both are in close relation to the tectonic movement in orogenic zone, and the formation of chrysotile asbestos deposits must be treated as one eprpentinization. Therefore, the mechanism of serpentinization must be cleared for the understanding of the mechanism of the formation of chrysotile asbestos deposits.

2.2. Properties of chrysotile asbestos.

Chrysotile asbestos is fibrous serpentine of hydrous magnesian silicates whose chemical composition is $\text{H}_2\text{Mg}_5\text{Si}_4\text{O}_{10}$ which is nearly equal to that of the massive serpentine, the mother rock of chrysotile asbestos. The values of chemical analyses of chrysotile asbestos fibre from some places in Japan are shown in Table 2.

The fibre of chrysotile asbestos is assumed as not crystalline but colloidal matter (11)(27). Accordingly to the recent researches by ultra microscope, it takes the form of tube (27). Commonly, it is considered that they grew to widen the walls of crack in mother rock. However, H. C. Cooke explained as follows. When the crack is narrow, microfibres were formed to fill it. But when it is wide, they cannot fill it and they grow simultaneously from both sides of wall to join at the center of crack (4). Chrysotile asbestos fibres present various greenish color, and sometimes present pale yellow, cream color or pale brown. Chrysotile asbestos fibres of good quality is very fine; the average diameter of canadian chrysotile asbestos fibre is 0.0014 mm, and it presents silkness appeareance. The breaking strenght is as high as 300 tons/mm², and the length of it is satisfactory so that it is suitable for spinning (9). The water of crystallization is related to the softness of fibre. That of chrysotile asbestos is

* According to the personal communication of S. Hashimoto and Y. Igi (1949).
ULTRABASIC ROCKS AND CHRYSOTILE ASBESTOS DEPOSITS
OF THE KAMUIKOTAN TECTONIC ZONE, HOKKAIDO.

Table 2. Chemical analysis table of chrysotile asbestos from some places of Japan.

<table>
<thead>
<tr>
<th>Locality</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>H₂O(+)H₂O(−)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozama Mine.</td>
<td>40.08</td>
<td>1.58</td>
<td>2.29</td>
<td>1.87</td>
<td>40.65</td>
<td>0.00</td>
<td>13.76</td>
<td>100.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shizunai district.</td>
<td>39.29</td>
<td>1.98</td>
<td>5.63</td>
<td>13.71</td>
<td>100.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abe-gun, Sizuoka prefecture</td>
<td>41.43</td>
<td>0.77</td>
<td>1.88</td>
<td>2.18</td>
<td>38.94</td>
<td>0.11</td>
<td>12.93</td>
<td>99.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yatsushiro-gun, Kumamoto prefecture</td>
<td>41.05</td>
<td>0.50</td>
<td>0.73</td>
<td>0.40</td>
<td>0.07</td>
<td>41.69</td>
<td>Tr.</td>
<td>13.32</td>
<td>2.07</td>
<td>99.83</td>
</tr>
<tr>
<td>Shimomasuki-gun, Kumamoto prefecture</td>
<td>42.08</td>
<td>0.04</td>
<td>1.27</td>
<td>0.64</td>
<td>41.35</td>
<td>Tr.</td>
<td>12.93</td>
<td>1.89</td>
<td>99.86</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. "
5. "
6. Geol. Surv. Japan
7. "

most abundant among that of other sort asbestos such as amphibole asbestos and blue asbestos. According to many results of chemical analyses of the amphibole asbestos from Kumamoto, Nagasaki and Ishikawa prefectures, water content attain sometimes to 7~8% (13) (22), but most are 3~4% and many present 1% level. The blue asbestos from South Africa present also less value than 4%, but chrysotile asbestos contains usually 10~13% of water (13) (22) (37) and someone contains more than 15% (13).

The chrysotile asbestos from Hokkaido is commonly white to pale green in color and is the aggregation of very flexible fibre with silky luster. Some are the aggregation of the in color, harsh and brittle, and show grease like lustre. These differences are seemed to due to the areas of production. Generally, that from Yamabe area is rich in former type and that from Usappu, Mitsuishi and Shizunai area are rich in latter type. They differ slightly in the refractive indicies of fibres; that from Yamabe area presents γ=1.554, and that from Shizunai area, γ=1.556~1.567 (37). However, the difference in fibres is not essential and comes from the mixing of impurities such as fine talc or magnetite filling interspaces of fibres or the replacement of fibres by talc.

As the cause of the harshness and brittleness of chrysotile asbestos, J. A. Diller proposed the replacement of fibres by calcite in previous (2). However, it has been known lately that the more harsh and brittle ones show higher value of SiO₂/MgO. So the cause of the brittleness of fibres is assumed as the conversion of chrysotile asbestos to talc. Namely, F. E. Keep found that the brittle fibre was composed of
the pseudomorph of talc, and he considered that the brittleness of fibres increased with talc content (18). H. C. Cooke indicated that brittle fibre contains small quantities of \( H_2O \) but rich in \( Al_2O_3 \). The effect of \( Al_2O_3 \) content to the properties of fibre is obscure. But the most important cause is the increase of \( SiO_2 \) or the increase of talc. Another causes are the lacking of \( H_2O \) or increase of Fe (3). Similar opinion was proposed by R. H. Beckurth who considered that the increase of \( SiO_2 \) came from the acidic igneous rock such as granite (2).

Tami Inoue described about the harshness and brittleness of the chrysotile asbestos from Yamabe and Shizunai area, Hokkaido. She mentioned as follows (17).

