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ON THE SILICA MINERALS OF THE ABUTA MINE IN HOKKAIDO, JAPAN

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Introduction

Quartz is one of most common minerals in the hydrothermal ore deposits. The present writer has given some descriptions of it (URASIMA: 1956). Cristobalite is a rare mineral in such deposits, and the occurrences of cristobalite are reported only from the Horobetu mine and the Abuta mine in Hokkaido (HAYASE: 1957, URASIMA: 1958).

Many bedded sulphur or iron sulphides ore deposits in the lava flow or pyroclastic rocks and the Quaternary limonite beds are distributed in the volcanic area of northern Japan. The Abuta mine yielded about 100,000 tons iron sulphides ore in 1957. Its iron sulphides ore deposits and the sulphur ore deposits are of similar type to those of the Horobetu sulphur deposits, and they are representatives of such ore deposits that are sometimes called the Abuta-type. The limonite ore deposits which have yielded about 900,000 tons ore (Fe 50%) since 1905 lie above and on the iron sulphides ore deposits of the mine. There are mainly two hypotheses about the geneses of these ore deposits: the sedimentation and replacement. So, it is considered that a study on the mutual genetic relations of these ore deposits of the Abuta mine might be very useful for the explanation and exploitation of the same-type ore deposits of other mines.

The shapes and structures of the ore bodies have been studied by the geologist of the Nittetu Mining Company, and some short papers of the deposits are published by HOTTA (1955), IKEGAMI (1956), and OTA (1956). But few descriptions have been given about the minerals of the ore deposits. The data on the silica minerals that are most widely distributed in three sorts of ore deposits are reported in this paper.

The mineral that has been called "opal" is mostly cristobalite; its distribution is in distinct contrast with that of quartz. Furthermore, cristobalite is everywhere distinguished from the other sulphur or iron sulphides and limonite ore deposits near the Abuta mine as a result of the writer's studies. It is believed that these facts may be useful for the genetic consideration of such ore deposits.

Geology and ore deposits of the Abuta mine

The Neogene Tertiary Series is widely distributed in the neighborhood of the Abuta mine. The series consists of the pyroclastics and the andesite lavas. They are covered by Pleistocene pumice beds and recent volcanic ash. The sulphur ore bodies are formed in the rhyolitic pyroclastics and the foot and hanging wall-rocks of the iron sulphides ore bodies are mostly andesitic and dacitic pyroclastics. Most of the moss limonite ore bodies occur in the Pleistocene formations.

The country rocks of the sulphur and iron sulphides ore deposits of the other mines—the Horobetu, the Tokusyunbetu, the Siraoi etc. (Fig. 1) are mostly andesitic lava or pyroclastics. The geological epochs of these rocks may perhaps be the upper Neogene Tertiary and the ore deposits have similar geological environments. Accordingly, it is considered that the metallogenetic epoch of such mineralization is generally the uppermost Neogene Tertiary or the lower Pleistocene, while the gold and silver or base metal ore deposits in northern Japan might have been mostly formed in the upper Miocene or the lower Pliocene.

The mineralized zone of the Abuta mine exhibits N-S trend. The sulphur ore body found in 1953, the first iron sulphides ore body found

TABLE 1. Dimensions of the ore deposits of the Abuta mine.

Oro deposits	Length (N-S) m	Width (E-W) m	Thickness m
Sulphur ore body	900	450	20
First iron sulphides ore body	700	150	20
Second iron sulphides ore body	600	150	20

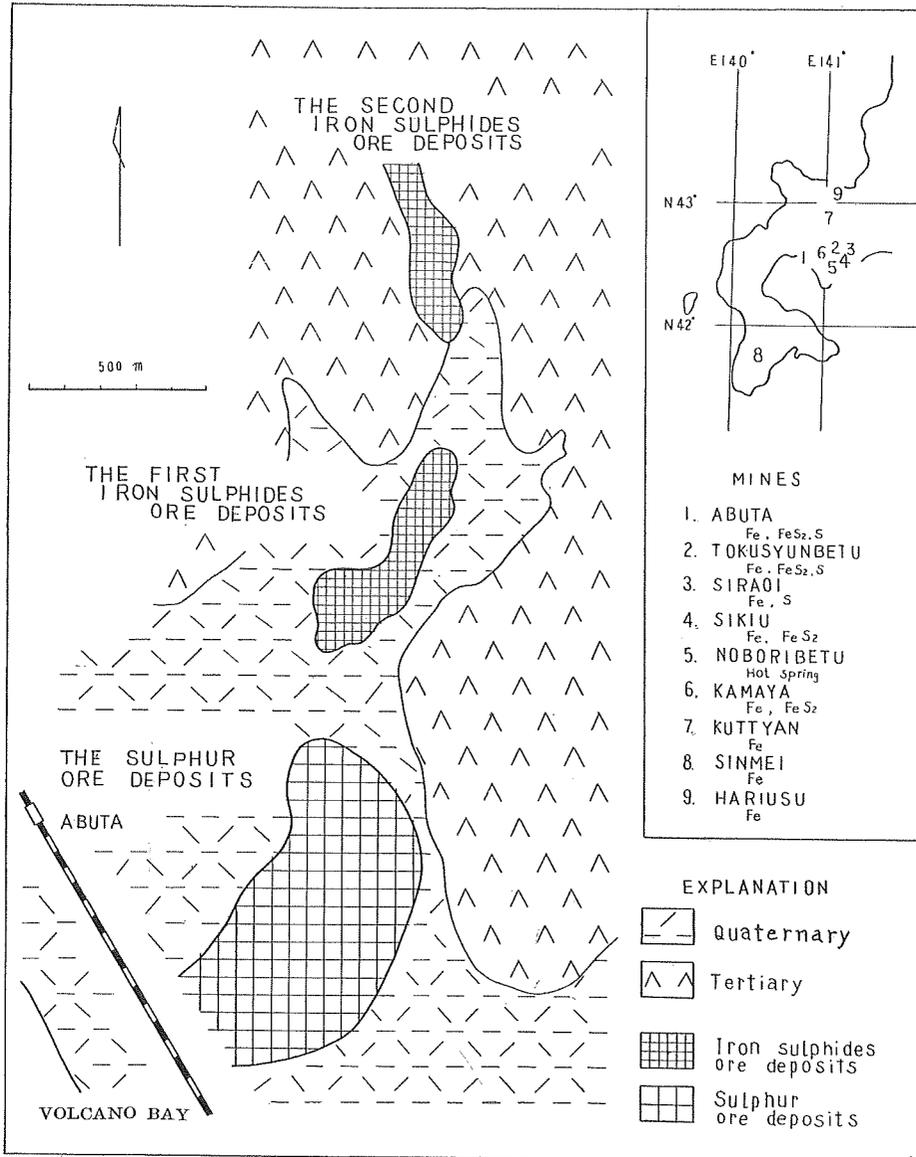


Fig. 1. Geological sketch of the Abuta mine and index map showing location of southwestern Hokkaido.

in 1951 and the second iron sulphides ore body found in 1955 are arranged from south to north in this zone. Figure 1 shows the distribution of these ore deposits. They are huge, bedded lenses with dimensions as in

Table 1.

