High-iron bustamite and fluorapatite from the Broken Hill mine, New South Wales, Australia

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SUMMARY. High-iron bustamite and apatite occur as subhedral large crystals up to 1 to 2 cm wide and 10 cm long in close association with spessartine in the disseminated sphalerite- and galena-bearing diopside–roepperite–calcite skarn at the New Broken Hill Consolidated mine (N.B.H.S.), New South Wales, Australia. Complete chemical analyses of the minerals have been made, together with physical, optical, and X-ray studies.

IN the course of an exploration trip to the New Broken Hill Consolidated mine (N.B.H.S.), Dr. Akira Satsuma, Sumitomo Metal Mining Co. Ltd., collected a number of beautiful crystals of bustamite and apatite from the disseminated galena- and sphalerite-bearing calcite–spessartine–bustamite–diopside skarn of the mine. The bustamite occurs in close association with reddish-brown spessartine. C. Osborn Hutton (1956) had reported the occurrence of high-manganese bustamite, manganpyrosmalite, and ferroan johansennite from the same mining area, together with the optical properties of the bustamite, but no chemical work on the mineral was carried out. Recently, Ryall and Threadgold (1968) found inesite from the Broken Hill mine and gave the results of the chemical, optical, morphological, and X-ray studies. We have found no record of the occurrence of apatite at Broken Hill mining area.

High-iron bustamite was found as subhedral crystals up to 2 cm wide and 10 cm long with rough {010}, {100}, and {110} planes. Observed perfect cleavage parallel to {100}, {110}, and {1Ī0} and a poor one parallel to {010} confirm the description by Winchell and Winchell (1951). The colour is pale pink with a slightly yellowish tint. The specific gravity was determined, using 1 ml pycnometer and 0·98 grams of the powdered specimen, to be 3·41$_7$; this is consistent with previous results (Sundius, 1931, and Hutton, 1956), and with the calculated one (= 3·421). Optical properties are: α 1·688, β 1·699, γ 1·703, γ–α 0·015 (Na-D light, all ±0·001), 2Vα 39° and $r < v$ distinct. The refractive indices are slightly higher and 2Vα smaller than the values given by Hutton (1956: α 1·686±0·002, β 1·697±0·002, γ 1·701±0·002, γ–α 0·015 and 2Vα 46°). Optical orientation is substantially identical with the results by Hey (1929) and by Sundius (1931). When compared with the physical properties of the discontinuous wollastonite–bustamite–rhodonite series given by Sundius (1931), high

refractive indices, small $2V\alpha$, and the high specific gravity imply higher manganese plus iron content, as was suggested by Hutton (1956). The higher refractive indices and smaller $2V\alpha$ of the present mineral also suggest similarity to the high-manganese bustamite described by Tilley (1946: α 1·692, β 1·705, γ 1·707, $2V\alpha$ 35° and S.G. 3·425) and by Sundius (1931: α 1·687, β 1·701, γ 1·703, $2V\alpha$ 36·2° and S.G. 3·410).

TABLE I. *Chemical composition of high-iron bustamite and fluorapatite from Broken Hill, N.S.W.*

Bustamite*					Fluorapatite†				
CaO	20·02	Ca	1·340		CaO	54·81	Ca	9·816	
FeO	6·68	Fe	0·349		Fe_2O_3		Fe	0·044	
MnO	24·81	Mn	1·312	} 3·053	FeO	} 0·35	Mn	0·042	} 10·000
MgO	0·25	Mg	0·023		MnO	0·30	Sr	0·008	
K_2O	0·36	K	0·028		SrO	0·08	Na	0·064	
Na_2O	nil				Na_2O	0·20	K	0·026	
Al_2O_3	0·52	Al	0·038	} 2·989	K_2O	0·12	P	5·746	
SiO_2	47·25	Si	2·951		P_2O_5	40·61	C	0·053	} 5·942
H_2O	n.d.	O	9·000		CO_2	0·23	Si	0·105	
Sum	99·89				SiO_2	0·63	S	0·036	
					SO_3	0·29	F	2·061	} 2·096
* Analyst: Kozo Nagashima.					F	3·90	Cl	0·034	
† Analyst: Hiroko Sekino.					Cl	0·12	O	23·718	
					H_2O^+	none			
					H_2O^-	0·08			

$$101\cdot72$$
$$O \equiv F, Cl \ \ 1\cdot67$$
$$\text{Sum} \ \ 100\cdot05$$

A chemical analysis was conducted by K. Nagashima by normal wet methods using 10 grams of pure bustamite to yield the result listed in Table I. Manganese was determined by the titration with a standard ferrous solution after oxidizing all manganese to Mn(III), the method reported by Nagashima, Codell, and Fujiwara (1964). The structural formula is in reasonable agreement with the bustamite formula $(Mn,Ca)_3Si_3O_9$.

X-ray powder diffraction data were obtained on an X-ray diffractometer with nickel-filtered copper radiation.

The data are in general agreement with the cell data of the bustamite from Franklin, New Jersey, given by Peacor and Buerger (1962). A programme developed by Momoi (1969) was used to index the data and to derive refined cell dimensions (Table II). However, the unit cell edges of the present material are a little smaller than the Peacor and Buerger's data, which suggests a higher manganese plus iron content since the ionic radii of Mn^{2+} (0·80 Å) and Fe^{2+} (0·53 Å) are much smaller than that of Ca^{2+} (0·99 Å).

