



## Article

# Hydroxylbastnäsite-(La), an ‘old new’ bastnäsite-group mineral

## Mineralogy, petrology and geochemistry of pegmatites: Alessandro Guastoni memorial issue

Igor V. Pekov<sup>1</sup>, Natalia V. Zubkova<sup>1</sup>, Anatoly V. Kasatkin<sup>2</sup> , Nikita V. Chukanov<sup>3</sup>, Natalia N. Koshlyakova<sup>1</sup> , Dmitry A. Ksenofontov<sup>1</sup>, Radek Škoda<sup>4</sup> , Sergey N. Britvin<sup>5</sup> , Anatoly S. Kirillov<sup>5</sup>, Anatoly N. Zaitsev<sup>5</sup>, Aleksey M. Kuznetsov<sup>6</sup> and Dmitry Yu. Pushcharovsky<sup>1</sup>

<sup>1</sup>Faculty of Geology, Moscow State University, Vorobievsky Gory, 119991 Moscow, Russia; <sup>2</sup>Fersman Mineralogical Museum of the Russian Academy of Sciences, Leninsky Prospekt 18-2, 119071 Moscow, Russia; <sup>3</sup>Federal Research Center of Problems of Chemical Physics and Medicinal Chemistry of the Russian Academy of Sciences, 142432 Chernogolovka, Moscow region, Russia; <sup>4</sup>Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37, Brno, Czech Republic; <sup>5</sup>St. Petersburg State University, University Emb. 7/9, 199034 St. Petersburg, Russia and <sup>6</sup>Independent researcher, 454071 Chelyabinsk, Russia

### Abstract

Hydroxylbastnäsite-(La), the OH- and La-dominant member of the bastnäsite group, in fact known for many years, was studied in detail and has been approved by the IMA–CNMNC as a new mineral species with the ideal, end-member formula  $\text{La}(\text{CO}_3)(\text{OH})$ . The holotype originates from the Vuoriyarvi (another spelling: Vuorijärvi) alkaline-ultrabasic complex, Northern Karelia, and the cotype from the Mochalin Log REE deposit, Potaniny Mts, South Urals, both in Russia. At Vuoriyarvi, hydroxylbastnäsite-(La) occurs as clusters (up to 1 mm) of light brown, honey-yellow or colourless hexagonal tabular to short-prismatic crystals up to 0.15 mm associated with fluorite and ancylite-(Ce) in cavities of calcite–dolomite carbonatites. At Mochalin Log, hydroxylbastnäsite-(La) forms light brown grains up to 0.2 mm included in massive aggregates of other LREE minerals: bastnäsite-(Ce), bastnäsite-(La), percleveite-(Ce), percleveite-(La), biraite-(Ce), biraite-(La), törnebohmitite-(La), ferriperbøeite-(Ce), allanite-(Ce), etc.  $D_{\text{meas}}$  is 4.75(2) and  $D_{\text{calc}}$  is 4.778 g cm<sup>-3</sup> (holotype). Hydroxylbastnäsite-(La) is optically uniaxial (+),  $\omega = 1.76(1)$  and  $\varepsilon = 1.86(1)$  (holotype). The chemical composition (wt.%, electron microprobe, CO<sub>2</sub> and H<sub>2</sub>O calculated: holotype/cotype) is: CaO 0.23/0.00, SrO 0.07/0.00, La<sub>2</sub>O<sub>3</sub> 39.47/39.58, Ce<sub>2</sub>O<sub>3</sub> 33.51/31.99, Pr<sub>2</sub>O<sub>3</sub> 1.03/1.51, Nd<sub>2</sub>O<sub>3</sub> 1.95/2.38, F 0.76/3.33, CO<sub>2</sub> 20.49/20.34, H<sub>2</sub>O 3.77/2.58, –O=F 0.32/1.40, total 100.96/100.31. The empirical formulae, calculated based on the sum of metal cations of 1 apfu and one CO<sub>3</sub> group pfu, are  $(\text{La}_{0.52}\text{Ce}_{0.44}\text{Nd}_{0.02}\text{Pr}_{0.01}\text{Ca}_{0.01})_{\Sigma 1.00}(\text{CO}_3)[(\text{OH})_{0.90}\text{F}_{0.09}]_{\Sigma 0.99}$  (holotype) and  $(\text{La}_{0.53}\text{Ce}_{0.42}\text{Nd}_{0.03}\text{Pr}_{0.02})_{\Sigma 1.00}(\text{CO}_3)[(\text{OH})_{0.62}\text{F}_{0.38}]_{\Sigma 1.00}$  (cotype). Hydroxylbastnäsite-(La) is hexagonal,  $P6$ , unit-cell parameters (from powder XRD data, holotype/cotype) are:  $a = 12.537(3)/12.533(1)$ ,  $c = 9.968(2)/9.908(1)$  Å,  $V = 1356.8(5)/1347.9(3)$  Å<sup>3</sup> and  $Z = 18$ . Strong reflections of the powder XRD pattern [ $d, \text{Å}(I)(hkl)$ ] are (holotype): 4.98(39)(002), 3.616(88)(300), 2.926(100)(302), 2.089(41)(330), 2.052(46)(304) and 1.927(40)(332). The crystal structure of holotype hydroxylbastnäsite-(La) was refined by the Rietveld method,  $R_{\text{wp}} = 0.0071$ ,  $R_{\text{p}} = 0.0050$ ,  $R_{\text{obs}} = 0.0466$ . It is isostructural to hydroxylbastnäsite-(Ce) and synthetic bastnäsite-type hydroxyl-carbonates  $\text{REE}^{3+}(\text{CO}_3)(\text{OH})$  ( $\text{REE} = \text{La}–\text{Er}$ ), but differs from fluorine-dominant bastnäsites which adopt the space group  $P62c$ .

**Keywords:** hydroxylbastnäsite-(La); new mineral; bastnäsite group; rare-earth carbonate; crystal structure; Vuoriyarvi complex; Mochalin Log REE deposit

(Received 19 July 2024; accepted 22 August 2024; Accepted Manuscript published online: 12 November 2024)

### Introduction

The minerals of the bastnäsite group (hereafter bastnäsites) are carbonates of rare-earth elements (REE) with the general formula

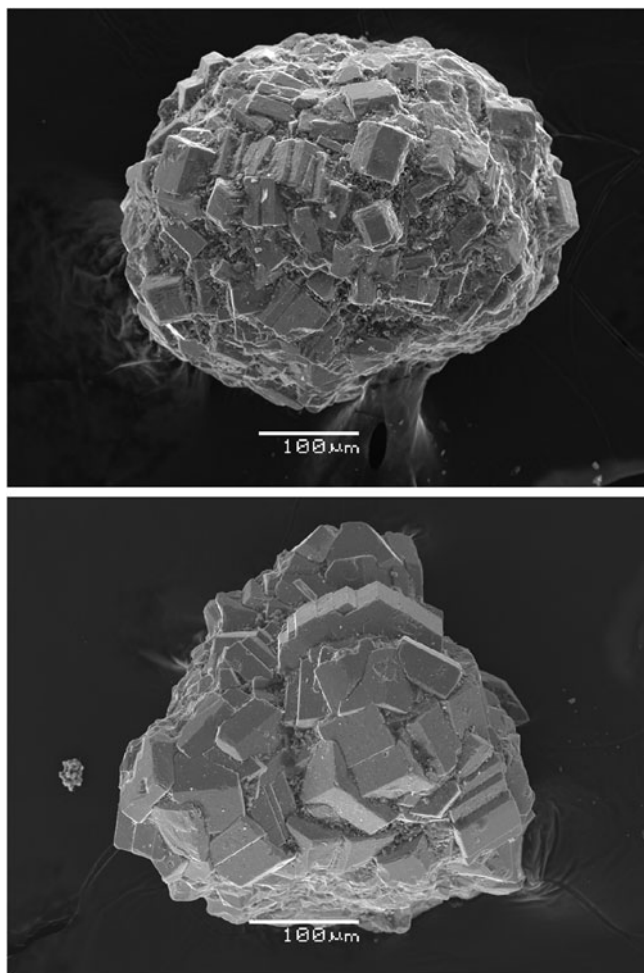
$\text{REE}^{3+}(\text{CO}_3)\text{X}^-$  in which species-defining REE = La, Ce, Nd, or Y and X = F or OH. The root names of F-dominant members are based on the term ‘bastnäsite’ whereas OH-dominant members are based on the term ‘hydroxylbastnäsite’, and the Levinson’s modifier indicates the prevailing REE. Bastnäsite-(Ce), ideally  $\text{Ce}(\text{CO}_3)\text{F}$ , is one of the most widespread rare-earth minerals, an important (in some deposits the major) ore mineral of REE. It has been known for two centuries being first described by Berzelius (1825) as *Basisk flusspatssyradt Cerium*. Other members of the

**Corresponding author:** Igor V. Pekov; Email: [igorpekov@mail.ru](mailto:igorpekov@mail.ru)

**Associate Editor:** Daniel Atencio

This paper is part of a thematic set on pegmatites in memory of Alessandro Guastoni

**Cite this article:** Pekov IV. *et al.* (2025). Hydroxylbastnäsite-(La), an ‘old new’ bastnäsite-group mineral. *Mineralogical Magazine*, 1–11. <https://doi.org/10.1180/mgm.2024.65>



**Figure 1.** Clusters of hydroxylbastnäsite-(La) crystals from Vuoriyarvi. Holotype specimen number 97514. SEM (secondary electron) images.

group have been defined as individual, valid mineral species since the 1960s, i.e. after the establishment of the International Mineralogical Association (IMA) Commission on New Minerals and Mineral Names in 1959, and they are: hydroxylbastnäsite-(Ce) (Kirillov, 1964); bastnäsite-(La) (Levinson, 1966); bastnäsite-(Y) (Mineev *et al.*, 1970); hydroxylbastnäsite-(Nd) (Maksimović and Pantó, 1985); bastnäsite-(Nd) (Miyawaki *et al.*, 2013); and the mineral described in the present paper, hydroxylbastnäsite-(La) (Pekov *et al.*, 2021). It should be noted that the histories of the definition of hydroxylbastnäsite-(Ce), bastnäsite-(La), bastnäsite-(Y) and hydroxylbastnäsite-(La) as mineral species are not very simple; for the three formers, a historical overview is reported by Pekov (1998), while for hydroxylbastnäsite-(La), which is first described as a valid mineral species in the present paper, it is given in the next paragraph.

