# CALCIOBURBANKITE, Na₃(Ca,REE,Sr)₃(CO₃)₅, A NEW MINERAL SPECIES FROM MONT SAINT-HILAIRE, QUEBEC, AND ITS RELATIONSHIP TO THE BURBANKITE GROUP OF MINERALS

JERRY VAN VELTHUIZEN, ROBERT A. GAULT AND JOEL D. GRICE

*Mineral Sciences Section, Research Division, Canadian Museum of Nature,*
*P.O. Box 3443, Station "D", Ottawa, Ontario K1P 6P4*

## ABSTRACT

Calcioburbankite, ideally Na₃(Ca,*REE*,Sr)₃(CO₃)₅, is a new mineral species found at Mont Saint-Hilaire, Quebec. It is the Ca-analogue of burbankite, (Na,Ca)₃(Sr,Ba,Ce)₃(CO₃)₅, and of khanneshite, (Na,Ca)₃(Ba,Sr,Ce,Ca)₃(CO₃)₅. All data were collected from a single, subhedral, deep orange, prismatic crystal 2 × 1.8 × 2 cm in size. Associated minerals include ancylite-(Ce), calcite, a chlorite-group mineral, donnayite-(Y), fluorapatite, natrolite, pyrite, rhodochrosite and rutile. It is elongate parallel to [001], with {100} dominant. It has a conchoidal fracture, a vitreous luster and indistinct {100} cleavage. The mineral is soft, Mohs hardness 3 to 4, gives a white streak and is brittle. Optically, the mineral is uniaxial negative, ω 1.636(1), ε 1.631(1) (λ 589 nm). It is transluscent, nonpleochroic and nonfluorescent. Combined X-ray powder-diffraction and precession studies show that the mineral is hexagonal, possible space-groups P6₃mc, P6₃mmc or P6̄2c. The unit-cell data, refined from the powder data, give a 10.447(3) c 6.318(3) Å, V 597.23(2) Å³, a:c 0.6048(4). The strongest eight reflections determined from the powder data [d in Å(I)(hkl)] are 2.601(10)(220), 2.130(6)(401), 3.01(5)(300,211), 5.20(4)(110), 3.68(3)(201), 1.649(3)(421), 4.54(2)(200) and 9.07(2)(100). Electron-microprobe results gave Na₂O 15.17, CaO 11.81, BaO 0.46, SrO 7.65, La₂O₃ 9.30, Ce₂O₃ 14.38, Pr₂O₃ 1.26, Nd₂O₃ 3.76, Sm₂O₃ 0.48 and CO₂ (calculated according to stoichiometry) 35.13, total 99.40 wt.%. The empirical formula (based on 15 atoms of oxygen) is Na₃.₀₇(Ca₁.₃₂Ce₀.₅₅Sr₀.₄₆La₀.₃₆Nd₀.₁₄Pr₀.₀₅Sm₀.₀₂Ba₀.₀₂)Σ₂.₉₂(CO₃)₅, for Z = 2, D_calc 3.46 and D_meas 3.45(3) g/cm³. The mineral formed late in the paragenesis, possibly in a vent. The name designates its calcium-dominant position within hexagonal members of the burbankite group of minerals. The physical data of calcioburbankite are compared to those of other members of the burbankite group.

*Keywords:* calcioburbankite, Ca-analogue, burbankite group, new mineral species, carbonate, Mont Saint-Hilaire, Quebec.

