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A NOTE ON SODA-AMPHIBOLES IN CRYSTALLINE SCHISTS FROM HOKKAIDÔ

By

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With 6 Text-Figures

Contributions from the Geological and Mineralogical Department, Faculty of Science, Hokkaidô Imperial University. No. 219.

INTRODUCTION

It is worthy of notice that various kinds of sodium bearing silicate minerals, such as glaucophane, crossite, riebeckite, crocidolite, aegirite-augite, albite, etc. occur in the especial facies of the crystalline schists of the so-called Kamuikotan System, which extends as a narrow belt along the western side of the central mountain range of Hokkaidô. In former times, the rocks which contained the above mentioned minerals were known only as boulders or sands in the beds of the Isikari(1) and the Obirasibe rivers(2), but lately the original outcrops of these rocks have been found here and there in the areas of the Kamuikotan formation, the typical localities being well known at Kamuikotan, Etanbetu and the Horokanai Pass in the Province of Isikari(3), Hôraisan near Mituisi in the Province of Hidaka(4), and Toikanbetu in the Province of Tesio. (Fig. 1)

The rocks from these localities show manifold varietal differences in structure and mineral composition, and contain abundant veins,

(1) H. S. WASHINGTON: Am. Jour. Sci., 4 Ser. Vol. XI (1901) p. 35. S. NAKAWO: Jour. Geol. Soc. Tokyo, Vol. XXXII (1925) p. 117.

(2) H. HATIYA: Jour. Geol. Soc. Tokyo, Vol. IX (1902) p. 98 & 147.

(3) J. SUZUKI: Jour. Geol. Soc. Tokyo, Vol. XXXIX (1932) p. 132. Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. VIII (1932) p. 184. Jour. Geol. Soc. Tokyo, Vol. XXXXI (1934) p. 392. J. SUZUKI & S. YAMAGUTI: Jour. Geol. Soc. Tokyo, Vol. XXXX (1933) p. 387.

(4) T. YOSIMURA: Jour. Jap. Ass. Petr. Min. & Econ. Geol. Vol. XV (1936) p. 26. M. ISIBASI: Jour. Geol. Soc. Vol. XXXXIV (1937) p. 487. K. TAKEUTI & M. SAMBONSUGI: Geol. Report, No. 1 (1938) Ind. Lab. Hokkaidô p. 6.

thus offering a very interesting field for petrological and mineralogical study. The properties of some especial rocks of this kind have often been reported by the writer and others[1] but comparatively few of the mineral species in themselves have been submitted to detailed investigation. The specific object of this paper is to present

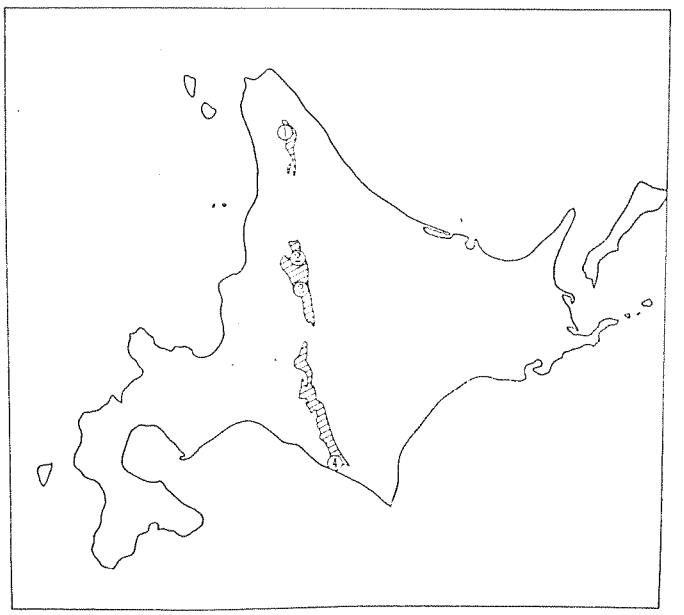

Fig. 1. Map showing the distribution of the Kamuikotan System and the main localities of soda-amphiboles in Hokkaidô. (1) Toikanbetu, Prov. Tesio, (2) Horokanai Pass. and Kamietanbetu Prov. Isikari, (3) Kamuikotan, Prov. Isikari, (4) Hôraisan near Mituisi, Prov. Hidaka. 1 : 7000 000.

a detailed account of the physical and chemical properties of some soda-amphiboles in the various crystalline schists from the above mentioned localities.

