

The mineralogy of the historical Mochalin Log *REE* deposit, South Urals, Russia. Part V. Zilbermintsite-(La), $(\text{CaLa}_5)(\text{Fe}^{3+}\text{Al}_3\text{Fe}^{2+})[\text{Si}_2\text{O}_7][\text{SiO}_4]_5\text{O}(\text{OH})_3$, a new mineral with ET2 type structure and a definition of radekškodaite group.

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Running title: Zilbermintsite-(La), a new mineral

Abstract

The new mineral zilbermintsite-(La), ideally $(\text{CaLa}_5)(\text{Fe}^{3+}\text{Al}_3\text{Fe}^{2+})[\text{Si}_2\text{O}_7][\text{SiO}_4]_5\text{O}(\text{OH})_3$, was found in a single polyminerale nodule from the Mochalin Log *REE* deposit, Chelyabinsk Oblast, South Urals, Russia. Zilbermintsite-(La) forms anhedral grains up to 0.65×0.20 mm at the contact of ferriperbøeite-(La), törnebohmit-(La) and ferriallanite-(Ce). Other associated minerals include bastnäsite-(La), biraite-(La), ferriallanite-(La), ferriperbøeite-(Ce), fluorbritholite-(Ce), monazite-(La), perbøeite-(La), percleveite-(Ce), percleveite-(La), perrierite-(Ce), perrierite-(La), thorianite, thorite and quartz. The new mineral is light brown, translucent in thin fragments with a vitreous lustre. It is brittle, with good {100}



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cleavage. Mohs' hardness is *ca.* 6. $D_{\text{calc}} = 4.684 \text{ g cm}^{-3}$. Optically, zilbermintsite-(La) is biaxial (+), $\alpha = 1.805(7)$, $\beta = 1.812(7)$, $\gamma = 1.867(8)$ (589 nm); $2V_{\text{meas}} = 40(15)^\circ$, $2V_{\text{calc}} = 40^\circ$. The empirical formula based on $\text{O}_{28}(\text{OH},\text{F})_3 \text{ apfu}$ is $(\text{Ca}_{0.94}\text{La}_{2.56}\text{Ce}_{2.18}\text{Nd}_{0.20}\text{Pr}_{0.10}\text{Th}_{0.02})_{\Sigma 6.00}(\text{Al}_{2.96}\text{Fe}^{3+}_{0.90}\text{Fe}^{2+}_{0.64}\text{Mg}_{0.34}\text{Mn}_{0.13}\text{Ti}_{0.03})_{\Sigma 5.00}\text{Si}_{7.00}\text{O}_{28}[(\text{OH})_{2.42}\text{F}_{0.58}]$. Zilbermintsite-(La) is monoclinic, $P2_1/m$; the unit-cell parameters are: $a = 8.9605(5)$, $b = 5.7295(2)$, $c = 25.1033(13) \text{ \AA}$, $\beta = 116.616(7)$, $V = 1152.21(12) \text{ \AA}^3$, and $Z = 2$. The crystal structure of zilbermintsite-(La) is solved from the single-crystal X-ray diffraction data [$R = 0.0757$ for 2857 unique reflections with $I > 2\sigma(I)$]. The new mineral is isotypic to radekškodaite-(La) and radekškodaite-(Ce) and together with them forms a newly defined radekškodaite group. All members of this group possess the ET2 type structure where one epidote-type module (E) regularly alternates with two törnebohmitite-type modules (T). The new mineral honors Professor Veniamin A. Zilbermints (1887–1939) who was a pioneer of the study of the Mochalin Log deposit. The Levinson's suffix-modifier -(La) indicates the predominance of La among rare-earth elements in the mineral.

Keywords: zilbermintsite-(La); new mineral; crystal structure; ET2 type; radekškodaite group; Mochalin Log; South Urals.

Introduction

This article continues a series of papers on the mineralogy and crystal chemistry of new mineral species containing rare-earth elements (*REE*; *lanthanoids* + *Y*) as species-defining cations (below – “*REE* minerals”) discovered at the Mochalin Log deposit, Chelyabinsk Oblast, South Urals, Russia (55°48'42" N, 60°33'46" E). A brief historical outline, the general description, geological and mineralogical data for this deposit were provided in the first paper which also contained the characterization of two new isostructural gatelite-group minerals, ferriperbøeite-(La) and perbøeite-(La) (Kasatkin *et al.*, 2020a). In the second article we described radekškodaite-(La) and radekškodaite-(Ce), two members of the epidote–törnebohmitite polysomatic series with a novel-type structure including one epidote and two törnebohmitite modules (ET2) (Kasatkin *et al.*, 2020b). The third paper contained data on the new mineral species percleveite-(La) (Kasatkin *et al.*, 2020c). The fourth paper reported on three new isotypic minerals alexkuznetsovite-(La), alexkuznetsovite-(Ce) and biraite-(La) and the establishment of the biraite group (Kasatkin *et al.*, 2021). Herein we describe another new *REE* mineral from the Mochalin Log deposit that is named zilbermintsite-(La) [Russian cyrilic зильберминцит-(La)] in honour of the outstanding Russian mineralogist and geochemist Professor Veniamin Arkadievich Zilbermints (other spelling: Silberminz) (1887–1939) who worked at the Moscow Mining Academy and in All-Union Scientific Research Institute of Mineral Resources (VIMS), Moscow. In 1927 Prof. Zilbermints discovered in the dumps of an outworked placer gold deposit of 19th century in Kyshtym region in the Urals an alluvial deposit of rare earth ores that he called “cerite deposit” and that is known now as the Mochalin Log *REE* deposit. Based on the results of fieldworks of 1927–1929, Prof. Zilbermints provided detailed geological and petrological

