

Bazirite, BaZrSi₃O₉, a new mineral from Rockall Island, Inverness-shire, Scotland

B. R. YOUNG, J. R. HAWKES, R. J. MERRIMAN, AND M. T. STYLES

Petrographical Department, Institute of Geological Sciences, Exhibition Road, London SW7 2DE

SUMMARY. Bazirite, BaZrSi₃O₉, is one of several late-stage interstitial minerals present in the aegirine-riebeckite granite of Rockall Island. Crystals are hexagonal, probably $\bar{6}m2$, colourless, chiefly as anhedral grains. Only forms noted $\{10\bar{1}0\}$ and probably $\{10\bar{1}4\}$, cleavage $\{0001\}$ and probably $\{10\bar{1}4\}$. 'Low' and 'high' titanium varieties with respective mean compositions: SiO₂ 39.71%, ZrO₂ 26.38%, BaO 33.69%, TiO₂ 0.17%, SnO₂ 0.06% and SiO₂ 39.59%, ZrO₂ 26.12%, BaO 34.12%, TiO₂ 0.51%, SnO₂ 0.11%. Low and high refractive index types exist; uniaxial positive with $\omega = 1.6751 \pm 0.0003$, $\epsilon = 1.6850 \pm 0.0003$ and $\omega = 1.6813 \pm 0.0003$, $\epsilon = 1.691$ (deduced); probably due to differences in titanium content. Fluorescence (2537 Å), moderately strong, pale whitish blue. Space group almost certainly $P6c2$. Cell dimensions: low R.I. variety, $a = 6.7690 \pm 0.0005$ Å, $c = 10.020 \pm 0.001$ Å; high R.I. variety, $a = 6.7662 \pm 0.0005$ Å, $c = 10.0158 \pm 0.0010$ Å. Strongest lines are 3.80 Å (100), 2.800 (100), 5.85 (35), 3.38 (35), $Z = 2$. $D_{\text{calc}} = 3.82$. Related minerals, benitoite and pabstite.

ROCKALL ISLAND (57° 36' N.; 13° 41' W.), an isolated pinnacle of Eocene aegirine-riebeckite granite, is situated in the North Atlantic approximately 294 km west of the St. Kilda Isles, Inverness-shire. Despite problems of access, the island has been a focus of scientific interest since the first documented landing by Lieutenant Basil Hall, R.N., in 1810 (MacCulloch, 1814; Judd, 1897; Washington, 1914; Lacroix, 1921; Sabine, 1960; Hawkes *et al.*, 1975). Lacroix's recognition of the hydrated sodium zirconium silicate, elpidite, in material obtained during the 1921 *Pourquois Pas* expedition is especially relevant in the context of this paper. Sabine (1960, p. 168) subsequently described a colourless accessory barium- and zirconium-bearing mineral in samples returned by the H.M.S. *Vidal* landing of 1955. The mineral was later isolated from granite specimens collected during the 1971 and 1972 R.F.A. *Engadine* expeditions and confirmed as a new species with composition BaZrSi₃O₉ (Hawkes *et al.*, 1975). The partly mnemonic name bazirite originally proposed has been approved by the International Commission on New Minerals and Mineral Names.

Bazirite is associated with a variety of interstitial constituents, which on cut or freshly broken surfaces occur in irregular, buff-coloured patches up to 5.0 mm across. The patches commonly aggregate in the granite with up to seven occurring per cm², although a more usual density is one per cm². These field observations, along with modal data from thin sections, suggest that the interstitial minerals constitute between 1 and 5% of the rock by volume, with the bazirite accounting for perhaps 0.1% by volume. Preferential weathering generally reduces the patches to rusty voids.

Elpidite, the most abundant interstitial mineral, is accompanied in places by acmite, albite, bazirite, disordered α -cristobalite, leucophosphite, monazite, and quartz. Crushes of the whole rock have yielded additional accessory minerals: apatite, eucolite-eudialyte, magnetite, pyrochlore, xenotime (Sabine, 1960); also baryte and sphene.