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(1) J. Suzuki: Proc. Imp. Acad., Vol. VII (1931) p. 283. Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. VIII (1932) p. 11. Ibid. Vol. VIII (1932) p. 184. Proc. Imp. Acad., Vol. IX (1933) p. 617. Jour. Fac. Sci. Hokkaidô Imp. Univ. Ser. IV Vol. II (1934) p. 339. Jour. Jap. Ass. Petr. Min. & Econ. Geol. Vol. XII (1934) p. 55. T. Yosimura: loc. cit. p. 26. K. Takeuti & M. Sambonsugi: loc. cit. p. 6.

MODE OF OCCURRENCE

The crystalline schists of the Kamuikotan System are roughly classified into three main types: siliceous schists, basic schists and calcareous schists. There are many large masses or lenses of ultra-basic rocks now mostly represented by serpentine, which intruded in these crystalline schists in relation with the great orogenic movements.

It is noticeable that the contact zone between the crystalline schists and ultra-basic rocks is characterized by a severely metamorphosed rock facies, containing an unusual amount of sodium-bearing silicate minerals. It is very reasonable to consider that the special rocks in the contact zones are the result by the action of heavy pressure as well as of the sodium rich hydrothermal solution which was derived from the ultra-basic intrusive masses. In other words, the occurrence of the various sodium-bearing silicates in the contact zones is due to the metasomatic action[1] between the original minerals in the normal Kamuikotan rocks and ascending sodium rich solution.

The soda-amphiboles, now about to be described, generally occur as an important member in the contact zone, and show a complex assemblage with various kinds of minerals. The typical soda-amphibole bearing crystalline schists which are found in the several representative localities in Hokkaidô, are tabulated as follows.

(A) Siliceous schists

1) Glaucophane quartz schist
2) Glaucophane-bearing garnet sericite quartz schist
3) Albite glaucophane quartz schist
4) Garnet-bearing albite glaucophane quartz schist
5) Epidote glaucophane quartz schist
6) Chlorite bearing glaucophane quartz schist
7) Zoisite garnet glaucophane quartz schist
8) Aegirite-augite-bearing garnet glaucophane quartz schist
9) Aegirite-augite-bearing riebeckite quartz schist
10) Garnet albite riebeckite quartz schist
11) Aegirite-augite garnet albite riebeckite quartz schist

(1) V. M. GOLDSCHMIDT: Neues Jahrbuch f. Min., Bd. XXXIX (1914) s. 193, and Econ. Geol., Vol. XVII (1922), p. 109.

(B) Basic schists

1) Garnet glaucophane schist
2) Muscovite garnet glaucophane schist
3) Zoisite plagioclase glaucophane schist
4) Calcite-bearing glaucophane schist
5) Calcite-bearing chlorite plagioclase glaucophane schist
6) Zoisite glaucophane schist
7) Epidote glaucophane schist
8) Diopside-bearing glaucophane chlorite schist