description of the deposit, collected and studied numerous *REE*-rich nodules and reported on main *REE* minerals composing them (Zilbermints, 1928, 1930; Silberminz, 1929). His destiny was tragic: he was falsely accused during Stalin's times, executed and rehabilitated only 20 years after. The Levinson modifier -(La) in the mineral name reflects the predominance of La among *REE*. The new mineral, its name and symbol (Zlb-La) have been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (IMA2023–063, Kasatkin *et al.*, 2023). The holotype specimen is deposited in the systematic collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences, Moscow with the catalogue number 98320.

Occurrence and general appearance

The polymineralic nodule containing zilbermintsite-(La) was collected in August 2018 during a fieldwork made by a group of the authors (AVK, RŠ, AMK) at the placer dump no. 2bis (Fig. 1). The new mineral occurs as a very few anhedral grains typically at the contact of ferriperbøeite-(La), törnebohmite-(La) and ferriallanite-(Ce) (Fig. 2). The largest grain found measures 0.65×0.20 mm. Apart the above mentioned species, the very rich *REE* mineral assemblage of this nodule include bastnäsite-(La), biraite-(La), ferriallanite-(La), ferriperbøeite-(Ce), fluorbritholite-(Ce), monazite-(La), perbøeite-(La), percleveite-(Ce), percleveite-(La), perrierite-(Ce) and perrierite-(La). Non-*REE* bearing minerals are represented by quartz, thorianite and thorite.

According to the distribution scale of *REE* minerals found at the Mochalin Log deposit (Kasatkin *et al.*, 2020a), zilbermintsite-(La) should be considered as very rare: among 300 nodules with *REE*-bearing minerals investigated by us, it was found in only one of them. In term of its internal structure, this nodule belongs to type 2 (Kasatkin *et al.*, 2020a) where *REE* minerals form thin and chaotic intergrowths with each other. However, the occurrence of zilbermintsite-(La) is restricted along the contact between törnebohmite-(La) and ferriperbøeite-(La) grains.

Physical properties and optical data

The new mineral is light brown and translucent in thin fragments, with brown streak and vitreous lustre. It does not fluoresce under ultraviolet light. One direction of good cleavage and one direction of imperfect cleavage were observed under the scanning electron microscope (SEM); from the structure data (see below) we assume that good cleavage could be on $\{100\}$. Parting is not observed. Zilbermintsite-(La) is brittle with a fracture stepped in the cleavage direction and uneven across it (observed under the SEM). The Vickers' micro-indentation hardness (load 150 g) is equal to 838 kg mm^{-2} (range 767–912, $n = 4$) corresponding to *ca.* 6 on the Mohs scale. Density could not be measured due to lack of sufficiently large monomineral fragments and the absence of heavy liquids with suitable density. A density value calculated

using the empirical formula and the unit-cell parameters from single-crystal X-ray diffraction (XRD) data is 4.684 g cm^{-3} .

In transmitted plane-polarized light zilbermintsite-(La) is weakly pleochroic in brown tones. The absorption scheme is $Z > Y > X$. Optically it is biaxial (+), with $\alpha = 1.805(7)$, $\beta = 1.812(7)$, $\gamma = 1.867(8)$ (589 nm), $2V_{\text{meas.}} = 40(15)^\circ$ and $2V_{\text{calc.}} = 40^\circ$. Dispersion of optical axes is very weak, $r < v$. Optical orientation was not determined due to the anhedral shape of the grains.

Raman Spectroscopy

The Raman spectra of zilbermintsite-(La) (Fig. 3) were obtained from polished section by means of a Horiba Labram HR Evolution spectrometer. This dispersive, edge-filter-based system is equipped with an Olympus BX 41 optical microscope, a diffraction grating with 600 grooves per millimetre, and a Peltier-cooled, Si-based charge-coupled device (CCD) detector. After careful tests with different lasers (473, 532 and 633 nm), the 532 nm Nd:YAG diode laser with the beam power of $\sim 5 \text{ mW}$ at the sample surface was selected for spectra acquisition to minimize analytical artefacts. Raman signal was collected in the range of $80\text{--}4000 \text{ cm}^{-1}$ with a 100x objective (NA 0.9) and the system being operated in the confocal mode, beam diameter was $\sim 1 \mu\text{m}$ and the axial resolution $\sim 2 \mu\text{m}$. No visual damage of the analysed surface was observed at these conditions after the excitation. Wavenumber calibration was done using the Rayleigh line and low-pressure Ne-discharge lamp emissions. The wavenumber accuracy was $\sim 0.5 \text{ cm}^{-1}$, and the spectral resolution was $\sim 2 \text{ cm}^{-1}$. Band fitting was done after appropriate background correction, assuming combined Lorentzian-Gaussian band shapes using Voigt function.

The assignment of the Raman bands is as follows.

$3595, 3313$ and 3199 cm^{-1} : O–H-stretching vibrations.

1013 cm^{-1} : stretching vibrations of Si–O–Si fragments in Si_2O_7 groups.

845 to 968 cm^{-1} : stretching vibrations of apical Si–O bonds.

