Mica

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1. General Remarks

There are four types of mica in Korea, muscovite, phlogopite, lepidolite and zinnwaldite. Among these four, lepidolite and zinnwaldite are not utilized as mica but as lithium ore, which is discussed in another paper.* Therefore, these two types of mica will not be discussed in this report.

Mica, "tolpinul" in Korean, is an important mineral resource in Korea. It has been used in medicines or as windows since olden times. However, Korean mica was brought to public attention after the discovery of large crystals of phlogopite at Yŏn'gol, Puktuil-myŏn, Tanch'ŏn-gun, South Hamgyŏng-do toward the end of 1906. This led to the discoveries of muscovite in Yanghwa-myŏn and Noji-myŏn, P'yŏngwŏn-gun, South P'yŏngan-do, and phlogopite in Changbaek-myŏn, Kilchu-gun, North Hamgyŏng-do. Mining of these two types of mica began for the first time in 1909, by the Japanese, prior to the exploitation of phlogopite in Tanch'ŏn-gun. This marked the beginning of the history of modern mica mining in Korea.

In 1910, the next year, the Nikkan Mica Co. Ltd. was established to exploit the phlogopite in Tanch'ŏn-gun. Active mining began, and about 2 tons of mica were immediately shipped to Europe in order to enhance its reputation. At that time, however, there was no demand for mica in Japan, and knowledge on the treatment of mica was lacking. Exploitation did not continue for long, and all mica mines in Korea were closed by 1911.

In 1914 the Tōyō Mica Co. Ltd., in Toyohashi city, Japan, began manufacturing mica paper from the phlogopite of Tanch'ŏn-gun, but the operation was stopped after only 3 months. Exploitation of mica in Korea was then interrupted for a long time, until 1919.

In the meantime (1916), KAWASAKI[4)] published his study of mica in Korea. This paper promoted the exploitation of mica in Korea, and the Hōshu mine in Puktuil-

* SHIBATA, Hidetaka, 1951, Lepidolite, *in* Geology and Mineral Resources of the Far East, Vol. I (Korea) Comp. Comm. Geology and Mineral Res. Far East, Tōkyō Geog. Soc.

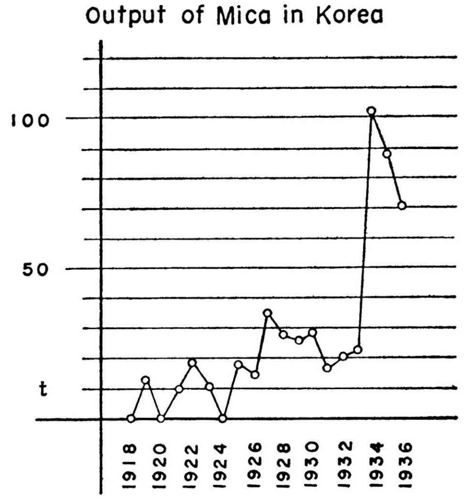

Fig. 1

myŏn, Tanch'ŏn-gun, South Hamgyŏng-do was opened by Shimakichi SEKI in 1919. However, no one followed him, and the Hōshu mine produced only 20 tons annually up to 1926.

Thereafter, the manufacture of micanite by companies such as the Nippon Rika Kōgyō sho (Japan Physicochemical Industry Co.) and the Nippon Mica Seisakusho (Japan Mica Manufacturing Co.) began in Japan. Demand for mica increased gradually as the manufacture of electric machinery advanced in Japan. The Imdong (Rindō) mine in Kilchu-gun, North Hamgyŏng-do, started operation in 1927 and the Tōyō mica mine (later the P'yŏngbuk mine) in Ch'ŏngyong-myŏn, Pakch'ŏn-gun, North P'yŏngan-do began in 1932. However, there were still less than four mining claims, and the maximum annual production was 35 metric tons (in 1927), the average being less than 30 metric tons.

However, in 1934, the demand for mica suddenly increased in Japan, and the total number of mines jumped to 9, and the output of mica rose to 103 metric tons. The number of mines increased to 14 in 1936, and to 20 in 1938. Thus the mica-mining industry gradually became prosperous.