## SOMMAIRE

Nous décrivons la calcioburbankite, nouvelle espèce minérale de composition idéale Na₃(Ca,TR,Sr)₃(CO₃)₅ (TR: terres rares), provenant du mont Saint-Hilaire, Québec. Il s'agit de l'analogue calcique de la burbankite, (Na,Ca)₃(Sr,Ba,Ce)₃(CO₃)₅, et de la khanneshite, (Na,Ca)₃(Ba,Sr,Ce,Ca)₃(CO₃)₅. Toutes les données obtenues ont été prélevées sur un seul cristal prismatique sub-idiomorphe, orange foncé, mesurant 2 × 1.8 × 2 cm. Lui sont associés ancylite-(Ce), calcite, une chlorite, donnayite-(Y), fluorapatite, natrolite, pyrite, rhodochrosite et rutile. Les cristaux sont allongés parallèles à [100], avec {100} dominant. Ils montrent une cassure conchoïdale, un éclat vitreux et un clivage {100} indistinct. Le minéral n'a qu'une dureté de 3 à 4; il possède une rayure blanche et il est cassant. La calcioburbankite est uniaxe négative, ω 1.636(1), ε 1.631(1) (λ 589 nm). Elle est translucide, non pléochroïque et non fluorescente. Des études par diffraction X sur poudre et sur cristal unique par précession montrent que le minéral est hexagonal, groupe spatial P6₃mc, P6₃mmc ou P6̄2c. Les paramètres réticulaires, affinés à partir des données sur poudre, sont: a 10.447(3) c 6.318(3) Å, V 597.23(2) Å³, a:c 0.6048(4). Les huit raies les plus intenses du spectre de diffraction X (méthode des poudres) [d en Å(I)(hkl)] sont: 2.601(10)(220), 2.130(6)(401), 3.01(5)(300,211), 5.20(4)(110), 3.68(3)(201), 1.649(3)(421), 4.54(2)(200) et 9.07(2)(100). Une analyse à la microsonde électronique a donné Na₂O 15.17, CaO 11.81, BaO 0.46, SrO 7.65, La₂O₃ 9.30, Ce₂O₃ 14.38, Pr₂O₃ 1.26, Nd₂O₃ 3.76, Sm₂O₃ 0.48 et CO₂ (calculé selon la stoechiométrie) 35.13, pour un total de 99.40% (poids). La formule empirique (sur une base de 15 atomes d'oxygène) est Na₃.₀₇(Ca₁.₃₂Ce₀.₅₅Sr₀.₄₆La₀.₃₆Nd₀.₁₄Pr₀.₀₅Sm₀.₀₂Ba₀.₀₂)Σ₂.₉₂(CO₃)₅, avec Z = 2, D_calc 3.46 et D_meas 3.45(3). La calcioburbankite a cristallisé tardivement, et peut-être dans un évent. Le nom rappelle sa composition à dominance calcique parmi les membres hexagonaux du groupe de la burbankite. Nous comparons les données physiques de la calcioburbankite à celles d'autres membres du groupe de la burbankite.

(Traduit par la Rédaction)

*Mots-clés:* calcioburbankite, analogue calcique, groupe de la burbankite, nouvelle espèce minérale, carbonate, mont Saint-Hilaire, Québec.

## INTRODUCTION

Burbankite-group minerals of general formula $A_3B_3(CO_3)_5$, where $A$ stands for Na, Ca, and $B$ represents Ca, Sr, Ba, and the rare-earth elements (REE), are common constituents of peralkaline rocks. At Mont Saint-Hilaire, Quebec, four members of this group were identified as a result of examination of specimens preserved in the National Mineral Collection of Canada and specimens more recently collected by staff of the Canadian Museum of Nature. This work has resulted in the characterization of two new members of the burbankite group, petersenite-(Ce) (Grice et al. 1994) and calcioburbankite, the subject of this study. Other members that were identified at Mont Saint-Hilaire include burbankite and remondite-(Ce). Khanneshite remains elusive there. However, given the potential of numerous chemical substitutions and the variety of environments at Mont Saint-Hilaire in which these minerals occur, additional new members of the group may well be found. The physical and optical properties of members of the burbankite group are similar (Table 1), hence new species were perhaps overlooked.

The specimen that was later designated the holotype was collected by Mr. Jacques Bradley during the late 1960s, and acquired by the Canadian Museum of Nature in 1972. The exact locality of the specimen, i.e., whether it originated from the Poudrette quarry or the Demix quarry, remains unknown. Both quarries are currently a single entity.

The name of this new species, calcioburbankite, reflects its Ca-dominant chemistry within the burbankite group of minerals. The new mineral and mineral name were approved by the Commission on New Minerals and Mineral Names, IMA. The holotype specimen is preserved at the Canadian Museum of Nature under catalogue number 50804.

## OCCURRENCE

Mont Saint-Hilaire, a complex agpaitic intrusion located at a triple junction and possibly the site of a mantle plume, is one of a number of compositionally different plutons and stocks that are aligned along the Ottawa–Bonnechère graben, a failed rift (Kumarapelli & Saull 1966) that extends from Temiscamingue, Quebec (Kipawa alkaline complex, ~900 to 1300 Ma; Sinclair et al. 1992) to the Newmount seamounts and the continental shelf. Periodic activation of the graben and triple junction, and the resultant igneous activity, are expressed by the Cretaceous (110 to 120 Ma) emplacement of Mont Saint-Hilaire (Currie 1989), numerous sills and dykes of the Montreal region, the Blackburn carbonatite (Hogarth et al. 1988), and other intrusive bodies within the Monteregian Hills petrographic province. A comprehensive overview of Mont Saint-Hilaire, including general information on mineral species, and a complete set of references, is found in Mandarino & Anderson (1989) and in Horváth & Gault (1990).

