

Sugilite in manganese silicate rocks from the Hoskins mine and Woods mine, New South Wales, Australia

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Abstract

Sugilite relatively rich in manganese has been found at two new localities, the Hoskins and Woods mines in New South Wales, Australia. The occurrences are in manganese-rich silicate rocks of middle to upper greenschist facies (Hoskins mine) and hornblende hornfels facies (Woods mine). Coexisting minerals are members of the namansilite-aegirine and pectolite-serandite series, Mn-rich alkali amphiboles, alkali feldspar, braunite, rhodonite, tephroite, albite, microcline, norrishite, witherite, manganian calcite, quartz, and several unidentified minerals. Woods mine sugilite is colour-zoned with pale mauve cores and colourless rims, whereas Hoskins mine sugilite is only weakly colour-zoned and pink to mauve. Within single samples, the chemical compositions of sugilite from both localities show wide ranges in Al contents and less variable ranges of Fe and Mn, similar to trends in sugilite from other localities. The refractive indices and cell dimensions tend to show systematic increases progressing from Al-rich to Fe-Mn-rich. The formation of the sugilite is controlled by the high alkali (especially Li) and manganese contents of the country rock, reflected in the occurrences of coexisting high alkali- and manganese-bearing minerals, and by high f_{O_2} conditions.

KEYWORDS: sugilite, manganese silicate rocks, milarite group, New South Wales, Australia

Introduction

SUGILITE, an uncommon hexagonal double-ring silicate, is a member of the milarite group of minerals (Kato *et al.*, 1976; Hawthorne *et al.*, 1991), and was first reported from an alkali syenite by Murakami *et al.* (1976). According to Armbruster and Oberhänsli (1988), it has an ideal formula of

$Na_2K(Fe^{3+}, Mn^{3+}, Al)_2Li_3Si_{12}O_{30}$. Careful analyses of sugilite and other members of the milarite group, however, often show the presence of water (Murakami *et al.*, 1976; Kato *et al.*, 1976; Černý *et al.*, 1980). It has subsequently been recorded from metamorphosed manganese silicate-oxide rocks (Dunn *et al.*, 1980; Clark *et al.*, 1980; Dixon, 1985, 1989; Hirowatari and Fukuoka,

1988; Cabella *et al.*, 1990; Armbruster *et al.*, 1993). Although the initial occurrence in syenite was Mn-free, sugilite reported from manganese deposits is Mn-bearing and coexists with other Mn- and alkali-bearing minerals.

We describe the first two recorded occurrences of sugilite in Australia. Both occurrences are within metamorphosed manganese silicate rocks and conform with what now appears to be a typical paragenesis for the mineral.

Geologic setting

Hoskins mine. The abandoned Hoskins mine is 3 km west of Grenfell in central-western New South Wales (UTM grid reference: FC039489). Regionally metamorphosed manganese silicate and oxide rocks were described by Ashley (1986, 1989), and occur within a late Ordovician sequence metamorphosed to middle to upper greenschist facies. Manganese-rich rocks were interpreted to have been chemical sediments formed by hot spring activity on the sea floor (Ashley, 1986, 1989). Two distinctive bedded facies of Mn-rich rocks are recognized: one a reduced assemblage of Mn²⁺-bearing silicates and carbonates, hausmannite, quartz and barite, the other an oxidized assemblage of apparently unique nature (Ashley, 1986). The latter contains Mn³⁺-bearing alkali-amphibole and clinopyroxene (aegirine–namansilite solid solution) (Eggleton and Ashley, *in press*), and norrishite (KMn₂³⁺LiSi₄O₁₂) (Eggleton and Ashley, 1989) among others. It is within the oxidized Mn-rich rocks that sugilite has been found.

Woods mine. Woods mine, 30 km NNE of Tamworth, New South Wales (UTM grid reference: LL099906) is within rocks of the Anaiwan Terrane of late Devonian–Carboniferous age (Brown *et al.*, 1992). The rocks of this terrane, dominated by siliceous mudstone and chert, represent a deformed subduction complex. The mine is within a few hundred metres of the early Permian Glenclair Adamellite. The deposit, worked for ornamental rhodonite, consists of steeply-dipping pod-shaped manganese silicate-rich masses up to a few metres across and 10 m long enclosed in chert and mudstone, thermally metamorphosed to hornblende hornfels facies. The mineral assemblage includes namansilite (Kawachi and Coombs, 1993), Mn-rich alkali amphibole (Kawachi, 1991), serandite (Kawachi, 1987), braunite, quartz, aegirine, hausmannite, tephroite, barite and apatite. The Mn-rich rocks of Woods mine are also interpreted as representing submarine exhalative chemical sediments (e.g. Brown *et al.*, 1992).

