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# Sugilite, a new silicate mineral from Iwagi Islet, Southwest Japan

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ABSTRACT

Sugilite occurs as an essential mineral amounting to 3-8 percent by volume in aegirine syenite from Iwagi Islet, Ehime Prefecture. It is associated with albite, aegirine, pectolite and a Ca-K-Ti silicate (a still to be identified mineral). Sugilite is light brownish yellow, luster vitreous, streak white. Symmetry hexagonal. Cleavage 0001 weak. Hardness 6-6$^1/_2$. Specific gravity $2.80_2$ (calc.), 2.74 (meas.).

Under the microscope, it is uniaxial negative with $\varepsilon=1.607$, $\omega=1.610$, $\omega-\varepsilon=0.003$, and colorless.

Estimated chemical composition is $SiO_2$ 71.38, $TiO_2$ 0.51, $Al_2O_3$ 2.97, $Fe_2O_3$ 12.76, FeO 0.19, $Li_2O$ 3.14, $Na_2O$ 4.37, $K_2O$ 3.76, $H_2O(+)$ 0.81, $H_2O(-)$ 0.12, total 100.01%, corresponding ideally to $(K, Na)((H_2O), Na)_2(Fe^{3+}, Na, Ti, Fe^{2+})_2(Li, Al, Fe^{3+})_3(Si_{12}O_{30})$ with $Z=2$.

The unit cell dimensions are $a_0=10.007(2)$, $c_0=14.000(2)$ Å. Space group $D^2_{6h}$—$P6/mcc$. X-ray powder data resemble those for sodgianite, milarite, osumilite, merrihueite, roedderite and brannockite.

It is clear from the above-cited data that sugilite has milarite-type structure and resembles sodgianite and brannockite in containing lithium in tetrahedral site, but it is distinguished by a high content of ferric iron in 6-coordination.

The name is given in honour of the late Professor Ken-ichi Sugi (1901–1948), who first found the occurrence of this mineral with Mr. M. Kutsuna.

## *Introduction*

Sugilite* occurs in the aegirine syenite from Iwagi Islet, Ōchi Gun, Ehime Prefecture, Southwest Japan. It was first found by Sugi and Kutsuna (1944), but they did not identify this mineral and described it as an eudialyte-like mineral mainly by its optical properties. Later, Murakami and Matsunaga (1944, 1966) re-examined this mineral and suggested that this is isostructural with osumilite-milarite group mineral from its X-ray powder data. About its chemistry, however, any satisfactory conclusion had not been reached, although it was roughly known. After about ten years, we investigated this mineral again and finally succeeded in identifying chemically and also structurally.

## *Occurrence*

As previously stated, sugilite occurs in the aegirine syenite which forms a small (0.20×0.15 km) stock-like mass in the late Mesozoic biotite granite at the northeastern part of Iwagi Islet, Ehime Prefecture (Fig. 1). The syenite grades into the granite through quartz syenite and aegirine granite, accompanying small dike-like masses of syenite aplite and syenite pegmatite. It is coarse-grained, hypidiomorphic in texture. The type rock consists of albite ($An_{2.3}Ab_{94.9}Or_{2.8}$) 87.0, aegirine 4.0, pectolite 2.3, sugilite 6.6 percent in volume. Besides these, minor

* The name sugilite has been approved by the Commission on New Mineral Names of the International Mineralogical Association, but the chemical composition of this mineral has been slightly revised.

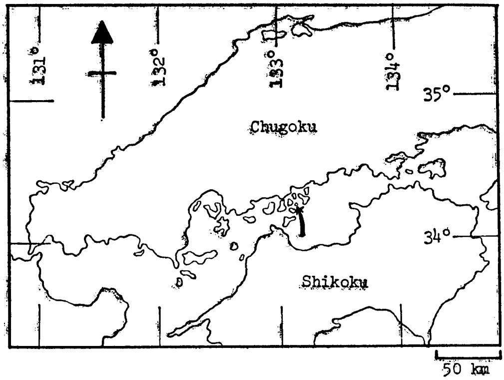


Fig. 1. Showing the locality of sugilite.

amounts of Ca-K-Ti silicate (an unidentified mineral), titanite, allanite, andradite, zircon and apatite are contained as accessory minerals. Occasionally, there are subordinate contents of microcline ($Or_{82.3}Ab_{16.0}An_{1.7}$) and quartz which tend to increase towards the margin (Murakami and Matsunaga, 1966). Table 1 gives the chemical compositions and atomic ratios of the above-cited main constituents.