Hydroxylbastnäsite-(La) is in fact ‘an old new’ mineral. Probably, the first recorded locality for this mineral species is the Mochalin Log REE deposit in South Urals, Russia. A bastnäsite-group mineral was first described from Mochalin Log in 1861 by Fedor Korovaev as ‘kyshtymoparisite’, or ‘Kischtim-Parisit’ (Korovaev, 1861; Korovaeff, 1862); some time later this name was modified to ‘kischtimite’ by Brush (1863). In the 20<sup>th</sup> Century, this mineral collected from Mochalin Log was systematically studied and reported as bastnäsite by Lacroix (1912), Silberminz (1929), Alimarin (1930) and Svyazhin (1965). The

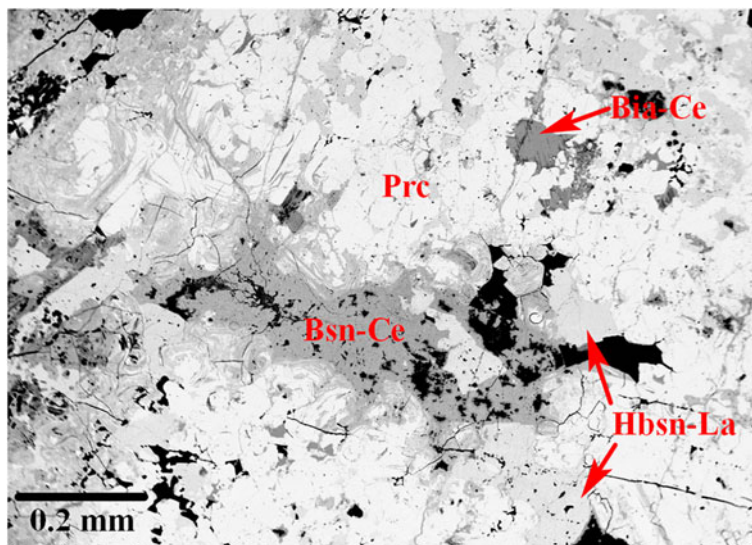
bastnäsite chemically analysed by Alimarin was La-rich and contained 2.24 wt.% F and 1.83 wt.% H<sub>2</sub>O (Alimarin, 1930) that corresponds to the OH/(OH+F) ratio equal to 0.63. Based on these data, Strunz (1962) concluded that “*kischtimite is bastnäsite with OH instead of F and relatively high La content*”. Svyazhin (1965) found that bastnäsite from Mochalin Log contains comparable amounts of Ce and La and also suggested preserving the name ‘kyshtymite’ (modified as ‘kischtimite’, in accordance with common English transliteration of Russian geographical names) for a La-rich and F-depleted variety of bastnäsite. The first quantitative electron-microprobe analyses of bastnäsite-group minerals from Mochalin Log were published by us in 2002: bastnäsite-(Ce), bastnäsite-(La), hydroxylbastnäsite-(Ce) and a potential mineral species ‘hydroxylbastnäsite-(La)’ were identified here (Pekov *et al.*, 2002). The latter mineral was also found at several other localities. Chemical data for its supergene Ce-depleted variety from bauxite deposits of Hungary, Greece and the former Yugoslavia were reported by Maksimović and Pantó (1983) and Pantó and Maksimović (2001) (see also: Hawthorne *et al.*, 1986; Jambor and Roberts, 2002). The mineral chemically corresponding to hydroxylbastnäsite-(La) was reported from rhyolites near Tisovec-Rejkovo, Slovakia (Ondrejka *et al.*, 2005).

However, despite the use of the name ‘hydroxylbastnäsite-(La)’ in the literature and databases, the natural OH- and La-dominant member of the bastnäsite group was not studied in detail and had never been formally accepted by the IMA as valid mineral species. To fill this lacuna, we examined hydroxylbastnäsite-(La) on the specimens from two localities and submitted the proposal on this mineral as a new species to the IMA Commission on New Minerals, Nomenclature and Classification (CNMNC). The specimen considered as the holotype (most studied) originates from the Vuoriyarvi (another spelling: Vuorijärvi) alkaline-ultrabasic complex, Northern (Polar) Karelia (near the border with the Kola Peninsula), Murmansk Oblast, Russia. The cotype material originates from the Mochalin Log REE deposit located in the valley of the Mochalin Log stream, a left tributary of the Borzovka river, in Potaniny Mts, 14 km N of the city of Kyshtym, Chelyabinsk Oblast, South Urals, Russia. Note, both these localities are also the co-type localities of hydroxylbastnäsite-(Ce) (see Pekov, 1998).

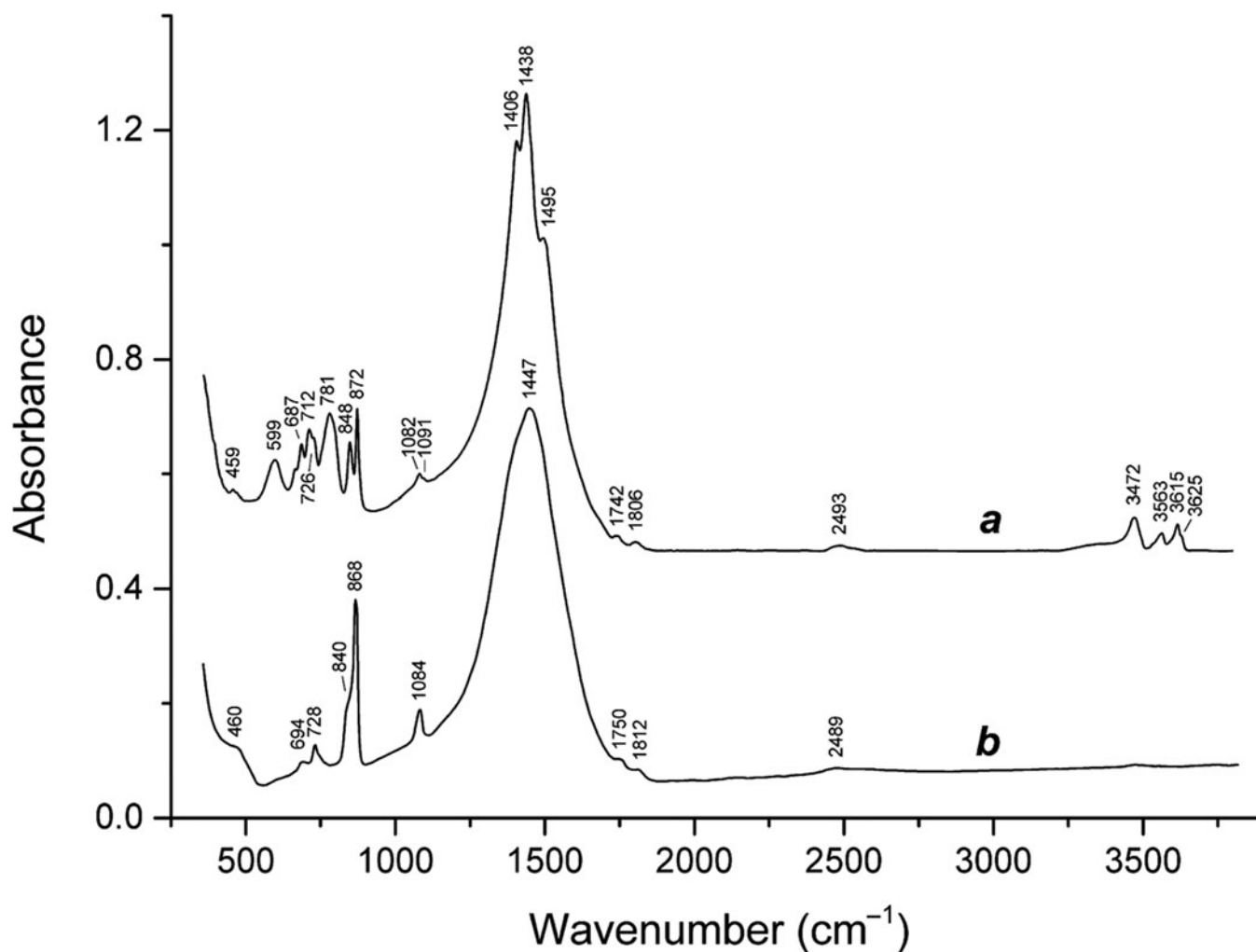
Both the mineral and its name, which is obvious for OH- and the La-dominant member of the bastnäsite group, have been approved by the IMA-CNMC, IMA2021-001 (Pekov *et al.*, 2021). The type specimens of hydroxylbastnäsite-(La) are deposited in the systematic collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences, Moscow, Russia with the catalogue numbers 97514 (holotype material from Vuoriyarvi) and 97515 (cotype from Mochalin Log). The symbol for this mineral is Hbsn-La (Warr, 2021; updated March 2023 version at <http://cnmnc.units.it/>).

