

JADEITE AND ASSOCIATED MINERALS OF META-  
GABBROIC ROCKS IN THE SIBUKAWA  
DISTRICT, CENTRAL JAPAN

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ABSTRACT

Jadeite was found in meta-gabbroic rocks of the Sanbagawa metamorphic terrain in the Sibukawa district, central Japan. Veins chiefly composed of jadeite were also found in the meta-gabbro. Metamorphic minerals associated with the jadeite are lawsonite, pumpellyite, chlorite, vesuvianite and grossularite. Besides these minerals, small amounts of quartz, sodic plagioclase, analcite and calcite were found, but it is not clear whether these minerals are in stable association with the jadeite.

The chemical, optical and x-ray data of jadeite and some associated minerals are given.

The jadeite was formed probably under high water pressure at low temperature during the Sanbagawa metamorphism. The desilication of its host-rock by the associated ultramafic rock may have promoted its formation.

INTRODUCTION

The Sanbagawa metamorphism is a typical glaucophanitic regional one widely developed in central and south-western Japan. The Upper Paleozoic formation, composed of pelitic, psammitic, cherty and calcareous sediments and mafic volcanic rocks was transformed into crystalline schists by regional metamorphism. The metamorphic terrain can be divided into several zones showing the progressive change of metamorphic grade (Sekii, 1958a; Miyashiro and Sekii, 1958a; Miyashiro and Banno, 1958; Sekii, Aiba and Kato, 1959a and 1959b). Mafic and ultramafic intrusives such as those of dolerite, gabbro, peridotite and serpentine are often observed in this metamorphic terrain. These intrusive rocks were probably emplaced prior to or during the regional metamorphism. No granitic intrusive can be seen in any part of the metamorphic terrain. The age of the Sanbagawa metamorphism has not been determined, but several geological evidences show that the metamorphism was completed before the deposition of the lower Cretaceous formation.

In low-grade parts of the metamorphic terrain, glaucophane, lawsonite and pumpellyite commonly occur. In January, 1959, the writers found jadeite in crystalline schists and meta-gabbroic rocks in the Sanbagawa metamorphic area of Sibukawa district, Sizuoka Prefecture, central Japan (Fig. 1).

In this paper, the mode of occurrence and mineral assemblages of the jadeite-bearing meta-gabbroic rocks are described and the genesis of the rocks is discussed.



FIG. 1. Map showing the distribution of Sanbagawa metamorphic rocks.

#### OUTLINE OF GEOLOGY

The Sanbagawa crystalline schists in the Sibukawa district were described in detail in other papers (Seki, Aiba and Kato, 1959a and 1959b). This metamorphic area was divided into the following three zones, probably representing progressive mineralogical change (Fig. 2).

- I: Epidote-pumpellyite-actinolite-glaucophane.
- II: Epidote-garnet-actinolite-glaucophane.
- III: Epidote-edenite.

In the first zone, there are some areas elongated parallel to the general trend of the schists where lawsonite and glaucophane are stably associated with epidote and pumpellyite (dotted areas in Fig. 2). This mineral assemblage may represent that of the "lawsonite-pumpellyite-epidote-glaucophane subfacies" defined by Miyashiro and Seki (1958b).

Several masses of mafic and ultramafic intrusives are present in these crystalline schists. The mafic intrusives are gabbroic and doleritic rocks containing olivine, augite and common hornblende. In these rocks, low-grade metamorphic minerals such as glaucophane, chlorite, actinolite, sodic plagioclase, epidote, lawsonite and pumpellyite occur. The ultramafic intrusives are partially serpentinized or chloritized peridotite and serpentinite.

The jadeite-bearing meta-gabbro was found within the serpentinite masses closely associated with the crystalline schists of the lawsonite-pumpellyite-epidote-glaucophane subfacies (triangular marks in Fig. 2).