Description of sugilite occurrences

Hoskins mine. Although not common, sugilite occurs in the oxidized Mn-rich rocks and individual samples may contain as much as 25 vol.% of the mineral. It is medium- to coarse-grained, forming aggregates up to 1.5 cm in width, with individual grains attaining 7 mm in length. It is translucent deep pink to mauve and vitreous to subvitreous. Most fracture surfaces are irregular to sub-conchoidal. Bladed and tabular mineral growth is parallel to foliation and scattered poikiloblasts are commonly wrapped by folia rich in amphibole or clinopyroxene; the latter minerals are the typical inclusions within poikiloblasts.

In thin-section, sugilite is seen to be pale pink to mauve, displaying weak colour zoning within grains, and showing pleochroism to slightly paler and darker shades. The mineral is uniaxial negative with $\omega = 1.584(2)$, $\epsilon = 1.582(2)$ and it has a moderately developed cleavage parallel to *c*. It is intergrown in apparent equilibrium with namansilite (62–95 mol. % NaMn³⁺Si₂O₆), Mn-rich alkali amphibole, manganian pectolite–serandite, tephroite, barite, quartz, microcline, albite, witherite and manganian calcite, uncommon flakes of norrishite, and braunite. Along cleavages and fractures and in broad turbid patches, the sugilite is altered to aggregates of fine-grained (typically <0.02 mm) pale pink to mauve manganian aegirine (13–34 mol.% NaMn³⁺Si₂O₆).

Woods mine. The sugilite at Woods mine occurs very sparsely as aggregates a few millimetres in diameter in a band rich in namansilite, Mn-rich alkali amphibole, braunite, and serandite, and is commonly accompanied by albite and an unidentified white Mn-rich silicate mineral that rapidly changes to brown upon exposure to the air. The sugilite has a striking mauve colour. Under the microscope, individual sugilite crystals are seen to be well crystallized and euhedral, hexagonal in cross-section, with a maximum width of 100 μ m and not more than a few hundred μ m in length. A weak cleavage is developed parallel to *c*. The mineral is colour-zoned with sharp boundaries between weakly pleochroic pale mauve cores and colourless rims 20 μ m or less in thickness. The refractive indices for cores are $\omega = 1.584(2)$ and $\epsilon = 1.582(2)$; those of the rims are marginally higher. The sugilite crystals are commonly embedded in aggregates of fibrous albite as much as a few millimetres in width, but are locally included in clear granular albite. The albite in turn is surrounded by the unidentified white Mn-rich silicate mineral. Unlike at the Hoskins

mine, there is no evidence of alteration of the sugilite.

Chemical and X-ray data

Sugilite was analysed for major elements other than Li with an automated JEOL 8600 wavelength-dispersive electron microprobe at the Geology Department, University of Otago, at 15 kV and 20 nA probe current with standard ZAF data reduction procedures. Lithium was determined on a hand-picked concentrate of Hoskins mine sample 820993 by atomic absorption spectroscopy after dissolving the sample in HF/HClO₄. The L.O.I. was determined on the same sample by heating in an electric furnace at 1000°C for 1 hr. If the oxidation state of Mn and Fe was unaffected

by this treatment, it implies that 0.42 wt.% H₂O was present. If any Mn or Fe were converted to higher oxidation states, the L.O.I. figure will underestimate the H₂O content. The sugilite sample from Woods mine OU63701 was checked for V, As, Zn, Cu, Sr and F with the electron microprobe, but none was found above the detection limits. The analyses are shown in Table 1. Cation proportions are calculated on the basis of O=28.5 where Li analyses are not available, and O=30 where available. Cation totals are close to the theoretical value of 17 (O=28.5) or 20 (O=30) for Hoskins sugilite, whereas they are invariably less than 17 (O=28.5) for Woods mine sugilite.