The Korean Mica Exploitation and Sales Co. Ltd. was established jointly by 12 major electric machine manufacturers in Japan in September 1939. Upon promulgation of the Korean mica distribution control law in December 1939, the company was officially designated as a control agency, and specifications for different grades of mica were set.[16)] On the other hand, the Tōyō-Takushoku (Oriental Colonization) Co. Ltd. embarked on the exploitation of mica in Korea. Thus, for the first time, great sums were invested for the exploitation of mica in Korea, and public interest rose remarkably. As a result, new mica deposits were discovered in succession since 1943, and the output of mica recorded was 146 metric tons in 1943 and 422 metric tons in 1944.

2. Properties of Mica

There are two kinds of mica produced in Korea, i.e., muscovite and phlogopite. Muscovite is colorless and transparent, in the form of thin cleavage sheets, but it is commonly gray or light-gray, semi-transparent, in thick sheets. It is often tinged with rose, brown or green, and has a silky or pearly luster. The crystals rarely appear perfect, and the side planes are often uneven and bear horizontal striations. The crystals are usually bent and crushed. A No. 1 mica sheet, namely a sheet 20 cm × 7.5 cm or 12 cm × 12 cm in size, is rarely found in the Kŭmgang mica mine, P'yŏngwŏn-gun, South P'yŏngan-do, the most common sizes being 2 or 3 cm in diameter, namely 6B or 6C grade. Muscovite is generally superior to phlogopite in electrical insulation properties, and muscovite from the Kŭmgang mica mine rivals the muscovite from India, and is superior to the muscovite from Brazil in insulation strength. It is brittle, having little flexibility, and is not very resistant to heat. Safe use is limited to temperatures below 450°C.

Phlogopite from Korea varies in color, transparency and luster. It is sometimes colorless and transparent, but mostly semi-transparent or sub-transparent and silver-gray, silver-green, reddish-green, brownish-green, brown, reddish-brown or blackish-brown. There are various degrees of depth of color, and dark-colored mica appears black. However, even black and opaque mica becomes almost colorless and transparent or light colored if split into thin sheets. Generally, light-colored mica has a silky luster, while dark-colored mica is either pearly or glassy.

The crystals seldom appear as perfect as those of muscovite, and streaks or cracks, which correspond to the sliding plane, run in all directions on the cleavage plane. Crystals split easily and regularly along the streaks or cracks and form so-called pseudocrystals, which sometimes appear as ribbon mica or triangular mica. Cleavage sheets free from cracks which are sold are generally smaller than No. 5 grade (4 cm × 4 cm or 2 cm × 7 cm).

Phologopite is characterized chemically by magnesia, but generally contains some iron. The color is inclined to become darker with iron content, and iron-rich mica appears dark-brown or black. Optical properties are related to the chemical composition and, consequently, to the depth of color. For example, in mica in the vicinity of the boundary between North and South Hamgyŏng-do, as the color becomes deeper the optic axial angle becomes larger, and light-colored mica shows an interference figure which appears uniaxial.[4] On the other hand, the optic axial angle of the mica from Pakch'ŏn-gun, North P'yŏngan-do, becomes smaller and the refractive index higher as the color becomes darker.[9]

Phlogopite is generally inferior to muscovite in electrical insulation properties, tensile strength, exfoliation ability and acid resistance, but is far superior to muscovite in heat resistance. A sudden decline in electrical resistance due to heating occurs at about 1,000°C, and phlogopite can generally be used up to 900°C with safety. Blackish-brown mica is especially heat resistant, and flexibility is generally excellent. Phlogopites from Korea are sorted into two, hard and soft.

Soft phlogopite is used for commutators, and varies from 2.5 to 2.7 in Mohs' hardness, and is less than 16 in Shoa hardness. Hard phlogopite, on the other hand, is more than 17 in Shoa hardness, is tinged with black and is used for punched micas.*

In summary, phlogopite from Korea varies in color, luster, hardness and other properties, among which color is related not only to the chemical properties but to various physical properties. In general, light-colored phlogopite, such as silver-gray or silver-green, is rather low in insulating quality, is flexible, soft and elastic. Creases will form if it is bent, but these creases do not decrease its insulating properties. Dark mica, such as brown or reddish-brown mica, has excellent insulating properties and high heat resistance. Black or blackish-brown mica has the highest heat resistance with a high hardness.