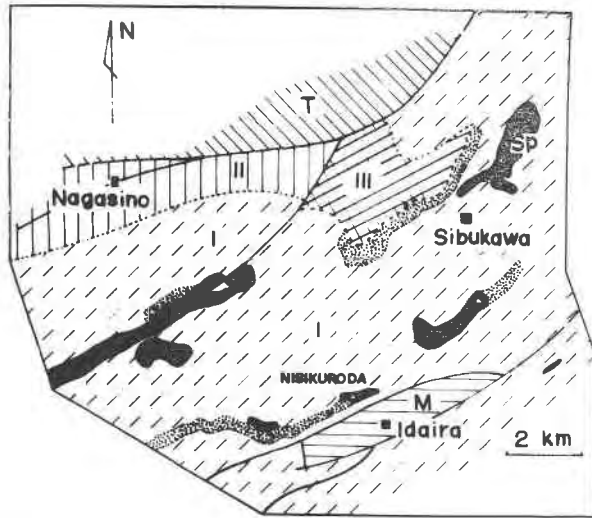


FIG. 2. Metamorphic zoning of the Sanbagawa crystalline schist area in the Sibukawa district.

- I: Epidote-pumpellyite-actinolite-glaucophane.  
 II: Epidote-garnet-actinolite-glaucophane.  
 III: Epidote-edenite.

In the dotted area within Zone I, lawsonite and jadeite occur in crystalline schists. The triangular marks in the serpentinite masses (Sp) represent localities of jadeite-bearing meta-gabbro. Full lines and broken lines represent faults and boundaries between the metamorphic zones respectively.

A detailed geologic map of the south of Nisikuroda is shown in Fig. 3.

M: Mesozoic formation.

T: Tertiary formation.

#### JADEITE-BEARING META-GABBRO

Six exposures of the jadeite-bearing meta-gabbro have been found in this area and there are probably many more, because meta-gabbro is common in the ultramafic masses. The jadeite-bearing meta-gabbro is in all cases completely surrounded by highly sheared and serpentinized ultramafic rocks of lenticular or dike-like form. The maximum width is 10 meters (Fig. 3).

The meta-gabbroic bodies are commonly separated by a slickensided surface from the surrounding serpentinites. However, the writers found an exposure which appears to show an intrusive relation of the gabbro to the serpentinites (Fig. 4).

Granular augite crystals less than 3 mm. in diameter are commonly found in the jadeite-bearing meta-gabbro. The augite, which is the only

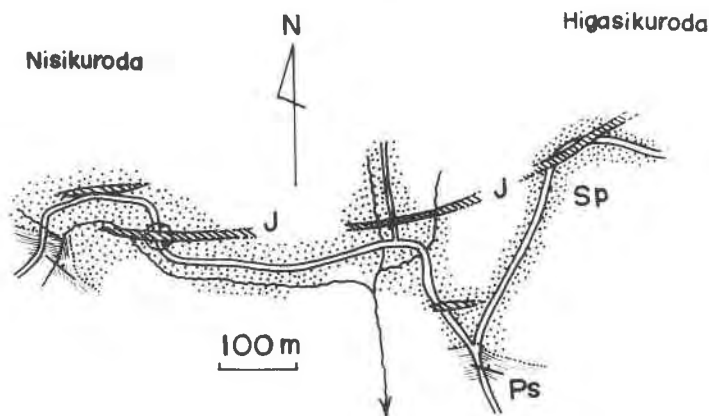


FIG. 3. Geological sketch map showing the distribution of jadeite-bearing meta-gabbro in a serpentinite mass of Nisikuroda-Higasikuroda, Sizuoka Prefecture, Japan.

- J: Jadeite-bearing meta-gabbro.  
 Sp: Serpentinite.  
 Ps: Pelitic schist.

relict mineral, shows weak wavy extinction and has innumerable dust-like inclusions (rutile?). From these features the mineral can be easily distinguished from jadeite, which is clear, and is granular, acicular or lath shaped. The optical properties of the augite are  $\beta = 1.711-1.714$ ,  $(+)$   $2V = 49-55^\circ$ .

All other minerals of the rocks are of metamorphic origin. They are jadeite, pumpellyite, vesuvianite, grossularite, chlorite, lawsonite, sericite, sodic plagioclase, leucoxene, analcite, quartz and calcite. The last three minerals are rare.