The limonite ore deposits lie widely upon and along the east side of the first iron sulphides ore body. They are subdivided into the moss type and dissemination type (Fig. 2).

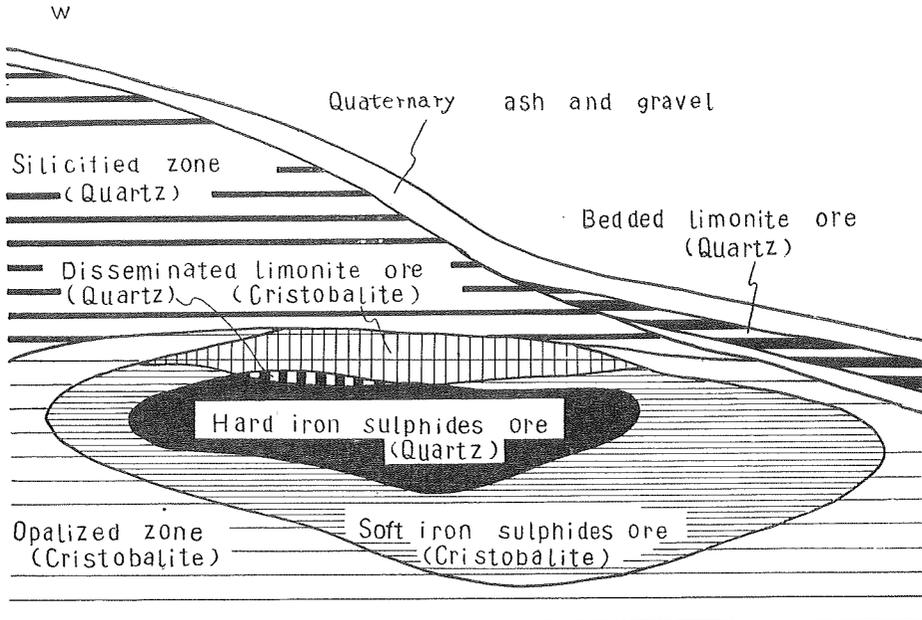


Fig. 2. Schematic explanation showing the occurrences of silica minerals in the cross section of the northern part of the first iron sulphides ore body of the Abuta mine in Hokkaido, Japan.

The sulphur and iron sulphides ore deposits are surrounded by a strongly altered zone of which the thickness is over 50 m. Alteration minerals are opal, cristobalite, quartz, kaolin, montmollironite, chlorite, epidote, alunite, native sulphur, pyrite, marcasite, and goethite. Although the alteration zone of the first iron sulphides ore body has very complex structures, there is a tendency for the outer part to consist of quartz and clay zone whilst opal and alunite are rich in the inner part. The boundaries between the wall-rocks and the ore bodies are not distinct for the most part (Fig. 2).

The sulphur ore consists of massive or disseminated yellow native sulphur. The iron sulphides ore bodies consist of two sorts of ores: so-called soft iron sulphides ore in the outer part and so-called hard one in the inner part (Fig. 2). The constituent minerals of the high-

grade iron sulphides ore are usually pyrite, marcasite, and a little quartz, while the low-grade ores sometimes contain alteration minerals and quartz derived from original rocks or chalcedonic quartz. There are rare occurrences of orpiment, realgar, gypsum, Sb mineral, and Cu mineral. The limonite ores generally consist of goethite and a little hydrohematite, but a large quantity of the alteration minerals are often included where they lie on the iron sulphides ore body.

Chalcedony and quartz of the Abuta mine

Silica minerals from the Abuta mine are chalcedony, quartz, opal, and cristobalite. Chalcedony from the Abuta mine has mostly suffered a change to fine grained fibrous quartz aggregates, and so the name "chalcedony" is used in this paper in the sense of quartz showing chalcedonic texture under the microscope.

Occurrence and microscopic properties.—Quartz from the Abuta mine is subdivided into five types: relic quartz, silicification quartz, siliceous breccia, interstitial quartz of ores, and quartz veinlets.

The silicified zone overlies the first iron sulphides ore body but such zone on the second iron sulphides and sulphur ore bodies have not been distinctly recognized because the latter has not been fully exploited. The rocks in the silicified zone become quartz aggregates. Sample KLa6 from this zone is a pale brownish white, hard rock; it shows original fragmental texture under microscopy. Clear and angular quartz grains are about 0.1 mm in diameter and sometimes have narrow rims. The grains are relict quartz derived from the original rock, and the rims are a secondary enlargement by diagenesis or silicification. Most of the matrix and the lithic fragments consist of fine grained, silicification quartz aggregates showing the chalcedonic radial extinction; there are also scattered alunite, epidote, and limonitic dirty materials.

The muddy rock which lies between the above-mentioned tuffaceous rocks and shows pale yellow and platy appearance consists of scaly alunite, interstitial chalcedonic quartz, and dusty materials. The quartz in sample KLb4 is too fine grained to identify under the microscope, but it is confirmed to be quartz by X-ray method. It is certain that the original rocks are mostly tuffaceous sediments.

Sometimes opal veinlets are found in the altered rocks, for example, those in the northeast side of the first iron sulphides ore body and those in the south side of the second iron sulphides ore body; details concerning will be described in the next chapter. A few chalcedony grains contained

in them which grains have lower index and weaker double refraction than usual quartz and show silky extinction.