Sugilite from both localities shows a wide compositional range, even within a single

TABLE 1. Electron microprobe analyses of sugilite from Hoskins and Woods mines, NSW, Australia

Locality No.	Hoskins mine 820993		Hoskins mine 820994		Woods mine OU63701 core		Woods mine OU63701 rim	
	mean (n=17)	range	mean (n=18)	range	mean (n=19)	range	mean (n=15)	range
SiO ₂	71.50	70.93–72.43	71.66	70.99–72.64	73.34	72.26–74.13	73.13	72.63–74.96
Al ₂ O ₃	3.59	2.72–5.36	4.88	3.82–6.05	7.14	4.69–8.77	5.76	4.38–7.08
TiO ₂	<0.07		0.11	<0.07–0.38	0.13	0.05–0.35	0.84	0.41–1.22
Fe ₂ O ₃ *	5.48	3.26–7.34	4.32	3.27–5.47	3.27	1.46–6.64	6.07	4.54–7.04
Mn ₂ O ₃ *	3.19	2.35–3.99	3.61	2.23–4.41	1.47	0.30–3.17	0.08	n.d.–0.15
Na ₂ O	6.09	5.74–6.43	6.10	5.28–6.49	5.87	5.44–6.29	5.66	5.30–6.12
K ₂ O	4.97	4.79–5.18	4.57	4.39–4.70	4.60	4.11–4.75	4.58	4.20–4.70
BaO	0.75	<0.03–1.65	<0.06	<0.06–0.14	tr		n.d.	
Li ₂ O [#]	3.67		n.a.		n.a.		n.a.	
L.O.I.	0.42		n.a.		n.a.		n.a.	
Total	99.66		95.25		95.82		96.12	
	O=30		O=28.5		O=28.5		O=28.5	
Si	12.095		12.018		12.047		12.043	
Al	0.716		0.965		1.382		1.118	
Ti			0.014		0.016		0.104	
Fe ³⁺	0.697		0.545		0.404		0.752	
Mn ³⁺	0.411		0.461		0.184		0.010	
Na	1.997		1.983		1.870		1.807	
K	1.072		0.978		0.964		0.962	
Ba	0.050							
Li	2.499							
OH	0.479							
Total	20.016		16.964		16.867		16.796	

tr = trace; n.a. = not analysed; n.d. = not detected.

* Determined by atomic absorption spectroscopy.

L.O.I. determined after heating at 1000°C for 1 hr.

Numbers preceded by OU designate those belong to Geology Department collection of the University of Otago. Numbers without OU are in the collection of the Department of Geology & Geophysics at the University of New England.