The chemical composition and mineral assemblage of one of these rocks are given in Table 1. Its locality is shown in Fig. 4.

Within the jadeite-bearing meta-gabbro, veins or veinlets composed chiefly of jadeite are often found. The veins are mostly from 2 mm. to 5 cm. wide (Fig. 4). It is usually milky white and occasionally pale green. Most jadeite crystals have their  $c$  axis perpendicular to the wall of the veins. The maximum length of the crystals in the direction of  $c$ -axis is approximately 2 cm. In some veins, small amounts of sodic plagioclase, chlorite, analcite, quartz and grossularite are also present besides jadeite.

#### MINERALOGY

##### *Jadeite*

Jadeite is a constituent of the meta-gabbro as well as of the veins. These two kinds of jadeite show no difference in physical properties and

TABLE 1. CHEMICAL COMPOSITION AND MINERALOGICAL ASSEMBLAGE OF JADEITE-BEARING META-GABBRO (F-28) FROM NISIKURODA IN SIZUOKA PREFECTURE, JAPAN (Analysis by C. Kato)

	Wt. %		Wt. %
SiO <sub>2</sub>	43.49	Relic augite	15
Al <sub>2</sub> O <sub>3</sub>	18.52	Pumpellyite	53
Fe <sub>2</sub> O <sub>3</sub>	1.37	Jadeite	15
FeO	3.90	Chlorite	8
MnO	0.64	Lawsonite	3
MgO	8.11	Sodic plagioclase, analcite and quartz	2
CaO	13.45	Sericite	1
Na <sub>2</sub> O	2.34	Leucoxene	3
K <sub>2</sub> O	1.22		
H <sub>2</sub> O+	6.94	Total	100
H <sub>2</sub> O-	0.30		
Total	100.28		

*x*-ray powder data (Tables 2 and 3). The *x*-ray data are practically identical to those given by Yoder (1950) and by Chihara (1958). The chemical composition of the vein jadeite is shown in Table 4. The jadeite of the meta-gabbro is usually acicular and rarely granular. Aggregates of acicular jadeites in random orientation and chlorites are commonly present

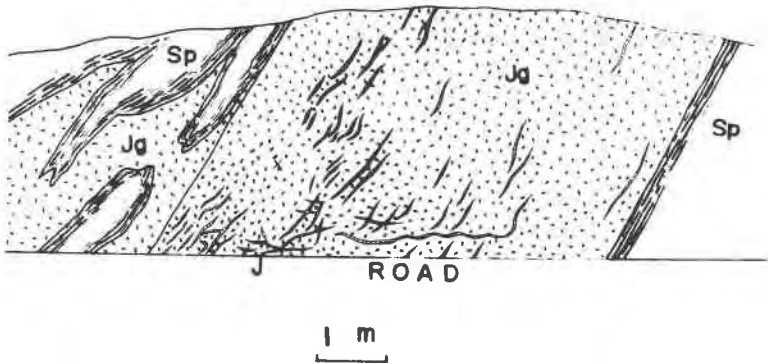


FIG. 4. Sketch of an exposure showing the mode of occurrence of jadeite-bearing meta-gabbro. The location of this exposure is marked with a circle in Fig. 3.

Sp: Serpentine. The marginal part of the serpentinite is strongly sheared and slickensided.

Jg: Jadeite-bearing meta-gabbro.

J: Jadeite-vein.

The cross mark in jadeite-bearing meta-gabbro represents the point from which sample F-28 came. The composition of this sample is shown in Table 1.

TABLE 2. PHYSICAL PROPERTIES OF JADEITES IN META-GABBRO AND IN JADEITE-VEINS FROM NISIKURODA, SIZUOKA PREFECTURE, JAPAN

	Jadeite in metagabbroic rocks	Jadeite in veins
Color to naked eye	Colorless	Colorless to pale green
Specific gravity	Not determined	3.30 ± 0.02
Hardness	Not determined	6.5
Cleavage	{110} good	{110} good
$\alpha$	1.654 ± 0.002	1.656 ± 0.002
$\beta$	1.660 ± 0.002	1.660 ± 0.002
$\gamma$	1.670 ± 0.002	1.668 ± 0.002
Optical orientation	Y = b	Y = b
(+) 2V	69-73°	68-73°
c^Z	36°	37°
Dispersion	r < v	r < v
Pleochroism	No	No

in thin sections of the meta-gabbro. These aggregates were probably formed from the augite of the original rocks.