The syenite is highly heterogeneous in appearance, varying irregularly from melanocratic part to leucocratic part. This heterogeneity and characteristic features in constituent minerals such as chequer structure in albite and mosaic aggregate in aegirine and pectolite together with highly sodic chemical composition of the whole rock lead to the conclusion that the syenite might have been formed through metasomatic process from biotite granite (Murakami and Matsunaga, 1966).

Sugilite is found in the quartz-free syenite part as an essential mineral amounting 3 to 8 percent, and is especially abundant in the albite-rich and aegirine-poor parts. It is absent or negligible in quartz syenite, syenite aplite and syenite pegmatite.

It rarely coexists with epidote and quartz in the small syenite masses distributed near the above-cited aegirine syenite.

Table 1. Chemical compositions and atomic ratios of some constituent minerals in aegirine syenite.

| No. | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.83 | | 51.83 | | 67.82 | | 65.28 | |
| $TiO_2$ | 0.40 | | 0.55 | | — | | — | |
| $Al_2O_3$ | 1.17 | | 0.45 | | 18.89 | | 18.14 | |
| $Fe_2O_3$ | 26.24 | | 0.59 | | 0.69 | | 0.37 | |
| FeO | 3.07 | | 0.18 | | 0.06 | | 0.00 | |
| MnO | 0.90 | | 0.26 | | — | | — | |
| MgO | 1.01 | | 0.02 | | — | | — | |
| CaO | 5.55 | | 33.48 | | 0.48 | | 0.34 | |
| $Na_2O$ | 10.04 | | 8.34 | | 10.99 | | 1.86 | |
| $K_2O$ | 0.08 | | 0.47 | | 0.50 | | 14.46 | |
| $H_2O(+)$ | 0.27 | | 3.11 | | 0.16 | | 0.21 | |
| $H_2O(-)$ | 0.00 | | 0.30 | | 0.00 | | 0.00 | |
| Total | 100.56 | | 99.58 | | 99.59 | | 100.66 | |
| Si | 1.987 | 2.00 (Si+Al) | 5.797 | | 2.992 | | 2.994 | |
| Al | 0.013 | | 0.059 | | 0.982 | | 0.981 | |
| Al | 0.040 | | | 5.95 (Si–Fe³⁺) | | 4.00 (Si–Fe³⁺) | | 3.99 (Si–Fe³⁺) |
| Ti | 0.012 | | 0.046 | | — | | — | |
| $Fe^{3+}$ | 0.757 | | 0.050 | | 0.023 | | 0.013 | |
| $Fe^{2+}$ | 0.098 | 0.99 (Al–Mg) | 0.017 | | 0.002 | | — | |
| Mn | 0.029 | | 0.025 | | — | | — | |
| Mg | 0.058 | | 0.003 | 4.05 (Fe²⁺–Ca) | — | | — | |
| Ca | 0.228 | | 4.009 | | 0.023 | 0.99 (Fe²⁺–K) | 0.017 | 1.03 (Fe²⁺–K) |
| Na | 0.746 | 0.98 (Ca–K) | 1.807 | | 0.940 | | 0.165 | |
| K | 0.004 | | 0.067 | 1.87 (Na+K) | 0.028 | | 0.846 | |
| OH | | | 2.318 | | | | | |

Analyst: N. Murakami (Aegirine and potash feldspar) and S. Matsunaga (Pectolite and albite).

1: Aegirine. 2: Pectolite. 3: Albite. 4: Potash feldspar. Atomic ratios calculated on the basis of 6 (O) in aegirine, 18 (O+OH) in pectolite, and 8 (O) in albite and potash feldspar.