3. Mica localities

Korea is one of the most important mica-producing countries in the world, with mica occurring in many districts. However, mica mines in the past were almost wholly confined to phlogopite mines. It is noteworthy that most of muscovite mines have been in operation only since 1940.

a. Muscovite

Muscovite is found all over the peninsula. Most of the mica is spoiled by many cracks and rents, so production is carried on at the following 8 regions only.

1. Pung-myŏn, Hŭich'ŏn-gun, North P'yŏngan-do (Ch'ŏnsang mica mine).
2. Yanghwa-myŏn, Noji-myŏn, Tongsong-myŏn, Chohŭng-myŏn, Tŏksan-myŏn, and Sunan-myŏn in P'yŏngwŏn-gun, and Sukch'ŏn-myŏn, Sukch'ŏn-gun in South P'yŏngan-do (Kŭmgang mica mine, Sunan mica mine, Huun mica mine, etc.).
3. Munhwa-myŏn, Yongmun-myŏn, and Kasan-myŏn in Sinc'hŏng-gun, Hwanghae-do (Munhwa mine, Paegsŏk mica mine, Sinch'ŏn mine, etc.).
4. Kosan-myŏn, Pyŏksŏng-gun, Hwanghae-do (Sŏktam mica mine).
5. Taegong-myŏn, Anak-gun, Hwanghae-do (Anak mica mine).
6. Wŏndŏng-myŏn, Samch'ŏk-kun, Kangwŏn-do (Samch'ŏk mine).
7. Pukhu-myŏn, Andong-gun, North Kyŏngsang-do (Tuwŏl mica mine).
8. Tonghyan-myŏn, Chinan-gun, and Kyebung-myŏn, Changsu-gun, North Chŏlla-do (Taeyu mica mine).

Among the above mines, the Kŭmgang mica mine, in Yanghwa-myŏn and Noji-myŏn, P'yŏngwŏn-gun, South P'yŏngan-do, is the oldest and most unique mine and was exploited in olden times. The others have been exploited only recently. The mines listed in (1), (4) and (6) were discovered in 1943 or 1944, and operation began immediately.

* E.N.: Mica is punched into small pieces and used for insulation.

b. Phlogopite

Phlogopite makes up most of the mica output in Korea, and there are many old mines which have a long history of exploitation, and also many mines now being worked. Phlogopite is concentrated in the following regions.

1. Changbaeng-myŏn, Yangsa-myŏn, and Tŏksan-myŏn in Kilchu-gun; Haktong-myŏn, Sŏngjin-gun, North Hamgyŏng-do, and Puktuil-myŏn, Tanch'ŏn-gun, South Hamgyŏng-do (Hōshu, Imdong, Taeam, Changbaek, Sangwŏl, Tansŏng, Osamp'o, etc., mines).
2. Hago-myŏn and Sanggo-myŏn, Myŏngch'ŏn-gun, North Hamgyŏng-do (Myŏngch'ŏn or Taiyō mica mine).
3. Ansu-myŏn, P'ungsan-gun, South Hamgyŏng-do (P'ungsan mica mine).
4. Huch'ang-myŏn and Sokhu-myŏn, Pukch'ŏng-gun, South Hamgyŏng-do (Pukch'ŏng mica mine).
5. Kogwan-myŏn, Ŭiju-gun, North P'yŏngan-do (Ŭiju mica mine).
6. Pura-myŏn, Yongch'ŏn-gun, North P'yŏngan-do (Kach'ado mica mine).
7. Ch'ŏngnyong-myŏn, Pakch'ŏn-gun, and Wŏn-myŏn, Changnim- myŏn, T'aech'ŏn-gun, North P'yŏngan-do (Nojŏn-dong or P'yŏng-buk, Unhŭng-dong, Changnyong, Sŏnyong, Ansimu, etc, mines).
8. P'unggi-myŏn, Yŏngju-gun, North Kyŏngsang-do (Tsuruhara-P'unggi mine).