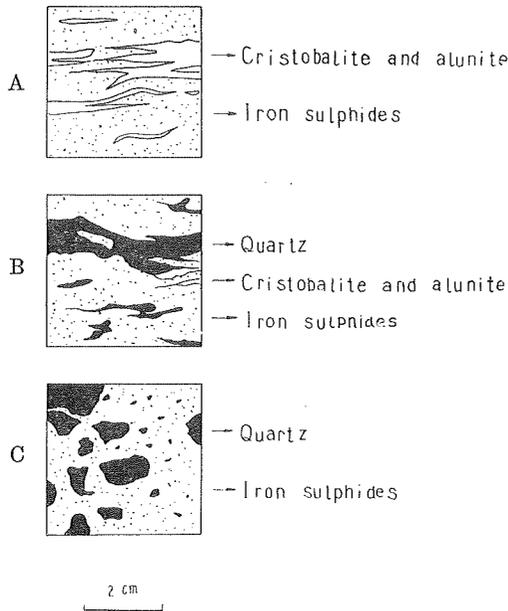


Fig. 3. Textures of the iron sulphides ores including quartz or cristobalite of the Abuta mine in Hokkaido, Japan.

A. So-called soft iron sulphides ore from the first iron sulphides ore body (sample LJb1).

B. So-called hard iron sulphides ore from the first iron sulphides ore body (sample KIN13).

C. So-called breccia iron sulphides ore from the second iron sulphides ore body (sample KLb2).

One of the iron sulphides ores with high silica contents is the so-called breccia ore (Fig. 3C), and another is the low grade ore in which there occurs an abundance of interstitial quartz grains. The breccia ore is abundant in the western part of the second iron sulphides ore body. The dimensions of the breccias are mostly from 0.5 cm to 2 cm in diameter and their appearances are angular, compact, and black. They are cemented and veined by massive iron sulphides. It is observed that the breccias consist of fine grained quartz and pyrite aggregates after lithic fragments under the microscope (Fig. 6). Fragments of clear quartz grains are also recognized here and there. Some of them are relict quartz derived from original rock and others are prismatic crystals of the vein quartz (0.1 mm in length). The matrix consists of fine grained aggregation of pyrite and marcasite. So, it is considered that the breccia ore is a particular iron sulphides ore with silicified fragments derived from country rocks.

Generally, the hard iron sulphides ores have the banding texture shown by grain size or sulphides rich and quartz rich zones (Fig. 3A, B).

Most of the quartz in the ore is contained in the interstitial aggregates with sulphide minerals, for example, sample KIN13 and 14, and rarely does it cut through the ores in veinlets. For instance, interstitial lenses of quartz are contained in sample KIN32 from the upper part of the first iron sulphides ore body under the microscope (Fig. 7).

The size of each lens is not definite, but the directions of the lenses have some similarity. Each lens has a mosaic texture in which the mosaic is formed of tiny fibers having mostly the same extinction position. Sometimes an intergranular paragenesis of pyrite and quartz is recognized in the outer parts of the lenses. The ores are sometimes cut by quartz veinlets, although they are sometimes too narrow to find out. Under the microscope, the quartz is coarse grained, but each grain consists of chalcedonic fibers (0.01 mm in length) with a similar orientation which shows almost no case of right angles against the walls of veinlet. It should be emphasized that both these lenses and veinlets consist of quartz having similar microscopic properties which are different from properties of silicification quartz.

Quartz in the limonite ore deposits also shows several varieties. One of the interstitial and veinlet-shaped quartzes is derived from the iron sulphides ores, and the properties are the same as those of the original quartz except for exchanging from iron sulphides to goethite. The limonite ores with such quartz occur on the first iron sulphides ore body and the two ores have distinct boundaries which are usually shown as narrow, pale colored zones seeming be front zones of limonitization against the iron sulphides ores.

Another type of interstitial quartz is found with moss limonite near a small spring between the first iron sulphides ore body and sulphur ore body. The moss limonite is very brittle and retains slightly the forms of the original plants. By the microscopic observation of sample KIN14, the cavities (about 0.1 mm in diameter within the network consisting of hydrogoethite) are often seen to be filled with chalcedony which has lower index and weaker double refraction than those of usual quartz and shows anomalous silky extinction (Fig. 8). There is no intergranular texture between goethite and chalcedony such as pyrite and quartz show in the iron sulphides ores.

A few relic quartz grains derived from the original rocks are found in the limonitized iron sulphides ores with the interstitial quartz. Sometimes there are abundant quartz grains in the southern part of the limonite ore body. By microscopic observation of sample KIN23, this ore has been found to have fragmental texture. These fragments are

clear quartz and somewhat limonitized plagioclase and felthic groundmass of volcanic rocks cemented by goethite. Such ores may be formed by limonitization against the rhyolitic tuffaceous sand in Pleistocene.

As mentioned above, quartz except the relict type is mostly contained in the upper alteration zone at some distance from the ore bodies and in the hard part of the iron sulphides ores. Such quartzes show usually chalcedonic texture, and the crystallinity under the microscope becomes generally lower from silicification quartz to interstitial one.

X-ray diffraction.—Silicification or interstitial quartz grains are sometimes too fine-grained for identification by microscopy were observation. Therefore, the descriptions in the previous chapter corroborated by X-ray powder method. Table 2 shows the representative examples. Both quartz and chalcedony show the patterns of quartz in X-ray powder diffraction; the peaks in Norelco diagrams of the chalcedony in the recent limonite are more diffuser than in those of other samples.

TABLE 2. X-ray powder patterns of quartz bearing samples from the Abuta mine

KL a6	KL b2	KL b4	KIN11	KIN14
d(Å) I/I ₁	d(Å) I/I ₁	d(Å) ₂ I/I ₁	d(Å) I/I ₁	d(Å) I/I ₁
4.26 22 Q	4.27 19 Q	7.25 2 K	4.25 20 Q	4.25 40 Q
3.35 100 Q	3.35 100 Q	5.67 3 A	3.34 100 Q	4.20 20 G
2.46 9 Q	3.13 9 P	5.06 12 A	3.12 40 P	3.53 20 ?
2.28 9 Q	2.71 25 MP	4.24 24 Q	2.98 40 M	3.35 100 Q
	2.46 9 Q	3.51 9 A	2.71 100 MP	2.71 20 G
	2.43 15 MP	3.35 100 Q	2.43 60 MP	2.46 30 QG
	2.28 12 Q	2.98 27 A	2.28 10B Q	1.82 20 Q
	2.21 12 P	2.87 5 A	2.21 50 P	1.72 10 G
	2.13 5 Q	2.46 8 Q	1.92 40 MP	
	1.92 12 MP	2.28 19 QA	1.82 10 Q	
	1.82 17 Q	2.24 3 Q	1.63 50 P	
	1.67 5 Q	2.12 6 Q	1.56 20 P	
	1.63 21 P	1.98 3 Q	1.50 20 MP	
		1.90 7 A	1.45 30 P	
		1.82 14 Q		
		1.74 7 A		
		1.68 3 Q		

Cu K_{α1}, 35KV., 13mA. (LK a6, KL b2 and KL b4); Fe K_{α1}, 40KV., 7mA. (KIN11 and KIN14), scale factor: 4, multiplier; 1, time constant: 4, scanning speed 2°/min. (Norelco). LK a6: silicified rock, KL b2: silicious breccia in the iron sulphides ore, KL b4: silicified and alunitized rock, KIN11: low grade iron sulphides ore, KIN14: bog iron ore. Q: quartz, P: pyrite, M: marcasite?, K: kaolin, A: alunite, G: goethite.