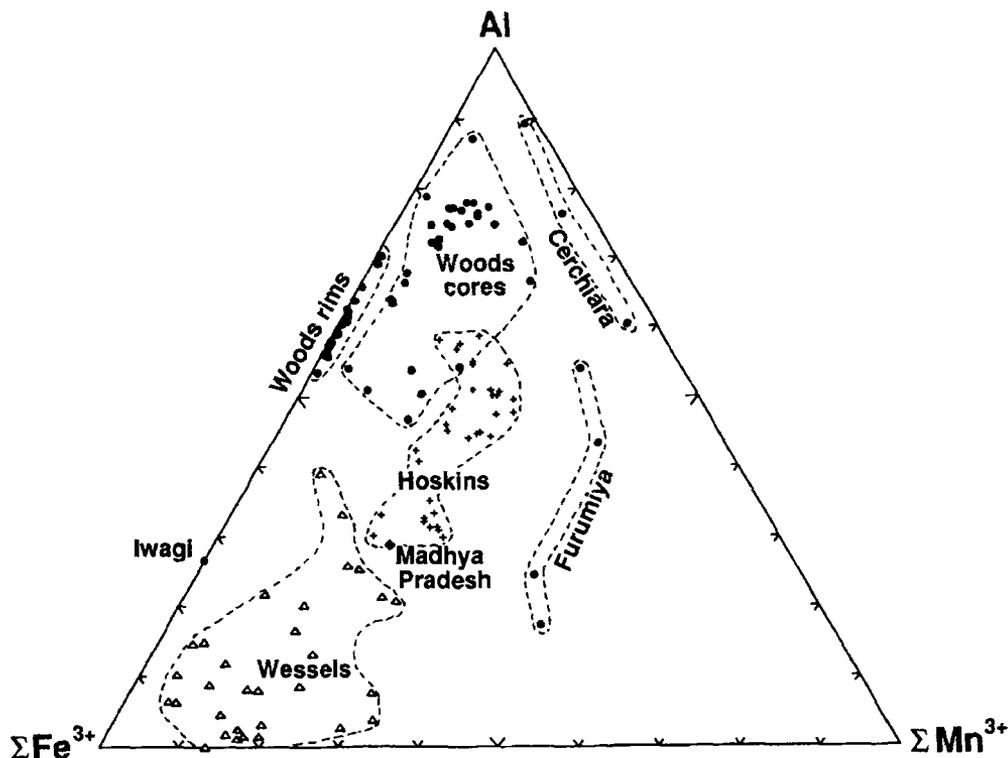


FIG. 1. Atomic Al- Σ Fe- Σ Mn diagram for sugilite from various localities. Data sources: Cerchiara (Cabella *et al.*, 1990), Furumiya (Hirowatari and Fukuoka 1988), Hoskins (820993 and 820994, this paper), Iwagi (Murakami *et al.*, 1976), Madhya Pradesh (Clark *et al.*, 1980), Wessels (Dunn *et al.*, 1980; Dixon, 1985, 1989; Armbruster *et al.*, 1993), and Woods cores and rims (OU63701, this paper). Two analyses (Nos. 25 and 26 from Wessels mine; Dixon, 1989) were excluded from the plot as No. 25 was well outside the range of other analytical results, and No. 26 was incomplete.

specimen. The TiO_2 is low for Hoskins material and cores of Woods sugilite, but higher in grain rims from the latter. Manganese contents, expressed as Mn_2O_3 , are conspicuously high in Hoskins material, but are generally lower in Woods sugilite, especially in the rims. The BaO is consistently detected from the Hoskins mine sample 820993, but is close to or below the detection limit in Hoskins mine sample 820994 and in Woods material. In terms of atomic Al, Σ Fe, and Σ Mn (Fig. 1), analyses of sugilites from both Hoskins and Woods mines show wide variation. Woods mine sugilite rims show, however, a narrower compositional range than the cores. High-Al cores are matched with high-Al rims, and vice versa, and the rims tend to be richer in Fe and poorer in Al than the cores. The Li_2O content of 3.67% in 820993 (Hoskins mine) falls in

the known range of 2.54% (Madhya Pradesh) (Clark *et al.*, 1980) to 4.40% (Wessels mine) (Armbruster *et al.*, 1993).

Powder X-ray diffraction data of sugilite for both localities were compiled from replicate charts obtained by Philips diffractometer at 50 kV and 20 mA using filtered Cu-K α radiation with monochromator. The chart speed employed was 1°/min. Varying quantities of quartz impurity were used as internal standards. Cell dimensions were calculated using Sakae's program (1986) on 13 preferred diffraction lines having $I > 3$ out of 18 indexed atomic planes between 5 and 69 degrees 2 θ .

The cell data for Hoskins sugilite 820994 are $a(\text{\AA}) = 10.005(6)$, $c(\text{\AA}) = 14.04(2)$, $V(\text{\AA}^3) = 1217(2)$, and that of Woods mine OU63701 are $a(\text{\AA}) = 9.941(7)$, $c(\text{\AA}) = 14.058(7)$, $V(\text{\AA}^3) = 1203(4)$.

Discussion

Available analyses from various localities plotted in Fig. 1 show a wide compositional range for sugilite. Compositions from the same locality tend to spread along a zone of restricted Fe-Mn ratios, and Cabella *et al.* (1990) reported a reciprocal relationship between Mn_2O_3 and Al_2O_3 contents for low- Fe_2O_3 sugilite from Cerchiara mine. A similar reciprocal relationship is seen by the spread of analyses for more Mn- and Fe-rich Furumiya mine sugilite (Hirowatari and Fukuoka, 1988) and the still more Fe-rich Wessels mine sugilite (Dunn *et al.*, 1980; Dixon, 1985, 1989; Armbruster *et al.*, 1993). For Furumiya mine and Wessels mine sugilite, as well as sugilite from Hoskins and Woods mines, a reciprocal relation between atomic Al and ($\Sigma Fe + \Sigma Mn$) is displayed in Fig. 1.