Of the above locations, (1) the neighborhood of the boundary between North and South Hamgyŏng-do and (7) Pakch'ŏn-gun, North P'yŏngan-do are the main sources of mica in Korea. The former especially has a long history of exploitation and produces most of the mica in Korea. Two types of phlogopite are produced in Korea, hard and soft, which have different uses. Mica in the neighborhood of the boundary between North and South Hamgyŏng-do is soft, while that from Pakch'ŏn-gun, North P'yŏngan-do, is hard. The mica from (8) Yŏngju-gun, North Kyŏngsang-do, is also hard and resembles biotite. Localities (5) and (8) were discovered in 1944 and exploitation began immediately.

4. Ore Deposits

All micas of Korea are intimately related to granite-pegmatite, and occur in pegmatite veins or in a type of contact deposit related to pegmatite.

a. Muscovite Deposits

All muscovite in Korea occurs in pockets in pegmatite veins, and the surrounding rocks are almost wholly limited to granite gneiss or granite. Muscovite sometimes occurs in pegmatite, traversing mica schist, but in this case biotite is usually found. The muscovite crystals of this type are generally small and are rarely used for making sheets.

Pegmatite veins occasionally consist of quartz, feldspar and muscovite, but usually consist only of quartz and muscovite. Beryl is often found in Korea, and it occurs mostly in pegmatite associated with muscovite. However, large muscovite crystals are rarely found in association with beryl, and muscovite of this type is commonly spoiled by creases or rents.

The ore deposit of the Kŭmgang mine, the oldest mine, in Yanghwa-myŏn and Noji-myŏn, P'yŏngwŏn-gun, South P'yŏngan-do, is a pegmatite vein traversing gray granite gneiss, and consists only of quartz and muscovite. There is a tendency for the quantity of mica in the center of the vein to be small, but large on either side. The crystals are generally large and sometimes No. 1, according to the specifications, which is 20 cm $\times$ 7.5 cm or 12 cm $\times$ 12 cm. The mica appears greenish-gray to white, and the optical properties are 2 E $\doteqdot 66^\circ$ and $\gamma \doteqdot 1.596$. Its electrical insulation properties rival that of Indian ruby and are superior to muscovite from Brazil.

b. Phlogopite Deposits

Phlogopite in Korea occurs in pegmatites or thermal metamorphic rocks at the contact region between limestone or dolomite and pegmatite. The shapes of the ore deposits are commonly irregular, and phlogopite occurs in the form of streaks, nests, pockets, veins or impregnations in ore deposits.

Typical phlogopite ore deposits are found in the Mach'ŏllyong system or the gray granite gneiss. The former is extensively developed in the neighborhood of the boundary between North and South Hamgyŏng-do, and forms the most important mica-producing area in Korea, where prominent mica mines, such as Hōshu, Imdong and others, are located. Phlogopite from this region accounts for most of the mica produced in Korea. Various kinds of mica are produced, but are generally used in commutators. The latter is found in Packch'ŏn-gun, North P'yŏngan-do, and always appears dark, such as black or blackish-brown, and is hard and highly resistant to heat.

Both are intimately related to limestone or dolomite, and even though phlogopite is found in pegmatite veins, it occurs only in veins which penetrate limestone or dolomite, and even though it occurs in gray granite gneiss, it is found only in that portion of dolomite captured by gneiss. The deposits of phlogopite in Korea include diopside, amphibole, calcite, etc., and are especially related to diopside. Accordingly, Mg in the phlogopite might not have been included in magma from the beginning, but some components might have derived from calcareous rocks as the result of a pneumatolytic process.

The thermal metamorphic rocks consist of crystalline limestone, dolomite, wollastonite rock, diopside rock, diopside-orthoclasite, etc. Phlogopites have different colors, hardness, optical properties and chemical composition, and are associated with different colored diopside, according to the mode of occurrence. Generally speaking, phlogopite found in pegmatite or strongly-altered rocks, such as wollastonite rock, diopside rock or diopside-orthoclasite appears dark colored, dark black, dark-brown or brown, is rich in Fe and is hard. On the contrary, phlogopite found in weakly-altered rocks, such as crystalline limestone, appears light-colored, white or green, and tends to have little iron content.