1. In harsh and brittle fibres, \( SiO_2 \) increases and \( MgO \) decreases in quantity.
2. The harsh and brittle fibre contains usually less water.
3. The harsh and brittle fibre is generally rich in total iron.
4. CaO is independent to the harshness and brittleness of fibres.
5. The effect of \( Al_2O_3 \) content to the natures of fibre is obscure.

As conclusion, the harshness and brittleness of chrysotile asbestos fibre is caused from the conversion of chrysotile asbestos to talc. Following causes assist it; the magnetite in fibres derived from mother rock, the Fe replacement to Mg in chrysotile asbestos molecule.

2.3. Place of chrysotile asbestos origination and shape of chrysotile asbestos vein.

The places where chrysotile asbestos originates, are considered the cracky zone along the margin of serpentinite mass (37). However, it is never restricted to such places. The largest serpentinite mass including Nittö and Yahata Chromite Mines in the catchmint of the Saru and Mu Rivers, and the Mt. Byobu Serpentinite Mass, contain chrysotile asbestos. Even in the center of the Takadomari Serpentinite Mass with long diameter of 16 km and short diamenter of 12 km, chrysotile asbestos is recognized (21)(29). Namely, in the case of the ultrabasic rock in the Kamuikotan Tectonic Zone, chrysotile asbestos seen in everywhere ultrabasic rock alters to seppentine. But workable ore deposits are rare, and they are restricted to the cracky zone such as the margin of serpentinite mass. Consequently, chrysotile asbestos originates in every places, but special conditions are neccessary to form ore deposit.

Chrysotile asbestos are fine veinlets filling joints or cracks in serpentinite. The fibres composing vein are usually cross fibre arranging vertical to the wall of vein. The length of cross fibre attains to whole or half thickness of vein width. Sometimes several layers compose one vein. In another case, fibres are parallel to the wall of vein. They are termed slip fibres which are situated at the sheared zone and are commonly found along shear plane. Slip fibres are converted from cross fibres by the disturbance changing their arrangement (27).

Although chrysotile asbestos has been assumed to originate in the form of irregular veinlets, there is distinct regularity when we observe in detail; two types of occurrence are divisible.
ULTRABASIC ROCKS AND CHRYSOTILE ASBESTOS DEPOSITS OF THE KAMUIKOTAN TECTONIC ZONE, HOKKAIDO.

The first is so-called ribbon-structure which is the parallel aggregation of numerous chrysotile asbestos veins (Fig. 8). This deposit is especially rich along the joint parallel to the elongation of serpentinite mass, and numerous cracks parallel to the joints. The place is just situated at the concentrated part of remarkable chrysotile asbestos veins in the enrichment zone of chrysotile asbestos deposit where is the swarm of numerous chrysotile asbestos veins. H. C. Cooke indicated that such part of ribbon-structure is usually formed in the place of severe compresion, and is excellent for the high content of asbestos (4). Good example is observed at the enrichment zone of chrysotile asbestos deposit in Nozawa Mine. Other instances are the Takadomari and Inushibeteu Serpentinite Masses where are partially recognized ribbon-structure like appearances of the swarm of numerous chrysotile asbestos veins parallel to the intrusion trend of dioritic aplite dykes in the serpentinite mass.

Another type is intersecting of chrysotile asbestos vein. This is most common shape among the chrysotike asbestos deposits in Hokkaidō, which is formed by the filling joints or cracks of two direction with chrysotile asbestos. The earliest form is very fine veinlets of chrysotile asbestos filling narrow cracks in serpentinite, the example of which is shown in (Fig. 9). This is observed at the Yamabe Mine and presents tortoise shell like form. Similar instances are seen in the Takadomari and Byobudake Serpentine Masses where are observed the lattice pattern of intersecting fine veinlets of chrysotile asbestos. (Fig. 10)

As above mentioned, chrysotile asbestos veins are apt to concentrate. However, the following phenomena are recognized about the shape of unit vein, when we observe

Fig. 8 Type of chrysotile asbestos vein occurrence, showing ribbon-structure. (Nozawa Mine).
Fig. 9 Earliest form of chrysotile asbestos veinlets, showing very fine veinlets of chrysotile asbestos fill to narrow cracks in serpentinite. (Yamabe Mine).

Fig. 10 Type of chrysotile asbestos vein occurrence, showing lattice pattern structure. (Nozawa Mine).

the crude class vein more than 1 cm in width at Nozawa Mine (Fig. 11).

The chrysotile asbestos vein is not continuous with uniform width but is intermittent. It becomes soon thin, along the elongation direction. This narrowing is not symmetrical thinning out brom both sides; it becomes thin from one side like as
spear. When chrysotile asbestos vein becomes thin like the edge of a spear, another vein appears keeping narrow distances of serpentinite, in the state of facing both edge-sides each other. Thick chrysotile asbestos vein of crude class is composed of the repeating of such phenomena. In this case, each veinlet is intermittent or thinig to continue another veinlet. In other case, somewhat large serpentinite block is enclosed by veins. In chrysotile asbestos vein, fine bands of about 1 mm thick are recognized in the state parallel to vein wall. Although fibres are usually not discontinuous at these bands, sometimes they are discontinuous. Such phenomena appear in very thin vein, and are assumed to common nature of chrysotile asbestos vein. They suggest that the formation of chrysotile asbestos is carried out during the process of the serpentinization of ultrabasic rock under the stress compression. They also suggest that the chrysotile asbestos vein came from not always one fissure. In very thin vein with thickness less than 1 mm, fibres are originated from one crack. However, in the case of long fibres in wider vein, serpentinization started along the numerous parallel cracks and the fibres gradually grew with the serpentinization and lastly they joined to one long fibre.*

2.4. Enrichment zone of chrysotile asbestos deposits.

Workable chrysotile asbestos deposits or enrichment zones are concentrated to such small serpentinite masses as Yamabe, Usappu and Mitsuishi, especially along their margins. The chrysotile asbestos veins in these deposits, are composed of numerous network parallel veinlets, and so-called main vein is never found.