Physical properties. Bazirite occurs as single or clustered, colourless anhedral grains and as subhedral or, more rarely, euhedral prismatic crystals with partially developed pyramidal terminations (fig. 1). Grains and crystals vary considerably in size up to about 0.25 × 0.25 × 0.65 mm (S 57923, 57926, 57937*). The mineral contains numerous minute cavities and unidentified inclusions, the largest observed measuring, respectively, 0.001 × 0.008 mm and 0.001 × 0.002 mm. Fractures are common in all grains and crystals, most apparently relating to a strong basal parting and to a cleavage, which parallels the rarely developed pyramidal faces. Measurements of about 20° for the acute angle between these planes of fracture and between the basal parting and pyramidal faces indicate that if the axial ratio c/a 1.4803 obtained from the unit cell is used, the latter faces may be the form $\{10\bar{1}4\}$. A third plane of fracture may reflect a poorly developed prismatic cleavage. A mean interfacial angle of 60° for prismatic faces (which single crystal

* Numbers prefixed by S refer to specimens in the Petrographical Department's Collections, Institute of Geological Sciences.

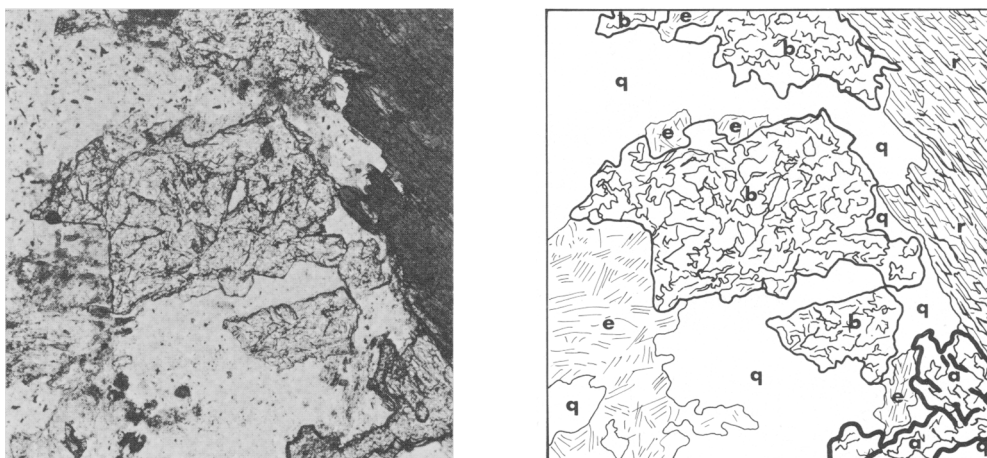


FIG. 1. A photomicrograph showing anhedral and subhedral crystals of bazirite (b) associated with quartz (q), acmite (a), and elpidite (e). A riebeckite crystal (r) forms one margin to this patch of interstitial minerals. (S 57926; plane polarized light; magnification $\times 110$.)

X-ray studies show to be the form $\{10\bar{1}0\}$ was obtained from basal sections. Finally, since it has been shown that the X-ray patterns of bazirite and benitoite are similar, bazirite probably belongs to the same crystal class, $\bar{6}m2$.

The following optical properties were established (using microscopy, Abbé refractometer, and UV-source techniques) on thin sections and grains separated from crushes by means of methylene iodide (sp. gr. 3.4). Bazirite is uniaxial positive, length slow, with straight extinction and moderately low birefringence (0.010). Refractive index (N_{α}) determinations indicate two sets of values: $\omega = 1.6751 \pm 0.0003$, $\varepsilon = 1.6850 \pm 0.0003$ and $\omega = 1.6813 \pm 0.0003$, $\varepsilon = 1.691$ (deduced from the maximum birefringence colour). Sabine (1960) also recorded two similar sets of values, which seem now to reflect compositional differences. The mineral does not fluoresce under long-wave UV light (3650 Å), but shows moderately strong pale whitish blue fluorescence under short-wave UV (2537 Å). Strong bright-blue cathodoluminescence is observed under electron-beam bombardment.