### Occurrence and general appearance

At the Vuoriyarvi alkaline-ultrabasic complex (for its description see e.g.: Kukharensko *et al.*, 1965; Karchevsky and Moutte, 2004 and references therein), hydroxylbastnäsite-(La) was identified in the material collected by one of the authors (A.S.K.) in the late 1950s. This mineral forms well-shaped hexagonal tabular to short-prismatic crystals up to 0.15 mm in size. The pinacoid {001} and the hexagonal prism {100} are their main forms, the narrow faces {103} and {201} were observed on some



**Figure 2.** Hydroxylbastnäsite-(La) (Hbsn-La) grains in an aggregate of other *LREE* minerals and quartz (black areas) from Mochalin Log. Prc – percleveite-(Ce)/percleveite-(La), Bsn-Ce – Ca-enriched variety of bastnäsite-(Ce), Bia-Ce – biraite-(Ce). Cotype specimen, number 97515. Polished section, SEM (back-scattered electron) image.



**Figure 3.** Powder infrared absorption spectra of (a) holotype hydroxylbastnäsite-(La) from Vuoriyarvi and (b) bastnäsite-(Ce) with the composition  $(\text{Ce}_{0.54}\text{La}_{0.26}\text{Nd}_{0.12}\text{Pr}_{0.06}\text{Sm}_{0.01}\text{Ca}_{0.01})_{21}(\text{CO}_3)\text{F}_{0.98}(\text{OH})_{0.01}$  from Mt. Ploskaya, Western Keivy, Kola Peninsula, Russia.

crystals. The crystals are typically combined in dense, sometimes spherical clusters (Fig. 1) up to 1 mm across. Some crystals consist completely of hydroxylbastnäsite-(La) whereas the others contain a core composed of hydroxylbastnäsite-(Ce), with

Ce > La. Hydroxylbastnäsites together with fluorite and ancylite-(Ce) occur in cavities of calcite-dolomite carbonatites. We consider this mineral assemblage as formed during a late, low-temperature hydrothermal stage of the carbonatite evolution.

**Table 1.** Chemical composition (in wt.%) of hydroxylbastnäsité-(La)

Constituent	Holotype (Vuoriarvi)			Cotype (Mochalin Log)			Probe standard
	Average*	Range	SD	Average**	Range	SD	
CaO	0.23	0.08–0.28	0.08	-	-	-	CaSiO <sub>3</sub>
SrO	0.07	0.03–0.14	0.04	-	-	-	SrSO <sub>4</sub>
La <sub>2</sub> O <sub>3</sub>	39.47	36.85–42.01	2.05	39.58	39.44–39.73	0.15	LaPO <sub>4</sub>
Ce <sub>2</sub> O <sub>3</sub>	33.51	31.75–35.17	1.34	31.99	31.75–32.12	0.21	CePO <sub>4</sub>
Pr <sub>2</sub> O <sub>3</sub>	1.03	0.97–1.07	0.05	1.51	1.37–1.70	0.17	PrPO <sub>4</sub>
Nd <sub>2</sub> O <sub>3</sub>	1.95	1.54–2.45	0.37	2.38	2.26–2.52	0.13	NdPO <sub>4</sub>
F	0.76	0.61–0.91	0.12	3.33	3.21–3.45	0.12	MgF <sub>2</sub> ***
CO <sub>2calc.</sub>	20.49			20.34			
H <sub>2</sub> O <sub>calc.</sub>	3.77			2.58			
-O=F	0.32			1.40			
Total	100.96			100.31			

\*For five spot analyses; \*\*for three spot analyses; \*\*\*for the cotype specimen, topaz was used as probe standard for F. SD – standard deviation. Dash means that the content is below detection limit.

**Table 2.** Powder X-ray diffraction data ( $d$  in Å) of holotype hydroxylbastnäsité-(La)

$l_{obs}$	$d_{obs}$	$l_{calc}^*$	$d_{calc}$	$hkl$
<b>39</b>	<b>4.98</b>	<b>51</b>	<b>4.984</b>	<b>002</b>
<b>88</b>	<b>3.616</b>	<b>81</b>	<b>3.619</b>	<b>300</b>
<b>100</b>	<b>2.926</b>	<b>100</b>	<b>2.928</b>	<b>302</b>
5	2.650	2	2.653	222
2	2.591	1	2.582	123
1	2.577	0.5	2.577	132
9	2.490	11	2.492	004
		0.5	2.490	230
5	2.304	3	2.305	411
1	2.278	1	2.280	223
2	2.235	1	2.231	133
3	2.138	1	2.140	412
<b>41</b>	<b>2.089</b>	<b>33</b>	<b>2.090</b>	<b>330</b>
<b>46</b>	<b>2.052</b>	<b>50</b>	<b>2.052</b>	<b>304</b>
<b>40</b>	<b>1.927</b>	1	1.929	413
		<b>34</b>	<b>1.927</b>	<b>332</b>
14	1.809	12	1.810	600
<b>24</b>	<b>1.701</b>	<b>20</b>	<b>1.701</b>	<b>602</b>
2	1.663	0.5	1.662	135
		2	1.661	006
16	1.601	15	1.601	334
8	1.509	11	1.510	306
12	1.464	11	1.464	604
9	1.368	8	1.368	360
<b>20</b>	<b>1.319</b>	<b>17</b>	<b>1.319</b>	<b>362</b>
7	1.300	7	1.300	336
1	1.244	2	1.246	008
6	1.224	7	1.224	606
3	1.207	4	1.207	900
14	1.199	14	1.199	364
9	1.173	5	1.178	308
		7	1.173	902
6	1.086	6	1.086	904
4	1.070	5	1.070	338
7	1.056	11	1.056	366

(Continued)

**Table 2.** (Continued.)

$l_{obs}$	$d_{obs}$	$l_{calc}^*$	$d_{calc}$	$hkl$
4	1.045	1	1.048	357
		3	1.045	660
6	1.023	5	1.026	608
		6	1.023	662

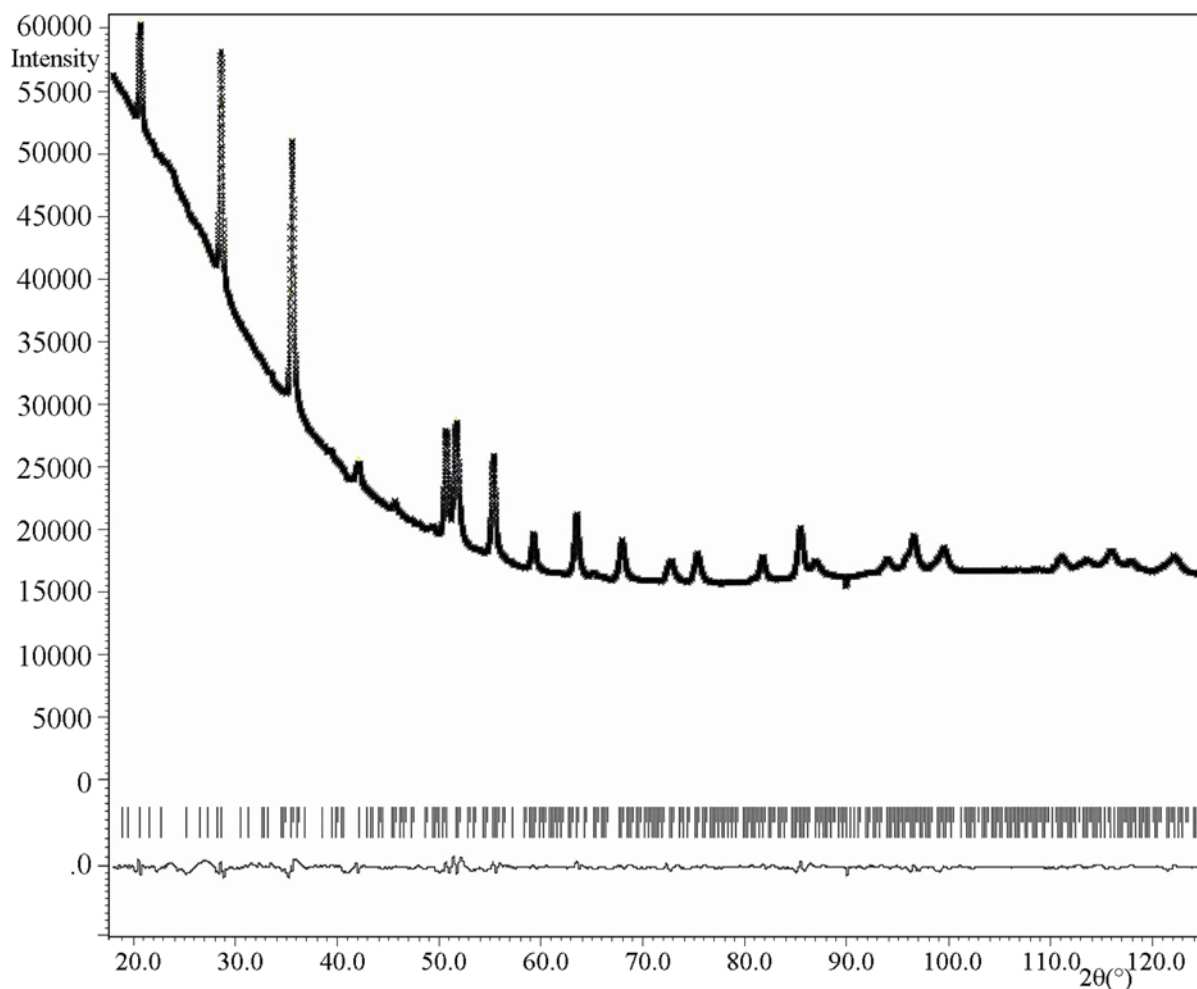
\*For the calculated pattern, only reflections with intensities  $\geq 0.5$  are given; the strongest reflections are marked in boldtype.