The types of the distribution of enrichment zone are different as to each rock

* T. Inoue also described such phenomena (17).
mass, but they correspond to the location of numerous cracks. These differences arise from the geological environment in which each mass is placed, especially the movement and mode of intrusion. In every cases, enrichment zone is just situated at the place of intense stress compression to the ultrabasic rock which intruded as an episode of tectonic movement history. Accordingly, the shape of each enrichment bears common nature.

Chrysotile asbestos enrichment zone exists as the zone along the margin of serpentine mass, and is parallel to the outline of it. For instance of the Asahi-usappu Mine, the inclination of the enrichment is $30^\circ \sim 50^\circ$ to the inward of rock mass. Besides, there are numerous leucocratic dykes with similar dip and strike along the margin of the rock mass. In the Pre-Cretaceous rocks intruded by serpentine, there are also the sheared zone with similar strike, which accompany the veinlets of quartz, calcite and albite. Even inside of such large serpentine mass as the Takadomari, there are many chrysotile asbestos veins in the environs of the lucocratic dyke (dioritic aplite) (29). Thus, it is adequate to say that chrysotile asbestos enrichment or ones approximate to enrichment originate at the so-called marginal zone formed by the local tension, or numerous crack zone formed by the tension of differentiated dyke intrusion.

In the strip stope of the Nozawa Mine, two joint systems of $N 30^\circ (\pm) E$ and $N 60^\circ (\pm) W$ are remarkable in the serpentine mass. Chrysotile asbestos enrichment zone elongates to the similar direction of the former joint system which is generally zonal and parallel to the outline of serpentine mass. However, each chrysotile asbestos veinlet in the enrichment zone, is parallel to the two systems of joints or cracks with similar direction. Although the chrysotile asbestos veins are not restricted to the joints and cracks of peculiar direction, they are remarkable rather along the joints parallel to the elongation of enrichment zone in the margin of serpentine mass. Chrysotile asbestos veins are not uniformly seen in the enrichment zone; there are part with numerous chrysotile asbestos veins, part with less veins or part lacking them. Above mentioned parts are alternately existence as lens. These phenomena are observed in horizontal and vertical direction. The vertical variation in Yamabe Mine is known from the results of boring exploration (Fig. 12).

Many serpentine in chrysotile asbestos enrichment zone are considerably foliated and contain lenticular relics of soft massive parts. This is caused from that it situates at the sheared zone in serpentine mass, and it contains such carbonate minerals as calcite or aragonite of vein or pocket shape. On the other hand, serpentine in these places are rich in talc and clayey, which due to the migration of hydrothermal solution after the formation of chrysotile asbestos. As the reaction advances chrysotile asbestos lose their fibrous forms.

2.4.1. The size of enrichment zone.

The extension, width or depth of chrysotile asbestos enrichment zone are scarecely
known, especially about depth. The largest enrichment zone among chrysotile asbestos deposits in Japan, is that in the Yamabe Serpentinite Mass. The second is the deposits in the Usappu and Mitsuichi Serpentinite Mass. In the Yamabe Serpentinite Mass, Nozawa Mine has the width of 100 m and extension of 300 m (25), and that in Yamabe Mine has the width of 100 m and extension of 200 m. That of Asashi-usappu Mine in the Usappu Serpentinite Mass has width of 30 m and extension of 200 m, and that of Nishihata ore deposits of Tōbetsu Mine in the Mitsuishi Serpentinite Mass has the width of 10 m and extension of 75 m. The depths of those mine's enrichment zone are ascertained to about 50 m in each case. But according to late boring exploration in the Nozawa and Yamabe Mines, the width, extension and depth of enrichment zone are supposed to increase.

The state of enrichment zone under deep ground is scareceely known. According to the results of boring in Nozawa and Yamabe mines, the content of chrysotile asbestos in enrichment zone is always variable and sometimes it lacks fibrous part. However, the underground state has been known less than about 100 m in depth. In Thetford area in Canada, F. G. Ross described that open air mining was carried out to 150 m in depth and the existence of chrysotile asbestos is ascertained to about 500 m in depth by boring, where the state is same to that in surface of ground (28).

But the maximum depth is unknown at all. G. Fischer who researched about the chrysotile asbestos deposits in Ostomark, indicated as follows (11). The chrysotile asbestos vein originates in filling the cracks formed by the faults of tectonic movement so the formation of chrysotile asbestos has no relation to ground surface. Accordingly,
the present position of mining for ore deposits are accidental. The content of the fibres is also not related to the depth. Concerning to only the toughness of fibre, it becomes tenacious in deeper place.

2.4.2. The content of chrysotile asbestos in enrichment zone

The chemical composition and specific gravity of chrysotile asbestos are nearly equal to those of serpentine, the mother rock of chrysotile asbestos. So that the precise grade of chrysotile asbestos ore is hardly determined. It has been decided from the ratio between mining ores and refined chrysotile asbestos fibres.