Density and hardness determinations were not attempted because of the numerous cavities, inclusions, and fractures. The calculated density is 3.82 g/cm^3 .

Chemistry. Nine grains of bazirite in one polished thin section (S 57923) were analysed by means of a Cambridge Instruments 'Geoscan' electron microprobe. An accelerating voltage of 20 kV, a specimen current of 1×10^{-7} amps, and wollastonite (Si), baryte (Ba), and Ti, Zr, and Sn metals were used as standards throughout. Raw data were corrected using the methods described by Sweat-

man and Long (1969) and the computer program of Mason, Frost, and Reed (1969).

Each grain was analysed several times. Some may possess slight chemical inhomogeneity but this could not definitely be proved. Table I shows the mean of the determinations for each grain and the calculated molecular percentages of Ti, Zr, and Sn. The latter figures indicate limited substitution of Ti for Zr with an approximately bimodal distribution. Such a distribution could account for the two sets of refractive index and cell-size values. The means of the compositions of the 'high' and 'low' titanium types are given in Table II, from which ionic formulae and densities have been calculated.

The new analyses of bazirite all differ from the previously published analysis (Hawkes *et al.*, 1975, p. 28) in having a higher Zr content. This is thought to be due to an erroneously high background measurement in the earlier work, which produced a low Zr value, and hence a low total. The K reported in the previous analysis is spurious, probably having come from surrounding feldspar or leucophosphate grains. Hafnium could not be detected in any of the grains.

X-ray crystallography. An X-ray powder pattern (X 7610*) obtained from three bazirite crystals (R.I. ω 1.6751, ε 1.6850) using an 11.46 cm diameter Gandolfi camera, is similar to that of benitoite, $\text{BaTiSi}_3\text{O}_9$, from San Benito County, California (X 7612). The bazirite spacings, however, are slightly larger due to the larger ionic radius of Zr^{4+} (0.79 Å)

* Numbers prefixed by X refer to X-ray films in the Petrographical Department's Collections, Institute of Geological Sciences.

TABLE I. *Electron microprobe analyses of bazirite*

	2	3	4	5	6	7	8	9	
SiO ₂	40.56	39.70	38.76	40.01	39.53	39.82	39.58	39.57	39.37
TiO ₂	0.19	0.12	0.12	0.24	0.16	0.68	0.43	0.47	0.47
ZrO ₂	26.27	25.94	26.50	26.62	26.57	26.06	26.09	26.14	26.17
SnO ₂	0.06	0.06	0.05	0.04	0.07	0.08	0.11	0.12	0.11
BaO	33.94	33.15	33.55	33.60	34.23	33.88	34.03	34.09	34.49
Sum	101.02	98.97	98.98	100.51	100.56	100.52	100.24	100.39	100.61
Molecular % of tetravalent cations:									
Ti	1.10	0.71	0.69	1.37	0.92	3.85	2.48	2.70	2.69
Zr	98.70	99.11	99.17	98.50	98.85	95.92	97.20	96.94	96.99
Sn	0.20	0.19	0.14	0.14	0.23	0.23	0.32	0.37	0.32

Analyses 1 to 5, 'low' Ti grains }
 Analyses 6 to 9, 'high' Ti grains } S 57923

NW. face of Rockall Island, 13.7 m above sea-level and 5.8 m from E. face.

TABLE II. *Mean compositions and ionic ratios of bazirite*

	'Low' Ti type	'High' Ti type
	39.71 ± 0.66	39.59 ± 0.18
	0.17 ± 0.05	0.51 ± 0.11
	26.38 ± 0.28	26.12 ± 0.05
	0.06 ± 0.01	0.11 ± 0.02
	33.69 ± 0.41	34.12 ± 0.26
	100.01	100.45
Number of ions on a basis of 9 oxygen:		
Ti	0.010	0.029
Zr	0.976	0.964
Sn	0.001	0.003
Σ	0.987	0.997
Si	3.013	2.997
Ba	1.002	1.012