Calcioburbankite occurs in the quarry at Mont Saint-Hilaire, Rouville County, Quebec, found in two distinct modes of occurrence, each hosting different mineral assemblages. On the holotype specimen, the associated species include ancylite-(Ce), calcite, a chlorite-group mineral, donnayite-(Y), fluorapatite, natrolite, pyrite, rhodochrosite and rutile, suggesting that the mineral may have formed in a vent (Van Velthuizen 1990). Many species (including various REE-bearing carbonates) are found in this mode of occurrence. However, because an overlap between assemblages in this environment and in altered pegmatites, the exact mode of occurrence for the holotype specimen remains unclear.

Subsequent to the characterization of this mineral, subhedral crystals of La-enriched calcioburbankite (Table 2) were encountered in a vug in a fragment of marble xenolith. These xenoliths are unique to the aureole surrounding the hornfels unit (Van Velthuizen 1990). Unlike other observed marble xenoliths at Mont Saint-Hilaire, which are characterized by the consistent presence of pectolite and sodic amphiboles, shortite is the dominant late-forming mineral present in this association. Calcioburbankite formed late in the paragenetic sequence, but before shortite. In this environment, the mineral forms nearly equant crystals less than 0.5 mm across that display {100}, have fibrous terminations and possess a silky white exterior and a light pink, translucent interior. Another crystal 0.5 mm across displays {100} and {001}.

TABLE 1. COMPARATIVE PHYSICAL PROPERTIES,
MINERALS OF THE BURBANKITE GROUP

| Symmetry | HEXAGONAL | | | | MONOCLINIC (pseudohexagonal) | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| S.G. | $P6_3mmc$ $P6_3mc$ | $P6_3mc$ | $P6_3mmc$ | $P6_3mc$ | $P2_1$ | $P2_1$ |
| UNIT CELL | | | | | | |
| $a$ (Å) | 10.447(3) | 10.514 | 10.53 | 10.65(1) | 20.872(4) | 10.444 |
| $b$ (Å) | | | | | 6.367(1) | 6.313 |
| $c$ (Å) | 6.318(3) | 6.520 | 6.47 | 6.58(1) | 10.601 | 10.445 |
| $\beta$ (°) | | | | | 120.50 | 119.86 |
| $V$ (Å³) | 597.23(2) | 613.76* | 621.0* | 650.20* | 1213.9(4) | 597(1) |
| OPTICS | | | | | | |
| Sign | (−) | (−) | (−) | (−) | (−,+) | (+) |
| $\omega$ | 1.636(1) | 1.616 | 1.627 | 1.622 | | |
| $\epsilon$ | 1.631(1) | 1.597 | 1.615 | 1.610 | | |
| $\alpha$ | | | | | 1.623 | 1.632 |
| $\beta$ | | | | | 1.636 | 1.633 |
| $\gamma$ | | | | | 1.649 | 1.638 |
| $2V_{calc}$ | | | | | 89.9 | 40 |
| $D_{calc}$ | 3.452 | 3.50 | 3.561* | 3.8–3–9 | 3.67 | 3.46 |

* calculated for this study. S.G.: space group.
Samples: 1 calcioburbankite, Mont Saint–Hilaire, Quebec; 2 burbankite, Mont Saint–Hilaire, Quebec (Chen & Chao 1974); 3 burbankite, Bearpaw Mountains, Montana (Pecora & Kerr 1953); 4 khanneshite, Khanneshin, Afghanistan (Eremenko & Bel'ko 1982); 5 petersenite–(Ce), Mont Saint–Hilaire, Quebec (Grice et al. 1994); 6 remondite–(Ce), Ebounja, Cameroon (Cesbron et al. 1988).