In comparison with ore deposits near the border of North and South Hamgyŏng-do, phlogopite deposits in Pakch'ŏn-gun, North P'yŏngan-do, are metamorphosed to a large extent. Comparing the two kinds of phlogopite, that from Pakch'ŏn-gun is darker, has a higher refractive index, is harder and is more highly resistant to heat than that of North and South Hamgyŏng-do.

1. Ore Deposits near the Boundary of North and South Hamgyŏng-do

The neighborhood of the boundary between North and South Hamgyŏng-do consists of metamorphic rocks of the Mach'ŏllyŏng system, involving thick layers of dolomite; and phlogopite occurs in pegmatite traversing dolomite, or in skarns along the margin of granite or pegmatite veins. This region forms the most important metallogenic area with regard to mica.

Phlogopite in this province appears colorless, or variously colored, such as silver-gray, light grayish-green, silver-green, dark-green, reddish-brown, brown, black, etc. It is soft and is highly regarded for use in commutators. In chemical composition, the magnesia content is commonly greater than 20 percent and never below 4.5 percent, and the iron content is commonly less than 3 percent, and sometimes mounts to 5.3 percent. In general, as the iron content increases, the color tends to deepen. Li_2O is often contained; phlogopite from Kilchu-gun is rich in Li_2O, containing 0.22 percent.[1)] Fluorine is always present and sometimes amounts to 1 percent.[1)]

Phlogopite found in pegmatite or strongly-altered rocks, such as wollastonite rock, diopside rock or diopside-orthoclasite, is generally dark-colored, such as dark-brown or brown, is rich in iron and has a comparatively large optic axial angle. On the contrary, phlogopite found in such weakly-altered rocks as crystalline limestone, appears light colored, white or green, contains little iron, has a small optic axial angle and shows an uniaxial interference figure.[4)]

Ore deposits of the Hōshu (P'osyu) mine

Ore deposits are scattered around Mt. P'osyu, which stands on the boundary between Taesil-li, Puktuil-myŏn, Tanch'ŏn-gun and Imdong, Changbaeng-myŏn, Kilchu-gun, and occur near the contact zone between pegmatite and dolomitic rocks or limestone. The metamorphic rocks gradually grade in the order, limestone to coarse-grained limestone, phlogopite-calcite rock, phlogopite-diopside-calcite rock, phlogopite-diopside rock, diopside-orthoclasite and pegmatite. This clearly suggests that granitic residual magma, rich in mineralizer, intruded dolomitic limestone and formed phlogopite and diopside by the replacement of mineralizer. The optical properties of the mica are as follows: $Np=1.546$, $Ng=1.584$, $2E=0°$.

Ore deposit of Yon-gol, Puktuil-myŏn, Tanch'ŏn-gun

This mica deposit marked the beginning of the exploitation of mica in Korea, and its discovery goes back to 1906. Yon-gol is located on the western side of the Mach'ŏllyŏng mountain range, and is 44 km north of Sŏngjin-ŭp and 48 km north of Tanch'ŏn-ŭp. This district is composed of phlogopite-bearing crystalline limestone, phlogopite- and diopside-bearing crystalline limestone, phlogopite-diopside rock, phlogopite-diopside-gneiss, diopside-hornblende-gneiss and mica schist, and the rock series strikes N 20°–30°E, dipping northwest from 30° to 50°. This complex is traversed by numerous younger dikes of pegmatite and porphyrite. The ore deposit is found in limestone, containing abundant diopside. It occurs close to or along pegmatite veins, traverses limestone, and makes up a zone about 200 m in breadth. There are various shapes and they appear as veins, pockets, masses or nests. The mica is colorless, white, light-green or light-brown. The chemical compositions are given in the table.

Ore deposits of Changmunnae, Imdong, Changbaeng-myŏn, Kilchu-gun

In the vicinity of Changmunnae, Imdong, there are many mica deposits in pegmatite veins traversing dolomite or in diopside skarns which were formed in the contact zone between pegmatite and dolomite. The ore deposits within pegmatite veins occur as veins and consist of diopside and phlogopite. The ore deposits in a diopside skarn, on the other hand, form either massive deposits, composed of large masses, or veins of phlogopite. In general, phlogopite is associated with diopside, forsterite and calcite, and appears dark-brown, light-brown or white.