compared with that of Ti⁴⁺ (0.68 Å), and there are also differences in the intensities of many of the lines. Indexed powder data and cell dimensions for both minerals are presented in Table III and are in agreement with published data for synthetic BaZrSi₃O₉ (Masse and Durif, 1973) and for benitoite (Robbins and Levin, 1961, p. 130). The line intensities were estimated visually by comparison with an intensity scale, but values quoted for the bazirite from reflections from planes with low multiplicity factors (such as 002 and 004) are less reliable because the Gandolfi device did not completely eliminate spottiness. Cell dimensions for both bazirite and benitoite were calculated from selected high-angle spacings and refined by plotting the values obtained against the Nelson and Riley function (cos²θ/sin θ + cos²θ/θ)/2 and extrapolating to θ = 90°. A slight difference between the observed and calculated *d*-spacings is presumably due to specimen absorption. Slightly smaller cell dimensions (*a* 6.7662 ± 0.0005 Å, *c* 10.0158 ± 0.0010 Å) were obtained from a Gandolfi film (X 7671) of a single bazirite crystal with the higher R.I. ω 1.6813, ε 1.691. This X-ray data reinforces the chemical evidence that observed differences in refractive index are probably due to limited replacement of Zr by Ti.

A Laue photograph confirmed the hexagonal symmetry of bazirite, while the space group was deduced from Weissenberg and precession photographs to be *P*6̄c2, the same as that of benitoite.

Related minerals and genesis. Bazirite becomes the third natural member of a group of barium silicates with the Si₃O₉ ring structure (Zachariasen, 1930) in which Ti⁴⁺, Sn⁴⁺, and Zr⁴⁺ show varying

degrees of substitution, and which probably all belong to the rare crystal class *6̄m2*. The titanium member, benitoite, BaTiSi₃O₉, was the first to be discovered (Louderback, 1907; 1909) and it has since been made synthetically with an upper stability limit reported as 965 ± 10 °C at 5000 lb. in.⁻² (345 bars) water-vapour pressure (Rase and Roy, 1955). Titanian pabstite, Ba(Sn_{0.77}Ti_{0.23})Si₃O₉, the second member, was described by Gross *et al.* (1965), who also synthesized BaSnSi₃O₉, in a hydrothermal apparatus at 330 °C and saturated water-vapour pressure, and at 500 °C and 15 000 lb. in.⁻² (1035 bars) water-vapour pressure. The zirconium member of the group, BaZrSi₃O₉, had been synthesized dry at 1250–1300 °C by Galkin and Chukhlantsev (1965) prior to the recognition of bazirite in 1971. In another experiment, Masse and Durif (1973) produced BaZrSi₃O₉ also under dry conditions at temperatures between 1000° and 1350 °C.

The similarity of the ionic radii of Ti⁴⁺ (0.68 Å) and Sn⁴⁺ (0.71 Å) suggests that a wide range of solid solution may be expected between benitoite and pabstite. However, other discoveries of bazirite will probably show (as in the present case) only limited substitution of Ti and/or Sn for Zr, because of the appreciably larger ionic radius of Zr⁴⁺ (0.79 Å).

A summary of some of the properties of bazirite, benitoite, titanian pabstite, and BaSnSi₃O₉, are shown in Table IV.

In contrast to the experimental preparations by Galkin and Chukhlantsev (1965) and by Masse and Durif (1973), the bazirite of Rockall Island seems to have formed at low temperatures. The mineral is

TABLE III. Observed and calculated X-ray powder diffraction data for bazirite (1) and benitoite (2) obtained from films taken in 11.46 cm diameter cameras at room temperature (around 23 °C) with Cu-K α radiation ($\lambda K\alpha_1 = 1.54051 \text{ \AA}$)