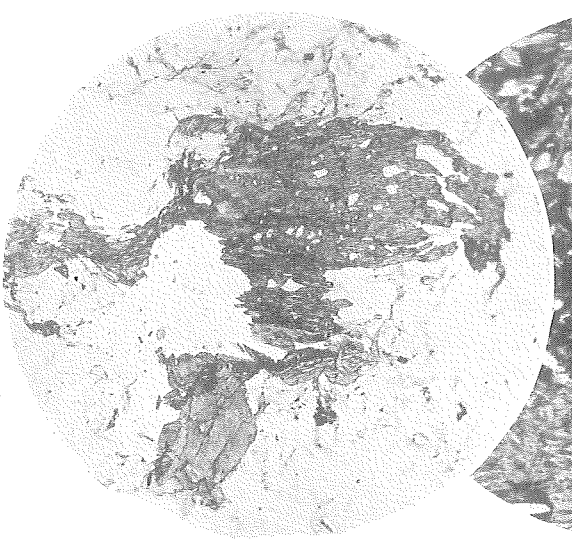

Fig. 2. Garnet-bearing albite glaucophane quartz schist. (Horokanai Pass. Prov. Isikari) ×15.

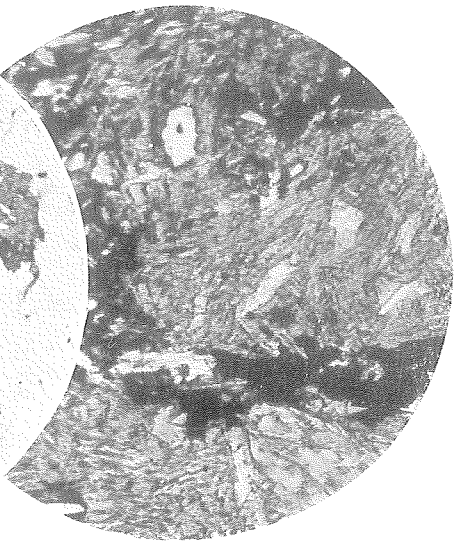

Fig. 3. Epidote crossite schist. (Kamuikotan, Prov. Isikari) ×15.

9) Diopside-bearing epidote glaucophane schist
10) Zoisite muscovite glaucophane schist
11) Albite glaucophane schist
12) Aegirite-augite albite glaucophane schist

Here it must be noted in addition that the place of glaucophane in the above cited rocks is some times taken by crossite and that the riebeckite often shows crocidolitic nature.

In many cases, both types of rocks, siliceous and basic, are finely crystalline and compact with light or dark bluish gray colour and show a schistose structure owing to especial orientation of the constituent crystals. When the rock is comparatively coarse-grained,

the individuals of the soda-amphibole often attain several millimeters in their length.

It is a remarkable thing that glaucophane and crossite are the chief constituents not only in the siliceous but also in the basic schists, while the riebeckite and crocidolite usually occur only in the high siliceous type, or rarely in the especial facies of the basic schists which were severely effected by the hydrothermal siliceous media.(1) So far as the writer knows, the association of glaucophane (or crossite) and riebeckite (or crocidolite) is not often seen in the same

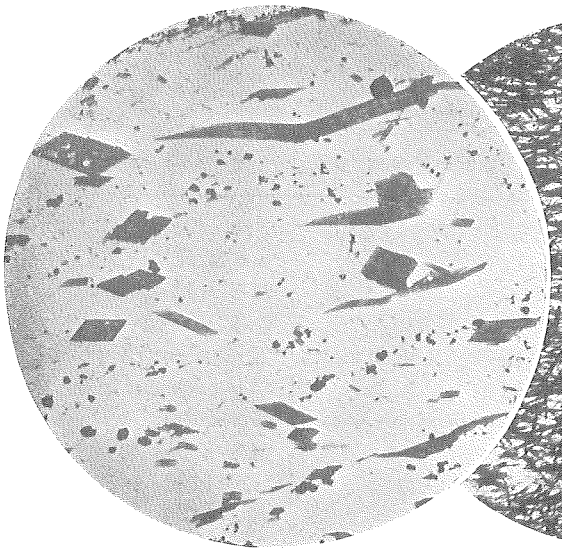

Fig. 4. Garnet bearing riebekite quartz schist (Kamietanbetu, Prov. Isikari) ×30.

