Jeppeite, a new K–Ba–Fe titanate from Walgidee Hills, Western Australia

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ABSTRACT. Jeppeite, a new mineral, similar in composition to and overgrown on priderite, has been found in the lamproite plug of Walgidee Hills (18° 19′ S, 124° 51′ E), Western Australia. The mineral is named for the discoverer, Dr J. Jeppe. It is monoclinic, C2/m, a 15.453 b 3.8368 c 9.123 Å β 99.25°, strongest powder lines 4.50(002) (4), 3.07(310) (10), 2.99(003,31$\bar{1}$) (10), 2.961(20$\bar{3}$) (4), 2.812(311,112) (10), 2.091 (6), 2.074 (6), 1.919 (8) similar to artificial $K_2Ti_6O_{13}$. The sparse eluvial crystals are black, elongated along b, bounded by $\{100\}$, $\{20\bar{1}\}$ faces (Λ 45°) and $\{010\}$; perfect 100 and good 20$\bar{1}$ cleavages or partings, submetallic lustre, pale-brown streak, brittle, and cleave into (100) flakes. D_{obs} 3.94, D_{calc} 3.98. Colour values for illuminant C from reflectance spectra for R_p, R_b, and R_g are: $Y\%$ 13.3, 14.4, 16.6; λ_d 474, 473, 475; and $P_e\%$ 5.1, 4.5, 4.3. Refractive indices from reflectances at 590 nm in air are 2.13, 2.21 and 2.35. In thin section, $\alpha\Lambda a10°$ blue, $\beta = b$ dark greenish brown almost to black, $\gamma = c$ brown. Bireflectance and birefringence positive. H 5–6, VHN_{100} orientation dependent; for indentations normal to b 664–773.

Jeppeite is common in the lamproite as prismatic to acicular aggregates associated with priderite, richterite, shcherbakovite, wadeite, perovskite, and apatite in a green and white celadonite and chlorite matrix, with a little calcite and sphene, after olivine, pyroxene, and leucite.

Electron probe analysis, using Fe, Ti, nepheline, and benitoite standards, gave K_2O 8.47, BaO 17.35, TiO_2 69.29, Fe_2O_3 (total Fe) 4.74, sum 99.85%; (Mg, Na, Zr detected). This analysis calculates to $(K_{1.15},Ba_{0.73})_{\Sigma 1.88}$ $(Ti_{5.56}, Fe^{3+}_{0.38})_{\Sigma 5.94}O_{13}$, or ideally, $(K,Ba)_2(Ti,Fe)_6O_{13}$.

In July 1969, while on a diamond exploration survey for Stellar Minerals Pty. Ltd., Dr J. Jeppe found some rhomboid crystals of the new mineral in scree samples from the Walgidee Hills (18° 19′ S,

124° 51′ E), Kimberley Division, Western Australia. The Walgidee Hills are the surface expression of a large leucite lamproite plug, the largest in diameter of some 23 post-Triassic plugs in the West Kimberley area and the source of several other new minerals (Prider, 1939; Norrish, 1951). The first crystals found, up to 2×2 mm in size, were hand sorted from jig concentrates obtained from about two tonnes of decomposed lamproite and eluvial material. Examination of the crystals by W. Smead and P. Bannister at the Geology Department, University of Western Australia, showed the mineral to be an undescribed K-titanate. In 1970 Dr Jeppe passed the material to L. Hodge, then an officer at the Government Chemical Laboratories, for new mineral description. Further sampling in 1981 at Walgidee Hills has shown the mineral to be plentiful in the solid lamproite.

The mineral, named for its discoverer, John Frederick Biccard Jeppe (1920–), geologist of Nedlands, Western Australia, was approved by the IMA (1980-80). Type material is preserved in the collection of the Government Chemical Laboratories, Western Australia, and at the British Museum (Natural History) in polished mounts E.870 and E.871 (BM 1983, 604). It has also been widely donated to other collections.