1				2			
I/I_1	d_{obs}	d_{calc}	hkl*	I/I_1	d_{obs}	d_{calc}	hkl*
35	5.85 Å	5.862 Å	100	18	5.74 Å	5.750 Å	
8	5.00	5.010	002	5	4.87	4.879	
100	3.80	3.809	102	100	3.72	3.720	
35	3.38	3.384	110	16	3.32	3.320	
16	3.20	3.207	111	16	3.14	3.143	
30	2.93	2.931	200	25	2.873	2.875	
100	2.800	2.805	112	80	2.742	2.745	
4	2.525	2.530	202	6	2.477	2.477	
12	2.498	2.505	004	12	2.438	2.439	
2	2.376	2.377	113	1	2.319	2.323	
5	2.301	2.303	104	12	2.245	2.246	
25	2.213	2.216	210	24	2.171	2.173	
6	2.160	2.163	211	12	2.119	2.121	
8	2.025	2.026	212	14	1.983	1.985	
30	2.012	2.013	114	26	1.965	1.966	
18	1.952	1.954	300	16	1.915	1.917	
14	1.902	1.904	204	22	1.859	1.860	
2	1.846	1.846	213	3	1.805	1.807	
22	1.819	1.820	302	18	1.783	1.784	
8	1.690	1.692	220	4	1.660	1.660	
14	1.657	1.660	214	12	1.621	1.623	
2	1.623	1.626	310	2	1.593	1.595	
24	1.603	1.606	106	10	1.563	1.565	
18b	1.542	1.546	312	14	1.515	1.516	
		1.541	304	7	1.506	1.507	
12	1.496	1.4976	116	12	1.459	1.4605	
3	1.460	1.4618	313	3	1.431	1.4320	
14b	1.402	1.4066	402	< 1	1.416	1.4156	
		1.4023	224	3	1.378	1.3790	
2	1.362	1.3638	314	8	1.372	1.3724	
3	1.344	1.3449	320	2	1.334	1.3349	
				2	1.319	1.3192	

1				2			
I/I_1	d_{obs}	d_{calc}	hkl*	I/I_1	d_{obs}	d_{calc}	hkl*
3	1.0766 Å	1.0771 Å	406	3	1.0766 Å	1.0771 Å	
3	1.0786	1.0793	332	3	1.0786	1.0793	
3	1.0631	1.0637	218	3	1.0631	1.0637	
4	1.0600	1.0607	422	4	1.0600	1.0607	
2	1.0391	1.0403	504	2	1.0391	1.0403	
3	1.0284	1.0291	308	3	1.0284	1.0291	
1	1.0320	1.0328	510	1	1.0320	1.0328	
2	1.0243	1.0245	336	2	1.0243	1.0245	
3	1.0099	1.0104	512	3	1.0099	1.0104	
4	1.0071	1.0078	334	4	1.0071	1.0078	
4	0.9928	0.9935	416	4	0.9928	0.9935	
		0.9927	424			0.9927	
3	0.9824	0.9829	228	3	0.9824	0.9829	
< 1	0.9686	0.9689	318	< 1	0.9686	0.9689	
1	0.9616	0.9620	1.0.10	1	0.9616	0.9620	
1	0.9507	0.9511	514	1	0.9507	0.9511	
< 1	0.9450	0.9454	430	< 1	0.9450	0.9454	
2	0.9360	0.9362	1.1.10	2	0.9360	0.9362	
—	—	0.9390	506	—	—	0.9390	
3	0.9400	0.9404	602	3	0.9400	0.9404	
1	0.9278	0.9281	432	1	0.9278	0.9281	
2	0.9206	0.9208	520	2	0.9206	0.9208	
3	0.9143	0.9149	336	3	0.9143	0.9149	
2	0.9044	0.9048	522	2	0.9044	0.9048	
1	0.8953	0.8956	328	1	0.8953	0.8956	
1	0.8896	0.8902	2.1.10	1	0.8896	0.8902	
1	0.8919	0.8920	604	1	0.8919	0.8920	
2	0.8811	0.8815	434	2	0.8811	0.8815	
10	0.8743	0.8746	3.0.10	10	0.8743	0.8746	
4	0.8692	0.8696		4	0.8692	0.8696	
< 1	0.8629	0.8631	612	< 1	0.8629	0.8631	
10	0.8612	0.8615	524	10	0.8612	0.8615	