*Chemistry*

Sugilite was separated from the host rock by means of magnetic separator and heavy liquid after sieving of crushed samples under 150 meshes. Minor amounts of pectolite were not completely removed because of its minute size. This was recognized also from X-ray powder data.

Separated specimen was analysed semi-quantitatively by X-ray fluorescence and spectrographic analyses, and nine elements were detected as shown in Table 2. Be and P were checked also by atomic absorption and spectrophotometric methods.

Chemical analyses for major elements were made by chelate titration ($Fe_2O_3$, MgO, CaO, $Al_2O_3$), flame photometry ($K_2O$, $Na_2O$, $Li_2O$), spectrophotometry ($TiO_2$), and gravimetric method ($SiO_2$). $H_2O(+)$ was obtained as loss on ignition for materials derived at 110°C.

Column (a) of Table 2 represents the chemical composition of the sugilite specimen including small amounts of pectolite. Column (b) of Table 2 is estimated composition of pectolite on the assumption that whole amount of CaO in (a) was attributed to the pectolite whose analytical data are given in Table 1; this assumption may be allowed because CaO was not detected in sugilite by electron microprobe analysis. Column (c) of Table 2 indicates the composition of sugilite recalculated into 100 percent after subtracting above-cited pectolite composition. As electron microprobe analyses reveal small compositional variation of K, Na, Al and Fe, it may be appropriate to think that this value is the average one. Atomic ratios calculated on the basis of Si=12.00 and the coordinated position of the atoms are listed in columns (d) and (e) of Table 2, respectively.

As is clearly seen in this table, sugilite is characterized by the high content of ferric iron in 6-coordination and lithium in T(2) site of 4-coordination. Large portion of 12-coordination is occupied by K, while the 9-coordination is presumed to be composed of Na and $H_2O$ with vacancy sites, although the site of $H_2O$ is not precisely confirmed. Infrared spectra show the absence of OH.

Consequently, sugilite is formulated ideally as $(K, Na)^{[12]}((H_2O, Na)_2{}^{[9]}(Fe^{3+}, Na, Ti, Fe^{2+})_2{}^{[6]}(Li, Al, Fe^{3+})_3{}^{[T(2)]}Si_{12}{}^{[T(1)]}O_{30}$.

Table 2. Chemical composition and atomic ratio of sugilite.

| | (a) | (b) | (c) | (d) | | (e) | | |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 69.74 | 4.20 | 71.38 | Si | 12.00 | Si | 12.00 | 12.00 |
| $TiO_2$ | 0.51 | 0.04 | 0.51 | Ti | 0.06 | Li | 2.12 | |
| $Al_2O_3$ | 2.77 | 0.04 | 2.97 | Al | 0.59 | Al | 0.59 | 3.00 |
| $Fe_2O_3$ | 11.77 | 0.05 | 12.76 | $Fe^{3+}$ | 1.61 | $Fe^{3+}$ | 0.29 | |
| FeO | 0.18 | 0.01 | 0.19 | $Fe^{2+}$ | 0.03 | $Fe^{3+}$ | 1.32 | |
| MnO | tr. | 0.02 | 0.00 | Li | 2.12 | Na | 0.59 | |
| MgO | tr. | 0.00 | 0.00 | Na | 1.42 | Ti | 0.06 | 2.00 |
| $Li_2O$ | 2.88 | | 3.14 | K | 0.81 | $Fe^{2+}$ | 0.03 | |
| BeO | nil | | | $H_2O$ | 0.91 | $H_2O$ | 0.91 | |
| CaO | 2.71 | 2.71 | | O | 29.64 | Na | 0.64 | 1.55 |
| $Na_2O$ | 4.69 | 0.68 | 4.37 | | | K | 0.81 | |
| $K_2O$ | 3.49 | 0.04 | 3.76 | | | Na | 0.19 | 1.00 |
| $P_2O_5$ | nil | | | | | | | |
| $H_2O(+)$ | 0.99 | 0.25 | 0.81 | | | | | |
| $H_2O(-)$ | 0.13 | 0.02 | 0.12 | | | | | |
| Total | 99.86 | 8.06 | 100.01 | | | | | |

Analyst: N. Murakami and H. Mitsunaga

(a) : Chemical composition of sugilite with pectolite inclusions.