TABLE 2. COMPARATIVE CHEMICAL DATA ON MEMBERS OF THE BURBANKITE GROUP FROM MONT SAINT-HILAIRE

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $Na_2O$ | 15.17 (14.99–15.43) | 13.81 (13.70–13.91) | 10.01 (10.01–13.60) | 15.59 (13.40–16.21) | 16.77 (15.36–16.77) |
| CaO | 11.81 (11.71–11.99) | 12.48 (12.08–12.88) | 13.40 (13.93–17.40) | 8.54 (2.74–8.54) | 5.07 (1.33–7.08) |
| BaO | 0.46 (0.45–0.47) | 6.00 (2.66–9.54) | 4.17 (1.30–7.90) | 1.35 (0.16–6.16) | 0.54 (0.10–1.87) |
| SrO | 7.65 (7.39–7.90) | 7.90 (4.93–13.52) | 36.48 (17.20–36.48) | 7.38 (3.50–11.30) | 2.37 (0.62–7.04) |
| $La_2O_3$ | 9.30 (9.12–9.40) | 12.51 (12.02–13.00) | 0.45 (0.18–7.98) | 12.46 (0.45–12.74) | 12.14 (12.14–14.76) |
| $Ce_2O_3$ | 14.38 (14.08–14.66) | 10.89 (9.60–12.18) | 0.85 (0.52–7.37) | 16.21 (14.73–18.75) | 21.29 (15.13–22.96) |
| $Pr_2O_3$ | 1.26 (1.41–1.23) | | | 1.33 (0.98–1.84) | 2.10 (1.02–2.34) |
| $Nd_2O_3$ | 3.76 (3.71–3.82) | 0.74 (0.50–0.97) | 0.12 (0.00–2.86) | 2.72 (2.33–5.41) | 5.04 (2.67–6.15) |
| $Sm_2O_3$ | 0.48 (0.38–0.58) | | (0.00–0.33) | 0.38 (0.18–0.86) | 0.66 (0.19–1.05) |
| $Eu_2O_3$ | | | | 0.10 (0.00–0.10) | |
| $CO_2$ | 35.13 (34.85–35.52) | 34.98 (34.59–35.37) | 34.89 (33.91–34.89) | 34.64 (31.64–36.33) | 34.07 (31.66–34.25) |
| | | | | | |
| Total | 99.40 | 100.64 | 100.37 | 100.70 | 101.26 |

Atomic proportions based on 15 atoms of oxygen

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Na | 3.063 (3.054–3.085) | 2.803 (2.793–2.813) | 2.037 (2.037–2.325) | 3.195 (3.007–3.480) | 3.495 (3.305–3.372) |
| Ca | 1.319 (3.054–3.085) | 1.400 (1.371–1.429) | 1.507 (0.856–1.507) | 0.967 (0.340–1.286) | 0.584 (0.190–0.832) |
| Ba | 0.019 (0.018–0.019) | 0.246 (0.102–0.387) | 0.172 (0.172–0.285) | 0.056 (0.006–0.137) | 0.023 (0.011–0.082) |
| Sr | 0.462 (0.448–0.481) | 0.560 (0.296–0.830) | 2.221 (1.077–2.221) | 0.452 (0.203–0.716) | 0.148 (0.042–0.458) |
| La | 0.357 (0.353–0.362) | 0.483 (0.469–0.497) | 0.017 (0.007–0.318) | 0.486 (0.017–0.634) | 0.481 (0.343–0.612) |
| Ce | 0.549 (0.549–0.561) | 0.417 (0.372–0.462) | 0.330 (0.021–0.501) | 0.627 (0.627–0.899) | 0.838 (0.621–0.968) |
| Pr | 0.048 (0.042–0.481) | | 0.019 (0.000–0.019) | 0.051 (0.048–0.067) | 0.082 (0.040–0.097) |
| Nd | 0.140 (0.139–0.141) | 0.028 (0.036–0.019) | 0.004 (0.000–0.110) | 0.103 (0.103–0.170) | 0.236 (0.103–0.247) |
| Sm | 0.017 (0.014–0.021) | | 0.010 (0.000–0.010) | 0.014 (0.011–0.034) | 0.024 (0.007–0.037) |
| Eu | | | | 0.004 (0.000–0.004) | |
| C | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| | | | | | |
| Sum | 10.977 | 10.938 | 10.991 | 10.955 | 10.915 |

Samples: 1 calcioburbankite: specimen from altered pegmatite or vent; 2 calcioburbankite (La–enriched), specimen from marble xenolith found in contact zone of hornfels unit; 3 burbankite, specimens from miarolitic cavities in nepheline–sodalite syenite; 4 remondite–(Ce), specimens from pegmatite in nepheline syenite in contact zone with hornfels unit; 5 petersenite–(Ce), specimens from pegmatite in nepheline–sodalite syenite in contact zone with hornfels unit.

Associated species in this marble xenolith include aegirine, calcite, fluorite, galena, leucophanite, mangan-neptunite, microcline, molybdenite-2$H$ and -3$R$, narsarsukite, pectolite, pyrite, schairerite, shortite, sodalite, sphalerite, thermonatrite and titanite.

## PHYSICAL AND OPTICAL PROPERTIES

The holotype specimen of calcioburbankite is a subhedral prismatic crystal, elongate parallel to {001}, measuring 2 × 1.8 × 2 cm. The exterior of the crystal is partially altered to ancylite-(Ce) and possibly carbocernaite. A second crystal, relatively unaltered, adjacent to the principal crystal, displays similar physical characteristics. The interior of the main crystal is deep orange in color, with a vitreous luster; it is translucent and gives a white streak. The Mohs hardness is 3 to 4. Calcioburbankite has an indistinct cleavage {100} and a conchoidal fracture; it is brittle. Fluorescence was not detected in either long or short-wave ultraviolet light. The measured density, 3.45(3) g/cm³, determined by the suspension method using Clerici solution, compares well with the calculated density of 3.46 g/cm³ derived from the empirical formula. It dissolves rapidly in 10% HCl. Calcioburbankite is uniaxial negative, ω 1.636(1), ε 1.631(1) (λ = 589 nm), and is nonpleochroic. A compatibility index of 0.004 was calculated using the Gladstone–Dale constants (Mandarino 1979, 1981); this indicates superior agreement between the physical and chemical data.