3	I:332	I:3336	216	2	I:302	I:3021	4	0:8615	0:8622	2.2.10	1	0:8407	0:8412
1	I:316	I:3184	117	1	I:284	I:2853	3	0:8526	0:8559	508	1	0:8365	0:8368
4	I:298	I:2989	322	2	I:274	I:2735	3	0:8461	0:8530	3.1.10	3	0:8322	0:8324
10	I:278	I:2792	410	6	I:255	I:2548	3	0:8428	0:8461	440	3	0:8300	0:8300
8	I:268	{I:2095	306	5	I:239	I:2401	6	—	0:8433	606	6	0:8255	0:8257
		{I:2689	411	< 1	I:245	I:2446	3	0:8376	{0:8383	338	< 1	0:8193	0:8196
		I:2626	315	2	I:236	I:2350	6	0:8341	{0:8374	530, 700	2	0:8216	0:8215
									0:8343	442	4	0:8180	0:8182
3b	I:250	{I:2525	008	1	I:2195	I:2198	3	0:8294	0:8298	428	2	0:8114	0:8114
		{I:2475	323	< 1	I:2218	I:2225	3	0:8269	0:8271	4.0.10	2b+	0:8076	0:8074
10	I:238	I:2394	412	6	I:2156	I:2153	—	—	0:8267	1.0.12	1	0:8052	0:8052
		I:2248	108	< 1	I:1935	I:1932	2	0:8257	0:8260	702, 532	2	0:8099	0:8101
		I:2023	217	< 1	I:1730	I:1734	6	0:8181	0:8183	526	4	0:8012	0:8013
7b	I:186	{I:1887	226	5b	I:1614	{I:1617	1	0:8122	0:8123	533	2	0:7965	0:7965
		{I:1849	324			{I:1604	4	0:8105	0:8107	1.1.12	2	0:7897	0:7898
4	I:174	I:1746	118	1	I:1446	I:1449	4	0:8058	0:8059	518	2	0:7881	0:7882
		I:1724	500	1	I:1501	I:1501	2	0:8030	0:8030	2.0.12	4	0:7825	0:7825
5	I:164	I:1649	316	4	I:1386	I:1387	4	0:8023	0:8024	622	4	0:7871	0:7870
3	I:152	I:1517	208	3	I:1226	I:1229	1	0:7947	0:7947	3.1.11	1	0:7751	0:7752
12	I:139	I:1393	414	4	I:1162	I:1159	4	0:7941	0:7942	704, 534	6	0:7786	0:7785
3	I:127	I:1282	330	< 1	I:1062	I:1067	10	0:7888	0:7888	4.1.10			
3	I:116	I:1167	325	< 1	I:0935	I:0930	6	0:7813	0:7814	2.1.12			
2	I:107	I:1078	420	< 1	I:0868	I:0867	10	0:7765	0:7765	710			

* Hexagonal indices hkl with third index omitted.

The intensities were estimated visually by comparison with an intensity scale. b = broad, + = broadening due to 702, 532 α_2 line.

1. Bazirite, Rockall Island (Registered No. S 57926), Gandolfi camera, a 6.769 \pm 0.0005 Å, c 10.020 \pm 0.001 Å (cell volume 397.60 Å³), space group $P\bar{6}c2$, $Z = 2$. (Data applies to bazirite with ω 1.6751, ϵ 1.6850.)

2. Benitoite, San Benito County, California, U.S.A. (Registered No. M.I. 31669), Debye-Scherrer camera, a 6.640 \pm 0.001 Å, c 9.758 \pm 0.001 Å (cell volume 372.59 Å³), space group $P\bar{6}c2$, $Z = 2$.