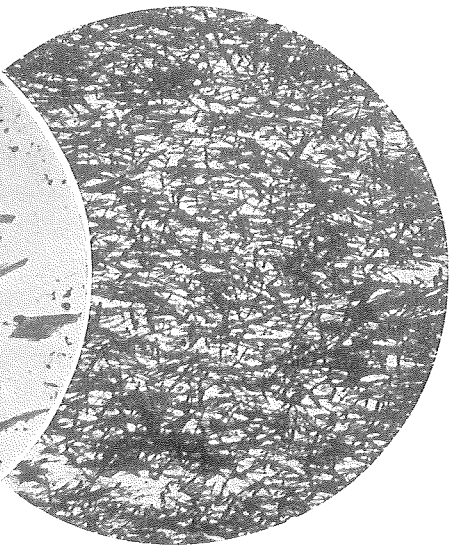

Fig. 5. Aegirite-augite bearing albite crocidolite quartz schist. (Kamuikotan, Prov. Isikari) ×30.

rock from Hokkaidô, though they respectively occur together with aegirite-augite. These facts may suggest that glaucophane and riebeckite were formed under some different condition.

PHYSICAL PROPERTIES

The soda-amphiboles in the various kinds of crystalline schists from Hokkaidô, are glaucophane, crossite, riebeckite and crocidolite, and the isomorphous forms among them.

(1) J. SUZUKI: Jour. Fac. Sci. Hokkaidô Imp. Univ., Ser IV, Vol. II (1934), p. 348 & Science (Kwagaku), Vol. VI (1936), p. 196. T. YOSIMURA: loc. cit. p. 34.

With some exceptions they show the short prismatic form with dark bluish colour. Two sets of cleavage planes parallel to the prismatic faces are strongly developed in the crystals though the terminal faces are usually absent. Fine cracks, commonly at right angles to the prismatic axis of the crystal are often seen. Under the microscope, nearly all of them show zonal structure and an undulate extinction due to the action of a distorting factor. The physical properties of the typical six examples of the soda-amphiboles from Hokkaidô are shown in Tables I and II.

TABLE I

(1) Glaucophane (K_{10} & O_4)	(2) Glaucophane (T_2)	(3) Crossite (T_{18})
Prismatic (0.5×0.1 mm)	Prismatic (2×0.3 mm)	Prismatic (0.5×0.1 mm)
b = Y, O.P. // (010)	b = Y, O.P. // (010)	b = Z, O.P. ⊥ (010)
c∧Z = 5~7°	c∧Z = 8~14°	c∧Y = 18~20°
(−) 2V = 35~40°	(−) 2V = 10~15°	(−) 2V = 45~50°
X = light yellowish violet	X = light yellowish violet	X = yellowish violet
Y = light bluish violet	Y = light violet	Y = prussian blue
Z = blue	Z = light prussian blue	Z = violet
X < Y < Z	X < Y < Z	X < Y > Z
n_1 = 1.651~1.663 (K_{10})	n_1 = 1.652~1.663	n_1 = 1.658~1.666
n_2 = 1.660~1.669	n_2 = 1.659~1.667	n_2 = 1.662~1.672
n_1 = 1.664~1666 (O_4)		
n_2 = 1.665~1.668		
$n_F - n_C$ = 0.018	$n_F - n_C$ = 0.018	$n_F - n_C$ = 0.018
$\rho > \nu$	$\rho > \nu$	$\rho < \nu$

(1) Glaucophane in epidote glaucophane schist (K_{10}) from Kamuikotan, Prov. of Isikari and in aegirite-augite glaucophane albite quartz schist (O_4) from Obirasibe, Prov. of Tesio.

(2) Glaucophane[1] in garnet-bearing albite glaucophane quartz schist from the Horokanai Pass, Prov. of Isikari.