(b) : Estimated composition of included pectolite calculated on the assumption that whole amount of CaO in (a) was attributed to the pectolite whose composition is given in Table 1.

(c) : Chemical composition of sugilite calculated into 100% after subtracting included pectolite (b).

(d) : Atomic ratios of sugilite on the basis of Si=12.00.

(e) : Coordinated site of atoms in sugilite.

### *X-ray data*

X-ray powder data are indicated in Table 3. As shown in this table, the strongest lines are 6.98(0002), 4.32($20\bar{2}0$), 4.06($11\bar{2}2$), 3.68($20\bar{2}2$), 3.50(0004), 3.19($21\bar{3}1$), 2.876($30\bar{3}0$, $11\bar{2}4$), 2.725($20\bar{2}4$), 2.499($22\bar{4}0$), 2.159 ($40\bar{4}0$), 1.983Å($32\bar{5}0$). X-ray single crystal study gave space group $D^2_{6h}$—$P6/mcc$. The unit cell dimensions determined by Syntex single crystal diffractometer are $a_0$=10.007(2), $c_0$=14.000(2)Å.

Crystal structure analysis has revealed that sugilite is isostructural with osumilite-milarite group minerals. The detailed description of crystal structure of sugilite is given in a separate paper (Kato, Miúra

Table 3. X-ray powder data of sugilite.

| $d_{obs.}$ | $I$ | $d_{cal.}$ | $hkil$ | $d_{obs.}$ | $I$ | $d_{cal.}$ | $hkil$ |
|---|---|---|---|---|---|---|---|
| 8.65 | 7 | 8.67 | $10\bar{1}0$ | 1.983b | 13 | 1.988 | $32\bar{5}0$ |
| 6.98 | 13 | 7.00 | 0002 | 1.890 | 8 | 1.891 | $41\bar{5}0$ |
| 4.78b | 7 | 4.71 | $11\bar{2}1$ | 1.874 | 11 | 1.874 | $41\bar{5}1$ |
| 4.32 | 100 | 4.33 | $20\bar{2}0$ | 1.827b | 8 | 1.829 | $32\bar{5}3$ |
| 4.06 | 57 | 4.07 | $11\bar{2}2$ | 1.820b | 7 | (1.826, 1.815) | ($41\bar{5}2$, $30\bar{3}6$) |
| 3.68 | 13 | 3.68 | $20\bar{2}2$ | 1.757b | 7 | 1.750 | 0008 |
| 3.50 | 24 | 3.50 | 0004 | 1.711b | 8 | 1.707 | $21\bar{3}7$ |
| 3.27 | 7 | 3.28 | $21\bar{3}0$ | 1.666b | 10 | 1.668 | $33\bar{6}0$ |
| 3.25 | 8 | 3.25 | $10\bar{1}4$ | 1.627b | 6 | 1.623 | $20\bar{2}8$ |
| 3.19 | 81 | 3.19 | $21\bar{3}1$ | 1.551b | 7 | (1.557, 1.553) | ($51\bar{6}0$, $50\bar{5}4$) |
| 2.876b | 51 | (2.889, 2.868) | ($30\bar{3}0$, $11\bar{2}4$) | 1.508b | 8 | 1.506 | $33\bar{6}4$ |
| 2.725 | 13 | 2.723 | $20\bar{2}4$ | 1.439 | 7 | 1.444 | $60\bar{6}0$ |
| 2.678b | 11 | 2.681 | $21\bar{3}3$ | 1.420b | 5 | 1.425 | $43\bar{7}0$ |
| 2.499 | 18 | 2.502 | $22\bar{4}0$ | 1.391 | 10 | 1.396 | $43\bar{7}2$ |
| 2.401b | 7 | 2.404 | $31\bar{4}0$ | 1.385 | 5 | 1.388 | $52\bar{7}0$ |
| 2.273b | 6 | 2.273 | $31\bar{4}2$ | 1.364 | 5 | 1.361 | $40\bar{4}8$ |
| 2.231b | 8 | 2.228 | $30\bar{3}4$ | 1.311 | 5 | 1.316 | $61\bar{7}1$ |
| 2.159 | 13 | 2.167 | $40\bar{4}0$ | 1.200 | 5 | 1.202 | $62\bar{8}0$ |

CuK$\alpha$, 32kV, 15 mA, 8-2-1, 1°/2 min., 1°-1°-0.15°. b: broad.

and Murakami, 1976).