The grade of ores in Japan is very low compared to that from Canada, South Africa and C. C. P. According to the publication in 1937, chrysotile asbestos of 409,813 tons are refined from ores of 6,447,805 tons in canada, the average grade is 6.32 %. In Barbant district in South Africa, high graed ores of 15~17 % are known. On the contrary, the average grade in Japan is 2~3 %, except local high grade ore of 6~10 % (37). However, such grade ores can be get only when the mine has been so worked that only enrichment ores can be dug out. When new mining begins, overburden and mother rocks, other than enrichment ores must be removed. Consequently, the ratio of refined chrysotile asbestos to the whole dug out rocks is assumed to 0.4~0.6 %.

Originally, the length of chrysotile asbestos fibre is various and some classes are classified according to their differences. During the mining and refining process that ores are dug out, dried, broken and refined, artificial damages of fibre must be considered. Therefore, the grade of chrysotile asbestos in enrichment zone calculated from the refined chrysotile asbestos, is not correct and it does not express the true value of ore deposit.

W. E. Sinclair pointed out the following good example (35). The long fibres were very abundant in the original ores at the working face of the stope, but the fibres of refined chrysotile asbestos became short and the value decreased to 25 % of original ores. These instances were caused from the harshness and brittleness of fibre and the damage of fibres by blasting. Ill treating of blasting or the inadequate setting of dynamites influence so strongly that even excellent long fibres are destroyed.

Such effects are observed at the deposits in Hokkaido. The Nozawa and Yamabe mines are situated at the neighbouring enrichment zone in same serpentineite mass. Therefore, the lengths of fibre in both mines are originally similar. Nevertheless, the damage of fibre in Yamabe Mine is remarkable because the faults develop in enrichment zone where the serpentinization alteration in the second stage is so remarkable that the fibres are fairly altered. Another cause is the method of mining, the intervals of digging benches overs than 10 m in Yamabe Mine, which is longer than in the Nozawa Mine. Consequently, the large amount of dynamite is necessary for blasting.

The damages during refining process of fibre of ores from following mines, the Asahi-usappu Mine in Usappu Serpentinite Mass and Tobetsu Mine in Mitsuishi Ser-
pentinite Mass, are commonly remarkable composed to the chrysotile asbestos from the Nozawa and Yamabe mines. This is also derived from that the positions of ore deposits are just situated at the strong alteration by the serpentinization of the second stage.

2.5. Serpentinization and formation of chrysotile asbestos.

The chrysotile asbestos formation is assumed to occur in the second stage of serpentinization. H. C. Cooke(4), T. Du Rietz(6), G. Fisher(11) and P. H. Riordon(27) considered that it was formed by the hydrothermal solution from acidic intrusive rocks such as granite. H. C. Cooke expressed that chrysotile asbestos and acidic intrusives were not always associated, but both came from common source (4). P. H. Riordon said that chrysotile asbestos was the last product of serpentinization and it was formed as the adjustment of the completion of serpentinization; the high temperature necessary to chrysotile asbestos formation derived from acidic intrusive rock mass chiefly granite (27). J. Suzuki pointed out the relation between leucocratic rocks in serpentinite and the chrysotile asbestos in Hokkaido, and considered that chrysotile asbestos originated after the completion of serpentinization (37).

However, many phenomena observed in Takadomari Serpentine Mass, Nozawa Mine and Asahiusappu Mine, suggest that chrysotile asbestos originates at the first stage of serpentinization, the autometamorphism of ultrabasic rock. In the second stage of serpentinization, the fibres of chrysotile asbestos change to harsh or brittle and sometimes lose their fibrous form, as to the degree of serpentinization.

As the Nozawa Mine, the Yamabe Mine at the south margin of Yamabe Serpentin Miteass is one of the working mines at present Japan. In the enrichment zone in this mine, serpentinite is fairly foliated, some of which are distinctly bounded

![Fig. 13 Exposure of serpentinite from Yamabe Mine, showing massive serpentinite transform into foliated serpentinite.](image)

A—dark greenish massive serpentinite (chrysotile asbestos veinlet can be seen).
B—yellowish massive serpentinite (near part to joint plane).
C—foliated serpentinite.
from massive serpentine by the joint plane (Fig. 13). In the darke greenish part at the center of that massive serpentine, there is yellowish part which is considered to remain peridotite structure and is without chrysotile asbestos veins. Near to the joint plane, it presents dark color and the lattice pattern of fine chrysotile asbestos veinlets (Fig. 14). More approaching to the joint plane, several cm in thickness along which presents yellowish brown in color. The foliated part before mentioned contacts to the yellowish brown part and the chrysotile asbestos veins are recognized throughout both the massive and foliated serpentinites.

![Image](image_url)

**Fig. 14** Chrysotile asbestos veins in massive serpentine from Yamabe Mine.

(Polished plane, A in Fig. 13, is vertical to the paper's surface.)

The central portion (1) of the massive serpentine retain its structure of peridotite, but the portion (2) near joint has completely altered to serpentine and shows a mesh structure. The transitional part between the two portions is peridotitic in the left half and entirely serpentinized in the right half, as shown by a and b of Fig. 16. Chrysotile asbestos veins occur in B of the serpentinized portion (2) near joint plane.

According to the microscopic observation for the massive serpentine, the dark green part in color without chrysotile asbestos veins is imperfectly serpentinized and remains peridotite structure. The dark color part containing many fine chrysotile asbestos veinlets is perfectly serpentinized presents mesh structure. The yellowish brown part contacted to joint plane is composed of amorphous serpentine. In following paragraphs, the results of microscopic observation to each part will be described.

Dark greenish central part without chrysotile asbestos veins (Fig. 15 a. b.).