Opal and cristobalite of the Abuta mine

Opal or cristobalite are more abundant in the altered wall-rocks than chalcedony or quartz at the Abuta mine. It is difficult to recognize a distinction between opal and cristobalite by their appearance or microscopic properties, but X-ray powder method is useful to distinguish between them.

Occurrence and microscopic properties.—There are three types of occurrences: opalization minerals, interstitial cristobalite, and opal veinlets. All the ore bodies of the Abuta mine are surrounded by strongly opalized rocks, and opal-like minerals generally increase in the area near the ore bodies. As described in the chapter on chalcedony and quartz, the samples from the outer altered zone on the first iron sulphides ore body contain few opal-like minerals. Opalized rocks are usually Tertiary tuff or tuff breccia, but it is recognized that the Pleistocene volcanic breccia also has suffered weak opalization. The pale gray andesitic balls (sample KIN24) in the limonite brown tuff gravel bed which lies unconformably on the opalized zone show the following microscopic properties: the material is augite-hypersthene andesite which has a porphyritic texture and hyalopilitic groundmass; plagioclase crystals are replaced by opal-like mineral along the cracks and zonal banding, and pyroxene crystals are also altered to fibrous clay minerals along the cracks. It is somewhat doubtful whether such a weak alteration is connected with the strong opalization of wall-rocks of the ore bodies. Under the microscope or by X-ray diffraction, some cristobalite is recognized in the altered Tertiary tuffaceous beds which are at some distance from the ore bodies. For example, the gray and clayey part in the altered zone above the first iron sulphides ore body (KLa5) and the sulphur ore body (LEd6) are mostly formed of montmorillonite with cristobalite and pyrite, and relic quartz. LEd6 contains kaolin, too.

Opal-like mineral is sometimes recognized in the limonite ores with high silica content which seem to have suffered limonite dissemination. The light yellowish brown, soft, and platy-fractured specimen (sample KLa4) from the limonitized wall-rocks on the first iron sulphides ore body is an aggregation of fine-grained opal-like mineral and goethite.

A pale brownish white sample (KLa1) in a so-called argillized zone at some distance from the first iron sulphides ore body consists of kaolin mineral and cristobalite as main constituents with scattered alunite.

Nearer the ore bodies, the wall-rocks become white and brittle or

soft; the dark gray bandings increase near the first and second iron sulphides ore bodies and yellow native sulphur is spotted near the sulphur ore body. Figure 3 shows an example of such parts; the bandings seem to be beddings of the original tuffaceous sediments (Fig. 4A). Sample KIN25 from the white band is soft and powder-like in dry state; the main constituents are cristobalite and alunite; the dark gray part consists of these minerals and iron sulphides. By microscope cristobalite is seen to be formed in aggregations of which the diameter is about 0.01 mm; it shows low index (LARSEN and BERMAN: 1934), isotropism or very

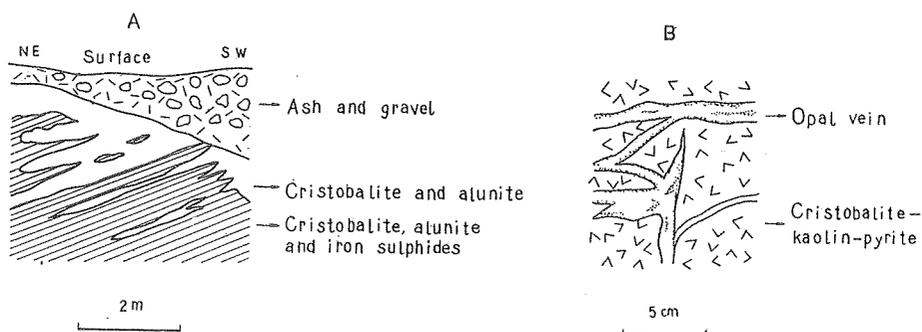


Fig. 4. Occurrences of the cristobalite and opal in the wall-rocks of the Abuta mine in Hokkaido, Japan.

- A. Northeastern end of the first iron sulphides ore body (sample KIN25).
 B. South side of the second iron sulphides ore body (sample KLb1).

weak double refraction and optical anomaly. Alunite is scaly (0.1-0.2 \times 0.05 mm). There is rarely an example of breccia (sample KIN27) in the soft rocks. Relic quartz grains derived from the original rock are often surrounded by an opal-like rim, and the matrix is formed of oolitic opal-like mineral and scattered iron sulphides.

There is often a pale colored band between the first iron sulphides ore body and the overlying limonitized part. Cristobalite shows more abundance in the pale brownish white part than in the relic gray part of sample LEc1 which shows concentric texture.

There is a network of white and soft veinlets in the strongly altered rocks. The examples are the veinlets in the pale yellow rock near the sample KIN25 and in the south wall-rock of the second iron sulphides ore body (Fig. 4). The latter is opal-kaolin-iron sulphides rock altered from porphyritic rock; the veinlets are 3 cm in maximum width (Fig.

4B). Under the microscope, the main constituents of the veinlets (sample KLb1) are irregular oolitic, isotropic opal with a few chalcedony grains. So-called soft iron sulphides ores in the outer zones of the ore bodies have similar banded texture and mineral assemblage to the dark gray bands of the wall-rocks. Impurities in such ores are mostly alunite, clay minerals (montmorillonite or kaolin), with a few occurrences of cristobalite and quartz. The fragmental quartz grains may be derived from the original rocks. The above mineral assemblage seems to be an important property showing the distinction between the soft and hard iron sulphides ores.