Mochalin Log is a classic, historical locality of Ce- and La-dominant bastnäsites including the hydroxyl-prevailing species (Korovaev, 1861; Korovaeff, 1862; Silberminz, 1929; Alimarin, 1930; Svyazhin, 1965; Pekov et al., 2002). Here they are part of a rich and diverse assemblage of light REE (LREE) minerals, which has a contact metasomatic origin. Most probably, it was formed during the fenitisation of granitic pegmatites located within granite-gneisses in the southern exocontact zone of the Vishnevogorskiy alkaline intrusive complex mainly consisting of syenites and miaskites. For the general data on the Mochalin Log deposit see recent summarising paper by Kasatkin et al. (2020) and references therein. At Mochalin Log, hydroxylbastnäsité-(La) occurs as anhedral grains up to  $0.1 \times 0.2$  mm included in massive aggregates of other LREE minerals (Fig. 2). In different samples, it is associated with bastnäsité-(Ce), bastnäsité-(La), percleveite-(Ce), percleveite-(La), biraite-(Ce), biraite-(La), törnebohmitite-(La), ferriperbœite-(Ce), allanite-(Ce), allanite-(La), ferriallanite-(La), alexkuznetsovite-(Ce), alexkuznetsovite-(La), perrierite-(Ce), perrierite-(La), fluorbritholite-(Ce), stillwellite-(Ce), thorianite, and quartz.

### Physical properties and optical data

Hydroxylbastnäsité-(La) from both type localities is transparent to translucent and typically has a light brown colour. Some crystals from Vuoriarvi are light honey-yellow or colourless. The streak is white. The lustre is strong vitreous on crystal faces and greasy on a broken surface. The mineral is brittle, no cleavage or parting was observed. The fracture is uneven. The Mohs hardness is ca. 4.





**Figure 4.** Observed and calculated powder X-ray diffraction patterns of hydroxylbastnäsite-(La). The solid line corresponds to calculated data, the crosses correspond to the observed pattern, vertical bars mark all possible Bragg reflections. The difference between the observed and calculated patterns is shown by curve at the bottom.

The density, measured by microvolumetric method for the holotype, is  $4.75(2) \text{ g cm}^{-3}$ . The density calculated for the holotype using the empirical formula and unit-cell volume found from powder X-ray diffraction (XRD) data is  $4.778 \text{ g cm}^{-3}$ .

Optical data were obtained for the holotype specimen. Hydroxylbastnäsite-(La) is optically uniaxial (+),  $\omega = 1.76(1)$  and  $\varepsilon = 1.86(1)$  (589 nm). In plane polarised transmitted light, it is colourless and non-pleochroic.

### Infrared spectroscopy

In order to obtain an infrared (IR) absorption spectrum, a powdered sample of the holotype hydroxylbastnäsite-(La) (curve *a* in Fig. 3) was mixed with anhydrous KBr, pelletised, and analysed using an ALPHA FTIR spectrometer (Bruker Optics) at a resolution of  $4 \text{ cm}^{-1}$ . A total of 16 scans were accumulated. The IR spectrum of an analogous pellet of pure KBr was used as a reference. The typical sample of bastnäsite-(Ce) involved for comparison (curve *b* in Fig. 3) was prepared and studied using the same procedures.

The assignment of absorption bands observed in different wavenumber ranges is as follows:  $3400\text{--}3700 \text{ cm}^{-1}$  are O–H

stretching vibrations;  $1400\text{--}1500 \text{ cm}^{-1}$  are assigned to degenerate asymmetric stretching vibrations of  $(\text{CO}_3)^{2-}$ .  $1080\text{--}1100 \text{ cm}^{-1}$  are assigned to nondegenerate symmetric stretching vibrations of  $(\text{CO}_3)^{2-}$ ;  $840\text{--}880 \text{ cm}^{-1}$  to out-of-plane bending vibrations of  $(\text{CO}_3)^{2-}$  (a nondegenerate mode);  $781 \text{ cm}^{-1}$  to  $LREE\cdots\text{O}\text{--H}$  in-plane bending vibrations (broad band, possibly, superposition of several bands);  $680\text{--}730 \text{ cm}^{-1}$  to in-plane bending vibrations of  $(\text{CO}_3)^{2-}$  (a degenerate mode); and  $599 \text{ cm}^{-1}$  to  $LREE\cdots\text{O}\text{--H}$  out-of-plane bending vibrations (rotation around the  $LREE\cdots\text{O}$  ionic bond) – broad band, possibly, superposition of several bands. Below  $500 \text{ cm}^{-1}$  bands are assigned to lattice modes involving  $LREE\cdots\text{O}$  and  $(\text{CO}_3)^{2-}$  librational vibrations.

The intrinsic fundamental modes of the  $(\text{CO}_3)^{2-}$  and  $(\text{OH})^-$  anions were assigned in accordance with Nakamoto (2008).

The remaining absorption bands with maxima at  $599$  and  $781 \text{ cm}^{-1}$  were assigned by analogy with numerous oxysalts with additional  $(\text{OH})^-$  anions in which  $M\cdots\text{O}\text{--H}$  bending vibrations are usually observed in the range of  $580\text{--}830 \text{ cm}^{-1}$  (see the reference books Chukanov and Chervonnyi, 2016; Chukanov and Viganina, 2020 and references therein). Note that in the IR spectra of F-dominant members of the bastnäsite group these bands are absent or are very weak.

**Table 3.** Coordinates and isotropic displacement parameters ( $U_{iso}$ , in Å<sup>2</sup>) of atoms for holotype hydroxylbastnäsite-(La)

Site	x	y	z	$U_{iso}$
REE1	0.112(6)	0.226(3)	0.240(3)	0.0112(10)
REE2	0.438(3)	0.217(4)	0.257(3)	0.0112(10)
REE3	0.1042(12)	0.560(3)	0.264(3)	0.0112(10)
C1	0.481 801	0.353 45	0	0.012
C2	0.200 085	0.084 242	0	0.012
C3	0.299 288	0.459 352	0	0.012
C4	0.549 888	0.422 032	½	0.012
C5	0.229 944	0.457 79	½	0.012
C6	0.198 725	0.036 634	½	0.012
O1	0.478(15)	0.244(7)	0	0.011(9)
O2	0.486(6)	0.403(4)	0.1139(14)	0.011(9)
O3	0.033(2)	0.160(15)	0	0.011(9)
O4	0.238(18)	0.15(3)	0.11(2)	0.011(9)
O5	0.081(12)	0.578(2)	0	0.011(9)
O6	0.252(5)	0.419(6)	0.1155(9)	0.011(9)
O7	0.49(4)	0.3041(8)	½	0.011(9)
O8	0.524(18)	0.100(9)	0.386(10)	0.011(9)
O9	0.3497(5)	0.52(2)	½	0.011(9)
O10	0.17(3)	0.425(17)	0.39(2)	0.011(9)
O11	0.074(5)	0.168(11)	½	0.011(9)
O12	0.250(12)	0.072(14)	0.385(4)	0.011(9)
O13 = OH	0	0	0.28(2)	0.011(9)
O14 = OH	⅔	⅓	0.24(4)	0.011(9)
O15 = OH	⅓	⅔	0.26(5)	0.011(9)
O16 = OH	0.322(4)	0.320(2)	0.332(8)	0.011(9)
O17 = OH	0.338(4)	-0.003(4)	0.189(12)	0.011(9)

Weak bands in the range of 1700–1500 cm<sup>-1</sup> correspond to overtones and combination modes.

The IR spectrum of hydroxylbastnäsite-(La) differs from that of bastnäsite-(Ce) by the presence of multiple bands of O–H stretching vibrations and *LREE*...O–H bending and libration bands as well as splitting of all bands related to the (CO<sub>3</sub>)<sup>2-</sup> groups. The band of nondegenerate symmetric stretching vibrations of (CO<sub>3</sub>)<sup>2-</sup> (*i.e.* mode which would be inactive in the IR spectrum of a mineral with undistorted CO<sub>3</sub> triangles) at 1082 with the shoulder at 1091 cm<sup>-1</sup> as well as splitting of the nondegenerate band of out-of-plane bending vibrations of (CO<sub>3</sub>)<sup>2-</sup> indicate the presence of non-equivalent distorted CO<sub>3</sub> triangles in the structure of hydroxylbastnäsite-(La).

Four bands in the O–H stretching region correspond to at least four non-equivalent OH groups, but taking into account asymmetry of the bands at 3472 and 3563, one can suppose that the number of non-equivalent OH groups is > 4.