550 to 700 cm^{-1} : Al–O \cdots H bending vibrations, stretching vibrations of Si–Ob–Si bonds.

300 to 630 cm^{-1} : mixed modes and overlapping bands of (Al,Fe³⁺,Mg)–O-stretching vibrations, as well as bending vibrations of silicate groups.

Below 300 cm^{-1} : lattice modes involving REE–O-, Ca–O- and Fe²⁺–O-stretching vibrations and librational vibrations of silicate groups.

The Raman spectrum of zilbermintsite-(La) is similar to those of radekškodaite-(La) and radekškodaite-(Ce) (Kasatkin *et al.*, 2020b). It is also similar to the spectra of västmanlandite-(Ce) (Holtstam *et al.*, 2005) and ferriperbøeite-(La) (Kasatkin *et al.*, 2020a) in the region of $300\text{--}1000 \text{ cm}^{-1}$ but significantly differs from them in the region of stretching vibrations of Si–O–Si fragments (1000 to 1100 cm^{-1}) and stretching vibrations involving REE and bivalent cations forming low-force-strength bonds (below 300 cm^{-1}). In particular, in the zilbermintsite-(La) spectrum, the bands of stretching vibrations of Si–O–Si

fragments are significantly weaker than in the ferriperbœite-(La) spectrum that reflects a lower $\text{Si}_2\text{O}_7:\text{SiO}_4$ ratio in the new mineral.

In the Raman spectrum of zilbermintsite-(La), three bands of O–H-stretching vibrations are observed, which corresponds to the number of independent sites occupied by OH groups. The band at 687 cm^{-1} in the Raman spectrum of zilbermintsite-(La) is close to the strong band at 689 cm^{-1} in the Raman spectrum of allanite-(Ce) (Andò and Garzanti, 2014; Čopjaková *et al.*, 2015) and ferriallanite-(Ce) (Sobek *et al.*, 2023) and can be assigned to the symmetric stretching vibrations of Si–O_b–Si bonds of the epidote-type module (Wang *et al.*, 1994).

Chemical Data

Chemical data (five spot analyses) were obtained using a Cameca SX-100 electron microprobe (WDS mode, acceleration voltage of 15 kV, a beam current of 20 nA, and a 3 μm beam diameter). The spectral interference of F $K\alpha$ and Ce $M\zeta$ were manually corrected using empirically determined correction factors. The content of H₂O was not determined directly due to the scarcity of pure material and was calculated by stoichiometry on the basis of $\text{O}_{28}(\text{OH},\text{F})_3$ taking into account that bond-valence sums for the O(1), O(2) and O(3) sites are close to 1 (see below). Both the crystal structure and Raman spectroscopy data confirm the presence of OH groups and the absence of B–O, C–O and N–O bonds in the mineral. Analytical data are given in Table 1. Contents of other elements with atomic numbers higher than carbon are below detection limits.

Zilbermintsite-(La) grains are chemically homogeneous and the WDS analyses reveal the uniform chemical composition with only minimal inter-*REE* chemical variation. Lanthanum significantly prevails among *REE* in all analyses. The empirical formula calculated on the basis of $\text{O}_{28}(\text{OH},\text{F})_3$ *apfu* is $(\text{Ca}_{0.94}\text{La}_{2.56}\text{Ce}_{2.18}\text{Nd}_{0.20}\text{Pr}_{0.10}\text{Th}_{0.02})_{\Sigma 6.00}(\text{Al}_{2.96}\text{Fe}^{3+}_{0.90}\text{Fe}^{2+}_{0.64}\text{Mg}_{0.34}\text{Mn}_{0.13}\text{Ti}_{0.03})_{\Sigma 5.00}\text{Si}_{7.00}\text{O}_{28}[(\text{OH})_{2.42}\text{F}_{0.58}]$. The ideal formula is $(\text{CaLa}_5)(\text{Fe}^{3+}\text{Al}_3\text{Fe}^{2+})[\text{Si}_2\text{O}_7][\text{SiO}_4]_5\text{O}(\text{OH})_3$ which requires CaO 3.46, La₂O₃ 50.18, FeO 4.43, Al₂O₃ 9.43, Fe₂O₃ 4.92, SiO₂ 25.92, H₂O 1.66, total 100 wt.%.

The Gladstone-Dale compatibility index $(1 - K_p/K_c)$ calculated for zilbermintsite-(La) using its empirical formula and the unit-cell parameters determined from single-crystal XRD data is 0.013 rated as superior (Mandarino, 1981).

Zilbermintsite-(La) does not react with either cold hydrochloric or nitric acid.

X-ray Crystallography and Crystal Structure

Powder XRD data were collected using a Rigaku R-AXIS Rapid II single-crystal diffractometer equipped with a cylindrical image plate detector (radius 127.4 mm) using Debye-Scherrer geometry, $\text{Co}K\alpha$ radiation (rotating anode with VariMAX microfocus optics), 40 kV and 15 mA. Angular resolution of the detector is $0.045^\circ 2\theta$ (pixel size 0.1 mm). The data were integrated using the software package

Osc2Tab (Britvin *et al.*, 2017). PXRD data of zilbermintsite-(La) are given in Table 2 in comparison to that calculated from SCXRD data using the *Atoms 5.1* program (Dowty, 2000). Parameters of monoclinic unit cell were calculated from the observed *d* spacing data using *UnitCell* software (Holland and Redfern, 1997) and are as follows: $a = 8.965(4)$, $b = 5.735(3)$, $c = 25.096(9)$ Å, $\beta = 116.68(4)^\circ$ and $V = 1152(8)$ Å³.