Opal-like minerals are scarcely found in the samples at hand from the hard part of the iron sulphides ore bodies and the moss part of the limonite ore bodies. Opal or cristobalite is, therefore, abundant in the altered wall-rocks near the iron sulphides and sulphur ore bodies, and they can scarcely be considered to have paragenesis with quartz.

To observe cristobalite crystals under the polarized microscope is actually difficult, but the electromicrographs may show the crystal form of the separated sample. This sample is the non-precipitate of KIN25 in water for twelve hours. The electromicrographs in Plate II are taken by the chrom-shadowing method by means of which the ratio of the length of the shadow to the crystal thickness is shown as 1.7:1. The graphs show hexagonal plates which are coarse or fine grained, and irregular aggregations. These crystals may be alpha cristobalite according to corroboration by X-ray refraction applied to the sample.

X-ray diffraction.—It is usually difficult to identify opal and cristobalite of the Abuta mine microscopically, but it is easily solved by X-ray diffraction whether these minerals are contained or not in the samples. Table 3 shows the data of X-ray diffraction of some samples taken from the altered rocks and veinlets. Table 4 shows X-ray patterns of the purified cristobalite which does not precipitate in water for twelve hours.

To compare these diagrams of KIN25 with KLb1 by Norelco (Fig. 5) the former has a sharp peak 4.05\AA , while the maximum peak of the latter shows 4.13\AA and it is diffuse from 3\AA to 5\AA . A representative pattern of alpha cristobalite (ASTM card, 4-0379) is 4.05\AA , and the diffuse peak of 4.13\AA shows opal though a sharp peak at the same position is the representative pattern of beta cristobalite (WYCKOFF: 1925). At the point of this distinction, the Norelco charts of non-separated samples show some tendencies for alpha cristobalite to be contained in the wall-rocks as the main component, while opal-type mineral forms the veinlets. These facts well agree with the microscopic observations. The ratios of the

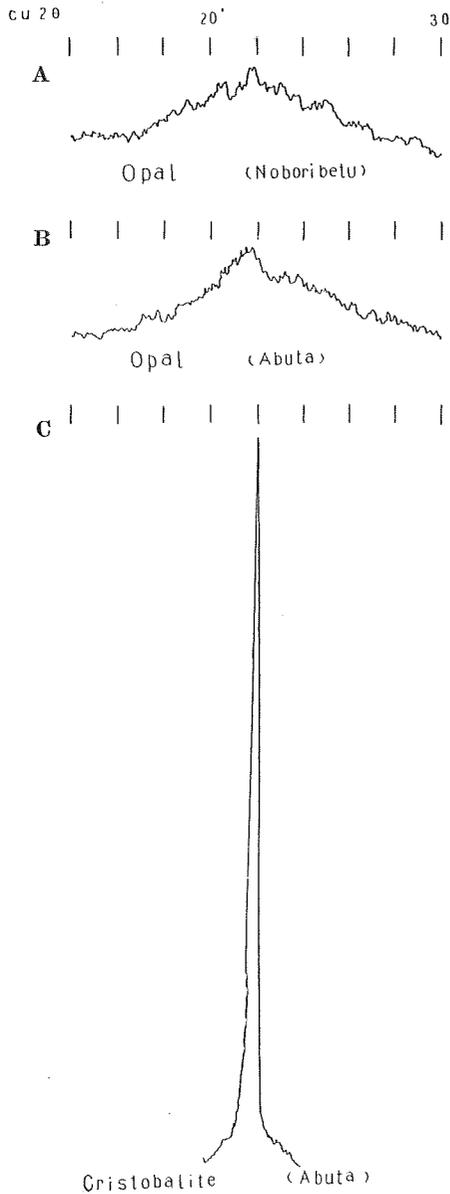


Fig. 5. X-ray diagrams of the opal and cristobalite from the Abuta mine and Noboribetu Hot Spring in Hokkaido, Japan. $\text{CuK}\alpha_1$, 35KV., 13mA., scale factor: 8, multiplier: 1, time constant: 4, (Norelco).
 A. Sample LBal from altered rock at the Noboribetu Hot Spring.
 B. Sample KLb1 from opal veinlet (Fig. 4B).
 C. Purified sample KIN25 (Fig. 4A).

peaks between alpha cristobalite type ($4.04\text{-}4.06\text{\AA}$) and opal-type ($4.1\text{-}4.3\text{\AA}$) are variable wherever they are in the wall-rocks, although the contents of the two are not easily known.

TABLE 3. X-ray powder patterns of cristobalite bearing samples from the Abuta mine.

KL _a 4	KL _a 5	KL _b 1	KIN26	LJ _a 1
d(Å) I/I ₁				
5.49 5 G	16.1 100 M	7.08 20B K	5.73 10 A	5.71 13 A
4.64 10 G	4.50 80 M	4.12 10 P	4.96 34 CA	4.95 62 A
4.19 20 G	4.07 100 C	4.06 100 C	4.06 31 C	4.05 27 C
4.06 100 C	3.17 25 C	3.14 35 P	3.50 14 A	3.52 19 A
3.36 10 GQ	3.13 30 P	2.86 10 C	3.14 3 C	3.02 100 A
3.14 10 C	2.72 70 P	2.49 20 C	2.99 100 A	2.88 22 CA
2.98 5 G	2.56 45B M		2.88 23 CA	2.71 2 P
2.84 5B C	2.49 30 C		2.50 7B CA	2.49 6 CA
2.70 15B G	2.43 35 P		2.28 47 A	
2.49 30 C	2.23 25 M		2.21 6 C?	
2.45 30 G	1.92 25 C P		2.02 3 C	
2.03 10 C	1.64 50 P		1.92 ? C	
1.94 5 C	1.50 25B M		1.90 29 A	
1.88 5 C	1.43 20 C		1.75 14 CA	
1.73 10 G			1.65 3 A	
1.70 10 CG			1.50 20 CA	
			1.37 3B CA	
			1.30 3 C	
			1.29 7 A	
			1.21 4B CA	

CuK α_1 , 35KV., 13mA; scale factor: 4 (KL_a4, KL_a5, KL_b1), 8 (KLN26), multiplier: 1, time constant: 4, scanning speed 2°/min. (Norelco). KL_a4: yellow platy limonite ore. KL_a5: gray clayey altered rock, KL_b1: gray soft rock veined with opal veinlets, KIN26: the white part of the altered banded rock, LJ_a2: the low grade part of the so-called soft iron sulphides ore. C: cristobalite, Q: quartz, G: goethite, M: montmorillonite, K: kaolin, A: alunite, P: pyrite.