### Chemical composition

The chemical composition of hydroxylbastnäsite-(La) was studied by electron microprobe in two laboratories. The holotype was investigated in the Laboratory of Analytical Techniques of High Spatial Resolution, Department of Petrology, Moscow State University, using a Jeol JSM-6480LV scanning electron microscope equipped with an INCA-Wave 500 wavelength-dispersive spectrometer, with an acceleration voltage of 20 kV and a beam current of 10 nA; the electron beam was rastered to the 5 × 5 μm area. The cotype was analysed in the Laboratory of Electron Microscopy and Microanalysis, Department of Geological Sciences, Masaryk University, Brno, using a Cameca SX-100 electron microprobe

**Table 4.** Selected interatomic distances (Å) in the structure of holotype hydroxylbastnäsite-(La)

REE1–O3	2.56(5)	C1–O1	1.36(11)
REE1–O4	2.6(3)	C1–O2	1.28(3) ×2
REE1–O6	2.50(6)	<C1–O>	1.31
REE1–O10	2.6(2)		
REE1–O11	2.66(4)	C2–O3	1.29(4)
REE1–O12	2.51(13)	C2–O4	1.3(2) ×2
REE1–O13	2.49(5)	<C2–O>	1.30
REE1–O16	2.46(8)		
REE1–O17	2.48(10)	C3–O5	1.35(3)
<REE1–O>	2.54	C3–O6	1.28(2) ×2
		<C3–O>	1.30
REE2–O1	2.60(3)		
REE2–O2	2.54(6)	C4–O7	1.280(10)
REE2–O4	2.6(2)	C4–O8	1.26(14) ×2
REE2–O7	2.60(4)	<C4–O>	1.27
REE2–O8	2.5(2)		
REE2–O12	2.50(9)	C5–O9	1.301(8)
REE2–O14	2.49(4)	C5–O10	1.3(2) ×2
REE2–O16	2.49(7)	<C5–O>	1.30
REE2–O17	2.48(7)		
<REE2–O>	2.53	C6–O11	1.34(7)
		C6–O12	1.28(6) ×2
REE3–O2	2.59(8)	<C6–O>	1.30
REE3–O5	2.67(4)		
REE3–O6	2.55(6)		
REE3–O8	2.59(10)		
REE3–O9	2.56(4)		
REE3–O10	2.6(3)		
REE3–O15	2.492(14)		
REE3–O16	2.53(7)		
REE3–O17	2.49(7)		
<REE3–O>	2.56		

(WDS mode, acceleration voltage of 15 kV, a beam current of 10 nA, and a 5 μm beam diameter). The chemical data in wt.% are given in Table 1, as well as the probe standards. Contents of other elements with atomic numbers > 4 were below detection limits. Special attention was paid to the correctness of quantitative determination of fluorine due to an overlap of the *K* line of F with the *M* line of Ce.

The amounts of H<sub>2</sub>O and CO<sub>2</sub> could not be determined directly because of the paucity of pure material. The presence of both (CO<sub>3</sub>)<sup>2-</sup> and (OH)<sup>-</sup> groups as species-defining constituents in hydroxylbastnäsite-(La) is undoubtedly shown by the crystal structure data (see below) and the IR spectrum. The presence of (CO<sub>3</sub>)<sup>2-</sup> (as in all other bastnäsite-group carbonates) is also confirmed by a common chemical test: the mineral dissolves in warm HCl aqueous solution or in cold dilute H<sub>2</sub>SO<sub>4</sub> with effervescence (CO<sub>2</sub> gas bubbling release).

The empirical formulae, calculated on the basis of the sum of metal cations of one atom per formula unit (apfu) and one CO<sub>3</sub> group pfu, are as follows: holotype (Vuoriyarvi) is (La<sub>0.52</sub>Ce<sub>0.44</sub>Nd<sub>0.02</sub>Pr<sub>0.01</sub>Ca<sub>0.01</sub>)<sub>Σ1.00</sub>(CO<sub>3</sub>)[(OH)<sub>0.90</sub>F<sub>0.09</sub>]<sub>Σ0.99</sub>; cotype (Mochalin Log) is (La<sub>0.53</sub>Ce<sub>0.42</sub>Nd<sub>0.03</sub>Pr<sub>0.02</sub>)<sub>Σ1.00</sub>(CO<sub>3</sub>)[(OH)<sub>0.62</sub>F<sub>0.38</sub>]<sub>Σ1.00</sub>.

The simplified formula is (La,Ce)(CO<sub>3</sub>)(OH,F). The idealised, end-member formula is La(CO<sub>3</sub>)(OH) which requires La<sub>2</sub>O<sub>3</sub> 75.45, CO<sub>2</sub> 20.38, H<sub>2</sub>O 4.17, total 100 wt.%.

**Table 5.** Comparative data for hydroxylbastnäsite-(La), hydroxylbastnäsite-(Ce), bastnäsite-(La) and bastnäsite-(Ce)

Mineral	Hydroxylbastnäsite-(La)*	Hydroxylbastnäsite-(Ce)	Bastnäsite-(La)	Bastnäsite-(Ce)
Ideal formula	La(CO <sub>3</sub> )(OH)	Ce(CO <sub>3</sub> )(OH)	La(CO <sub>3</sub> )F	Ce(CO <sub>3</sub> )F
Crystal system	Hexagonal	Hexagonal	Hexagonal	Hexagonal
Space group	$P\bar{6}$	$P\bar{6}^{**}$	$P\bar{6}2c$	$P\bar{6}2c$
Unit cell data:				
<i>a</i> (Å)	12.537(3)	12.41–12.47	7.12–7.16	7.08–7.12
<i>c</i> (Å)	9.968(2)	9.85–9.96	9.67–9.81	9.72–9.76
<i>V</i> (Å <sup>3</sup> )	1357(5)	1314–1342	424–436	421–428
<i>Z</i>	18	18	6	6
Optical data:	Uniaxial (+)	Uniaxial (+)	Uniaxial (+)	Uniaxial (+)
$\omega$	1.76(1)	1.760	1.714–1.717	1.717–1.722
$\epsilon$	1.86(1)	1.870	1.818	1.818–1.823
Sources	This work	Kirillov (1964, 1966); Yang <i>et al.</i> (2008); Michiba <i>et al.</i> (2013)	Kupriyanova (1968); Pekov <i>et al.</i> (2002); Anthony <i>et al.</i> (2003)	Aleksandrov (1965); Ni <i>et al.</i> (1993); Terada <i>et al.</i> (1993); Anthony <i>et al.</i> (2003); Miyawaki <i>et al.</i> (2013)

\*Data for holotype. \*\*Both natural samples of hydroxylbastnäsite-(Ce) with determined crystal structure possess the space group  $P\bar{6}$  and unit-cell parameters  $a = 12.41\text{--}12.47$  and  $c = 9.85\text{--}9.96$  Å ( $Z = 18$ ) (Yang *et al.*, 2008; Michiba *et al.*, 2013) [synthetic bastnäsite-like hydroxyl-carbonates REE(CO<sub>3</sub>)(OH) with REE = trivalent La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er have the same space group and unit-cell metrics: Christensen, 1973; Kutlu and Meyer, 1999; Michiba *et al.*, 2011], whereas in older publications, hydroxylbastnäsite-(Ce) and hydroxylbastnäsite-(Nd) were reported, by analogy with a fluorine-rich bastnäsites, with the hexagonal unit cell with parameters  $a = 7.19\text{--}7.23$  and  $c = 9.92\text{--}9.98$  Å ( $Z = 6$ ) (Kirillov, 1964, 1966; Aleksandrov, 1965; Maksimović and Pantó, 1985; Minakawa *et al.*, 1992), and the space group  $P\bar{6}2c$ , found for the structurally studied F-rich members of the bastnäsite-(Ce) – bastnäsite-(La) series (Oftedal, 1931; Donnay and Donnay, 1953), was also suggested in this period for hydroxylbastnäsites (Anthony *et al.*, 2003).

The values of the Gladstone–Dale compatibility index  $1 - (K_p/K_c)$  (Mandarino, 1981) for the holotype hydroxylbastnäsite-(La) calculated with  $D_{\text{meas}}$  and  $D_{\text{calc}}$  are  $-0.009$  and  $-0.003$ , respectively (both rated as superior).

### X-ray crystallography and crystal structure determination details

Single-crystal XRD studies of the holotype sample of hydroxylbastnäsite-(La) were carried out at room temperature using an Xcalibur S diffractometer equipped with a CCD detector (MoK $\alpha$ -radiation). The mineral is hexagonal,  $a = 12.562(2)$ ,  $c = 10.015(2)$  Å and  $V = 1368(1)$  Å<sup>3</sup>.

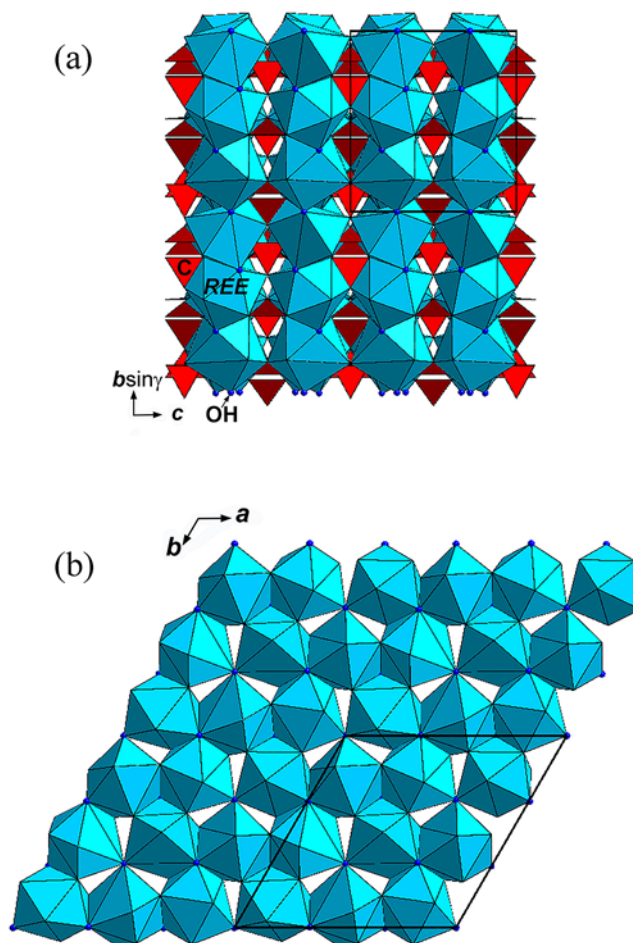
Powder XRD data for both holotype and cotype samples were collected with a Rigaku R-AXIS Rapid II single-crystal diffractometer equipped with a cylindrical image plate detector (radius 127.4 mm) using Debye-Scherrer geometry, CoK $\alpha$  radiation (rotating anode with VariMAX microfocuss optics), 40 kV, 15 mA and exposure 15 min. Angular resolution of the detector is 0.045° (2 $\theta$ ; pixel size 0.1 mm). The data were integrated using the software package *Osc2Tab* (Britvin *et al.*, 2017). Powder XRD data for the holotype are given in Table 2, the powder XRD pattern of the cotype shows no significant differences. The hexagonal unit cell parameters calculated from powder data for holotype/cotype are:  $a = 12.537(3)/12.533(1)$ ,  $c = 9.968(2)/9.908(1)$  Å,  $V = 1356.8(5)/1347.9(3)$  Å<sup>3</sup> and  $Z = 18$ .