### *Optical and physical properties*

Under the microscope, sugilite occurs as aggregates of several grains, and sometimes as isolated subhedral to anhedral crystals. The size of the aggregates reaches 4 mm in maximum, although the individual grains are less than 0.2 mm across. Minute grains of pectolite, albite and aegirine are sporadically present. Sugilite is almost colorless but alters often to a yellowish brown dusty mineral* along its periphery and cleavage plane near the surface of exposure. This alteration tends to become prominent in aegirine-rich parts.

Weak (0001) cleavages are observed, habit being tabular parallel to the cleavage plane.

Sugilite is light brownish yellow in color to the naked eye, bu tbecomes greenish by alteration and/or weathering. The crystal is uniaxial negative with $\varepsilon=1.607$, $\omega=1.610$, and characterized by very weak birefringence $\omega-\varepsilon=0.003$, as noted by Sugi and Kutsuna (1944) and

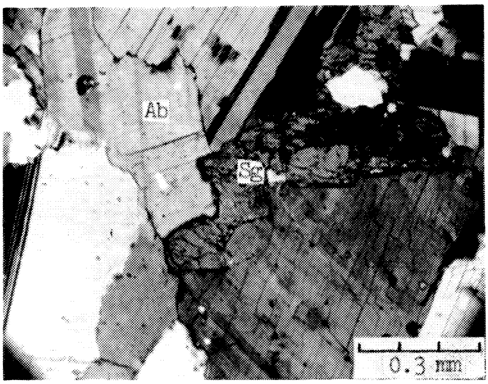


Fig. 2. Microphotograph of sugilite
Sg: Sugilite. Ab: Albite.

* According to the electron probe microanalysis, this mineral is high in Fe and Al and low in Si, suggesting a mica group mineral.

Taneda (1952).

The specific gravity measured by a suspension method using Thoulet's solution is 2.74 (Murakami and Matsunaga, 1966), while the calculated value is $2.80_2$.

Hardness (Mohs) is 6–6$^1/_2$. Luster is vitreous and streak is white.

*Comparison of sugilite with other osumilite-milarite group minerals*

As listed by Forbes *et al.* (1972), several minerals belonging to osumilite-milarite group have been found up to present. Recently, White *et al.* (1973) added a new mineral 'brannockite' to this group. Among these sugilite has a close resemblance to sodgianite (Dusmatov *et al.*, 1968), but it differs from the latter in lacking Zr and containing high content of $Fe^{3+}$. Brannockite also resembles sugilite in containing Li in tetrahedral site [T(2)] as shown in Table 5.

These three minerals have also similar unit cell dimensions, specific gravities and optical properties as given in Tables 4 and 6. They possibly constitute a subgroup separated from other minerals in which the tetrahedral site [T(2)] is occupied mainly by Mg, $Fe^{2+}$, Be and Al, and octahedral site by Mg, $Fe^{2+}$ and Ca.

Table 4. Unit cell dimensions and specific gravities of natural milarite-type minerals.

| | *a*(Å) | *c*(Å) | s. g. | References |
|---|---|---|---|---|
| Sugilite | 10.007 | 14.000 | 2.802 | |
| Sodgianite | 10.09 | 13.98 | 2.90 | Dusmatov *et al.*, 1968 |
| Brannockite | 10.0167 | 14.2452 | 3.08 | White *et al.*, 1973 |
| Milarite | 10.40 | 13.80 | 2.57 | Bakakin *et al.*, 1974 |
| Osumilite | 10.17 | 14.34 | 2.64 | Miyashiro, 1956 |
| Roedderite | 10.139(1) | 14.275(1) | 2.63 | Fuchs *et al.*, 1966 |
| Merrihueite | 10.16(6) | 14.32(6) | 2.87 | Dodd *et al.*, 1965 |
| Yagiite | 10.09(1) | 14.29(3) | 2.70 | Bunch & Fuchs, 1969 |
| Armenite | 10.69 | 13.90 | 2.76 | Tennyson, 1960 |