## CHEMICAL COMPOSITION

Chemical analyses were performed using a JEOL 733 Superprobe utilizing Tracor Northern 5600 automation. The wavelength-dispersion mode was used. A conventional ZAF correction routine for data reduction was employed using the Tracor Northern Task series of programs. The operating voltage was 15 kV, and the beam current, 0.020 μA. To prevent sample decomposition, the electron beam was defocused to 50 μA. Chemical homogeneity was checked using the electron-backscatter detector prior to analysis. For each analysis Na was sought first, with the data for Na collected for 10 seconds. Data collection for all other elements present was collected for 25 seconds or 0.50% precision, whichever was attained first.

The average result of three analyses on three grains is given in Table 3. A 100-second energy-dispersion scan indicated no other elements with Z greater than 8, except those reported here. The elements Y, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Th were sought using

TABLE 3. COMPARATIVE CHEMICAL DATA
FOR MEMBERS OF THE BURBANKITE GROUP

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $Na_2O$ | 15.17 | 8.30 | 9.69 | 6.77 | 17.38 | 17.16 |
| $CaO$ | 11.81 | 12.03 | 13.46 | 6.72 | 1.32 | 10.54 |
| $BaO$ | 0.46 | 11.02 | 13.56 | 38.58 | 0.32 | |
| $SrO$ | 7.65 | 32.35 | 19.42 | 6.15 | 1.70 | 3.98 |
| $La_2O_3$ | 9.30 | | 2.34 | | 14.49 | 11.60 |
| $Ce_2O_3$ | 14.38 | 2.12 | 4.65 | | 23.66 | 14.99 |
| $Pr_2O_3$ | 1.26 | | 0.37 | | 2.00 | 1.49 |
| $Nd_2O_3$ | 3.76 | 0.13 | 1.40 | | 5.82 | 3.34 |
| $Sm_2O_3$ | 0.48 | 0.10 | | 0.60 | 0.50 | |
| $Dy_2O_3$ | | 0.08 | | | | 0.07 |
| $Gd_2O_3$ | | | 0.08 | | | 0.24 |
| $Yb_2O_3$ | | 0.10 | | | | 0.03 |
| $CO_2$ | [35.13] | 33.17 | 32.55 | 23.61 | 32.92 | 35.24 |
| Total | [99.40] | 99.30 | 99.31 | 99.47 | 100.21 | 99.55 |
| | | * | * | * | | |
| Na | 3.06 | 1.76 | 2.08 | 2.08 | 3.75 | 3.47 |
| Ca | 1.32 | 1.42 | 1.59 | 0.92 | 0.16 | 1.18 |
| Ba | 0.02 | 0.48 | 0.59 | 1.69 | 0.01 | |
| Sr | 0.46 | 2.07 | 1.24 | 0.47 | 0.11 | 0.24 |
| La | 0.36 | | 0.10 | | 0.59 | 0.45 |
| Ce | 0.55 | 0.09 | 0.19 | | 0.96 | 0.57 |
| Pr | 0.05 | | 0.02 | | 0.08 | 0.06 |
| Nd | 0.14 | | 0.06 | | 0.23 | 0.12 |
| Sm | 0.02 | | | | 0.02 | 0.02 |
| Dy | | | | | | 0.07 |
| Gd | | | | | | 0.24 |
| C | 5 | 5 | 5 | 4.93 | 5 | 5 |
| Sum | 10.98 | 10.84 | 10.86 | 10.85 | 10.91 | 11.42 |

* calculated from published data.