For the single-crystal XRD study, a grain of zilbermintsite-(La), $0.04 \times 0.13 \times 0.16$ mm³ in size, extracted from the polished section and previously analysed using electron microprobe and Raman spectroscopy, was mounted on a glass fiber and examined with an Xcalibur S single-crystal diffractometer equipped with a CCD detector. A full sphere of three-dimensional data was collected. Data reduction was performed using *CrysAlisPro* software Version 1.171.39.46 (Rigaku OD, 2018). The data were corrected for Lorentz factor, absorption and polarization effects.

The crystal structure of zilbermintsite-(La) was solved by direct methods and refined with the use of SHELX software package (Sheldrick, 2015) to $R_1 = 0.0757$ for 2677 unique reflections with $I > 2\sigma(I)$. Two O atoms (O1 and O19) were refined in isotropic approximation of displacement parameters. The crystal data, data collection information and structure refinement details are given in Table 3, atomic coordinates and thermal displacement parameters of atoms in Tables 4 and 5, and selected interatomic distances in Table 6. Bond valence calculations are given in Table 7. Assigned site occupancies (s.o.f.) based on the results of the crystal structure refinement are given in Table 8. The crystallographic information file has been deposited with the Principal Editor of Mineralogical Magazine and is available as Supplementary material (see below).

The crystal structure of zilbermintsite-(La) (Fig. 4) consists of the chains of edge-sharing octahedra running along the *b* axis: single chains of the *M*(2)- and *M*(4)-centred octahedra and branched chains with the *M*(1)-centred octahedra in the central part, and the *M*(3)-centred octahedra attached to them from both sides. The chains are linked *via* isolated [SiO₄] tetrahedra and disilicate groups [Si₂O₇] [the angle Si–O–Si in the disilicate group is equal to $149.6(9)^\circ$]. The *A*(1–6) sites occur in large cavities. Despite La³⁺ is a dominant *REE* in zilbermintsite-(La), the Ce³⁺ scattering curve was used during the structure refinement for the *A*(1–6) sites because of the significant content of Ce³⁺ cations, minor amounts of heavier Nd³⁺ and Pr³⁺, and very minor amount of Th⁴⁺. According to the s.o.f. refinement, the *A*(2–6) sites are fully occupied by *REE* cations. The *A*(1) site is Ca-dominant with minor *REE* admixture; Ca *vs* Ce was refined that gave Ca_{0.955(7)}Ce_{0.045(7)}. There are four octahedrally coordinated *M* sites, *M*(1–4). For the *M*(1), *M*(2) and *M*(4) sites, Al *vs* Fe was refined, and for the *M*(3) site, Fe *vs* Mg was refined. The *M*(2) and *M*(4) sites are Al-dominant with the refined occupancy Al_{0.936(16)}Fe_{0.064(16)} and Al_{0.91(2)}Fe_{0.09(2)}, respectively. These sites center the smallest octahedra with the mean distances 1.912 Å [*M*(2)–O] and 1.918 Å [*M*(4)–O]. The *M*(1)-centred octahedron is slightly larger, with the mean *M*(1)–O distance of 1.995 Å. This site is Fe³⁺-dominant, with refined occupancy Fe_{0.55(2)}Al_{0.45(2)}, corresponding to number of electrons (e_{ref}) = 20.2(4). Based on the chemical information, the *M*(1) occupancy was hence fixed to Fe_{0.57}Al_{0.17}Mg_{0.26} in

the final stage of refinement. The largest $M(3)$ octahedron with the mean $M(3)$ –O distance of 2.136 Å is predominantly occupied by Fe^{2+} with subordinate Mn, Mg and Fe^{3+} in the atomic ratio $\text{Fe}^{2+}:\text{Mn}:\text{Fe}^{3+}:\text{Mg} = 0.64:0.15:0.11:0.10$, according to both electron microprobe data and refined number of electrons ($e_{\text{ref}} = 24.46$). During the refinement, splitting was found for the O(23) and O(24) sites which deviate from the m plane as well as it occurs in the structures of radekškodaite-(La) and radekškodaite-(Ce).

Bond-valence calculations (Table 7) confirm the above conclusions about distribution of cations between different sites: specifically, Fe^{3+} at $M(1)$ and Fe^{2+} at $M(3)$.

Discussion

Zilbermintsite-(La) is isotypic to radekškodaite-(La) and radekškodaite-(Ce) (Kasatkin *et al.*, 2020b). They are considered as ET2-type polysomes which structures can be described as a regular alternating of one module of the epidote-type structure (E) with two modules of the törnebohmite-type structure (T2) (Kasatkin *et al.*, 2020b). Zilbermintsite-(La) differs from radekškodaite-(La) and radekškodaite-(Ce) by the Fe^{3+} predominance at the $M(1)$ site which is Al-dominant in the latter. The E module in zilbermintsite-(La) has ferriallanite-(La) composition while in radekškodaite-(La) and radekškodaite-(Ce) it has allanite-(La) and allanite-(Ce) compositions, respectively. According to the mineral group nomenclature (Mills *et al.*, 2009), the radekškodaite group could be established that includes radekškodaite-(La), radekškodaite-(Ce) and zilbermintsite-(La). For their comparison see Table 9.