Where total Fe and Mn are expressed in a divalent state, the calculated totals of cation proportions for Woods material are either close to, or slightly above, the theoretical 17 atoms per formula unit. For about two-thirds of the analyses, some Fe^{3+} is required by calculations using the method of Droop (1987) to satisfy the theoretical total cation number of 17, whereas the rest are at or close to 17 with all Fe as Fe^{2+} . There is no difference in the amount of calculated Fe^{3+} between core and rim compositions of the Woods mine material. The appearance or non-appearance of calculated Fe^{3+} is very sensitive to the analytical accuracy, and furthermore all sites may not be fully occupied, but the trend is consistent with the relative oxidation state of the host rocks, i.e. the Hoskins mine oxidized assemblage would have a higher bulk Mn^{3+}/Mn^{2+} (in addition to having all its iron as Fe^{3+}) than the Woods mine assemblage. Colour and associated minerals with Fe^{3+} and Mn^{3+} imply that at least some of the Mn and most or all of the Fe will be in a trivalent oxidation state.

Sugilites from the Cerchiara, Furumiya, and Wessels mines give cation proportion totals greater than the theoretical 17 for $O = 28.5$, even after all the Fe is cast as Fe_2O_3 . This is indicative that in these cases also at least some Mn must be in the trivalent state. Sugilite from Madhya Pradesh is similar in composition to that from Hoskins mine, and only some Fe is required to be in the Fe^{3+} state to satisfy the theoretical cation total. An estimate of Fe^{2+}/Fe^{3+} (and Mn^{2+}/Mn^{3+}) of the sugilite (Droop, 1987) from microprobe analysis may indicate the oxidation state of sugilite-bearing host rocks.

Whereas the original type sugilite has $Fe > Al$ ($\gg Mn$), Woods mine and Hoskins mine sugilites, like that from Cerchiara, have $Al > Fe$, and in

some Furumiya specimens Mn is the most abundant of these three elements, suggesting that the known range represents three end-member species. However, it is not clear whether all Al, Fe and Mn are in the *A* octahedral sites; some Al in particular could well be in *T* sites if these are not fully occupied by Li (Hawthorne *et al.*, 1991). To date, Mn-rich sugilite plotting close to the Mn apex in Fig. 1 has not been reported.

The reciprocal relationship between the amounts of atomic Ca and Mn reported by Cabella *et al.* (1990) was not observed for the Hoskins and Woods materials as no detectable Ca was found in sugilite from either locality.

For the reported compositions of Mn-poor to moderately Mn-rich sugilites, a relationship between the reported *a* cell dimension and composition is shown in Fig. 2. The reported *a* decreases from Al-poor, Fe-rich to Al-rich, Fe-poor from Wessels mine (10.040 Å), through Iwagi (10.007 Å), Hoskins mine (10.005 Å), Madhya Pradesh (10.002 Å), Cerchiara (9.986 Å), and Furumiya mine (9.977 Å), to Woods mine (9.941 Å). The trend conforms with the difference in ionic radii of Al and Fe^{3+} . No consistent relationship exists between chemical compositions and *c* cell dimension. The refractive indices also tend to decrease from Al-poor, Fe-rich to Al-rich, Fe-poor (Fig. 3). Again, this is in general consistent with the Gladstone-Dale specific refractivity relations of Al (0.207), Fe (0.268), and Mn (0.301) (Jaffe, 1988). The alkali-rich environment in which sugilite occurs is shown by the occurrences of a

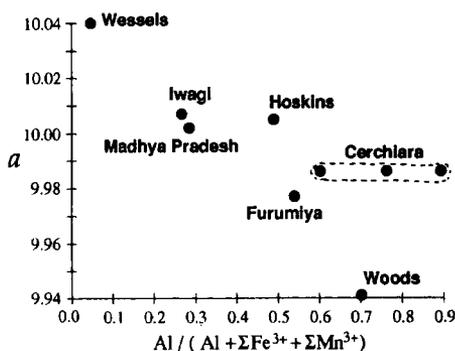


FIG. 2. Relationship between *a* (Å) and atomic Al/(Al + ΣFe^{3+} + ΣMn^{3+}) for sugilite from various localities. Data sources: Cerchiara (Cabella *et al.*, 1990), Furumiya (Hirowatari and Fukuoka, 1988), Hoskins (820994, this paper), Iwagi (Murakami *et al.*, 1976), Madhya Pradesh (Clark *et al.*, 1980), Wessels (Dunn *et al.*, 1980), and Woods cores and rims (OU63701, this paper).