Mineralogy. Jeppeite occurs in the scree as sparse single crystals bounded by flat, bright $\{100\}$ $\{20\bar{1}\}$, and uneven $\{010\}$ faces, giving the form of prisms with sharp 45° corners. The striking crystals of the original find in 1969 represent only the few most resistant grains. In the solid rock, jeppeite is plentiful as black finely prismatic to acicular, fragile

aggregates closely associated with and overgrown on priderite (Norrish, 1951) which is brown and resinous with a perfect 001 cleavage. The lamproite matrix is mainly composed of green and white celadonite and chlorite pseudomorphs of olivine, pyroxene, and leucite. Small patches of secondary sphene and calcite also occur.

Scattered through the matrix are the residual lamproite minerals richterite, priderite, perovskite, wadeite, shcherbakovite, apatite, and jeppeite, the latter one of the last to form.

Physical and optical properties. Jeppeite has perfect 100 and good 20$\bar{1}$ cleavages or partings, submetallic lustre, and pale-brown streak; it is brittle and cleaves readily into (100) flakes; D_{obs} (sink-float) 3.94, D_{calc} 3.98. In transmitted light in thin section the optical properties are $\alpha \Lambda a$ 10°, Capri Blue 43i (Ridgway, 1912); $\beta = b$, dark greenish brown (total absorption in thicker sections);

$\gamma = c$, Dark Olive Buff 21'''; relative absorption $\beta > \gamma > \alpha$. Transmission measurements made at the BM(NH) from 400 to 700 nm on thin sections cut parallel to b and c gave values at 590 nm of 9.5% and 34%, respectively. Absorption coefficients calculated from these values, assuming a thickness of 30 μm, are 0.004 and 0.002. The mean refractive index $\bar{n}$ calculated from the measured density (Gladstone–Dale) is 2.245 (Mandarino, 1981).

In reflected light, on polished and crystallographically oriented crystals, jeppeite is grey in air and weakly bireflectant; in oil the bireflectance is slightly stronger. Internal reflections are not common except in areas damaged by the hardness indenter where they are golden white. The rotation tints in crossed polars are greys. At the thinned or fractured edges of some crystals brilliant interference colours—green, golden brown, and light blue—are apparent.

TABLE I   Reflectances, refractive indices and colour values

λ nm	R_p 2	R_p 3	$R_m //b$ 1	$R_m //b$ 4	R_g 1	R_g 2	R_g 3	R_g 4	$^{im}R_p$ 2	$^{im}R_p$ 3	$^{im}R_m //b$ 1	$^{im}R_m //b$ 4	$^{im}R_g$ 1	$^{im}R_g$ 2	$^{im}R_g$ 3	$^{im}R_g$ 4
$R\%$ / **$^{im}R\%$**																
470	14.3	14.3	15.3	15.4	17.5	17.8	17.8	17.5	3.48	3.50	4.02	4.07	5.37	5.53	5.56	5.30
546*	13.3	13.3	14.3	14.4	16.5	16.8	16.7	16.4	3.05	3.07	3.59	3.62	4.80	4.99	5.03	4.81
590	13.1	13.0	14.1	14.2	16.2	16.4	16.4	16.1	2.92	2.93	3.49	3.51	4.72	4.82	4.84	4.64
650	12.9	12.9	14.0	14.0	16.0	16.2	16.2	15.8	2.86	2.86	3.44	3.47	4.49	4.69	4.72	4.51
n																
470	2.22	2.22	2.28	2.29	2.44	2.46	2.46	2.42	2.23	2.23	2.29	2.30	2.45	2.46	2.47	2.44
546*	2.15	2.15	2.21	2.22	2.37	2.38	2.38	2.36	2.16	2.16	2.23	2.23	2.38	2.39	2.39	2.37
590	2.13	2.13	2.20	2.21	2.35	2.36	2.36	2.34	2.14	2.14	2.21	2.21	2.36	2.37	2.37	2.35
650	2.12	2.12	2.19	2.20	2.33	2.34	2.34	2.32	2.13	2.13	2.20	2.20	2.33	2.35	2.35	2.33
Colour values relative to the CIE illuminant C																
x	.300	.300	.302	.301	.302	.301	.302	.302	.292	.292	.295	.295	.296	.295	.295	.296
y	.304	.304	.306	.306	.307	.306	.306	.306	.294	.294	.297	.297	.300	.299	.299	.299
$Y\%$	13.3	13.3	14.3	14.4	16.5	16.7	16.7	16.4	3.0	3.1	3.6	3.6	4.9	5.0	5.0	4.8
$P_e\%$	5.0	5.1	4.4	4.5	4.2	4.3	4.3	4.3	9.5	9.5	7.8	8.0	7.1	7.5	7.4	7.3
λ_d	474	474	473	473	475	475	475	475	473	474	472	473	475	474	475	475