Silica minerals of other mines

The writer studied some similar ore deposits to compare the distributions and properties of silica minerals of the Abuta mine with those of some other mines.

The Simeikawa sulphur ore body of the Tokusyumbetu mine presents similarity to the iron sulphides ore deposits of the Abuta mine in shape; it consists of native sulphur, pyrite and marcasite. The so-called hard ores sometimes contain quartz as one of the gangue minerals. However, so-called soft ores occurring in the outer part of the ore body usually contain small quantities of cristobalite, alunite and montmorillonite or kaolin as occasional impurities. The wall-rocks of the ore body are

TABLE 4. X-ray powder patterns of cristobalite from the Abuta mine.

Abuta (KIN25)*			ASTM 4-0379**		
d (Å)	I/I ₁		d (Å)	I/I ₁	hkl
5.68	3	A			
4.92	6	C?A			
4.04	100	C	4.04	100	101
3.50	5	A			
3.13	9	C	3.138	12	111
2.98	14	A			
2.84	13	C A	2.845	14	102
2.49	18	C	2.489	18	200
2.47	?	A			
2.28	9	A			
2.12	3	C	2.121	4	211
2.02	3	C	2.024	3	202
1.932	5	C	1.932	4	113
1.897	?	A			
1.872	5	C	1.874	4	212
			1.759	1	220
1.742	3	C A			
			1.736	1	004
1.695	3	C	1.692	3	203
			1.642	1	104
1.613	4	C	1.612	5	301
			1.574	1	104
1.534	3	C	1.535	2	311
1.497	7	C	1.495	3	302
1.434	3	C	1.432	2	312
1.422	2	C A	1.423	2	204
1.399	1	C	1.401	1	223
1.367	1	C	1.368	1	214
			1.353	1	321
			1.345	1	303
1.336	1	C	1.336	1	105
1.300	1B	C	1.301	2	313
1.284	3	C A	1.282	2	322
1.225	1	C	1.225	3	224
1.208	3	C A	1.207	1	410
1.186	1	C	1.842	2	323
1.176	1B	C	1.762	2	215
1.165	1	C A	1.1659	1	315
			1.1112	1	420
1.099	3	C	1.0989	3	421

* CuK α_1 , 35KV., 13mA. scale factor: 8, multiplier: 1, time constant: 4, scanning speed: 2°/min. (Norelco). C: alpha cristobalite, A: alunite.

** Alpha cristobalite.

generally altered to opalized rocks. The so-called opal is usually cristobalite which has been discovered in the Horobetu mine by HAYASE (1955, 1957). For example, it is ascertained by X-ray diffraction that the soft and white wall-rock from the south side of the body is formed of cristobalite, alunite and native sulphur. Opal veinlets are recognized at the Sikiu mine. These phenomena are recognized in various places; the Siraoi mine, the Siraoi sulphur mine etc; the occurrences and properties of the silica minerals resemble those of the Abuta mine.

The tuffaceous wall-rocks near Noboribetsu Hot Spring suffer strong alteration to soft and white. The sample shows a typical peak of opal-type in Norelco chart (Fig. 5).

On the other hand, opal or cristobalite is not yet found in the altered wall-rocks of the hematite-pyrite-marcasite ore body of the Kamaya mine; they are mostly formed of pyrophyllite and quartz.

Limonite ore deposits abound in southwestern Hokkaido. The moss-type ores are usually formed of goethite. The existence of a few fragmental quartz grains is common, whilst opal and cristobalite are rarely contained in them. But cristobalite is sometimes contained in the clay beds or so-called yellow earth which are accompanied by the limonite ore deposits. For instance, the dark gray clay under the third ore body of the Kuttyan mine consists of montmorillonite with cristobalite. Some examples of the so-called yellow earth containing cristobalite in the limonite ore deposits have been reported by SHIKAWA (1957). The altered rocks which suffer dissemination by limonite sometimes contain relic cristobalite in the neighborhood of the bedded sulphur or iron sulphides ore deposits. Cristobalite in some of the limonite ores near the Simeikawa sulphur ore deposits of the Tokusyunbetu mine seem to belong to this group.

On the other hand, the limonite ore deposits of the Hariusu mine take the form of a network in the silicified Tertiary volcanic rocks; the ores consist of aggregates of fine grained goethite and quartz after pyrite and quartz veins. They resemble some parts of the limonitized zone after the so-called hard iron sulphides ores of the Abuta mine only in respect to the mineral assemblage and secondary limonitization.

The ore deposits of the Sinmei mine are limonite beds occurring in Miocene conglomerate and mudstone. The main constituents are goethite and quartz. Most of the quartz is in the form of fragments derived from the grains in the original rock, but quartzes in siliceous nodules have a fine granular paragenesis with goethite. According to the existence of the nodules, pyrite-quartz paragenesis, and barite, some

parts of the deposits may have been formed under hydrothermal conditions. But cristobalite has not yet been recognized in the limonite ores studied by the writer.

Thus, the silica minerals from some of the above-mentioned mines, with the exception of the siliceous nodules from the Sinmei mine, bear a resemblance to those of the Abuta mine in occurrences and properties.

Considerations

The above descriptions of the silica minerals from the sulphur and iron sulphides ore deposits of the Abuta mine may be summarized into the following three points.

(1) There exist chalcedony, quartz, opal and alpha cristobalite, as silica minerals at the Abuta mine.

(2) Chalcedony and quartz formed by mineralization are distributed in the silicified rocks, so-called hard iron sulphides ores, and recent bog limonite ore. On the other hand, opal and cristobalite are abundant only in the wall-rocks near the ore bodies and the sulphur ores.

(3) It is very rare that both mineral groups have a paragenesis.

The occurrences of tridymite in the sulphur ores and their wall-rocks are reported at the Zao mine (MUKAIYAMA: 1954) and the Horobetu mine (HAYASE: 1955, 1957). Tridymite and keatite (KEATS: 1954) are not yet known at the Abuta mine. A concentric zonal distribution of chalcedony-quartz and opal-cristobalite occurs at the Abuta mine; such distribution is scarcely known about the other bedded sulphur or iron sulphides ore deposits (HAYASE: 1956) in Japan.

The genetic problem resolves itself into the following two points:

(1) the formation of two types of silica, and (2) the genetic relations between chalcedony and quartz or between opal and cristobalite.