*Pumpellyite*

The pumpellyite in jadeite-bearing meta-gabbro is always acicular and is colorless in thin section. Its optical and x-ray powder data are shown in Table 5. The optical data show that the pumpellyite is very poor in ferric and ferrous iron (Coombs, 1953; Seki, 1958b).

TABLE 3. X-RAY POWDER PATTERNS OF JADEITE IN META-GABBRO (F-28) OF NISIKURODA, SIZUOKA PREFECTURE, JAPAN

hkl	d(Å)	I	hkl	d(Å)	I
110	6.19	1	330}	2.068	2
020	4.28	2	331}		
021	3.25	0.5	421	2.052	0.5
220	3.10	2	420	1.997	<0.5
221	2.919	7	041	1.966	3
310}	2.835	10	241	1.888	0.5
311}			132}	1.764	1
202	2.533	4	510}	1.683	0.5
002	2.495	3	150		
22 $\bar{1}$	2.416	3	531	1.574	1
312	2.211	2	440	1.552	2
022	2.160	0.5			

Note: Peaks were indexed on the basis of a monoclinic unit-cell with the following dimensions: a = 9.46 Å, b = 8.56 Å, c = 5.25 Å,  $\beta = 72^\circ 34'$ .

Quartz powder was used as an internal standard.

TABLE 4. THE CHEMICAL COMPOSITION AND ATOMIC RATIOS OF JADEITE OCCURRING IN A VEIN IN JADEITE-BEARING META-GABBRO (F-28), NISIKURODA, SIZUOKA PREFECTURE, JAPAN (Analysis by C. Kato)

	Wt. %		Atomic ratios
SiO <sub>2</sub>	59.67	O	6.00
Al <sub>2</sub> O <sub>3</sub>	23.61	Si	2.02
Fe <sub>2</sub> O <sub>3</sub>	0.33	Al	0.94
FeO	0.16	Fe'''	0.01
MnO	0.16	Fe''	0.00
MgO	0.47	Mn	0.00
CaO	0.82	Mg	0.02
Na <sub>2</sub> O	14.24	Ca	0.03
K <sub>2</sub> O	0.71	Na	0.93
H <sub>2</sub> O+	0.13	k	0.03
H <sub>2</sub> O-	0.00		
Total	100.30		

TABLE 5. OPTICAL PROPERTIES AND X-RAY POWDER DATA OF PUMPELLYITE IN JADEITE-BEARING META-GABBROIC ROCK (F-28) FROM NISIKURODA, SIZUOKA PREFECTURE, JAPAN

$$\left. \begin{array}{l} \alpha = 1.676 \pm 0.002 \\ \beta = 1.680 \pm 0.002 \\ \gamma = 1.688 \pm 0.002 \end{array} \right\} \gamma - \alpha = 0.011$$

(+ )  $2V = 16^\circ$   
 $a \wedge X = 16^\circ$ ,  $r < v$ ,  
colorless in thin section.

<i>hkl</i>	<i>d</i> (Å)	I	<i>hkl</i>	<i>d</i> (Å)	I
004	4.74	20	125	2.20	30
111	4.67	20	026	2.16	5
200	4.39	20	224	2.11	10
20 $\bar{2}$	4.19	10	40 $\bar{4}$	2.09	10
005	3.81	40	118	2.07	15
11 $\bar{4}$	3.54	10	027	2.01	10
20 $\bar{4}$	3.45	10	130	1.92	10
10 $\bar{6}$	3.12	10	404	1.89	5
204	3.04	15	119	1.88	5
021	2.91	100	028	1.85	5
20 $\bar{6}$	2.74	45	422	1.69	10
31 $\bar{1}$	2.63	35	318	1.67	10
024	2.51	20	424	1.59	25
312	2.44	30	0.0.12	1.57	20
222	2.32	15	22 $\bar{1}$ 0	1.55	10
315	2.27	15			