* indicates an interpolated value.

Reflectance spectra in air and in oil (Zeiss, N_D 1.515), relative to Zeiss SiC no. 472, were measured at the BM(NH) using Zeiss equipment, from 400 to 700 nm at an interval of 10 nm on four crystallographically oriented crystals in polished mounts E.870 and E.871 (BM 1983, 604). These spectra, with details of the experimental procedure and a discussion of the results, will be reported separately. The reflectance values in Table I are for the four wavelengths recommended by the Commission on Ore Microscopy. R_m measurements made on two sections parallel to the diad crystallographic axis b are symbolized as R_b; R_p and R_g were measured on sections parallel to the a and c crystallographic axes. The dispersion of R and ^{im}R for all three vibration directions is low and of similar trend, in keeping with the unremarkable grey appearance of jeppeite. Colour values relative to the CIE illuminant C confirm the visual impression: the dominant wavelengths (λ_d) are nearly constant (472-5 nm) and the excitation purities ($P_e\%$) which vary inversely with the luminance ($Y\%$) are low in both air and oil.

Refractive indices (Table I) were calculated using the Fresnel relation, assuming k to be zero (the values determined by transmission are insignificant in the calculation of n). Thus, the dispersion of n is similar in trend to that of R, and the signs of the bireflectance and birefringence are both positive.

The arithmetic mean refractive indices $\bar{n}$ at 590 nm from the air and oil measurements were used with the measured and calculated densities to calculate Mandarino's (1981) compatibility index for the Gladstone-Dale relationship. For the measured density both air- and oil-derived refringences are in the 'superior' category (-0.0128 and -0.0064 respectively), and for the calculated density the air-derived refringence is 'excellent' (0.0226) and the oil, 'superior' (0.0161).

The Mohs' hardness number is in the range 5-6. Measurements of VHN_{100} were made with a Leitz Durimet Hardness Tester on eight grains, but the indentations on two of these grains were not measured due to excessive fracturing. Three grains, normal to b, gave: 681-744, $mean_{10}$ 700; 673-719, $mean_{10}$ 690; 654-773, $mean_{10}$ 698. All of the indentations were slightly fractured and concave-sided. Two sections normal to a were more fractured but perfect in shape: 606-30, $mean_9$ 621 and 585-627, $mean_{10}$ 601. The results for a grain thought to be oriented normal to c should be regarded with caution—the indentations were barely measurable due to fracturing: 548-739, $mean_{11}$ 658.

Analysis. Electron microprobe analyses were made by R. Vigers at the CSIRO Laboratories in Perth, Western Australia, on a MAC instrument using Fe and Ti metals, nepheline and benitoite standards with the MAGIC-IV matrix correction program (Colby, 1968). The average of seven analyses spaced for representative coverage on an original crystal gave K_2O 8.47, BaO 17.35, TiO_2 69.29, Fe_2O_3 (total Fe) 4.74, sum 99.85%, with Mg, Na, and Zr detected. This analysis corresponds to $(K_{1.15},Ba_{0.73})_{\Sigma 1.88}(Ti_{5.56},Fe^{3+}_{0.38})_{\Sigma 5.94}O_{13}$, or ideally, $(K,Ba)_2(Ti,Fe)_6O_{13}$.