Texture blastoporphyrritic. Fine relict minerals fill the interspace of coarse relict minerals as paving stones, and the remained space is filled with network of fibrous
Fig. 15 a. Photomicrograph of thin section of dark greenish serpentine (part 1 in Fig. 14), showing peridotite structure remains. Ordinary light and crossed nicols, ×20.

o—olivine, m—monoclinic pyroxene.

r—rhombic pyroxene, c—chromite.
Fig. 16 a. b. Photomicrography of thin section of dark greenish massive serpentineite (part A in Fig. 14), showing peridotite structure remain at left but is perfectly altered to mesh-structure serpentine. Ordinary light and crossed nicols, ×20.

b—bastite, m—monoclinic pyroxene,
r—rhombic pyroxene, c—chromite
chrysotile. Composition minerals are rhombic pyroxene, monoclinic pyroxene and olivine in abundant order. Accessory minerals are chrysotile, chromite and magnetite. Rhombic pyroxene is 1~2.5 mm in size, porphyroblastic, irregula and with remarkable fine cleavages. The parting vertical to the cleavage is recognized along which it shows wavy extinctions. $-2v = 71$~$85^\circ$. Monoclinic pyroxene is 0.1~0.5 mm in size, and fill the interspaces of rhombic pyroxenes as paving stones. Form irregular or mortar-like. $+2v = 58$~$63^\circ$. $C\wedge Z = 39$~$40^\circ$. Olivine is 0.1~0.5 mm in size and the mode of occurrence similar to monoclinic pyroxene. $2v = +85$~$-89^\circ$. Chrysotile of network replaces three minerals above mentioned and make them sporadic as paving stones. These three minerals are partially replaced to perfect amorphous serpentinite.

The part near to joint plane; perfectly serpentinized and with fine chrysotile asbestos veinlets (Fig. 16 a. b and 17).

Mesh structure. Composition minerals, chrysotile, bastite, chrysotile asbestos vein, chromite and magnetite. Fine chrysotile is uniformly seen as net or lattice form. Under single nicol observation, serpentinized pseudomorph minerals of 0.5 mm in size are recognized, along the margin of which is enclosed dusty magnetites, and it presents mesh structure as a whole. Angular bastite of 1~2 mm in size are spotted which show very good cleavage and remarkable bending. It is serpentinized along the cleavages and partings; it appears very fine dusty form. The perferctly serpentinized part of mesh structure is shown in Fig. 16; it gradually changes from peridotitic part and chrysotile asbestos veins begin to grow at about 5 mm distant.

Fig. 17 Photomicrography of thin section of dark greenish massive serpentinite (part [ in Fig. 14), showing chrysotile asbestos vein begin to grow in mesh-structure seepentine. Ordinary crossed nicols, $\times 20$. →chrysotile asbestos vein.
from former part (Fig. 17). Chrysotile asbestos vein has width of about 0.1 mm at terminal part, but it gradually widens to 0.5~0.7 mm. At the same time, banding structure develops in chrysotile asbestos vein.

Fig. 18 a.

Fig. 18 b. Photomicrography of thin section of yellowish massive serpentine (part □ in Fig. 14, a part along joint), showing altered to amorphous serpentine. Ordinary light and crossed nicols, ×20. a—amorphous domain, c—chromite
The part yellowish and composed of amorphous serpentine (Fig. 18 a. b.). Composition minerals, amorphous serpentine, fine re-crystallized serpentine and chromite. As a whole, fine amorphous minerals are uniformly seen, the interspaces of which are filled with dusty re-crystallized serpentine. Amorphous domains are sporadically observed (blanc part in Fig. 18 a.).

The microscopic observation of another massive serpentine which is attended with chrysotile asbestos vein is as follows. Chrysotile asbestos vein of about 12 mm in width is formed in amorphous serpentine. Amorphous serpentine is replaced by the re-crystallized serpentine of network or fine lattice form, and relict minerals are scarecly observed. Near to the wall of chrysotile asbestos vein, re-crystallized serpentines are replaced by pennine in part. The walls are largely composed of amorphous part which is replaced partially by the twing of chrysotile asbestos vein. The crear banding structure of chrysotile asbestos vein beautiful crape-like suture line structure, indicates the origination of it in disturbance stage (Fig. 19). Uvarovite concentrates to the wall of vein but is fine grained (0.05~0.3 mm) and small in quantity.

![Fig. 19 Photomicrography of thin section of chrysotile asbestos vein from Yambe Mine, showing beautiful crape-like suture line structure. Ordinary crossed nicols, ×20.](image)

In the Takadomari Serpentine Mass, it is observed that the serpentinization of the first stage is started from the joints and cracks in rock mass and chrysotile asbestos veins originate there. In this mass, very compact part remaining peridotie structure is seen where the joint system indicating the intrusive structure of mass is well reserved. The joints and cracks parallel to joints are serpentinized in narrow
where chrysotile asbestos veins originate. The microscopic obervation of it is as follows.

With the advance of serpentinization, relics of olivine gradually disappear and are replaced by serpentine of mesh structure. When it is filled with numerous slender chrysotile in later, chrysotile asbestos vein start to grow. With the extending of chrysotile area, chrysotile asbestos veins become abundant. In one thin section sample, this relation is observed one another. Similar phenomena is reconocized also in Byōbudake Serpentinite Mass. Namely, at the stage of chrysotile formation which is after the stage of mesh structure formation, chrysotile asbestos vein originate where the ultrabasic rock lost original structure. In this stage, serpentinite becomes more amorphous, chrysotile asbestos formation grows most prosperous and each of the fibres filled cracks grows to unite to long fibre. This is not peculiar local phenomena.