Samples: 1 calcioburbankite, Mont Saint–Hilaire, Quebec; 2 burbankite, Mont Saint–Hilaire, Quebec (Chen & Chao 1974); 3 burbankite, Bearpaw Mtns., Montana (Pecora & Kerr 1953), the reported composition of which includes $K_2O$ 0.15, $SiO_2$ 0.16, $Fe_2O_3$ 0.03, MgO 0.14, $P_2O_5$ 0.12, $H_2O$ 0.18, $SO_3$ 0.24, $Al_2O_3$ 0.25, $Y_2O_3$ 0.10 wt%, and estimated impurities, 4%; 4 khanneshite, Khanneshin, Afghanistan (Eremenko & Bel'ko 1982), the reported composition of which is the average of two analyses, and includes $K_2O$ 0.69, $Fe_2O_3$ 0.19, $Al_2O_3$ 0.19, $SiO_2$ 0.55, $REE_2O_3$ 8.57, $SO_3$ 5.95, $H_2O$ 1.38, (OH) 0.04; the presence of barite, chlorite and dolomite was corrected for in the cation numbers; 5 petersenite–(Ce), Mont Saint–Hilaire, Quebec (Grice et al. 1994), the reported composition of which is the average of three analyses; 6 remondite–(Ce), Ebounja, Cameroon (Cesbron et al. 1988), the reported composition of which includes $Eu_2O_3$ 0.09, $Ho_2O_3$ 0.01, $Er_2O_3$ 0.03, $Y_2O_3$ 0.24, $Lu_2O_3$ 0.04.

## X-RAY CRYSTALLOGRAPHY

X-ray precession photographs show calcio-burbankite to be hexagonal with possible space-groups $P6_3mc$, $P6_3mmc$ or $P\bar{6}2c$. The unit-cell parameters of calcioburbankite were refined by comparison with the reported cells for burbankite [space group $P6_3mc$, a 10.514, c 6.520 Å (Chen & Chao 1974)]. The mean of five sets of data, corrected for film shrinkage, were refined using the program CELREF (Appleman & Evans 1973). The indexed powder pattern is presented in Table 4. The cell parameters and cell volume for calcioburbankite are compared to other hexagonal members of the group in Table 1. The comparison demonstrates strong similarities of the X-ray-diffraction data. Minor differences are noted with

TABLE 4. CALCIOBURBANKITE: X–RAY POWDER–DIFFRACTION DATA

| Calcioburbankite | | | | Burbankite[1] | | | | Khanneshite[2] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_{obs}$ | $d_{obs}$ | $d_{calc}$ | hkl | $I_{obs}$ | $d_{obs}$ | $d_{calc}$ | hkl | I | d Å | hkl |
| 2 | 9.07 | 9.05 | 100 | 2 | 9.10 | 9.10 | 100 | 2 | 9.25 | 100 |
| 4 | 5.20 | 5.22 | 110 | 5 | 5.28 | 5.30 | 101 | 3 | 5.34 | 101 |
| | | | | | | 5.25 | 110 | | | |
| 2 | 4.54 | 4.52 | 200 | 2 | 4.53 | 4.55 | 200 | 2 | 4.62 | 200 |
| 3 | 3.68 | 3.68 | 201 | 5 | 3.73 | 3.73 | 201 | 5 | 3.78 | 201 |
| 1 | 3.42 | 3.42 | 210 | 1 | 3.44 | 3.44 | 210 | 1 | 3.50 | 210 |
| 2 | 3.16 | 3.16 | 002 | 3 | 3.26 | 3.26 | 002 | 3 | 3.29 | 002 |
| 5 | 3.01 | 3.01 | 300 | | | | | | | |
| | | 3.00 | 211 | 1 | 3.04 | 3.04 | 211 | 6 | 3.08 | 211 |
| 2 | 2.714 | 2.721 | 301 | 4 | 2.754 | 2.752 | 301 | 2 | 2.80 | 301 |
| | | | | 8 | 2.651 | 2.651 | 202 | 3 | 2.69 | 202 |
| 10 | 2.601 | 2.612 | 220 | 10 | 2.631 | 2.628 | 220 | 10 | 2.66 | 220 |
| .5 | 2.509 | 2.509 | 310 | | | | | | | |
| 2 | 2.331 | 2.332 | 311 | 1 | 2.354 | 2.355 | 311 | | | |
| 1 | 2.263 | 2.262 | 400 | .5 | 2.278 | 2.276 | 400 | .5 | 2.30 | 400 |
| 1 | 2.180 | 2.181 | 302 | .5 | 2.220 | 2.221 | 302 | 1 | 2.27 | 302 |
| 6 | 2.130 | 2.130 | 401 | 5 | 2.150 | 2.149 | 401 | 5 | 2.19 | 401 |
| 1 | 2.050 | 2.051 | 103 | .5 | 2.112 | 2.114 | 103 | | | |
| 2 | 2.013 | 2.013 | 222 | 3 | 2.046 | 2.046 | 222 | 2 | 2.09 | 222 |
| 2 | 1.971 | 1.971 | 321 | 2 | 1.989 | 1.987 | 410 | 3 | 2.02 | 410 |
| | | 1.974 | 410 | | | | | | | |
| 2 | 1.908 | 1.909 | 203 | 2 | 1.960 | 1.961 | 203 | 2 | 1.998 | 203 |
| 1 | 1.838 | 1.839 | 402 | 1 | 1.867 | 1.866 | 402 | 1 | 1.904 | 402 |
| | | | | .5 | 1.837 | 1.838 | 213 | | | |
| .5 | 1.793 | 1.793 | 213 | 3 | 1.756 | 1.759 | 322 | 2 | 1.783 | 322 |
| 2 | 1.737 | 1.740 | 501 | | | | | | | |
| .5 | 1.674 | 1.674 | 412 | .5 | 1.698 | 1.697 | 412 | 4 | 1.691 | 421 |
| 3 | 1.649 | 1.650 | 421 | .5 | 1.664 | 1.664 | 421 | | | |
| .5 | 1.613 | 1.613 | 313 | | | | | .5 | 1.636 | 004 |
| .5 | 1.574 | 1.574 | 511 | .5 | 1.586 | 1.586 | 511 | .5 | 1.575 | 114 |
| 1 | 1.541 | 1.541 | 403 | .5 | 1.570 | 1.572 | 403 | | | |
| | | | | .5 | 1.537 | 1.535 | 204 | .5 | 1.551 | 204 |
| .5 | 1.525 | 1.525 | 332 | | | | | | | |
| 1 | 1.505 | 1.505 | 422 | .5 | 1.520 | 1.522 | 422 | 1 | 1.528 | 323 |
| .5 | 1.491 | 1.491 | 204 | | | | | | | |
| 1 | 1.448 | 1.448 | 431 | .5 | 1.460 | 1.459 | 431 | | | |
| | | 1.445 | 512 | | | | | | | |
| .5 | 1.412 | 1.412 | 521 | | | | | | | |
| .5 | 1.399 | 1.400 | 304 | | | | | | | |
| .5 | 1.380 | 1.380 | 610 | | | | | | | |
| .5 | 1.361 | 1.361 | 602 | | | | | | | |
| 1 | 1.351 | 1.352 | 224 | | | | | | | |
| 1 | 1.328 | 1.327 | 423 | | | | | | | |
| .5 | 1.316 | 1.317 | 522 | | | | | | | |
| 1 | 1.306 | 1.306 | 440 | | | | | | | |
| .5 | 1.295 | 1.295 | 404 | | | | | | | |
| .5 | 1.266 | 1.266 | 531 | | | | | | | |
| .5 | 1.255 | 1.257 | 721 | | | | | | | |
| 1 | 1.231 | 1.230 | 621 | | | | | | | |
| .5 | 1.217 | 1.216 | 205 | | | | | | | |
| .5 | 1.207 | 1.207 | 442 | | | | | | | |
| 1 | 1.195 | 1.196 | 702 | | | | | | | |