Magnetic measurements at the Chemistry Dept., University of Western Australia, showed that most, if not all, the Fe present is in the trivalent state. On the acquisition of plentiful material in 1981 additional analyses were made by the same method on a number of crystals, the results being very similar to the original analysis. Jeppeite has a significantly higher BaO content with less TiO_2 and a much lower iron content than the associated priderite. It is obviously the later mineral, occurring as overgrowths and partial rims on the corroded remnants of priderite.

X-ray data. Unit cell refinement from approximate parameters supplied from Weissenberg film data was carried out by A. H. White, Chemistry Dept., University of Western Australia, as part of crystal structure data collection on an automatic diffractometer (Bagshaw et al., 1977).

Jeppeite is monoclinic, $C2/m$, with parameters a 15.543(3), b 3.8368(7), c 9.123(2) Å, β 99.25(1)°, $a:b:c$ 4.0276:1:1.3778, V 533.9(2) Å³. The refined values are similar to those of artificial $K_2Ti_6O_{13}$ (Cid-Dresdner and Buerger, 1962): a 15.582 ± 0.006, b 3.82 ± 0.01, c 9.112 ± 0.001 Å, β 99.764 ± 0.008°, $a:b:c$ 4.0791:1:1.3853, V 534.5 Å.

The X-ray powder data for jeppeite (Table II) are

TABLE II. *Table of X-ray powder data for jeppeite; Guinier focusing camera, Cu-Kα, with KCl internal standard, I visual*

hkl	I	d_{obs}	d_{calc}	I	d_{obs}	I	d_{obs}	I	d_{obs}
001	1	8.98	9.004	3	2.649	1	1.639	2	1.326
200	3	7.64	7.626	2	2.557	1	1.620	2	1.313
20Ī	3	6.37	6.344	2	2.381	3	1.607	1	1.302
201	1	5.40	5.407	1	2.347	1	1.594	2	1.296
002	4	4.50	4.502	1	2.236	2	1.560	3	1.237
40Ī	1	3.73	3.733	6	2.091	1	1.550	2	1.233
110	1	3.71	3.721	6	2.074	2	1.533	3	1.228
202	1	3.63	3.630	2	2.043	1	1.524	3	1.221
011	1	3.51	3.530	1	1.997	1	1.520	2	1.197
401	1	3.33	3.325	2	1.958	1	1.511	3	1.192
40Z̄	2	3.17	3.172	8	1.919	2	1.500	3	1.177
310	10	3.07	3.063	3	1.909	1	1.490	1	1.750
003	10	2.990	3.001	2	1.889	1	1.459	1	1.167
31Ī			2.989	1	1.841	2	1.429	1	1.160
203	4	2.961	2.960	2	1.804	5	1.412	2	1.146
11Ī	3	2.924	2.925	2	1.762	3	1.409	2	1.131
311	10	2.812	2.817	1	1.714	1	1.402	1	1.122
112			2.814	1	1.701	1	1.373	1	1.115
402	4	2.702	2.703	2	1.665	1	1.358	1	1.104

from Guinier films taken with Cu-$K\alpha$, KCl internal standard, I visual. The line measurements correlate approximately with the unindexed data of Berry *et al.* (1960) and with the indexed set of Plumley and Orr (1961), PDF card No. 13–574 for artificial $K_2Ti_6O_{13}$. However, due to inaccurate cell parameters, most of the indexing in the latter data is incorrect and incompatible with $C2/m$. The disparity in intensities between equivalent lines of jeppeite and the two sets of $K_2Ti_6O_{13}$ data can be attributed to the Ba content of jeppeite and preferred orientation effects. The list of crystal structure data (Bagshaw *et al.*, 1977) was used to check that in the jeppeite powder data all sets of indices allotted correspond to a significant structure factor.

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