All the single crystals of hydroxylbastnäsite-(La) tested were not very high in quality: even though they appeared to be perfect (Fig. 1), in fact they have a mosaic character in the inner structure and consist of blocks slightly disoriented with respect to each other. The crystal structure of holotype hydroxylbastnäsite-(La) was refined with the powder XRD data (for the data collecting details see above) using the Rietveld method. Data treatment and the Rietveld structure analysis were carried out using the *JANA2006* program package (Petříček *et al.*, 2006). The structure model of hydroxylbastnäsite-(Ce) (Yang *et al.*, 2008) was taken as the starting one. The scattering curve of Ce was used

for the REE sites. The profiles were modelled using a pseudo-Voigt function. The structure was refined in isotropic approximation of atomic displacements, the values of  $U_{\text{iso}}$  for all atoms of each sort were restricted to be equal, atomic coordinates and  $U_{\text{iso}}$  of C atoms were fixed on the last stages of the refinement. The cation–anion interatomic distances were restricted nearby the values of the starting structure model. The space group is  $P\bar{6}$ , for the refined unit-cell parameters see above. Final agreement factors are:  $R_{\text{wp}} = 0.0071$ ,  $R_p = 0.0050$  and  $R_{\text{obs}} = 0.0466$ . The observed and calculated powder XRD diagrams demonstrate a very good agreement (Fig. 4). Coordinates and displacement parameters of atoms are given in Table 3 and selected interatomic distances in Table 4. The crystallographic information file has been deposited with the Principal Editor of *Mineralogical Magazine* and is available as Supplementary material (see below).

### Discussion

Fluorine- and hydroxyl-dominant members of the bastnäsite group are structurally close but not isostructural. Fluorine-dominant minerals of the bastnäsite-(Ce) – bastnäsite-(La) series and bastnäsite-(Nd) adopt the space group  $P\bar{6}2c$  and are characterised by a unit cell with the following parameters:  $a = 7.1\text{--}7.2$ ,  $c = 9.7\text{--}9.8$  Å and  $V = 422\text{--}436$  Å<sup>3</sup> ( $Z = 6$ ) (Oftedal, 1931; Donnay and Donnay, 1953; Ni *et al.*, 1993; Terada *et al.*, 1993; Mi *et al.*, 1996; Miyawaki *et al.*, 2013). The crystal structure of bastnäsite-(Y) was not studied. Among hydroxyl-dominant minerals of the group, only hydroxylbastnäsite-(Ce) was structurally studied earlier, on samples from Trimouns, Luzenac, France and Kamihouri, Miyazaki Prefecture, Japan. It crystallises in the space group  $P\bar{6}$  and has a unit cell with the following parameters:  $a = 12.41\text{--}12.47$ ,  $c = 9.85\text{--}9.96$  Å and  $V = 1314\text{--}1342$  Å<sup>3</sup> ( $Z = 18$ ) (Yang *et al.*, 2008; Michiba *et al.*, 2013): see Table 5. Synthetic bastnäsite-like hydroxyl-carbonates REE<sup>3+</sup>(CO<sub>3</sub>)(OH) with REE = La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho and Er demonstrate the same space group  $P\bar{6}$  and unit-cell metrics as hydroxylbastnäsite-(Ce) (Christensen, 1973; Kutlu and Meyer, 1999; Michiba *et al.*,



**Figure 5.** The crystal structure of hydroxylbastnäsité-(La) projected along the  $a$  axis (a) and the layer of  $REE$ -centred polyhedra in it (b). The unit cell is outlined. Drawn using *Diamond* Version 3.2k.

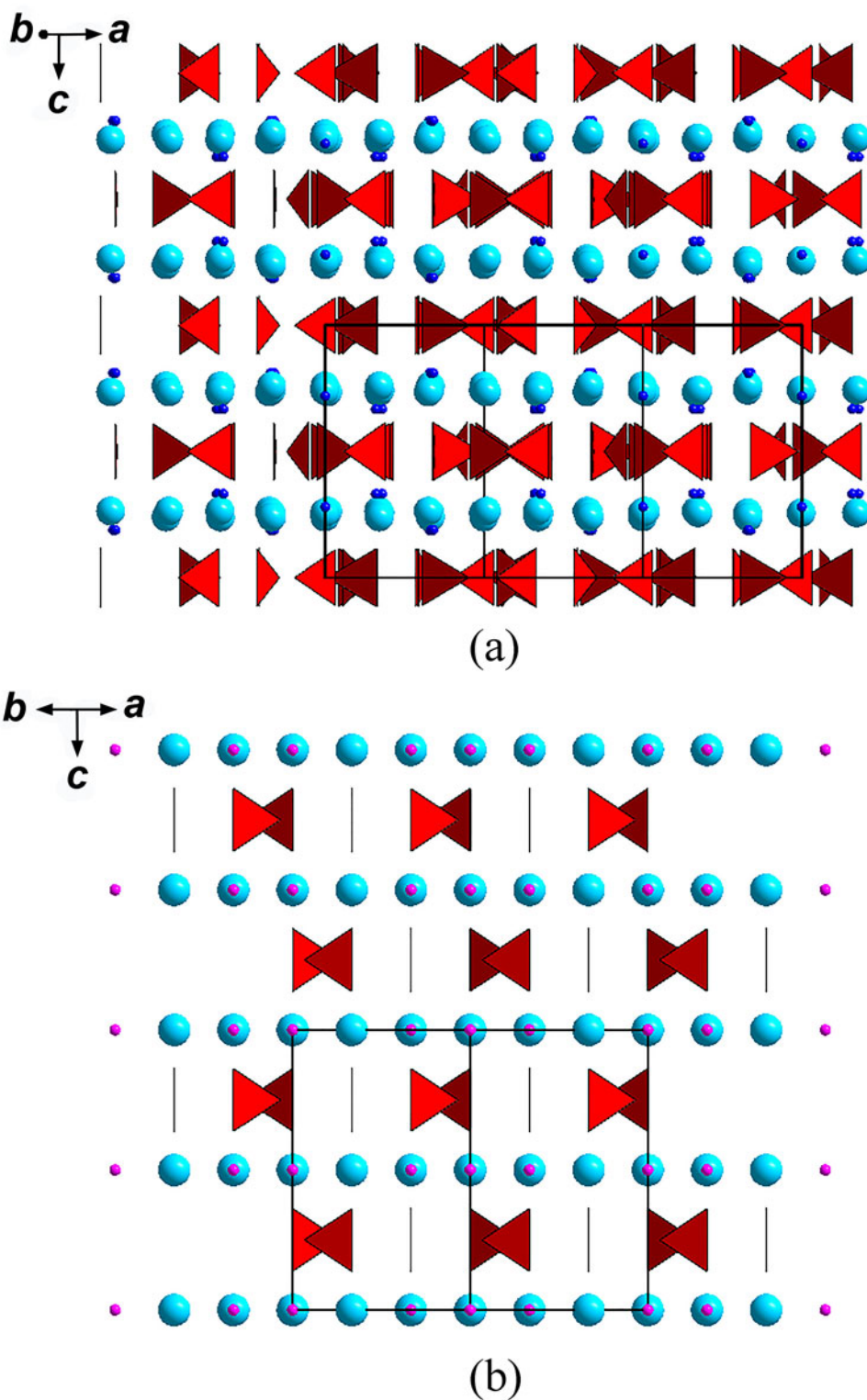
2011). Note, synthetic bastnäsité-like  $\text{La}(\text{CO}_3)(\text{OH})$ , an analogue of the end-member hydroxylbastnäsité-(La) is known (Hsu *et al.*, 1992; Michiba *et al.*, 2011). The relationship between unit cells of F- and OH-dominant bastnäsites is as follows:  $a_{\text{hydroxylbastnäsité}} \approx a_{\text{bastnäsité}}\sqrt{3}$ ,  $c_{\text{hydroxylbastnäsité}} \approx c_{\text{bastnäsité}}$ . The difference between F- and OH-dominant bastnäsites is in their atomic arrangement (Figs 5 and 6). In particular, there are 6, 3 and 5 symmetrically non-equivalent  $\text{CO}_3$  groups,  $REE^{3+}$  cations, and  $X^-$  anions, respectively, in hydroxylbastnäsites as distinct to 1, 1 and 2, respectively in F-dominant bastnäsites (see references above). However, the crystal structures of the bastnäsité-like compounds crystallised in the space groups  $P\bar{6}$  and  $P\bar{6}2c$  exhibit many common features: they are based on the layers of  $REE$  and F/OH alternating with the layers of  $\text{CO}_3$  groups (Fig. 6).