One of the crucial points for the definition of zilbermintsite-(La) is the distribution of M cations including di- and trivalent iron. The arrangement of Fe^{2+} , Fe^{3+} , Al, Mg and Mn between M sites is suggested taking into account electron microprobe data (Table 1), refined numbers of electrons (Tables 4 and 8), M –O distances (Table 6) and BVS values (Table 7). Unfortunately, we could not determine the valence of iron directly, by means of wet chemical analysis or Mössbauer spectroscopy due to the scarcity of pure material. The methods using electron microprobe data (measurement of chemical shift of Fe analytical lines depending on iron valence state) are not effective in this case because of relatively low content of total Fe in the mineral (*ca.* 5 wt.% Fe). However, the distribution of species-defining Fe^{2+} and Fe^{3+} between two major for iron M sites, $M1$ and $M3$, is reliably found from the structure data. The refined numbers of electrons demonstrate that both these sites are Fe-dominant (Tables 4 and 8) and interatomic distances show that the $M1$ site contains Fe^{3+} ($M1$ –O = 1.995 Å) whereas Fe^{2+} is concentrated in $M3$ ($M3$ –O = 2.136 Å): Table 6. This conclusion is clearly confirmed by bond valence calculations: the BVS values for $M1$ and $M3$ are 2.90 and 2.20 v.u., respectively (Table 7). Finally, the correctness of the site occupancies given in Table 8, as well as the $\text{Fe}^{2+}:\text{Fe}^{3+}$ ratio found, are confirmed by the lowest value of the Gladstone-Dale compatibility index.

The genetic position of zilbermintsite-(La) respects the general geochemical and crystal chemical trend in the mineral assemblage of some zonal REE nodules from Mochalin Log deposit. The REE

content decreases and the silicate (Si, Al, Fe, Mg, Ca) content increases from central parts of the nodules outwards. The occurrence of zilvermintsite-(La) is situated at the contact between törnebohmitte-(La) and ferriperbøeite-(La) and it is in accordance with the generalized genetic sequence (center to rim) of the epidote-törnebohmitte polysomatic series: törnebohmitte → radekškodaite/zilvermintsite → perbøeite/ferriperbøeite → allanite/ferriallanite → REE-rich epidote. This mineral assemblage also reflects the changes in the trend of alternation between epidote (E) and törnebohmitte (T) modules. The abovementioned mineral sequence can be schematized as T→ET₂→ET→E. According to the textural relations observed from dozens of REE nodules investigated, the minerals of the epidote-törnebohmitte polysomatic series are rather cogenetic and probably their distribution mirrors the different activity of REE and the other necessary elements (Si, Al, Fe, Ca, Mg, etc) in different parts of the nodules during the crystallization.

Supplementary material

To view supplementary material for this article, please visit: <https://doi.org/...>

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Table 1. Chemical composition of zilbermintsite-(La).

Constituent	Wt.%	Range	Stand. Dev.	Probe Standard
CaO	3.21	3.19 – 3.24	0.02	Wollastonite
La ₂ O ₃	25.47	25.31 – 25.88	0.23	LaPO ₄
Ce ₂ O ₃	21.84	21.75 – 21.90	0.06	CePO ₄
Pr ₂ O ₃	1.03	0.98 – 1.07	0.04	PrPO ₄
Nd ₂ O ₃	2.01	1.91 – 2.15	0.09	NdPO ₄
ThO ₂	0.26	0.25 – 0.28	0.02	CaTh(PO ₄) ₂
MgO	0.84	0.82 – 0.88	0.02	Mg ₂ SiO ₄
MnO	0.55	0.52 – 0.57	0.02	Spessartine
Al ₂ O ₃	9.20	8.97 – 9.30	0.13	Sanidine
FeO*	2.82	6.70 – 6.85**	0.06**	Almandine
Fe ₂ O ₃ *	4.40			

TiO ₂	0.14	0.12 – 0.17	0.02	Anatase
SiO ₂	25.68	25.40 – 25.88	0.24	Sanidine
F	0.67	0.65 – 0.69	0.02	Topaz
H ₂ O***	1.33			
–O=F	– 0.28			
Total	99.17			

* Total Fe content corresponding to FeO content of 6.78 wt.% was divided into Fe²⁺ and Fe³⁺ based on the occupancies of the M1–M4 sites found from crystal structure refinement data: see Table 8. Thus, 2.82 wt.% FeO and 4.40 wt.% Fe₂O₃ were calculated based on the found Fe²⁺: Fe³⁺ atomic ratio: 0.64 Fe²⁺ and 0.90 Fe³⁺ *pfu*, respectively (Fe³⁺: Fe²⁺ = 1.40).