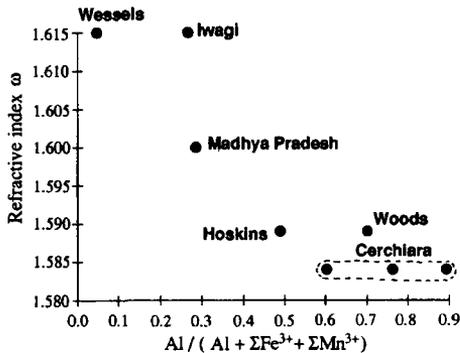


FIG. 3. Relationship between ω and atomic $Al/(Al + \Sigma Fe^{3+} + \Sigma Mn^{3+})$ for sugilite from various localities. Data sources: Cerchiara (Cabella *et al.*, 1990), Furumiya (Hirowatari and Fukuoka, 1988), Hoskins (820994, this paper), Iwagi (Murakami *et al.*, 1976), Madhya Pradesh (Clark *et al.*, 1980), Wessels (Dunn *et al.*, 1980), and Woods cores and rims (OU63701, this paper).

variety of alkali-bearing minerals such as namansilite-aegirine, Mn-rich alkali amphibole, serandite, alkali feldspar, and in the case of the Hoskins mine, norrishite. The host rock to sugilite in sample 820994, for example, contains 1100 ppm Li. High f_{O_2} conditions are indicated by the occurrences of the above Fe^{3+} - and Mn^{3+} -bearing minerals, as well as braunite.

Conclusions

Manganese-bearing sugilite has been found at the Hoskins mine and Woods mine, in New South Wales, Australia. Chemical compositions of the mineral from both localities have wide ranges as shown on an atomic $Al-\Sigma Fe-\Sigma Mn$ diagram (Fig. 1). In this, analytical points spread along a restricted range of Fe/Mn for each locality, but range from Fe dominant to Al dominant. This is also the case for sugilites from other localities. For moderately Mn-rich sugilites, the a cell dimensions (Fig. 2) and refractive indices (Fig. 3) show a regular decrease from Al-poor, Fe-rich members to Al-rich, Fe-poor members. The formation of manganese-bearing sugilite is controlled by high alkali (including Li) and Mn contents of the rocks and high f_{O_2} above the hematite-magnetite buffer as shown by occurrences of unusual combinations of coexisting minerals including namansilite-aegirine, Mn-rich alkali amphibole, serandite, alkali feldspar, braunite, and in the case of Hoskins mine, norrishite.

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References

- Armbruster, T. and Oberhänsli, R. (1988) Crystal chemistry of double-ring silicates: Structure of sugilite and brannockite. *Amer. Mineral.*, **73**, 595–600.
- Armbruster, T., Oberhänsli, R. and Kunz, M. (1993) Taikanite, $BaSr_2Mn_2^{3+}O_2[Si_4O_{12}]$, from the Wessels mine, South Africa: A chain silicate related to synthetic $Ca_3Mn_2^{3+}O_2[Si_4O_{12}]$. *Amer. Mineral.*, **78**, 1088–95.
- Ashley, P. M. (1986) An unusual manganese silicate occurrence at the Hoskins mine, Grenfell district, New South Wales. *Austr. J. Earth Sci.*, **33**, 443–56.
- Ashley, P. M. (1989) Geochemistry and mineralogy of tephroite-bearing rocks from the Hoskins manganese mine, New South Wales, Australia. *Neues Jahrb. Mineral. Abh.* **161**, 85–111.
- Brown, R. E., Brownlow, J. W. and Krynen, J. P. (1992) Manilla-Narrabri 1:250000 Metallogenic Map SH/56-9, SH/55-12: Metallogenic Study and Mineral Deposit Data Sheets. Geological Survey of New South Wales, Sydney. 319 pp.
- Cabella, R., Lucchetti, G. and Palenzona, A. (1990) Al-rich, Fe-poor manganese sugilite in a pectolite-bearing assemblage from Cerchiara Mine (Northern Apennines, Italy). *Neues Jahrb. Mineral. Mh.*, **10**, 443–8.
- Černý, P., Hawthorne, F. C. and Jarosewich, E. (1980) Crystal chemistry of milarite. *Can. Mineral.*, **18**, 41–57.
- Clark, A. M., Bearne, G. S., Fejer, E. E., Din, V. K. and Couper, A. G. (1980) Additional data on sugilite. *Mineral. Mag.*, **43**, 947–9.
- Dixon, R. D. (1985) Sugilite and associated minerals from Wessels mine, Kalahari manganese field. *Trans. Geol. Soc. S. Africa*, **88**, 11–17.
- Dixon, R. D. (1989) Sugilite and associated metamorphic silicate minerals from Wessels mine,