2. Ore Deposits of Pakch'ŏn-gun, North P'yŏngan-do

Many mica deposits occur in C'hŏngnyong-myŏn, Pakch'ŏn-gun, North P'yŏngan-do, forming either veins, which conspicuously vary in breadth, or pockets in gray granite gneiss. No calcareous rock is found in the vicinity, but phlogopite occurs with diopside in phlogopite-diopside rock, as seen in North and South Hamgyŏng-do; it is thought that the calcareous rocks which formerly existed there were captured by granite gneiss and were perfectly altered.

Table 1. Chemical Compositions of Phlogopites from North and South Hamgyŏng-do.

Localities	Color	MgO	FeO	Li_2O
Yon-gol, Tanch'ŏn-gun	Colorless	7.05	1.43	None
,, ,,	Colorless	6.43	1.73	Present
,, ,,	Colorless	8.71	0.48	None
,, ,,	Light grayish-green	19.36	2.74	Present
Osamp'o, Tanch'ŏn-gun	Colorless	17.44	1.64	Present
Sogyŏlsu, Tanchŏn-gun	Dark-green	7.45	2.15	None
Sangangaji, Sŏngjin-gun	Colorless	23.77	1.14	Present
So-dong, Kilchu-gun	Dark-green	14.80	5.30	Present
Tŭngch'angŏgu, Kilchu-gun	Dark-green	20.45	1.32	Present
Imdong-ni, Kilchu-gun	Dark-green	11.68	1.19	Present
Taesungbang-dong, Kilchu-gun	Black	4.52	2.69	None

(Analyzed by the Commerce and Industry Bureau, 1910)

Table 2

	Hōshu mine Tanch'ŏn-gun	Hōshu mine Kilchu-gun	Yŏn-gol	Sogyŏlsu	Sodŭngnyŏng-dong, Imdong
SiO_2	40.31	39.27	—	—	—
Al_2O_3	15.51	17.52	—	—	—
Fe_2O_3	1.08	0.68	0.16	1.68	0.39
FeO	1.48	1.52	0.76	2.07	2.05
MgO	25.58	26.37	27.48	26.48	25.43
CaO	0.06	—	—	—	—
Na_2O	1.54	0.69	1.03	0.89	1.09
K_2O	9.52	8.40	8.72	9.40	8.98
H_2O (+)	3.35	—	—	—	—
H_2O (−)	0.69	—	—	—	—
F	1.27	0.63	0.64	1.00	0.74
TiO_2	0.50	—	—	—	—
P_2O_5	0.02	—	—	—	—
MnO	0.03	—	—	—	—
Li_2O	—	—	None	None	None
Ignition loss	—	4.23	—	—	—
Total	100.95	99.31	—	—	—
Color	—	—	Light-green	Dark-green	Black
Analyzer	TSURUMI[19]	T. MIZUMA[21]	Central Experimental Station, Government-general, 1915[4]		

Table 3

	Color	Optic axial angle	Refractive indices	Color of diopside	Color of spinel
Nojŏn-dong, Ch'ŏngnyong-myŏn	Brown	2E≒ 15°	γ≒1.575–1.578	White	
Wiyŏng-dong, ,,	Light-brown	2E≒ 7°	γ≒1.580–1.582	Light-brown	Bluish-green
Nojŏn-dong mine, ,,	Black	2V≒ 0°	$1.587 > \gamma > 1.583$	White or Light-green	
Unhŭng-dong, ,,	Black	2V≒ 0°	$1.587 > \gamma > 1.583$	Green	Black
Ŭllyong-dong, ,,	Dark brown or black	2V≒ 0°	γ≒1.581	Light-green	

The mica is dark colored, such as black or brown, is hard and very heat resistant; it is used in the manufacture of spark plugs. Generally speaking, dark-colored mica has small optic axial angles and high refractive indices. There is a tendency for dark-colored mica to be associated with green diopside, while light-colored mica is associated with white diopside.

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