(3) Crossite in zoisite-bearing epidote crossite chlorite schist from the Horokanai Pass, Prov. of Isikari.

(1) The chemical composition of the specimen is given in Table III in this paper.

TABLE II

(4) Riebeckite (U_1)	(5) Riebeckite (E_{19} & E_{12})	(6) Crocidolite (K_{11})
Prismatic (0.5×0.1 mm)	Prismatic (3×0.2 mm)	Fibrous (1×0.01 mm)
b = Y, O.P. // (010)	b = Y, O.P. // (010)	b = Y, O.P. // (010)
c∧X = 5~8°	c∧X = 0~3°	c∧X = 0~2°
(−) 2V = 70~75°	(−) 2V = 50~53°	(−) 2V = ?
X = prussian blue	X = dark prussian blue	X = dark prussian blue
Y = grayish violet blue	Y = grayish violet blue	Y = grayish violet blue
Z = light yellowish brown	Z = light yellowish brown	Z = light yellowish brown
X > Y > Z	X > Y > Z	X > Y > Z
n_1 = 1.678~1.682	n_1 = 1.680~1.687 (E_{19})	n_1 = 1.700~1.706
n_2 = 1.683~1.686	n_2 = 1.686~1.690	n_2 = 1.712~1.719
	n_1 = 1.689~1.699 (E_{12})	
	n_2 = 1.697~1.705	
$n_F - n_C$ = 0.025	$n_F - n_C$ = 0.023	$n_F - n_C$ = 0.023
$\rho \geqslant \nu$	$\rho \geqslant \nu$	

(4) Riebeckite in aegirite-augite bearing riebeckite quartz schist from Takadomari, Prov. of Isikari.

(5) Riebeckite in garnet bearing riebeckite quartz schist from Kamietanbetu, Prov. of Isikari.

(6) Crocidolite in aegirite-augite bearing albite crocidolite quartz schist from Kamuikotan, Prov. of Isikari.

Comparing the properties of the soda-amphiboles noted in the above tables, one can see remarkable differences in them. For instance the glaucophane is lighter in colour and shows lower indices of refraction on cleavage flakes than those of riebeckite amphibole. (Fig. 6) The crossite shows intermediate indices of refraction between glaucophane and riebeckite and is characterized by its optical plane being perpendicular to (010), consequently b = Z, and c∧Y = 18~20°, so that the character of elongation is positive or negative.(1)

(1) It is lately reported by Y. HORIKOSI and S. ZIZAIMARU that crossite shows comparatively wide distribution in the crystalline schists in the Titibu district in eastern Japan, Sikoku and Kyûsyû in southwestern Japan. (Y. HORIKOSI: Jour. Geol. Soc. Japan, Vol. XXXXII (1935) p. 48, Jap. Jour. Geol. Geogr. Vol. XIII (1936) p. 151. S. ZIZAIMARU: Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. XVII (1937) p. 290. Ibid. Vol. XVIII (1937) p. 30, 62.)

In the special amphibole schist or amphibolite in the contact zone along a serpentine mass, the minute crystals or fibers of the soda-amphiboles often develop on the periferies, cleavages and cracks of the green or yellowish green hornblende, showing the partial metasomatism of the original constituent. Good examples of this kind are seen in the rocks from Hôraisan near Mituisi and the Horokanai Pass. The green hornblende associated with riebeckite fibres in the amphibolite from the former locality, was studied by T. YOSIMURA,