Apatite occurs as rough hexagonal prisms generally smaller than 10 cm long and 1 cm wide with perfect parting along {0001} and in close association with bustamite and

calcite. Colour is pale bluish brown with vitreous lustre suggesting fluorapatite rather than chlorapatite. The specific gravity determined with a 1 cc pycnometer using 2 grams of powdered pure sample was $3\cdot14_7$. Refractive indices determined by the immersion method at 20 °C in sodium light were ω 1·634, ϵ 1·631, ω–ϵ 0·003, all $\pm$0·001. Specific gravity and optical data fit well to the values for fluorapatite given by Young et al. (1969).

TABLE II. *X-ray powder diffraction data of the bustamite from Broken Hill*

I	$2\theta_{obs}$	$2\theta_{calc}$	d_{calc}	hkl	I	$2\theta_{obs}$	$2\theta_{calc}$	d_{calc}	hkl
17	14·96	14·96	7·4392	200	4	54·01	54·02	2·1314	422
7	16·21	16·24	6·8583	002	4	54·55	54·54	2·1125	6$\bar{2}$2
2	23·11	23·13	4·8322	202	11	54·89	54·88	2·1003	$\bar{6}$04
2	25·34	25·36	4·4134	$\bar{3}$11	15	56·97	56·97	2·0301	$\bar{4}$06
42	30·19	30·19	3·7196	400	2	59·11	59·10	1·9629	42$\bar{4}$
4	31·17	31·20	3·6022	31$\bar{1}$	—	—	59·12	1·9620	$\bar{6}$24
30	32·82	32·82	3·4292	004	8	60·25	60·23	1·9294	604
7	33·09	33·11	3·3992	$\bar{4}$02	6	62·74	62·73	1·8598	800
4	33·59	33·63	3·3486	$\bar{3}$13	2	63·71	63·70	1·8343	6$\bar{2}$4
100	34·96	34·95	3·2255	$\bar{2}$04	2	64·34	64·32	1·8184	820
5	35·77	35·77	3·1539	402	3	65·98	66·01	1·7770	$\bar{2}$40
3	36·26	36·26	3·1126	31$\bar{3}$	3	66·90	66·90	1·7562	226
31	37·49	37·50	3·0137	204	—	—	66·91	1·7559	802
2	38·06	38·02	2·9734	$\bar{5}$11	23	68·74	68·74	1·7146	008
—	—	38·14	2·9646	313	5	69·20	69·21	1·7044	$\bar{2}$08
8	38·98	39·05	2·8987	220	5	70·64	70·64	1·6743	$\bar{6}$26
7	39·28	39·32	2·8791	$\bar{4}$20	3	71·18	71·21	1·6626	$\bar{8}$24
33	43·03	43·03	2·6414	$\bar{4}$04	7	73·76	73·77	1·6128	$\bar{4}$08
3	44·18	44·21	2·5742	$\bar{1}$15	2	76·95	76·95	1·5557	8$\bar{2}$4
4	45·11	45·12	2·5250	11$\bar{5}$	8	81·17	81·17	1·4878	$\bar{1}$0.0.0
27	45·98	45·99	2·4797	600	5	82·12	82·11	1·4739	24$\bar{4}$
4	47·23	47·18	2·4203	024	3	83·90	83·81	1·4493	440
—	—	47·27	2·4161	404	—	—	83·98	1·4469	228
5	47·60	47·62	2·3992	2$\bar{2}$4	3	84·67	84·69	1·4371	4$\bar{2}$8
4	50·06	50·06	2·2896	420	7	85·33	85·36	1·4279	10.0.2
7	50·46	50·43	2·2736	$\bar{6}$20	8	86·57	86·58	1·4117	$\bar{1}$0.0.4
48	51·16	51·15	2·2421	$\bar{2}$06					

a 15·333$\pm$0·003, b 7·108$\pm$0·002, c 13·772$\pm$0·003 Å, α 89·60°$\pm$0·02, β 95·07°$\pm$0·01, γ 103·03°$\pm$0·02, V 1456·5 Å^3$\pm$0·2.

Using 10 grams of pure sample, a wet chemical analysis of the apatite was conducted by H. Sekino. The analytical procedure is reported elsewhere (Harada et al., 1971) and the result is listed in Table I.

The ω index of refraction, calculated by using the correlation factors advocated by Young et al. (1966), is 1·635$_2$, in fair agreement with the observed 1·634.

The X-ray powder data were obtained on diffractometer with nickel-filtered copper radiation. Observed d-spacings were processed by a least-squares computer programme by Momoi (1956): a 9·363$\pm$0·002 Å, c 6·883$\pm$0·001 Å, and V 552·5$\pm$0·2 Å^3). They agree well with the data for fluorapatite by Young et al. (1969).

If we apply the equation of the relationship between chemical composition and $a(\text{Å})$ of apatite advocated by McConnell (1970) and McConnell (1973), we obtain: $a = 9 \cdot 373$ Å, in good agreement with the observed value (a $9 \cdot 363$ Å).

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