TABLE 6. OPTICAL PROPERTIES AND X-RAY POWDER DATA OF THREE VESUVIANITES IN JADEITE-BEARING META-GABBRO FROM NISIKURODA, SIZUOKA PREFECTURE, JAPAN

	I YSMACK59022203		II YSMACK59022204		III YSMACK59022205	
$\gamma$ (+) 2V	1.715 8°		1.720 0°		1.743 17°	
<i>hkl</i>	<i>d</i> (Å)	I	<i>d</i> (Å)	I	<i>d</i> (Å)	I
004	3.06	m	3.08	w	3.06	m
	3.01	m	3.01	s	3.01	m
	2.96	s	2.96	s	2.96	s
	2.91	w	2.90	m	2.93	w
	2.88	w	2.88	w	2.88	m
	2.84	w	2.84	w	2.84	m
440	2.83	w	2.83	w	2.83	w
	2.75	vs	2.76	vs	2.76	vs
600	2.67	m	2.67	m	2.67	m
	2.60	s	2.60	s	2.60	s
	2.56	w	2.56	m	2.56	m
620	2.54	w	2.54	s	2.54	m
	2.46	s	2.47	s	2.47	s
	2.38	m	2.38	m	2.39	m

*Vesuvianite*

Vesuvianite occurs probably in stable association with jadeite, grossularite and chlorite. No vesuvianite was found in lawsonite-bearing portions of the meta-gabbroic rocks. In the meta-gabbro having vesuvianite, pumpellyite is very rare. The vesuvianite usually has tabular or acicular forms with distinct (110) cleavage. The optical and x-ray powder data of some vesuvianites are given in Table 6. Chemical composition of a vesuvianite is shown in Table 7. The vesuvianite of Column 3 in Table 6 has strong brownish pleochroism and extraordinary high refractive indices.

*Grossularite*

Grossularite, always granular in form, occurs in association with jadeite, chlorite and vesuvianite. Its refractive index and unit-cell dimension are as follows:

$$n = 1.732 \pm 0.002$$

$$a = 11.87 \text{ \AA}$$

*Chlorite*

All the jadeite-bearing meta-gabbroic rocks have a considerable amount



of chlorite. The chlorite, judging from the optical properties shown below, may belong to rumpfite or prochlorite.

$$\begin{aligned} \alpha &= 1.585-1.590, & (+) 2V &= 10-12^\circ, \\ \gamma &= 1.592-1.594, & \text{Colorless in thin section.} \end{aligned}$$

### Lawsonite

Lawsonite, tabular in form, is rarely present. It is in stable association with jadeite, pumpellyite and vesuvianite. An attempt to separate pure lawsonite from the host rocks by means of the isodynamic separator and Clerici solution was unsuccessful. The optical properties of the lawsonite are as follows:

$$\begin{aligned} \alpha &= 1.664, & \beta &= 1.675, & \gamma &= 1.686; & \gamma - \alpha &= 0.002 \\ (+) 2V &= 78-84^\circ, & \text{Colorless in thin section,} & & \text{Elongation negative.} \end{aligned}$$

### Other minerals

Small amounts of sodic plagioclase, analcite and quartz are present in the jadeite-bearing meta-gabbro and in the jadeite veins. They usually fill the interstices between jadeite crystals or are developed along their cleavage planes. These silic minerals are easily determined under the microscope and by the  $x$ -ray powder method. It is not clear, however, whether these silic minerals are in stable association with jadeite. Calcite is also observed in some of meta-gabbroic rocks.