** For total iron calculated as FeO.

*** Calculated by stoichiometry: (OH + F) = 3 apfu

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

<i>d</i> _{obs}	<i>I</i> _{obs}	<i>d</i> _{calc} *	<i>I</i> _{calc} *	<i>h k l</i>	<i>d</i> _{obs}	<i>I</i> _{obs}	<i>d</i> _{calc} *	<i>I</i> _{calc} *	<i>h k l</i>
22.4	54	22.443	36	0 0 1	1.929	5	1.931	5	2 0 -13
8.01	21	8.011	44	1 0 0			1.926	6	1 2 7
4.661	10	4.660	4	1 1 0	1.871	6	1.869	2	1 0 -13
4.296	10	4.294	2	2 0 -4	1.797	14	1.793	4	3 2 -10
4.017	12	4.009	2	2 0 -5			1.792	2	5 0 -6
3.966	7	4.006	7	2 0 0			1.791	9	2 0 -14
3.742	14	3.741	2	0 0 -6	1.763	5	1.767	8	0 2 -10
3.528	9	3.519	3	2 1 -3			1.760	2	4 2 -6
3.335	17	3.336	20	2 0 -7			1.752	2	4 0 -13
		3.330	5	2 0 2	1.745	18	1.743	15	4 2 -3
3.017	45	3.014	34	2 0 3			1.668	3	4 0 -14
		2.985	10	3 0 -4	1.664	14	1.665	3	2 0 10
2.861	100	2.865	100	0 2 0			1.662	2	0 2 -11
		2.863	10	3 0 -6	1.648	14	1.643	20	4 2 -10
2.733	25	2.732	45	2 0 4	1.611	5	1.610	2	1 2 10
2.704	26	2.698	19	1 2 0	1.604	9	1.602	3	5 0 0
2.602	14	2.602	2	1 0 7			1.601	5	2 2 -13
		2.588	8	1 2 -4	1.520	4	1.518	9	2 2 -14
2.534	7	2.537	5	1 2 2			1.518	2	5 2 -7
		2.486	2	2 0 5			1.480	5	1 2 -14
2.483	11	2.483	3	1 2 -5	1.475	3	1.474	5	6 0 -10
		2.467	3	1 0 -10			1.473	3	5 2 -10
2.431	20	2.424	13	1 2 3	1.442	11	1.439	6	4 2 4
2.193	16	2.196	20	4 0 -3	1.390	4	1.398	2	5 2 0
2.178	45	2.174	35	2 2 -7	1.322	6	1.324	2	6 2 -7
2.141	11	2.136	11	0 2 -7			1.320	4	0 0 -17
2.077	12	2.076	21	2 2 3			1.319	4	6 2 -6
2.044	11	2.040	2	0 0 -11	1.282	3	1.283	6	4 2 7
		2.025	4	3 2 -6	1.269	2	1.269	6	2 4 4
2.012	11	2.013	2	3 0 -12	1.214	4	1.216	2	3 4 -10
		2.006	12	4 0 -10			1.210	2	6 2 0
1.982	16	1.977	29	2 2 4	1.194	2	1.200	3	4 4 -3

* For the calculated pattern, only reflections with intensities ≥ 2 are given.

** For the unit-cell parameters calculated from single crystal data.

Strongest reflections are given in boldtype.

Table 3. Crystal data, data collection information and structure refinement details for zilbermintsite-(La).

Formula from refinement	$A^{11}(\text{Ca}_{0.955}\text{Ce}_{0.045})A^{12-6}\text{Ce}_5M^1(\text{Fe}_{0.57}\text{Mg}_{0.26}\text{Al}_{0.17})M^2(\text{Al}_{1.87}\text{Fe}_{0.13})M^3(\text{Fe}_{0.75}\text{Mn}_{0.15}\text{Mg}_{0.10})M^4(\text{Al}_{0.91}\text{Fe}_{0.09})[\text{Si}_2\text{O}_7][\text{SiO}_4]_5\text{O}(\text{OH})_3$
Formula weight	1620.40
Temperature, K	293(2)
Radiation and wavelength, Å	MoK α ; 0.71073
Crystal system, space group, Z	Monoclinic, $P2_1/m$, 2
Unit cell dimensions, Å/°	$a = 8.9605(5)$ $b = 5.7295(2)$ $\beta = 116.616(7)$ $c = 25.1033(13)$
V , Å ³	1152.21(12)
Absorption coefficient μ , mm ⁻¹	11.63
F_{000}	1488
Crystal size, mm	0.04 × 0.13 × 0.16
Diffractometer	Xcalibur S CCD
Absorption correction	Gaussian
θ range, °	2.723 – 27.870
Index ranges	$-11 \leq h \leq 11$, $-7 \leq k \leq 7$, $-32 \leq l \leq 33$
Reflections collected	16325
Unique reflections	2857 ($R_{\text{int}} = 0.0639$)
Unique reflections with $I > 2\sigma(I)$	2677
Refinement method	Full-matrix least-squares on F^2
Number of refined parameters	274
Final R indices [$I > 2\sigma(I)$]	$R_1 = 0.0757$, $wR_2^* = 0.1951$
R indices (all data)	$R_1 = 0.0811$, $wR_2^* = 0.1994$
GoF	1.262
Largest diff. peak and hole, e/Å ³	5.59 and -5.48

$$*w = 1/[\sigma^2(F_o^2) + (0.1030P)^2 + 21.2454P]; \quad P = \{[\max(0 \text{ or } F_o^2)] + 2F_c^2\}/3$$

Table 4. Atom coordinates and equivalent thermal displacement parameters (U_{eq} , in Å²) and site occupancy factors (s.o.f.) for zilbermintsite-(La).