Table 5. Chemical compositions of natural milarite-type minerals.

| | A[6] | B[9] | C[12] | D[18] | $T_2$[4] | $T_1$[4] | References |
|---|---|---|---|---|---|---|---|
| Sugilite | $Fe^{3+}$, Na, Ti, $Fe^{2+}$ | $H_2O$, Na | K, Na | | Li, Al, $Fe^{3+}$ | Si | |
| Sodgianite | Zr, $Fe^{3+}$, Ti, $Fe^{2+}$ | Na, K | K | | Li, Al, $Fe^{3+}$ | Si | Dusmatov *et al.*, 1968 |
| Brannockite | Sn | | K, Na | | Li | Si | White *et al.*, 1973 |
| Milarite | Ca, Sr, Mn, $Fe^{2+}$ | Na, K, $H_2O$ | K, Na | | Be, Al, $Fe^{3+}$ | Si, Al | Olsen & Bunch, 1970 |
| Osumilite | Mg, $Fe^{2+}$, Mn | | K, Na, Ca | | Al, $Fe^{3+}$ | Si, Al | Olsen & Bunch, 1970 |
| Roedderite | Mg, $Fe^{2+}$ | Na | K, Na | | Mg | Si, Al, Mg | Fuchs *et al.*, 1966 |
| Merrihueite | $Fe^{2+}$ | Na | K, Ca | | $Fe^{2+}$, Mg | Si | Dodd *et al.*, 1965 |
| Yagiite | Mg | Na | Na, K | | Al, Mg, $Fe^{2+}$, Ti | Si, Al | Bunch & Fuchs, 1969 |
| Armenite | Ca | Na, K, $H_2O$ | Ba | $H_2O$ | Al | Si, Al | Neumann, 1941 |

Table 6. Optical properties of natural milarite-type minerals.

| | $\omega$ | $\varepsilon$ | $\omega-\varepsilon$ | Optic sign | Color in thin section | Color | References |
|---|---|---|---|---|---|---|---|
| Sugilite | 1.610 | 1.607 | 0.003 | − | colorless | yellow | |
| Sodgianite | 1.608 | 1.606 | 0.002 | − | colorless | elegant violet | Dusmatov *et al.*, 1968 |
| Brannockite | 1.567 | 1.566 | 0.001-0.002 | − | colorless | | White *et al.*, 1973 |
| Milarite | 1.532 | 1.529 | 0.003 | − | colorless | pale green to colorless | Winchell, 1951 |
| Osumilite | 1.546 | 1.550 | 0.004 | + | $\omega$=light blue, $\varepsilon$=colorless | dark blue | Miyashiro, 1956 |
| Roedderite | 1.537 | 1.542 | 0.005 | + | colorless | colorless | Fuchs *et al.*, 1966 |
| Merrihueite | 1.559 ～ 1.592 | | | | colorless | greenish blue | Dodd *et al.*, 1965 |
| Yagiite | 1.536 | 1.544 | 0.008 | + | $\omega$=very light blue, $\varepsilon$=colorless | | Bunch & Fuchs, 1969 |
| Armenite | $\alpha=1.551$, $\beta=1.559$, $\gamma=1.562$ | | $\gamma-\alpha=0.011$ | | colorless | colorless or green | Neumann, 1941 |

### *Name and type specimen*

The name sugilite is given in honour of the late Professor Ken-ichi Sugi (1901-1948), an eminent petrologist, who first found the occurrence of this mineral with Mr. M. Kutsuna.

Type specimen will be deposited at Yamaguchi University, National Museum, Tokyo, Sakurai Museum, Tokyo and U. S. National Museum, Washington, D. C.

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