TABLE 7. CHEMICAL COMPOSITION OF VESUVIANITE IN JADEITE-BEARING META-GABBRO FROM NISIJURODA, SIZUOKA PREFECTURE, JAPAN

The optical properties and  $x$ -ray powder data of this vesuvianite are represented in Column I in Table 6  
(Analysis by C. Kato)

	Wt. %		Atomic ratio*
SiO <sub>2</sub>	39.77	Si	9.34
TiO <sub>2</sub>	0.47	Ti	0.08
Al <sub>2</sub> O <sub>3</sub>	17.41	Al	4.82
Fe <sub>2</sub> O <sub>3</sub>	3.60	Fe'''	0.63
FeO	0.76	Fe''	0.15
MnO	1.48	Mn	0.29
MgO	0.32	Mg	0.11
CaO	33.39	Ca	8.40
Na <sub>2</sub> O	n.d.	H <sub>2</sub> O	1.83
K <sub>2</sub> O	n.d.		
H <sub>2</sub> O+	2.34		
H <sub>2</sub> O-	0.30		
	99.84		

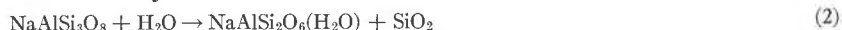
\* Atomic ratio was calculated on the anhydrous basis O=36.

DISCUSSION

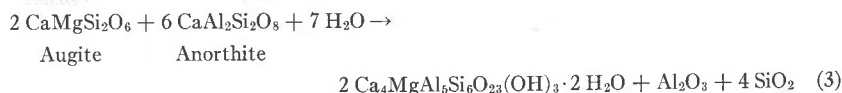
The metamorphic minerals composing the jadeite-bearing meta-gabbro may have been formed by the following chemical reactions:



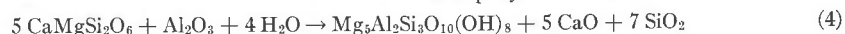
Albite            Jadeite



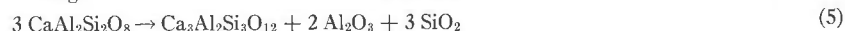
Albite            Analcite



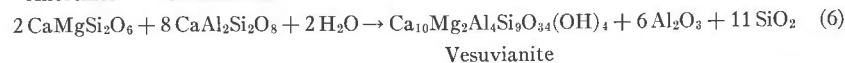
Pumpellyite



Augite            Chlorite



Anorthite        Grossularite



Vesuvianite



Anorthite        Lawsonite

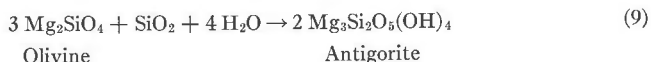


Ilmenite            Leucocoxene

CaO liberated in reaction (4) may have been used by reaction (8) to form leucocoxene from ilmenite. It is also very probable that  $\text{Al}_2\text{O}_3$  liberated in reactions (3), (5) and (6) has been used to form chlorite from augite by reaction (4).

FeO in the right hand side of equation (8) may have entered into chlorite, vesuvianite or pumpellyite.

Some of  $\text{SiO}_2$  liberated in reactions (1), (2), (3), (4), (5) and (6) seems to have been consumed to form leucocoxene from ilmenite. However, most of the liberated silica may have been diffused into the surrounding ultramafic rocks where it was used in the following reaction:



Olivine

Antigorite

If this is true, the chemical composition of the jadeite-bearing rock given in Table 1 should represent that of a desilicated gabbro.

Chemical reactions (2), (3), (4), (6) and (7) involve addition of water. High water pressure (or high chemical potential of water) probably promoted these reactions. The presence of jadeite, analcite, lawsonite, pumpellyite and chlorite suggests that the temperature prevailing during the formation of the jadeite-bearing meta-gabbro was not high. Synthetic experiments of Robertson et al. (1957) showed that jadeite is a

high pressure mineral and that the stable association of jadeite and quartz probably requires pressures higher than 9 kilobars at room and higher temperatures.

In the present case, however, the amount of quartz in the jadeite-bearing rocks and in jadeite-veins is very small and it is not clear whether the quartz is in stable association with jadeite. As has been already stated, the silica liberated by the formation of jadeite from albite may have diffused into the surrounding ultramafic mass. Probably the formation of jadeite in the gabbroic rocks was promoted by this desilication of the host rocks under low temperature and high water pressure conditions. It is hard to believe that high solid pressure was necessary for the formation of jadeite in this case.

Jadeite forming veins is very rare, although Coleman has already reported the occurrence of jadeite-veins in albite-glaucophane-acmite schists of California (Coleman, 1956).

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