Site	x	y	z	U_{eq}	s.o.f.
A(1)	0.2267(4)	$\frac{3}{4}$	-0.06465(14)	0.0162(11)	$\text{Ca}_{0.955(7)}\text{Ce}_{0.045(7)}$
A(2)	0.59163(11)	$\frac{1}{4}$	0.47069(4)	0.0125(3)	Ce _{1.00}
A(3)	0.43319(11)	$\frac{3}{4}$	0.23679(4)	0.0110(3)	Ce _{1.00}
A(4)	0.61610(11)	$\frac{1}{4}$	0.17695(4)	0.0119(3)	Ce _{1.00}
A(5)	0.77138(15)	$\frac{1}{4}$	0.34770(5)	0.0330(4)	Ce _{1.00}
A(6)	0.75178(14)	$\frac{1}{4}$	0.64024(4)	0.0264(3)	Ce _{1.00}
M(1)	0	$\frac{1}{2}$	0	0.0069(5)	$\text{Fe}_{0.57}\text{Mg}_{0.26}\text{Al}_{0.17}^*$
M(2)	0.0289(3)	0.4997(5)	0.20902(12)	0.0074(10)	$\text{Al}_{0.936(16)}\text{Fe}_{0.064(16)}$
M(3)	0.3129(3)	$\frac{3}{4}$	0.08724(11)	0.0128(5)	$\text{Fe}_{0.75}\text{Mn}_{0.15}\text{Mg}_{0.10}^*$
M(4)	0	$\frac{1}{2}$	$\frac{1}{2}$	0.0101(14)	$\text{Al}_{0.91(2)}\text{Fe}_{0.09(2)}$
Si(1)	0.2044(5)	$\frac{1}{4}$	0.13379(19)	0.0066(8)	Si _{1.00}

Si(2)	0.3563(5)	1/4	0.29821(18)	0.0053(8)	Si _{1.00}
Si(3)	0.7040(5)	3/4	0.11733(19)	0.0073(8)	Si _{1.00}
Si(4)	0.8405(5)	3/4	0.28071(19)	0.0089(8)	Si _{1.00}
Si(5)	0.6726(5)	3/4	0.40963(19)	0.0072(8)	Si _{1.00}
Si(6)	0.1825(5)	1/4	0.4256(2)	0.0092(8)	Si _{1.00}
Si(7)	0.3440(5)	1/4	0.01530(18)	0.0076(8)	Si _{1.00}
O(1) = OH	0.9239(14)	1/4	0.5297(5)	0.010(2)**	O _{1.00}
O(2) = OH	0.1064(13)	3/4	0.1791(5)	0.007(2)	O _{1.00}
O(3) = OH	0.9516(15)	1/4	0.2390(5)	0.011(2)	O _{1.00}
O(4)	0.0659(15)	3/4	0.0561(5)	0.017(3)	O _{1.00}
O(5)	0.583(2)	3/4	0.3387(6)	0.042(4)	O _{1.00}
O(6)	0.2405(10)	0.4905(14)	0.0118(3)	0.0144(16)	O _{1.00}
O(7)	0.3735(16)	1/4	-0.0435(6)	0.022(3)	O _{1.00}
O(8)	0.4875(16)	1/4	0.2710(6)	0.025(3)	O _{1.00}
O(9)	0.0538(14)	1/4	0.4578(5)	0.012(2)	O _{1.00}
O(10)	0.9728(14)	3/4	0.2501(5)	0.013(2)	O _{1.00}
O(11)	0.0921(14)	1/4	0.1705(5)	0.011(2)	O _{1.00}
O(12)	0.3053(11)	0.4757(15)	0.4440(4)	0.0193(19)	O _{1.00}
O(13)	0.8165(10)	0.5146(12)	0.1430(4)	0.0129(16)	O _{1.00}
O(14)	0.3297(9)	0.4745(14)	0.1492(3)	0.0098(15)	O _{1.00}
O(15)	0.7842(10)	0.5126(13)	0.4332(4)	0.0129(16)	O _{1.00}
O(16)	0.7148(11)	0.5256(14)	0.2606(4)	0.0153(17)	O _{1.00}
O(17)	0.0551(14)	1/4	0.0638(5)	0.015(2)	O _{1.00}
O(18)	0.2425(10)	0.4885(13)	0.2765(4)	0.0133(16)	O _{1.00}
O(19)	0.5212(14)	1/4	0.0722(5)	0.009(2)**	O _{1.00}
O(20)	0.5551(18)	3/4	0.1367(5)	0.024(3)	O _{1.00}
O(21)	0.458(2)	1/4	0.3679(6)	0.036(4)	O _{1.00}
O(22)	0.5367(19)	3/4	0.4344(6)	0.033(4)	O _{1.00}
O(23)	0.062(2)	0.320(3)	0.3567(7)	0.017(4)	O _{0.50}
O(24)	0.959(2)	0.818(2)	0.3508(7)	0.012(3)	O _{0.50}

*Fixed during the refinement. For $M(1)$ Al vs Fe was refined ($e_{\text{ref}} 20.15$), for $M(3)$ Fe vs Mg was refined ($e_{\text{ref}} 24.46$) (see Table 8). Thus, on the basis of chemical data and e_{ref} $M(1)$ site was assumed to be occupied by ($\text{Fe}_{0.57}\text{Mg}_{0.26}\text{Al}_{0.17}$) possibly with minor Ti^{4+} admixture and $M(3)$ site by ($\text{Fe}_{0.75}\text{Mn}_{0.15}\text{Mg}_{0.10}$). ** U_{iso} .

Table 5. Anisotropic displacement parameters (in \AA^2) in zilbermintsite-(La).