As our data show, hydroxylbastnäsité-(La) is isostructural to hydroxylbastnäsité-(Ce) (Yang *et al.*, 2008; Michiba *et al.*, 2013) and synthetic bastnäsité-like hydroxyl-carbonates  $REE^{3+}(\text{CO}_3)(\text{OH})$  with  $REE = \text{La-Er}$  (Michiba *et al.*, 2011 and references therein) rather than F-dominant bastnäsites. The crystal structure of hydroxylbastnäsité-(La) (Fig. 5a) is based upon the (001) layers of  $REE^{3+}$  cations and  $(\text{OH})^-$  anions interspersed with carbonate layers in a 1:1 ratio. Three crystallographically non-equivalent  $REE$  sites occupy nine-fold polyhedra  $REE\text{O}_6(\text{OH})_3$ . Hydroxyl groups are located inside  $REE$  layers where  $REE$ -centred polyhedra are connected *via* common O–OH

edges and OH vertices (Fig. 5b). Neighbouring  $REE$  layers are connected *via*  $\text{CO}_3$  groups and one common O vertex of  $REE$ -centred polyhedra. As well as in hydroxylbastnäsité-(Ce), the coordination of  $REE^{3+}$  cations is formed by three  $(\text{OH})^-$  anions and five  $(\text{CO}_3)^{2-}$  anions four of which are monodentate ligands and one is a bidentate ligand in contrast with F-dominant bastnäsites crystallising in space group  $P\bar{6}2c$  where  $REE$  sites are coordinated by three  $\text{F}^-$  anions and six monodentate  $(\text{CO}_3)^{2-}$  anions. The comparison of the atomic arrangements in the structures of bastnäsité-(Ce) and hydroxylbastnäsité-(La) is given in Fig. 6.

The difference in symmetry causes the difference (not too strong but distinct) in powder XRD patterns of F- and OH-dominant bastnäsites, at the first instance, due to additional systematic absences in the patterns of F-dominant bastnäsites (space group  $P\bar{6}2c$ ) in comparison with the patterns of hydroxylbastnäsites ( $P\bar{6}$ ). The powder XRD pattern of hydroxylbastnäsité-(La) (Table 2) shows the similarity with the calculated pattern of  $REE^{3+}(\text{CO}_3)(\text{OH})$  with the space group  $P\bar{6}$ . In particular, hydroxylbastnäsité-(La) demonstrates three reflections in the region 2.7–2.5 Å in which the calculated powder XRD pattern of hydroxylbastnäsites ( $P\bar{6}$ ) also contains three reflections with  $I \geq 0.5\%$ , whereas the calculated pattern of F-dominant bastnäsites ( $P\bar{6}2c$ ) contains only one reflection. A distinct reflection with  $d = 2.235$  Å is present in both measured and calculated powder XRD patterns of





**Figure 6.** The crystal structures of hydroxylbastnäsite-(La) (projected along [120]; (a) and bastnäsite-(Ce) (projected along [110]; (b); drawn after Donnay and Donnay, 1953). For legend see Figure 5; fluorine atoms in bastnäsite-(Ce) are shown as small reddish-pink circles. The unit cells are outlined.

hydroxylbastnäsite-(La) but is absent in the patterns of F-dominant bastnäsites ( $P\bar{6}2c$ ). These and some other features of the powder XRD pattern causes the choice of the space group  $P\bar{6}$  and corresponding unit-cell metrics for hydroxylbastnäsite-(La).

The IR spectrum of hydroxylbastnäsite-(La) (curve **a** in Fig. 3), unlike the IR spectra of F-dominant bastnäsite-group minerals (see, e.g. curve **b** in Fig. 3), clearly demonstrates the presence of several non-equivalent  $(\text{CO}_3)^{2-}$  and  $(\text{OH})^-$  groups (see above)

that confirms its lower symmetry in comparison with F-dominant bastnäsites.

Hydroxylbastnäsite-(La) and hydroxylbastnäsite-(Ce) have distinctly higher values of unit-cell dimensions and volume (easily comparable in the same setting) and refractive indices in comparison with their F-dominant analogues (Table 5). The triple unit-cell volumes of bastnäsite-(Ce)–bastnäsite-(La) series minerals ( $Z = 18$ ) varies from 1266 to 1308 Å<sup>3</sup> whereas minerals of the hydroxylbastnäsite-(Ce)–hydroxylbastnäsite-(La) series have a unit-cell volume from 1314 to 1357 Å<sup>3</sup>. Unit-cell dimensions of two samples of hydroxylbastnäsite-(La), from Vuoriyarvi and Mochalin Log (see above), are in agreement with the OH:F ratio. The refractive indices of hydroxylbastnäsites are higher than corresponding values of F-dominant bastnäsites, with the significant difference of 0.04–0.05 (Table 5). The distinct increase of unit-cell dimensions with the substitution of F<sup>-</sup> by (OH)<sup>-</sup> is typical in such pairs of isotypic or structurally close compounds [e.g. the fluorapatite Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>F – hydroxylapatite Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>(OH) (White et al., 2005) or fluorborite Mg<sub>3</sub>(BO<sub>3</sub>)F<sub>3</sub> – hydroxylborite Mg<sub>3</sub>(BO<sub>3</sub>)(OH)<sub>3</sub> series (Cámara and Ottolini, 2000; Rudnev et al., 2007)], as well as refractive indices. These characteristics can be used as good indicators of the prevailing of F<sup>-</sup> or (OH)<sup>-</sup> in rare-earth minerals of the bastnäsite group. The correctness of determination of chemical and crystal data and density of hydroxylbastnäsite-(La) is confirmed by the very low (superior) value of the Gladstone–Dale compatibility index.

In terms of end-member compositions, hydroxylbastnäsite-(La) is dimorphous with kozoite-(La), ideally La(CO<sub>3</sub>)(OH), a member of the ancylite supergroup (Miyawaki et al., 2003; Wang et al., 2024).

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1180/mgm.2024.65>.

**Acknowledgements.** We thank three anonymous referees for their valuable comments. The mineralogical and crystal chemical studies of hydroxylbastnäsite-(La) from Vuoriyarvi was performed in accordance with the State Task of the RF No. 121061600049-4. The IR spectra were obtained and interpreted in accordance with the State Task of the RF No. 124013100858-3. Powder XRD study was done at the Center for X-ray Diffraction Studies of the Research Park of St. Petersburg State University within the project No. AAAA-A19-119091190094-6.

**Competing interests.** The authors declare none.

## References

- Aleksandrov I.V., Ivanov V.I. and Sin'kova L.A. (1965) New data on bastnäsite. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, **94**, 323–326 [in Russian].
- Alimarin I.P. (1930) On the chemical analysis of bastnäsite – in: “Rare-Earth Minerals of Kyshtym Area”. *Trudy Instituta Prikladnoy Mineralogii (Proceedings of the Institute of Applied Mineralogy)*, **44**, 47–57 [in Russian].
- Anthony J.W., Bideaux R.A., Bladh K.W. and Nichols M.C. (2003) *Handbook of Mineralogy. V. Borates, Carbonates, Sulfates*. Mineral Data Publishing, Tucson, 813 pp.
- Berzelius J.J. (1825) Flusspatzsyradt och kolsyradt cerium. *Årsberättelser om Vetenskapernas Framsteg*. Afgivne af Kongl. Vetenskaps-Academiens Embetsman: 31 Mars 1824, 201–202.
- Britvin S.N., Dolivo-Dobrovolsky D.V. and Krzhizhanovskaya M.G. (2017) Software for processing the X-ray powder diffraction data obtained from the curved image plate detector of Rigaku RAXIS Rapid II diffractometer. *Zapiski Rossiiskogo Mineralogicheskogo Obshchestva*, **146**, 104–107 [in Russian].
- Brush G.J. (1863) Kischtimite, a new mineral. *American Journal of Science*, **35**, 427–428.
- Cámara F. and Ottolini L. (2000) New data on the crystal-chemistry of fluorborite, by means of SREF, SIMS and EMP analysis. *American Mineralogist*, **85**, 103–107.
- Christensen A.N. (1973) Hydrothermal preparation of rare earth hydroxycarbonates. The crystal structure of NdOHCO<sub>3</sub>. *Acta Chemica Scandinavica*, **27**, 2973–2982.
- Chukanov N.V. and Chervonnyi A.D. (2016) *Infrared Spectroscopy of Minerals and Related Compounds*. Springer, Cham, Switzerland, 1109 pp.
- Chukanov N.V. and Vigasina M.F. (2020) *Vibrational (Infrared and Raman) Spectra of Minerals and Related Compounds*. Springer, Dordrecht, 1376 pp.
- Donnay G. and Donnay J.D.H. (1953) The crystallography of bastnaesite, parisite, roentgenite and synchysite. *American Mineralogist*, **38**, 932–963.
- Hawthorne F.C., Fleischer M., Grew E.S., Grice J.D., Jambor J.L., Puziewicz J., Roberts A.C., Vanko D.A. and Zilcher J.A. (1986) New mineral names. *American Mineralogist*, **71**, 1277–1282.
- Hsu L.C. (1992) Synthesis and stability of bastnaesites in a part of the system (Ce, La)-F-H-C-O. *Mineralogy and Petrology*, **47**, 81–101.
- Jambor J.L. and Roberts A.C. (2002) New mineral names. *American Mineralogist*, **87**, 765–768.
- Karchevsky P.I. and Moutte J. (2004) The phoscorite-carbonatite complex of Vuoriyarvi, northern Karelia. Pp. 163–199 in: *Phoscorites and Carbonatites from Mantle to Mine: The Key Example of the Kola Alkaline Province* (F. Wall and A.N. Zaitsev, editors). Mineralogical Society Series, **10**. Mineralogical Society, London.
- Kasatkin A.V., Zubkova N.V., Pekov I.V., Chukanov N.V., Škoda R., Polekhovskiy Yu.S., Agakhanov A.A., Belakovskiy D.I., Kuznetsov A.M., Britvin S.N. and Pushcharovskiy D.Yu. (2020) The mineralogy of the historical Mochalin Log REE deposit, South Urals, Russia. Part I. New gatelite-group minerals ferriperbøeite-(La), (CaLa<sub>3</sub>)(Fe<sup>3+</sup>Al<sub>2</sub>Fe<sup>2+</sup>)[Si<sub>2</sub>O<sub>7</sub>][SiO<sub>4</sub>]<sub>3</sub>O(OH)<sub>2</sub>, and perbøeite-(La), (CaLa<sub>3</sub>)(Al<sub>3</sub>Fe<sup>2+</sup>)[Si<sub>2</sub>O<sub>7</sub>][SiO<sub>4</sub>]<sub>3</sub>O(OH)<sub>2</sub>. *Mineralogical Magazine*, **84**, 593–607.
- Kirillov A.S. (1964) Hydroxyl bastnäsite, a new variety of bastnäsite. *Doklady Akademii Nauk SSSR, Earth Science Sections*, **159**, 93–95.
- Kirillov A.S. (1966) Hydroxyl-bastnäsite, a new mineral variety. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, **95**, 51–59 [in Russian].
- Korovaev Th. (1862) Der Kischtim-Parisit, ein neues Mineral. *Bulletin de l'Académie Impériale des Sciences de Saint-Petersbourg*, **IV**, 401–408.
- Korovaev F. (1861) Kyshtymoparisite, a new mineral. *Gornyi Zhurnal (Mining Journal)*, **4**, 445–454 [in Russian].
- Kukharenskiy A.A., Orlova M.P., Bulakh A.G., Bagdasarov E.A., Rimskaya-Korsakova O.M., Nefedov E.I., Ilinskiy G.A., Sergeev A.S. and Abakumova N.B. (1965) *The Caledonian Complex of Ultramafic, Alkaline Rocks and Carbonatites of Kola Peninsula and Northern Karelia*. Nedra Publishing, Leningrad, 772 pp. [in Russian].
- Kupriyanova I.I. (1968) Bastnäsite from albitites. *Novye Dannye o Mineralakh SSSR (Proceedings of Fersman Mineralogical Museum)*, **18**, 206–209 [in Russian].
- Kutlu I. and Meyer G. (1999) Basische Carbonate des Dysprosiums: Dy<sub>2</sub>O<sub>2</sub>(CO<sub>3</sub>) und Dy(OH)(CO<sub>3</sub>). *Zeitschrift für Anorganische und Allgemeine Chemie*, **625**, 402–406.
- Lacroix A. (1912) Sur l'existence de la bastnaesite dans les pegmatites de Madagascar. Les propriétés de ce mineral. *Bulletin de la Société Française de Minéralogie*, **35**, 108–113.
- Levinson A.A. (1966) A system of nomenclature for rare-earth minerals. *American Mineralogist*, **51**, 152–158.
- Maksimović Z. and Pantó G. (1983) Mineralogy of yttrium and lanthanide elements in karstic bauxite deposits. *Travaux du Comité International pour l'Etude des Bauxites, de l'Alumine et de l'Aluminium*, **13**, 191–200.
- Maksimović Z. and Pantó G. (1985) Hydroxyl-bastnaesite-(Nd), a new mineral from Montenegro, Yugoslavia. *Mineralogical Magazine*, **49**, 717–720.
- Mandarino J.A. (1981) The Gladstone-Dale relationship. Part IV. The compatibility concept and its application. *The Canadian Mineralogist*, **14**, 498–502.