Similar phenomena is observed in the Nozawa Mine in Yamabe Serpentinite Mass where picrolite is seen in place of chrysotile asbestos. Picrolite is different from chrysotile asbestos in physical properties and thermal reaction and is assumed to grow after chrysotile asbestos formation because the vein of picrolite usually crosses to the chrysotile asbestos vein (Fig. 20).

![Fig. 20](image)

**Fig. 20** Relation of chrysotile asbestos and picrolite veins.

\[ c — \text{chrysotile asbestos vein} \quad \text{p} — \text{picrolite vein} \quad \text{s} — \text{serpentinite} \]

But, some of chrysotile asbestos vein convert to picrolite vein, so that the latter is considered to originate just or slightly later than chrysotile asbestos vein (41). Lately, P. H. RiORDON found that there are many chrysotile asbestos veins composed of chrysotile asbestos and picrolite, the both of which are transitional each other. He considered that picrolite originated in high pressure and low temperature condition, and converted to chrysotile asbestos according to the decrease of pressure and increase of temperature. In both cases, pecrolite and chrysotile asbestos are very intimate and there is no large time interval between both formation stages (27). The Yamabe
Serpentinite Mass contains the relict of peridotite structure in part where picrolite grows along narrow serpentinized zone near to joint (29). In the mother rock with fresh olivine and pyroxene, there is observed the picrolite vein of 1.5 mm in width accompanying serpentinized zones of about 2~3 mm in width at both sides. According to the microscopic observation, the process of picrolite formation is seen; serpentinization advances to definite direction along the cracks in mother rock and picrolite occures in serpentinized part of mesh structure.

In every thin section samples, followings are obserued; sporadical fine magnetite grains originate during the formation process of chrysotile asbestos or picrolite as the results of serpentinization of olivine along the network of mesh structure. Besides, following phenomena are occasionally recognized. At the boundary between chrysotile asbestos or picrolite vein and mother rock, fine minerals along or slightly apart from vein present network or so-called "Suminagashi (irregular flow)" structutre. It is judged equiualent to so-called "black wall zone" of J. Suzuki. According to J. Suzuki, the component mineral of the black wall zone is magnetite which has been considered to be close relation to chrysotile asbestos formation because of the comparison of chemical components of chrysotile asbestos, serpentine and black wall zone (17)(38)(39).

Such black fine grains as seen in black wall zone, are occassionally fill the interspaces of chrysotile asbestos fibres as is known in Asahi-usappu mine. Similar ones are observed in canada by J. A. Dresser (Fig. 21) (5). The black wall zone is not

Fig. 21 Photomicrography of thin section of chrysotile asbestos vein. Polarized light, ×20. Serpentine can be seen at left and right. Central parting and other interstices are filled by iron ore. (By J. A. Dresser)
always accompanied to chrysotile asbestos veins. Some materials like as black wall zone is recognized when chrysotile asbestos vein does not exist. Citing the case of Yahata Chromite Mine, black fine minerals of “Suminagashi” pattern concentrate in the mother rock serpentinite of chromite ores. It is not seen in peridotite part but in very serpentinized part where is recognized much chromite as one of the rock forming minerals. Moreover, the chromite in these parts alters to nearly opaque black material, along the margin of which fine black minerals are separated and are transitional gradually to the aggregation of black opaque minerals of “Suminagashi” pattern. According to the observation of polished section, the black opaque minerals are identified to magnetite. Such conversion is the phenomena in the last of the first stage, before mentioned.

Accordingly, the materials like as black wall zone indicate the last stage of the autometamorphism which is the first stage of serpentinization. They are remarkable at the place where chromite is abundant as rock-forming mineral. Although J. Suzuki considered that the black wall zone has intimate relation to the formation of chrysotile asbestos, it is questionable.

After serpentinization advanced to the second stage, serpentinize changes foliated or clayey and the joint system in rock becomes indistinct as is described before. In such rock, the interspaces of chrysotile asbestos fibres are filled with very fine talc. As alteration advances, cross fibre converts to slip fibre which is replaced by talc to lose fibrous form and becomes to be crushed easily with fingers. The state of transition is commonly observed in chrysotile asbestos deposits in Hokkaidō. Generally such phenomena are remarkable in the ore deposits originated in the serpentinite mass in Hidaka district such as the Asahi-usappu and Tōhetsu mines.

2.6. Consideration about the mechanism of chrysotile asbestos deposit formation.

On the origin of chrysotile asbestos veins, many researchers have discussed from old days. These theories are grouped into following three, replacement theory, fissure filling hypothesis and Taber’s theory. The first was proposed by J. A. Dresser (5) who considered that solution permeated to the tight crack along which serpentine was recrystallized to chrysotile asbestos vein. F. Cinkel considered as follows (37). When ultrabasic rock was serpentinized, its volume increased. The joints and sicken cracks occurred as the contraction of rock or the intrusion of granite dykes. Along these cracks, serpentine solutine separated and permeated from surrounding walls of cracks are recrystallized to chrysotile asbestos vein. The second theory is that serpentine solution or the liqued solved mother rock fills open cracks. The third is as follows; the solution or vapour permeated to the pores in mother rock reacts and replaces serpentinite, and grows to chrysotile asbestos veins as enlarging the fissures (4).