It is a perplexing problem to understand why the sorts of silica minerals are different in different localities of the ore deposits and their wall-rocks, because the common conditions under which two types of silica minerals were formed seem to be not narrow and because quartz in many other hydrothermal ore deposits is very common. But CORWIN *et al.* (1953) synthesized quartz in alkaline and cristobalite in acid. ILER (1955) says "during the growth of crystals the repulsion of the charges on the ionic silicate tetrahedra may come the twisting spiral formation of alpha quartz. The less ionic forms, or molecular orthosilicic acid, lead to the formation of alpha cristobalite."

It is considered that the silicification quartz and interstitial quartz

are formed in hydrothermal solution under low temperature an account of their radial or fibrous texture (ADAMS: 1905 etc.), and their parageneses with clay minerals or with opal. Further, as the chalcedony and quartz have some parageneses with kaolin, alunite, pyrite-marcasite, and goethite, the solution seems to be generally not alkaline.

Chalcedony and quartz have both the same crystal structure as ordinary quartz, but the chalcedony in the recent limonite ore of the Abuta mine shows a somewhat low crystallinity under the microscope or by X-ray powder diffraction. It is suggested that amorphous silica crystallizes to quartz through chalcedony. The fibrous texture of chalcedony aggregating in mosaic is an interesting texture which is scarcely known in common hydrothermal ore deposits.

Opal is also a product under a not high temperature, because it occurs usually as wood opal, the sinter of a hot spring, the last mineral of the gold-quartz vein (WADA et al: 1947), etc. Cristobalite is generally stable above 1470°C because the higher temperature form of silica is an open structure; but cristobalite recognized in some sedimentary rocks (BELJANKIN et al.: 1938), kaolin ore deposits, MURAOKA: 1952, MURAOKA and TANEMURA: 1954, SUENO and IWAO: 1958, etc.), bentonite ore deposits (DITTER and KIRNBAUER: 1933, GRUNER: 1930a, HOFFMANN et al.: 1934, SUDO: 1950), and the sulphur ore deposits (HAYASE: 1955, 1957). In most of these cases, cristobalite occurs in the Cenozoic rocks which have suffered alteration by gas or hydrothermal solution.

There is a close relation between opal and cristobalite of the Abuta mine and the other sulphur mines in respect to occurrences. It is, therefore, assumed that they were formed under not different genetic conditions. They have often the parageneses with alunite, kaolin, and pyrite-marcasite, which can be well synthesized under the low temperature and acidic condition (LEONARD: 1927, KERR: 1955, ALLEN et al.: 1914, etc.).

X-ray diffraction of silica gel or opal often shows the wide peak in the situation of beta cristobalite (DITTER and KIRNBAUER: 1933, HAUSER: 1955, HOFMANN et al: 1934, ILER: 1955, KREJCI and OTT: 1931, LEVIN and OTT: 1932, 1933, SUDO: 1950, WARREN: 1933, 1937, etc.). The relation between alpha and beta cristobalite is approximate in their crystal structures (BRAGG and ZACHARIASEN: 1930). Some authors consider that cristobalite nuclei are formed by crystallization of opal under low temperature (BUERGER: 1935, GREIG: 1932, HAYASE: 1957, ROGERS: 1928, SUDO: 1950). CARR and FYFE'S (1958) experiment shows the conversion to cristobalite from opal.

Some impurities in silica seem to have exerted influence on this

crystallization; for example, small amounts of alumina (ILER: 1955). BUEGER (1935) states "somewhat impure silica cannot be deposited as quartz, but must be deposited either as tridymite or cristobalite, and isotropic cristobalite crystals may be solid solutions of the foreign oxides in silica." It is also reported that NaHCO_3 promotes the synthesis of cristobalite from quartz (KAGAMI: 1958). The writer think that BUEGER's statement concerning beta cristobalite may be applicable to alpha cristobalite. Actually, it is known that chemical analyses show many impurities present in silica gel or opal, such as iron oxide, alumina, lime, magnesia, and some of the alkalis (DAKE et al: 1938, WADA et al.: 1947). Vom RATH's analysis shows that SiO_2 in cristobalite which is beta type is 91% (BUEGER: 1935). Cristobalite may, therefore, keep open structure at room temperature.

The opal in the veinlets of the Abuta mine and opalized rock of the Noboribetu Hot Spring remain in amorphous state. It is considered that they have not suffered the polialteration or recrystallization after their genesis owing to their later genesis, and so geologic experience or time is also another factor concerned in the genesis of cristobalite (GRUNER: 1940b).

In view of the above discussion, it is considered that the geneses of the silica minerals of the Abuta mine are summarized under the following points.

(1) Mineralization of the sulphur and iron sulphide minerals may cause movements of silica, alumina etc. in the rocks. These components may form a so-called silicified rocks in the outer peripheral zone of the ore bodies under neutral or weakly acidic conditions, and may form a so-called opalized rocks in the inner part of the altered zone under acidic condition.

(2) The cristobalite may be formed of opal as alteration mineral; it is sometimes enriched in the supergene leaching zone.

(3) The silica in the so-called hard iron sulphides ore bodies was added by mineralization and it may mostly turn into chalcedony under neutral or weakly acidic conditions. Some of early alteration minerals are replaced by such a silica.

(4) Most of the silica minerals in the limonite ores of the Abuta mine may be relic quartz or cristobalite derived from the original rocks or iron sulphides ores except the interstitial chalcedony.

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(* : in Japanese.)

Explanation of
Plate 1

Explanation of Plate I

- Fig. 6. Microscopic photograph showing breccia ore from the second iron sulphides ore body of the Abuta mine in Hokkaido, Japan. White and gray, quartz; black, pyrite and marcasite. Crossed nicol, $\times 20$.
- Fig. 7. Microscopic photograph showing limonitized iron sulphides ore from the first iron sulphides ore body of the Abuta mine in Hokkaido, Japan. White and gray, quartz; black, goethite. Crossed nicol, $\times 50$.
- Fig. 8. Microscopic photograph showing moss limonite ore of the Abuta mine in Hokkaido, Japan. White and gray, quartz; black, hydrogoethite. Crossed nicol, $\times 20$.
- Fig. 9. Microscopic photograph showing siliceous nodule from the limonite ore deposits of the Sinmei mine in Hokkaido, Japan. White and gray, quartz; black, pyrite and marcasite. Crossed nicol, $\times 20$.