- Mi J., Shen J., Pan B. and Liang J. (1996) Crystal structure refinement of bastnäsite-(Ce) and fluocerite-(Ce). *Earth Science – Journal of China University of Geosciences*, **21**, 63–67 [in Chinese with English abstract].
- Michiba K., Tahara T., Nakai I., Miyawaki R. and Matsubara S. (2011) Crystal structure of hexagonal RE(CO<sub>3</sub>)OH. *Zeitschrift für Kristallographie*, **226**, 518–530.
- Michiba K., Miyawaki R., Minakawa T., Terada Y., Nakai I. and Matsubara S. (2013) Crystal structure of hydroxylbastnäsite-(Ce) from Kamihourai, Miyazaki Prefecture, Japan. *Journal of Mineralogical and Petrological Sciences*, **108**, 326–334.
- Minakawa T., Adachi T. and Matsuda M. (1992) Hydroxylbastnaesite-(Ce), a new occurrence from Japan. *Chigaku Kenkyu*, **41**, 155–159.
- Mineev D.A., Lavrishcheva T.I. and Bykova A.V. (1970) Yttrium bastnaesite, a product of gagarinite alteration. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, **99**, 328–332 [in Russian].
- Miyawaki R., Matsubara S., Yokoyama K., Iwano S., Hamasaki K. and Yukinorii I. (2003) Kozoite-(La), La(CO<sub>3</sub>)(OH), a new mineral from Mitsukoshi, Hizen-cho, Saga Prefecture, Japan. *Journal of Mineralogical and Petrological Sciences*, **98**, 137–141.
- Miyawaki R., Yokoyama K. and Husdal T.A. (2013) Bastnäsite-(Nd), a new Nd-dominant member of the bastnäsite group from the Stetind pegmatite, Tysfjord, Nordland, Norway. *European Journal of Mineralogy*, **25**, 187–191.
- Nakamoto K. (2008) *Infrared and Raman Spectra of Inorganic and Coordination Compounds, Theory and Applications in Inorganic Chemistry*. John Wiley and Sons, NY. 350 pp.
- Ni Y., Hughes J.M., and Mariano A.N. (1993) The atomic arrangement of bastnäsite-(Ce), Ce(CO<sub>3</sub>)F, and structural elements of synchysite-(Ce), röntgenite-(Ce), and parisite-(Ce). *American Mineralogist*, **78**, 415–418.
- Oftedal I. (1931) Zur Kristallstruktur von Bastnäsit (Ce,La)FCO<sub>3</sub>. *Zeitschrift für Kristallographie, Mineralogie und Petrographie*, **78**, 462–469.
- Ondrejka M., Uher P., Pršek J., Ozdín D. and Putiš M. (2005) Arsenian monazite-(Ce) and REE arsenates and carbonates: Composition and substitution in the REEPO<sub>4</sub> – REEAsO<sub>4</sub> system. Example from Tisovec – Rejkovo thymolite (Western Carpathians, Slovakia). *Geophysical Research Abstracts*, Vol. 7, 04857.
- Pantó G. and Maksimović Z. (2001) Two new rare earth minerals in an unusual mineralization of the Nissi bauxite deposit, Greece. *Acta Geologica Hungarica*, **44**, 81–93.
- Pekov I.V. (1998) *Minerals First Discovered on the Territory of the Former Soviet Union*. OP, Moscow, 369 pp.
- Pekov I.V., Alimova A.N., Kononkova N.N. and Kanonov A.A. (2002) On the mineralogy of Mochalin Log at Southern Urals I. Minerals of the bastnäsite family: history of studies and new data. *Uralskiy Geologicheskii Zhurnal (Uralian Geological Journal)*, **4**, 127–144 [in Russian].
- Pekov I.V., Zubkova N.V., Kasatkin A.V., Chukanov N.V., Koshlyakova N.N., Ksenofontov D.A., Škoda R., Britvin S.N., Kirillov A.S., Zaitsev A.N., Kuznetsov A.M. and Pushcharovsky D.Y. (2021) Hydroxylbastnäsite-(La), IMA2021–001. CNMNC Newsletter 61. *Mineralogical Magazine*, **85**, 461.
- Petríček V., Dušek M. and Palatinus L. (2006) *Jana2006. Structure Determination Software Programs*. Institute of Physics, Praha, Czech Republic.
- Rudnev V.V., Chukanov N.V., Nechelyustov G.N. and Yamnova N.A. (2007) Hydroxylborite, Mg<sub>3</sub>(BO<sub>3</sub>)(OH)<sub>3</sub>, a new mineral species and isomorphous series fluoborite-hydroxylborite. *Geology of Ore Deposits*, **49**, 710–719.
- Silberminz V. (1929) Sur le gisement de cerite, de bastnäsite et d'un minéral nouveau la lessingite dans le district minier de Kychtym (Oural). *Comptes Rendus de l'Academie des Sciences de Russie*, **A**, **3**, 55–60 [in French].
- Strunz H. (1962) *Mineralogicheskie Tablitsy (Mineralogical Tables, with additions by A.S. Povarennykh)*. Gosgortekhzdat, Moscow [in Russian].
- Svyazhin N.V. (1965) Kyshtymite as a bastnäsite variety. *Trudy Instituta Geologii Uralskogo Filiala AN SSSR (Proceedings of the Institute of Geology of the Uralian Branch of Academy of Sciences of USSR)*, **70**, 249–252 [in Russian].
- Terada Y., Nakai I. and Kawashima T. (1993) Crystal structure of bastnäsite (Ce,La,Nd,Sm,Gd)CO<sub>3</sub>F. *Analytical Sciences*, **9**, 561–562.
- Wang Y., Nestola F., Hou Z., Miyawaki R., Pekov I.V., Gu X., Dong G. and Qu K. (2024) Nomenclature of the ancylite supergroup. *Mineralogical Magazine*, **88**, <https://doi.org/10.1180/mgm.2024.8>
- Warr L.N. (2021) IMA-CNMNC approved mineral symbols. *Mineralogical Magazine*, **85**, 291–320.
- White T., Ferraris C., Kim J. and Srinivasan M. (2005) Apatite – an adaptive framework structure. Pp. 307–402 in: *Micro- and Mesoporous Mineral Phases* (G. Ferraris and S. Merlino, editors.). Reviews in Mineralogy and Geochemistry, **57**. Mineralogical Society of America and the Geochemical Society, Chantilly, Virginia, USA.
- Yang H., Dembowski R.F., Conrad P.G. and Downs R.T. (2008) Crystal structure and Raman spectrum of hydroxyl-bastnäsite-(Ce), CeCO<sub>3</sub>(OH). *American Mineralogist*, **93**, 698–701.