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THE AMERICAN MINERALOGIST, VOL. 45, NOVEMBER–DECEMBER, 1960

VOLBORTHITE FROM BRITISH COLUMBIA

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Volborthite, $Cu_3(VO_4)_2 \cdot 3H_2O$, is present as a weathering product of a thin, interlava sedimentary rock of Upper Triassic age which crops out west of Menzies Bay on Vancouver Island, and north of Gowland Harbour on Quadra Island, British Columbia.

The vanadium-bearing rock is a black, extremely finely laminated, fossiliferous, non-clastic sediment which consists chiefly of carbonaceous matter and microcrystalline to cryptocrystalline quartz. Spectrographic analyses indicate that the carbonaceous material contains vanadium. Hypogene chalcocite is generally an additional major constituent of the sediment, in some cases making up over 50% of the rock. The associated volcanic flows are predominantly pillowform and massive porphyritic basalts, andesites, and spilites which are commonly amygdaloidal. The amygdule material is largely quartz, calcite, chlorite, zeolites, epidote, and pumpellyite. Prehnite, chalcocite, chalcopyrite, bornite, and native copper, as amygdule fillings, are widespread in small amounts; analcite, heulandite, and greenockite are of rare occurrence.

Minor quantities of volborthite coat exposed surfaces of the laminated sediment, but the mineral is more abundant along planes exposed by splitting the rock along the laminae.

Physical Properties

The vanadate assumes many colors and habits, most of which are briefly summarized below:

Dark green to yellowish green, habit massive, compact, with good cleavage. Scaly crusts and rosette-like, honey-combed, or boxwork-like aggregates. Scales with a triangular or hexagonal outline, occasionally with impurities some distance from the center arranged in a hexagonal outline. Scaly bright yellow to brownish yellow incrustations on massive or cleavable emerald green to dark green hexagonal cores of up to 0.6 mm. diameter. Yellow, brownish yellow, light brown, and blackish brown, with habit flocculent or reticulated; also radiating fibrous and circular in outline, occurring singly or in groups, usually with a succession of colored zones and a minute, massive, central teat. Less commonly bright yellow and spherulitic.

Most of the British Columbia volborthite is yellow or brownish yellow. The mineral is translucent in immersion oil, and not pleochroic. Lamellar twinning is common; the units are length fast and are twinned in a plane almost perpendicular to perfect (001) cleavage. Rare plaid twinning was also observed. The measured indices, determined on yellowish green scales and cleavage fragments, depart greatly from those reported in the literature:

α 1.793 ± .005	Biaxial negative
β 1.801 ± .005	(−) 2V large
γ 1.816 ± .005	$r < v$

Dilute acids readily attack the mineral, turning it reddish-brown and leaving a clear silica residue. The results of several spectrographic analyses are given in Table I. Abundant water is yielded in the closed tube.

TABLE 1. SPECTROGRAPHIC ANALYSES OF B.C. VOLBORTHITE

Habit	Major	Minor	Strong trace
Flocculent	Cu, V	Si, Al	Ca
Flocculent	Cu, V	Al	Si, Ca
Hexagonal cores[1]	Cu, V	Si	Fe, Al
Rosette scales	Cu, V	Si	Al, Mg, Ca

[1] Identical results were obtained from three separate analyses. Ca is present in trace amounts.

X-ray powder photographs of volborthite were taken with 57.3 and 114.59 mm. diameter Philips cameras, using nickel-filtered copper radiation. The observed intensities and measured spacings (corrected for shrinkage) are listed in Table II.

The British Columbia volborthite is associated with abundant malachite and brochantite, and small amounts of cuprite, tenorite, azurite, calcite, cyanotrichite, connellite, and an unidentified light blue hydrous copper sulphate. Although carnotite was reported from the locality by

TABLE II. VOLBORTHITE; *X*-RAY POWDER PATTERN

I	*d*(meas) Å	I	*d*(meas) Å	I	*d*(meas) Å
1	7.9	3	2.64	4	1.79
10	7.18	6	2.57	4	1.71
½	5.15	<½	2.46	3	1.68
½	4.43	6	2.39	½	1.57
½	4.26	½	2.28	½	1.55
2	4.10	2	2.23	5	1.51
½	3.59	½	2.13	3	1.50
2	3.10	3	2.04	1	1.49
4	3.00	<½	1.96	1	1.47
6	2.88	½	1.92	1	1.46
2	2.72	3	1.80	2	1.44
				1	1.43

Ellsworth (1932), no additional carnotite or uranium minerals have been found in the area. The maximum reported value of V_2O_5 in the sediment is over 3 per cent, but the lack of sufficient quantities of the copper and vanadium-bearing rock has resulted in the deposits generally being classified as uneconomical.

ACKNOWLEDGMENT

The writer is grateful for the supervision and assistance of Dr. R. M. Thompson, Professor of Mineralogy, the University of British Columbia.

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THE AMERICAN MINERALOGIST, VOL. 45, NOVEMBER–DECEMBER, 1960

THE BULK COMPOSITION OF A ZONED CRYSTAL*

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Quantitative petrographic studies often require an estimate of the bulk composition of zoned crystals, such as plagioclase feldspars. Bowen (1928, p. 143) pointed out in this connection that "the outer shell of a crystal requires to have only about one-tenth the thickness of the whole crystal in order to constitute half the volume." *X*-ray or oil immersion methods of bulk composition determination suffer from similar diffi-

* Publication authorized by the Director, U. S. Geological Survey.