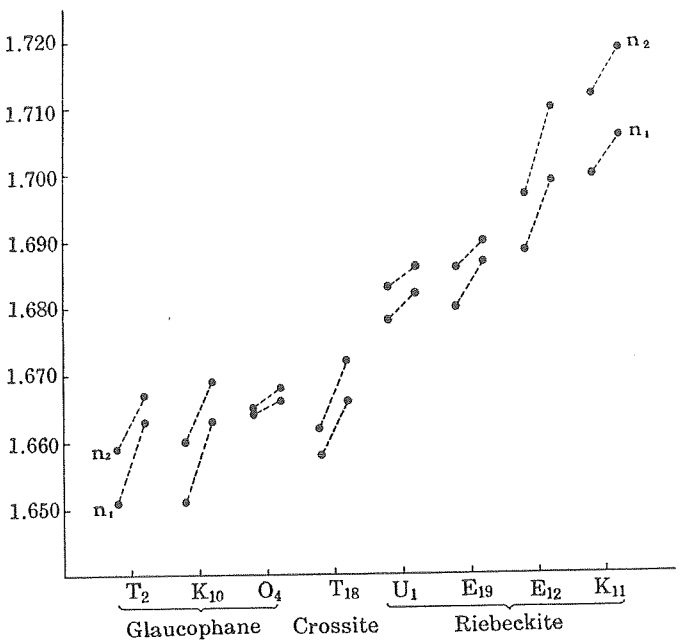

Fig. 6. Diagram showing the indices of refraction of soda-amphiboles from Hokkaidô.

showing the following characters: X = light yellow, Y = dark yellowish green, Z = dark greenish blue; Absorption is $Y \geq Z \ll X$. Optical plane is parallel to 010. Extinction angle $c \wedge Z = 3 \sim 4°$, $n_1 = 1.656$, $n_2 = 1.670$ $(-)2V \fallingdotseq 50°$. The riebeckite fibrès, developing mainly on both the terminals of the above mentioned green hornblende are: X = dark prussian blue, Y = reddish purple, Z = light yellow. Absorption is $X > Y > Z$. Optical plane is parallel to 010. Extinction angle $c \wedge X' = 0 \sim 3°$. $n_1 \fallingdotseq n_2 = 1.682 \pm 0.005$. 2V is medium.

The green hornblende with glaucophanized margin in the amphibolite from the Horokanai Pass shows similar characters to those of the Hôraisan hornblende, though its indices of refraction are slightly lower: $n_1 = 1.651 \sim 1.658$, $n_2 = 1.658 \sim 1.664$ or partly $n_1 = 1.669 \sim 1.677$, $n_2 = 1.680 \sim 1.687$. The glaucophane on the margin shows nearly the same characters as those of the glaucophane schist from Kamuikotan, cited in Table I (1). It is worthy to note that in the example from Hôraisan, the riebeckite is found as a member of the amphibolite, in spite of the fact that the mineral occurs as usual in the rather siliceous rock. Regarding this fact T. YOSIMURA explains that the riebeckite might have originated at the part which was severely effected by comparatively high siliceous and sodiferous solution derived from the neighbouring serpentine.

CHEMICAL PROPERTIES

For the chemical study of the soda-amphiboles from Hokkaidô the writer selected samples, from two different rocks; siliceous schist and basic schist. But as to the material from the latter source, the mineral could not be purified satisfactorily because it shows complex intergrowth with minute crystals of epidote, and chlorite. Thus only material from the siliceous schist collected at the southern foot of the Horokanai Pass, was used for chemical analysis reported in this paper, because the mineral is quite readily separable from the matrix in the rock. Aside from the principal objects of the present paper, some short descriptions on the rock in which the mineral was found, will be noted here for the purpose of reference. The rock is bluish gray in colour and shows a hard compact schistose appearance, being essentially composed of quartz, glaucophane and albite associated with minute amounts of garnet, rutile, chlorite, magnetite and apatite. The chemical analysis of the siliceous schist is set out in table below.

From the chemical composition, the rock may be considered as a derivative of siliceous sedimentary rock.

The glaucophane crystals assume the form of a short prism, 1 ~ 2 mm in length being disposed with parallel orientation in the rock. In determination by the integration apparatus, the mineral is found to occupy nearly 15 percent of the whole rock; the optical properties of the mineral were already mentioned in Table I (2) of this paper.