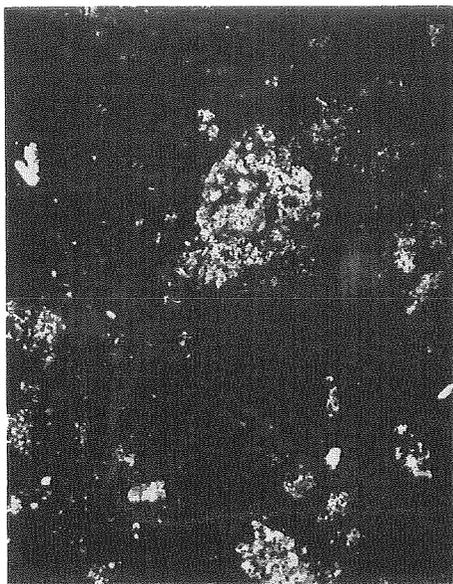


Fig. 6.

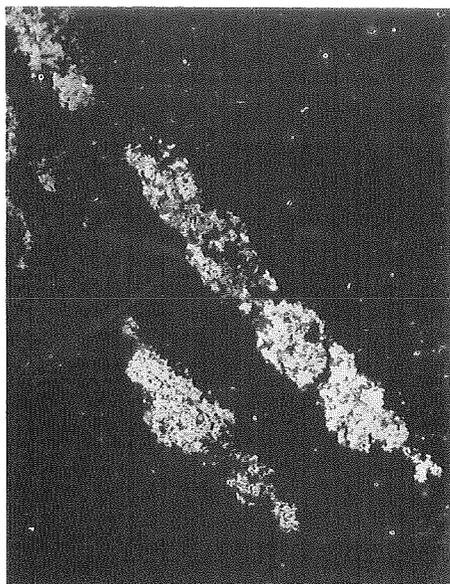


Fig. 7.



Fig. 8.

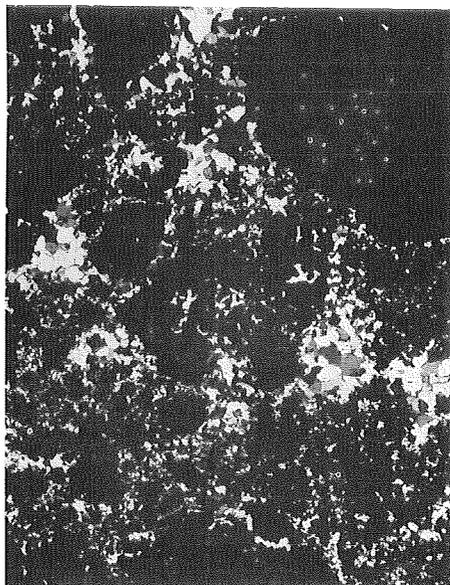


Fig. 9.

Explanation of
Plate 2

Explanation of Plate II

- Fig. 10. Electromicrograph showing cristobalite from the wall-rock of the first iron sulphides ore body of the Abuta mine in Hokkaido, Japan. $\times 13,000$. (By KUMAI.)
- Fig. 11. (=Photo. 10.) $\times 17,700$.

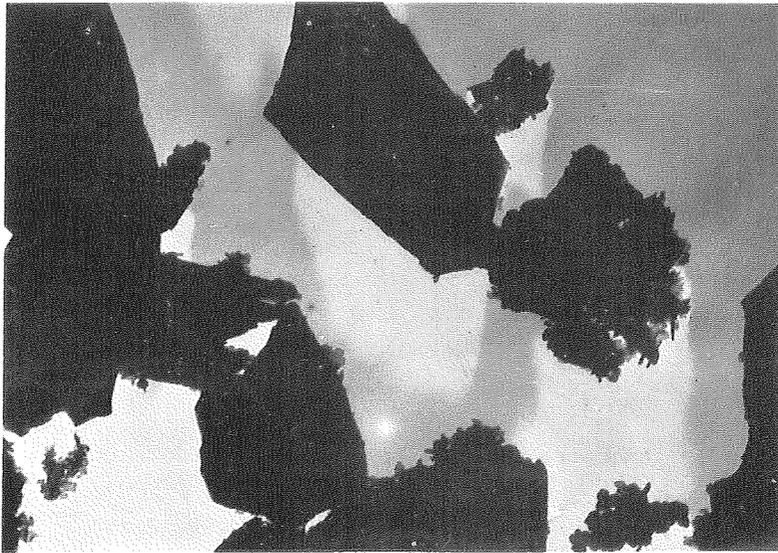


Fig. 10.

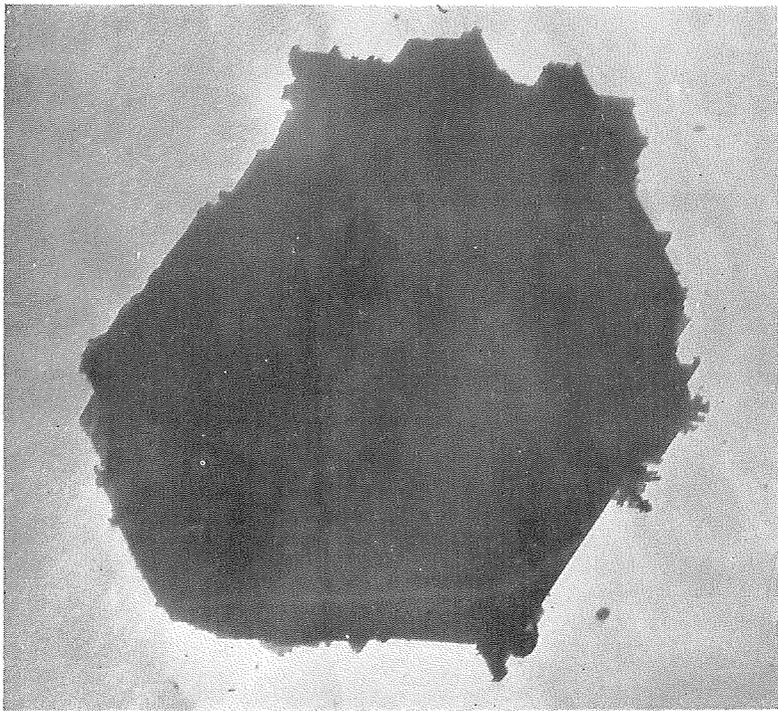


Fig. 11.