- Kalahari manganese field. *Bull. Geol. Surv. S. Africa*, **93**, 1–47.
- Droop, G. T. R. (1987) A general equation for estimating Fe^{3+} concentrations in ferromagnesian silicates and oxides from microprobe analyses, using stoichiometric criteria. *Mineral. Mag.*, **51**, 431–5.
- Dunn, P. J., Brummer, J. J. and Belsky, H. (1980) Sugilite, a second occurrence: Wessels mine, Kalahari manganese field, Republic of South Africa. *Can. Mineral.*, **18**, 37–9.
- Eggleton, R. A. and Ashley, P. M. (1989) Norrishite, a new manganese mica, $\text{K}(\text{Mn}_2^3\text{Li})\text{Si}_4\text{O}_{12}$, from the Hoskins mine, New South Wales, Australia. *Amer. Mineral.*, **74**, 1360–7.
- Eggleton, R. A. and Ashley, P. M. (1994) Namansilite, $\text{NaMn}^{3+}\text{Si}_2\text{O}_6$ pyroxene, from the Hoskins mine, New South Wales, Australia. *Neues Jahrb. Mineral.* (in press).
- Hawthorne, F. C., Kimata, M., Černý, P., Ball, N., Rossman, G. R. and Grice, J. D. (1991) The crystal chemistry of the milarite-group minerals. *Amer. Mineral.*, **76**, 1836–56.
- Hirowatari, F. and Fukuoka, M. (1988) Some problems of the studies on the manganese minerals in Japan. (in Japanese) *J. Mineral. Soc. Japan*, **18**, 347–65.
- Jaffe, H. W. (1988) *Crystal Chemistry and Refractivity*. Cambridge University Press, Cambridge. 335 pp.
- Kato, T., Miura, T. and Murakami, N. (1976) Crystal structure of sugilite. *Mineral. J.*, **8**, 184–92.
- Kawachi, Y. (1987) Rhodonite and serandite in the manganese deposits in Tamworth-Manilla region, New South Wales, Australia. In *Preliminary Report on the Geology of the New England Fold Belt, Australia*. No.1. (Iwasaki, M., project leader), Cooperative Research Group of Japan and Australia, 159–77.
- Kawachi, Y. (1991) 'Rhodonite'-bearing manganese deposits in the New England fold belt of eastern Australia, with special reference to the deposit of Woods mine. In *Bending of the Great Serpentine Belt and Tectonic History of the Arc-type Crust around the Belt, Eastern Australia. Preliminary Report on the Geology of the New England Fold Belt, Australia*. No.2. (Honma, H., project leader), Cooperative Research Group of Japan and Australia, 55–61.
- Kawachi, Y. and Coombs, D. S. (1993) Namansilite, $\text{NaMn}^{3+}\text{Si}_2\text{O}_6$: a widespread clinopyroxene? *Mineral. Mag.*, **57**, 533–8.
- Murakami, N., Kato, T., Miura, Y. and Hirowatari, F. (1976) Sugilite, a new silicate mineral from Iwagi Islet, southwest Japan. *Mineral. J.*, **8**, 110–21.
- Sakae, T. (1986) A least squares program for calculation of unit-cell dimensions. (in Japanese) *Earth Sci.*, **40**, 207–20.

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