For the collection of pure glaucophane crystals, the finely crushed grains of the rock were treated by means of the electro-magnet and

TABLE III

	Wt. %	Mol. %	Niggli's value	
SiO_2	84.40	83.80	si	765
TiO_2	0.53	0.42	al	14.5
Al_2O_3	2.80	1.62	fm	53
Fe_2O_3	1.18	0.42	c	16
FeO	1.54	1.25	alk	16.5
MnO	0.42	0.36	k	0.30
MgO	2.27	3.36	mg	0.57
CaO	1.62	1.77	t	4
Na_2O	1.30	1.25	h	45
K_2O	0.82	0.54	c/fm	0.30
P_2O_5	0.50	0.25		
H_2O (+)	1.50	4.96		
H_2O (−)	0.44	—		
Total	99.32	100.00		

Garnet-bearing albite glaucophane quartz schist, Horokanai Pass, Prov. of Isikari (Anal. A. Kannari).

Clerici solution. Material secured by the above manner of treatment was examined as carefully as possible under the binocular microscope and found to be quite free from attached matrix. The chemical analysis of the purified materials, as made by T. NEMOTO, is shown in Table IV, in which are given the calculations leading to the formula of the mineral.

From the calculations in the above table, the glaucophane now in question, may be represented by the following molecular formation, where the deficiency of OH is supplied by O, as was adapted by H. BERMANN and E. S. LARSEN[1] for alkali hornblende and by Y. KAWANO[2] for basaltic hornblende.

$$(O.OH)_{2.00}(Na, Ca, K)_{1.86}(Mg, Fe'', Fe''', Ti, Mn, Al)_{4.82}[Si_{8.13}O_{22.00}]$$

It is moderately near to the general formula for the soda-amphibole group: $(OH)_2Na_2(Mg,Fe,Al)_5[Si_8O_{22}]$. If we consider the general

(1) H. BERMANN & E. S. LARSEN: Am. Min., Vol. XVI (1931), p. 142.
(2) Y. KAWANO: Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. XII (1934) p. 37. Proc. Imp. Acad., Vol. X (1934) p. 351.

TABLE IV

	Wt. %	Mol. %		Atomic ratio (when O+OH = 24.00)		
SiO_2	59.30	59.50		Si	8.13	
TiO_2	0.25	0.18		Ti	0.03	4.82
Al_2O_3	8.66	5.10	7.08	Al	1.40	
Fe_2O_3	5.21	1.98		Fe‴	0.54	
FeO	8.05	6.75	22.19	Fe″	0.93	
MnO	0.12	0.12		Mn	0.01	
MgO	9.37	14.00		Mg	1.91	
CaO	1.24	1.32		Ca	0.18	1.86
Na_2O	6.11	5.94	6.30	Na	1.63	
K_2O	0.55	0.36		K	0.05	
H_2O (+)	1.42	4.75		OH	1.30	24.00
H_2O (−)	0.32	—		O	22.70	
Total	100.60	100.00				

Glaucophane from the Horokanai Pass. Prov. of Isikari (Anal. T. Nemoto).

soda-amphibole as an isomorphous mixture of the molecules of the three mineral units, actinolite, glaucophane and riebeckite, as was proposed by W. KUNITZ,(1) the mineral from the Horokanai Pass is represented by the following proportion;

Actinolite	$(OH)_2Ca_2Mg_5Si_8O_{22}$	= 10.56 Mol. %
Glaucophane	$(OH)_2Na_2Al_2Mg_3Si_8O_{22}$	= 49.97 ,, ,,
Riebeckite	$(OH)_2Na_2Fe_2^{III}Fe_3^{II}Si_8O_{22}$	= 27.72 ,, ,,
	$R_2^{I}SiO_3$	= 1.39 ,, ,,
	$R_2^{II}SiO_4$	= 1.50 ,, ,,
	$R_2^{III}SiO_5$	= 3.06 ,, ,,

Beside the above proportion, there are 7.26 mol. % of SiO_2 in excess and a less amount of 1.46 mol. % of H_2O.