TABLE IV. Summary of data for bazirite, benitoite, pabstite, and synthetic BaSnSi₃O₉

	Bazirite Rockall, Scotland		Benitoite San Benito County, California	Pabstite* Santa Cruz, California	Synthetic barium tin silicate*	
	A	B				
Composition	BaZrSi ₃ O ₉		BaTiSi ₃ O ₉	Ba(Sn _{0.77} Ti _{0.23})Si ₃ O ₉	BaSnSi ₃ O ₉	
Refractive indices	ω	1.6751	1.6813	1.757†	1.685	—
	ϵ	1.6850	1.691‡	1.804	1.674	—
Optic sign	Uniaxial + ve		Uniaxial + ve	Uniaxial - ve	—	
Unit cell (hexagonal)	a	6.769 Å	6.766 Å	6.640 Å	6.706 Å	6.724 Å
	c	10.020	10.016	9.758	9.829	9.854
Measured density	—		3.65 g/cm ³	4.03 g/cm ³	—	
Calculated density	3.82 g/cm ³	3.82 g/cm ³	3.68(5) g/cm ³	4.07 g/cm ³	4.17 g/cm ³	
Space group	P6c2		P6c2	P6c2	?P6c2	

A, 'low' Ti type; B, 'high' Ti type. * Gross *et al.*, 1965. † Louderback, 1909. ‡ Deduced from birefringence.

associated with interstitial constituents that apparently developed after a partial conversion of albite to K-feldspar and of pyroxene to riebeckite had occurred in the main body of the granite (Hawkes *et al.*, 1975). As the K-feldspar is maximum microcline, the interstitial minerals probably crystallized at temperatures within or below the maximum microcline stability range of 250–300 °C. Hydrous conditions are indicated both by the K-feldspar and riebeckite conversions and by the dominance of elpidite among the interstitial constituents. Even lower temperatures of formation can be contemplated if account is taken of the occurrence of albite, acmite, magnesio-riebeckite, and elpidite in the Eocene Green River Formation, U.S.A. These minerals have grown authigenically in unmetamorphosed calcareous shale where temperatures are thought not to have exceeded 200 °C (Milton *et al.*, 1960).

The low-temperature hydrous conditions inferred for bazirite accord well with the hydrothermal environments in which benitoite and titanian pabstite are found (Louderback, 1909; Gross *et al.*, 1965).

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REFERENCES

- Galkin (Yu. M.) and Chukhlantsev (B. G.), 1965. *Izv. Akad. Nauk SSR, Neorg. Mater.* **2**, 529–36.
- Gross (E. B.), Wainwright (J. E. N.), and Evans (B. W.), 1965. *Am. Mineral.* **50**, 1164–9.
- Hawkes (J. R.), Merriman (R. J.), Harding (R. R.), and Darbyshire (D. P. F.), 1975. *Rep. Inst. Geol. Sci.* **75/1**, 15–51.
- Judd (J. W.), 1897. *Trans. R. Irish Acad.* **31**, 48–58.
- Lacroix (A.), 1921. *C.R. Acad. Sci. Paris*, **173**, 267–73.
- Louderback (G. D.), 1907. *Univ. Calif. Publ. Geol.* **5**, 149–53.
- 1909. *Univ. Calif. Publ. Geol.* **5**, 331–80.
- MacCulloch (J.), 1814. *Trans. Geol. Soc.* **2**, 392.
- Mason (P. K.), Frost (M. T.), and Reed (S. J. B.), 1969. *Natl. Phys. Lab. I.M.S. Rep.* **1**.
- Masse (R.) and Durif (A.), 1973. *C.R. Acad. Sci. Paris*, **276**, Ser. C, 1029–31.
- Milton (C.), Chao (E. C. T.), Fahey (J. J.), and Mrose (M. E.), 1960. *Int. Geol. Congress.* 21st Session (Norden), Sec. 21, 171–84.
- Rase (D. E.) and Roy (R.), 1955. *Am. Mineral.* **40**, 542–4.
- Robbins (C. R.) and Levin (E. M.), 1961. *J. Res. NBS*, **65A**, 127–31.
- Sabine (P. A.), 1960. *Bull. Geol. Surv. G.B.* **16**, 156–78.
- Sweatman (T. R.) and Long (J. V. P.), 1969. *J. Petrol.* **10**, 332–76.
- Washington (H. S.), 1914. *Q. J. Geol. Soc. London*, **70**, 294–302.
- Zachariasen (W. H.), 1930. *Zeit. Kristallogr.* **74**, 139–146.

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