Concerning to the chrysotile asbestos vein, in Hokkaidō, from Taber’s view point J. Suzuki considered that fibres grew as frost growth (38)(39)(41). He mentioned as follows (37). The chrysotile asbestos veins in Hokkaidō originate after the completion
of serpentinization of ultrabasic rock, especially along the craky zone at the marginal part of the rock mass. These veins are probably derived from the mutual reaction between mother ultrabasic rock and high temperature hydrothermal solution uprised from deep underground through spaces or cracks. The hydrothermal solution bred chrysotile asbestos veins in generally assumed to the post igneous activity of ultrabasic rock intrusion. However, so many leucocratic dykes are seen in the area rich in chrysotile asbestos veins that the intrusion of these dyke rocks perhaps have something to do with them. T. Isoue who has been taught by J. Suzuki, menthond as follows. In strongly serpentinized craky part, high temperature vapour probably upwells, solves surrounding serpentine and originates fine chrysotile asbestos crystals. The mother rock is successively solved by high temperature vapour and chrysotile asbestos grows up. The velocity of crystal growth and progressing of metasomatic front in both sides of wall are in nearly equilibrium so that the fibres grow widening both sides of wall without bending of fibre. In this case, excess iron for fibre growth is separated and put forward of both walls. When temperature becomes very high, the crystallization of chrysotile asbestos ceases and fused materials change to recrystallized serpentine (sometimes picrolite). Some of chrysotile asbestos may crystallize from removing solution, but almost are assumed to replace neighbouring mother rock. The origin and stage of high temperature vapour is obscure except that it occurred after serpentinization. However, there are so many leucocratic rocks in the area rich in chrysotile asbestos that the vapour may be related to them (17).

Concerning to the places where chrysotile asbestos veins are formed, the joints originated as the contraction of rock during cooling process, and the fissures from the deformation of rock by compression, are considered (5) (19). Others considered that cracks were caused from expansion of volume by serpentinization (26).

As above mentioned, J. Suzuki et. al. mentioned vaguely that chrysotile asbestos originates where are many cracks around serpentine mass. On the other hand, H. C. Cooke and G. Fischer who agreed to the Tabor's theory, explained as the fault of tectonic movement especially tension crack by thrust fault.

H. C. Cooke stated as follows; wavy undulation of fibres occasionally seen were not derived from later deformation but from the changing of removal detection of vein wall during chrysotile asbestos vein growth. Besides he mentioned; although chrysotile asbestos fibres were usually assumed to vertical to vein walls, such cases were less than 50 % and almost were crossed with angle less than 45°. His conclusion is that the shape of chrysotile asbestos vein is very hardly explained by replacement theory or simple fissure filling hypothesis. Chrysotile asbestos started to crystallize through the course which Tabor's theory explained, and the growth of fibres widened the vein walls. However, the most adequate opinion is that it is widened by not only fibre's growth but also tension deformation of rock (4).

G. Fischer mentioned similar opinion from following reasons (11). (1) When the
direction of vein gradually changes, the angle of fibre to vein wall does not present so marked changing. As gradual bending, fibres also change in the vertical state to walls. (2) When chrysotile asbestos vein branches or crosses, the direction of fibre is constant as a whole vein, and the fibres are continuous in the branch of vein. As approaching to branching point, the fibre gradually curves and it is bended in sharp angle at just branching point. (3) The evidences that the fibre was subjected to mechanical deformation during its growth, are recognized in vein.

The theories above mentioned are summarized and generalized as follows. At the last stage of serpentinization, chrysotile asbestos originated at the place of remarkable tension cracks accompanied with the thrust fault of tectonic movement. It is derived from the uprising of high temperature hydrothermal solution from granite or other acidic intrusive rock under weak compression. Under the circumstance that the solution or vapour permeates and reacts to mother rock, chrysotile asbestos fibres grew in replacing mother rock and widening cracks under tensile stress.

However, according to the results of author's researches before described, chrysotile asbestos vein was formed in successive to the serpentinization of ultrabasic rock, in the first stage of serpentinizaton or the stage when ultrabasic rock altered to serpentinite by autometamorphism. This process is summarized in following order; the replacement of olivine or rhombic pyroxene to serpentine→the formation of chrysotile asbestos vein→the formation of amorphous serpentine (the prosperous stage of chrysotile asbestos vein formation)→the formation of picrolite. In the second stage of serpentinization, massive serpentinite is destroyed to so-called foliated or clayey one. At same time, chrysotile asbestos vein is filled or replaced the interspaces of fibres by talc, and becomes brittle and loses fibrous form.

The Kamuikotan Tectonic Zone was the place of large tectonic movement during latest Mesozoic to Tertiary. The tectonic movements have occurred at latest Mesozoic to early Tertiary and latest Tertiary, and the ultrabasic rock intruded in the first movement. During the process of intrusion and consolidation of ultrabasic rock, so-called intrusive structure such as marginal fissure zone or joint system is formed along its margin where are many intrusions of differentiated dyke of leucocratic or melanocromatic rocks. Thus numerous cracks in close relation to joint system were formed in parallel state to joints. It is considered to be remarkable at the places subjected to the thrust movement of ultrabasic rock intrusion and the local tension by intrusion of differentiated dykes, or especially at the margin of rock mass subjected to former movement.

As this way, marginal zone of ultrabasic rock mass proposed so good condition for the removal of high temperature vapour or hydrothermal solution, that serpentinization advanced along the joints or cracks and chrysotile asbestos vein was also formed as an episode of it. Consequently, the formation of chrysotile asbestos vein was not restricted to special places but it was carried out in the serpentinized zone
of ultrabasic rock mass in common. However, it was remarkable in the very cracky zone such as the margin of rock mass or place intruded by differentiated dyke. Especially in the margin of mass, enrichment zone originated and developed to chrysotile asbestos deposits with excellent volume and quality (or length of fibres).