For the convenience of comparison five analyses of glaucophane from Otakisan,(2) Syra,(3) Rocca Bianca(4) and San Pablo(5) are shown in Table IV, together with the analysis of the Horokanai glaucophane.

(1) W. KUNITZ: Neues Jahrbuch f. Min. B. Bd. LX, A (1929) s. 171.
(2) B. KOTÔ: Jour. Coll. Sci. Tokyo Imp. Univ., Vol. 1 (1887) p. 88.
(3) H. S. WASHINGTON: Am Jour. Sci., 161, Vol. XXXV (1909), p. 40.
(4) F. ZAMBONINI: Neues Jahrb., (1906) II s. 121.
(5) W. C. BLASDALE: Bull. Dep. Geol. Univ. Calif., Vol. II (1901), p. 338.

TABLE V

	(1)	(2)	(3)	(4)	(5)	(6)
SiO_2	59.30	56.71	57.67	56.72	54.52	52.39
TiO_2	0.25	—	—	—	0.39	0.14
Al_2O_3	8.66	15.14	11.07	12.47	9.25	11.29
Fe_2O_3	5.21	9.78	3.20	2.40	4.44	3.74
FeO	8.05	4.31	9.68	8.10	9.81	9.13
MnO	0.12	—	0.06	tr.	0.46	tr.
MgO	9.37	4.33	9.85	9.50	10.33	11.37
CaO	1.24	4.80	0.95	2.11	1.98	3.03
Na_2O	6.11	4.83	6.80	5.88	7.56	6.14
K_2O	0.55	0.25	0.42	0.33	0.16	tr.
H_2O (+)	1.42	—	0.36	—	—	—
H_2O (−)	0.32	—	0.12	2.91	1.78	2.57
Total	100.60	100.15	100.18	100.88	100.78	99.80

(1) Glaucophane from Horokanai Pass, Prov. of Isikari (Anal. T. Nemoto).
(2) ,, from Ôtakisan, near Tokusima City (Anal. H. Yosida).
(3) ,, from Syra, Greece (Anal. H. S. Washington).
(4) ,, from Rocca Bianca, Italy (Anal. F. Zambonini).
(5) ,, from San Pablo, Calif., U. S. A. (Anal. W. C. Blasdale).
(6) ,, Ibid.

On comparing the analyses in the above table, the glaucophane from Horokanai (1) and that from San Pablo (5) show the closed agreement in their chemical composition, though the only features worthy of note are the relatively higher amount of SiO_2 and slight poorness of Na_2O in the former mineral. It is noticeable that the glaucophane from Ôtakisan (2) shows marked variations in comparison with the Horokanai glaucophane. It is characteristic of the former that the extremely low percentages of FeO, MgO and Na_2O are largely compensated for by the higher contents of Al_2O_3, Fe_2O_3 and CaO. On calculating the percentage of (Al_2O_3, Fe_2O_3), (FeO, MnO, MgO, CaO) and (Na_2O, K_2O) by molecular weight, the ratio of bases of these two samples may be represented as follows:

Glaucophane from Horokanai $R_2^{I}O : R^{II}O : R_2^{III}O_3 = 17.7 : 62.4 : 19.9$
Glaucophane from Ôtakisan $R_2^{I}O : R^{II}O : R_2^{III}O_3 = 15.0 : 46.6 : 38.4$

If these calculated values of the types are plotted in a ternary diagram for the amphibole groups after P. NIGGLI,[1] the loci of the former falls practically within the field of typical glaucophane, on the other hand the latter shows an extremely lower percentage of $R^{II}O$ and higher contents of $R_2^{III}O_3$, its loci being out of the field.

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(1) P. NIGGLI: Lehrbuch d. Min., II (1926) s. 475.