114.6 mm Debye–Scherrer camera, Ni–filtered CuKα radiation, visually estimated intensities. Indexed on a cell a 10.447(3), c 6.318(3) Å; five additional lines to 1.079 Å. Data from the literature: [1] Chen & Chao (1974), [2] Eremenko & Bel'ko (1982).

wavelength-dispersion scans, but were not detected. The concentrations of the REE were corrected for peak overlaps. The following standards were used: albite (NaKα), calcite (CaKα), sanbornite (BaLα), celestine (SrLα), LaPO₄ (LaLα), CePO₄ (CeLα), PrPO₄ (PrLα), NdPO₄ (NdLα) and SmPO₄ (SmLα). Carbon was detected utilizing a Perkin Elmer 240c elemental analyzer. The proportion of $CO_2$ was calculated by stoichiometry on the basis of the structure analysis of burbankite by Voronkov et al. (1967), which was later refined by Effenberger et al. (1985).

Infrared analysis, using a Bomen Michelson MB 100 FTIR spectrometer equipped with a cryogenic MCT detector, failed to detect the presence of OH or $H_2O$. Dawsonite, $NaAl(CO_3)(OH)_2$, was used as a comparative standard.

The empirical formula of calcioburbankite, based on 15 atoms of oxygen, is $Na_{3.07}(Ca_{1.32}Sr_{0.46}Ce_{0.55}La_{0.36}Nd_{0.14}Pr_{0.05}Sm_{0.02}Ba_{0.02})_{\Sigma 2.92}(CO_3)_5$ or, ideally, $Na_3(Ca,REE,Sr)_3(CO_3)_5$ for $Z = 2$.

respect to variations in intensity and shifted reflections among calcioburbankite, burbankite, khanneshite and remondite-(Ce). Petersenite-(Ce) is distinguished by the presence of several extra reflections (Grice *et al.* 1994). Identification of members of the burbankite group by X-ray means is tenuous, and additional optical and chemical data are necessary.