Namely, chrysotile asbestos deposits originated in cracky zone such as the marginal cracky zone of ultrabasic rock mass, when high temperature vapour or hydrothermal solution had passed through there. At first, olivine and pyroxene near to joint or crack in ultrabasic rock alter to serpentine from their margins or fissures, and they change from mesh structure serpentine, amorphous serpentine, flame-like serpentine to blade-like antigorite. Chrysotile asbestos vein begins to grow soon after the starting of serpentinization; it is successive from the picrolite formation with gradual increase of temperature. When temperature decreases again, picrolite becomes abundant. The chrysotile asbestos vein formed in these ways, are intensively changed by the local serpentinization accompanied with the secondary deformation of mass by tectonic movement. Followings are occured during the process of such tectonic movement; conversion of cross fibres to slip fibres, filling the interspaces of fibres with calcite, talc or magnetite, and the replacement of fibres by talc. At last, fibres become powdery.

**BIBLIOGRAPHY**

(* Indicates articles written in Japanese.)


*23 ÔTATSUME, K., Stratigraphical relation between lower ammonite bed and schalstein formation of central Hokkaido: Geol. Soc. Hokkaido, Bull., No. 11, 1940.


26 RINGREn, W., Mineral deposits. 1933.


*34 SATÔ, H., Study of the asbestos deposits in Manchuria: Manshii Kogyôkaihatsu Kôsanshigen chôsajô Tokuho, No. 5, 1943.


*38 ________ & INOUE, T., A contribution to the knowledge of the origin of chrysotile vein: Jour.
神居古柴構造帯の超塩基性岩と湿石銅鉱床

斋藤 昌之

神居古柴構造帯にみられる超塩基性岩は、北は天塩国間寒別から南は日高国三石にいたるまでの間に、断続的に、いくつもの進入活動の中心とみられる岩体をもって、延々南北300 kmにわたってみとめられる。これらの岩体は、造山帯における大きな構造域に、造山運動の過程において侵入したものである。この構造域は、単なる衝断断層帯ではなく、断層運動と物質の注入が相まってはげしく行なわれ、幅広い断層帯である。これら各地の超塩基性岩は、神居古柴層谷を境として、その北と南で性格が若干異なっている。北では、原白岩脈はほとんど謝墨岩脈アブライトであるのに反して、南では、石英長石巖である。また、北では、クロム鉱鉱床は湿砂鉱床で塊（山）クロム鉱床は皆無に近く、わが国唯一の砂白金鉱床地帯となっている。これに反して南では、わが国の代表的な塊クロム鉱床地帯であって湿砂鉱床は存在せず、砂白金鉱床もきわめて少ない。

超塩基性岩は、各地において蛇紋岩化している。これら岩体の野外調査の結果、ならびに顕微鏡観察の結果、蛇紋岩化作用は、自家変質による第1期と、構造変化にともなう熱水溶液の注入による第2期と、二つの段階にわかれが明らかとなった。現在、野外でみられる蛇紋岩化は冷地により、その外観がいちじるしく相違するが、これは、進入後におかった地質環境の相違によるものと解釈される。

石銅は鉱物学上、湿石銅と角閃石質石銅とに大別されるが、わが国に産する後者は、ほとんど、使用に耐えるものがない。湿石銅には蛇紋岩を母岩とするものと、苦土質石灰岩を母岩とするものがあるが、わが国に産する湿石銅は、蛇紋岩を母岩とするものである。わが国の湿石銅の産地は、北海道のほか新潟、鳥取、熊本などの諸県があるが、実用的価値のあるものはほとんど全ては、北海道から産している。

北海道の湿石銅鉱床は、神居古柴構造帯の蛇紋岩体とともなって各地に産するが、石狩国山部、日高国右左府、三石の3地域圏が、その中心地となっている。湿石銅は、蛇紋岩の礫理とそれに関係のある亀裂を埋める微細脈として形成されはじめが、詳細に観察すると規則性がみとめられる。湿石銅の形成は、蛇紋岩化作用と密接な関係があり、造山帯における構造変化とも切り離せない。湿石銅が形成されるところは、特定の場所ではない。ほとんどの場合、蛇紋岩体の中どこでも形成されている。しかし、それが優勢に形成されて富銅体となり、鉱床として稼働できるものは、どこでもあるわけではない。それは、蛇紋岩体の周縁部のように、進入の際に、多数の亀裂を生ずる条件が満足される、特定の場所ということになる。

湿石銅の成因については、古くから多々の学説によって論ぜられ、いろいろな説が唱えられている。筆者は、調査研究の結果にもとづいて、次のような見解を下した。湿石銅の形成は、超塩基性岩の蛇紋岩化作用の第1期の段階に、蛇紋岩化を追って行なわれた。その後、斜方輝石や斜方輝石・単斜輝石の蛇紋石置換→湿石銅
脈の形成→非品質蛇紋石の形成（温石綿脈の形成発展）→硬蛇紋石の形成。の順序をとったものである。超塩基性岩の進入は、神居古瀬構造帯の造構造運動の過程において行なわれたため、進入岩体の周辺部に、周縁裂壊帯や節理が形成され、このような部分が、高温蒸気や熱水溶液の上昇に適した条件を具えているため、温石綿の形成が優勢に行なわれ富鉱体が形成された。