## DISCUSSION

Pecora & Kerr (1953) described burbankite from silicate – carbonate – sulfide veins in shonkinite and mafic monzonite from the Bearpaw Mountains, Montana, and proposed the general formula $Q_6(CO_3)_5$, where $Q$ stands for Na, Ca, Sr, Ba, and *REE*. Effenberger *et al.* (1985) proposed the formula $A_3B_3(CO_3)_5$, with $A$ [8]-coordinated, $A$–O = 2.488 Å, and $B$ [10]-coordinated, $B$–O = 2.683 Å. The $A$ site is occupied by Na and Ca atoms, and the $B$ site, by varying amounts of Sr, Ba, and *REE*, based on their structure refinement of burbankite from the type locality.

Based on chemical data provided in Table 3 for hexagonal members of the burbankite group, Sr, Ba, and Ca are the dominant cations in the $B$ site in burbankite, khanneshite, and calcioburbankite, respectively. Lesser amounts of Sr, Ba, and *REE* are present in calcioburbankite, but the $A$ site is fully occupied by Na. Although the proportion of La is greater than that of Ce in the $B$ site in La-enriched calcioburbankite, the total Ca content exceeds total *REE* in this site.

## ACKNOWLEDGEMENTS

## REFERENCES

APPLEMAN, D.E. & EVANS, H.T., JR. (1973): Job 9214: Indexing and least-squares refinement of powder diffraction data *U.S. Geol. Surv., Comput. Contrib.* **20** (NTIS Doc. PB-16188).

CESBRON, F., GILLES, C., PELISSON, P. & SAUGES, J.-C.; (1988) La remondite(Ce), un nouveau carbonate de terres rares de la famille de la burbankite. *C.R. Acad. Sci. Paris, Sér.* **11 307**, 915-920.

CHEN, T.T., & CHAO, G.Y. (1974): Burbankite from Mont Saint-Hilaire, Quebec. *Can. Mineral.* **12**, 342-345.

CURRIE, K.L. (1989): Geology and composition of the Mont Saint-Hilaire pluton, southern Quebec. *Geol. Surv. Can., Open-File Rep.* **2031**.

EFFENBERGER, H., KLUGER, F., PAULUS, H. & WÖLFEL, E.R. (1985): Crystal structure refinment of burbankite. *Neues Jahrb. Mineral., Monatsh.*, 161-170.

EREMENKO, G.H. & BEL'KO, V.A. (1982): Khanneshite $(Na,Ca)_3(Ba,Sr,Ce,Ca)_3(CO_3)_5$, a new mineral of the burbankite group. *Zap. Vses. Mineral. Obshchest.* **111**, 321-342 (in Russ.).

GRICE, J.D., VAN VELTHUIZEN, J. & GAULT, R.A. (1994): Petersenite-(Ce), a new mineral from Mont Saint-Hilaire, and its structural relationship to other REE carbonates. *Can. Mineral.* **32**, 405-414.

HOGARTH, D.D., RUSHFORTH, A. & McCORKELL, R.H. (1988): The Blackburn carbonatite near Ottawa, Ontario: dykes with fluidized emplacement *Can. Mineral.* **26**, 377-390.

HORVÁTH, L. & GAULT, R.A. (1990): The mineralogy of Mont Saint-Hilaire, Quebec. *Mineral. Rec.* **21**, 284-359.

KUMARAPELLI, P.S. & SAULL, V.A. (1966): The Saint Lawrence valley rift system: a North American equivalent of the East African rift valley system. *Can. J. Earth Sci.* **3**, 639-658.

MANDARINO, J.A. (1979): The Gladstone–Dale relationship. III. Some general applications. *Can. Mineral.* **17**, 71-76.

———— (1981): The Gladstone–Dale relationship. IV. The compatibility concept and its application. *Can. Mineral.* **19**, 441-450.

———— & ANDERSON, V. (1989): *Monteregian Treasures: the minerals of Mont Saint-Hilaire, Quebec.* Cambridge University Press, London, U.K.

PECORA, W.T. & KERR, J.H. (1953): Burbankite and calkinsite, two new carbonate minerals from Montana. *Am. Mineral.* **38**, 1169-1183.

SINCLAIR, W.D., JAMBOR, J.L. & BIRKETT, T.C. (1992): Rare earths and the potential for rare-earth deposits in Canada. *Explor. Mining Geol.* **1**, 265-281.

VAN VELTHUIZEN, J. (1990): A hornfels unit in the Poudrette quarry. *Mineral. Rec.* **21**, 360-362, 368.

VORONKOV, A.A., SHUMYATSKAYA, N.G. & PYATENKO, YU.A. (1967): Crystal structure of burbankite. *Sov. Phys. Crystallogr.* **12**, 107.