Site	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
A(1)	0.0244(19)	0.0117(15)	0.0161(17)	0.000	0.0124(13)	0.000
A(2)	0.0075(5)	0.0190(5)	0.0085(5)	0.000	0.0015(4)	0.000
A(3)	0.0074(4)	0.0146(4)	0.0098(5)	0.000	0.0027(3)	0.000
A(4)	0.0087(5)	0.0150(5)	0.0103(5)	0.000	0.0028(4)	0.000
A(5)	0.0160(6)	0.0704(9)	0.0091(5)	0.000	0.0024(4)	0.000
A(6)	0.0173(6)	0.0494(7)	0.0081(5)	0.000	0.0018(4)	0.000
M(1)	0.0034(12)	0.0062(12)	0.0115(12)	0.0004(10)	0.0035(10)	-0.0008(9)
M(2)	0.0045(16)	0.0059(16)	0.0117(17)	0.0003(11)	0.0036(13)	-0.0001(11)
M(3)	0.0089(12)	0.0100(11)	0.0141(12)	0.000	0.0003(10)	0.000
M(4)	0.007(2)	0.008(2)	0.016(2)	0.0013(16)	0.0052(18)	-0.0001(15)
Si(1)	0.0041(18)	0.0059(17)	0.012(2)	0.000	0.0059(16)	0.000
Si(2)	0.0011(18)	0.0036(17)	0.0089(19)	0.000	0.0001(15)	0.000
Si(3)	0.0045(18)	0.0037(17)	0.012(2)	0.000	0.0029(16)	0.000

Si(4)	0.0062(19)	0.0093(18)	0.011(2)	0.000	0.0033(16)	0.000
Si(5)	0.006(2)	0.0056(18)	0.008(2)	0.000	0.0014(16)	0.000
Si(6)	0.006(2)	0.0094(19)	0.013(2)	0.000	0.0048(17)	0.000
Si(7)	0.0069(19)	0.0047(16)	0.0094(18)	0.000	0.0019(15)	0.000
O(2)	0.004(5)	0.004(4)	0.013(5)	0.000	0.004(4)	0.000
O(3)	0.015(6)	0.010(5)	0.010(5)	0.000	0.007(4)	0.000
O(4)	0.015(6)	0.019(6)	0.013(6)	0.000	0.003(5)	0.000
O(5)	0.044(10)	0.068(12)	0.010(6)	0.000	0.010(7)	0.000
O(6)	0.016(4)	0.010(3)	0.019(4)	0.000(3)	0.010(3)	0.001(3)
O(7)	0.021(7)	0.027(7)	0.018(6)	0.000	0.009(5)	0.000
O(8)	0.012(6)	0.043(8)	0.017(6)	0.000	0.004(5)	0.000
O(9)	0.006(5)	0.017(6)	0.014(5)	0.000	0.006(5)	0.000
O(10)	0.004(5)	0.013(5)	0.018(5)	0.000	0.002(4)	0.000
O(11)	0.013(5)	0.016(5)	0.008(5)	0.000	0.009(4)	0.000
O(12)	0.018(4)	0.008(4)	0.037(5)	-0.003(4)	0.017(4)	-0.001(3)
O(13)	0.015(4)	0.003(3)	0.018(4)	-0.002(3)	0.006(3)	0.001(3)
O(14)	0.006(3)	0.015(4)	0.009(3)	-0.002(3)	0.003(3)	-0.002(3)
O(15)	0.010(4)	0.004(3)	0.019(4)	0.003(3)	0.001(3)	0.002(3)
O(16)	0.021(4)	0.008(3)	0.024(4)	-0.002(3)	0.015(4)	-0.003(3)
O(17)	0.008(5)	0.019(6)	0.017(6)	0.000	0.005(5)	0.000
O(18)	0.012(4)	0.003(3)	0.020(4)	0.001(3)	0.004(3)	0.004(3)
O(20)	0.028(7)	0.035(7)	0.009(6)	0.000	0.008(5)	0.000
O(21)	0.028(8)	0.057(10)	0.008(6)	0.000	-0.004(6)	0.000
O(22)	0.024(7)	0.056(10)	0.014(6)	0.000	0.004(6)	0.000
O(23)	0.029(9)	0.008(7)	0.010(7)	0.001(5)	0.007(7)	0.001(6)
O(24)	0.019(8)	0.007(7)	0.016(7)	-0.003(5)	0.013(7)	0.000(5)

Table 6. Selected interatomic distances (Å) and angles (°) in the structure of zilbermintsite-(La).

<i>A</i> (1) – O(19)	2.350(11)	<i>A</i> (4) – O(19)	2.374(11)
– O(13)	2.374(8) x 2	– O(16)	2.454(8) x 2
– O(6)	2.388(8) x 2	– O(14)	2.669(8) x 2
– O(17)	2.535(12)	– O(3)	2.696(12)
– O(11)	2.902(12)	– O(13)	2.761(8) x 2
– O(7)	3.097(5) x 2	– O(20)	3.005(4) x 2
< <i>A</i> (1) – O>	2.612	– O(8)	3.055(13)
		< <i>A</i> (4) – O>	2.718
<i>A</i> (2) – O(21)	2.306(13)	<i>A</i> (5) – O(8)	2.406(13)
– O(12)	2.477(9) x 2	– O(23)	2.546(18)
– O(1)	2.666(12)	– O(16)	2.557(8) x 2
– O(12)	2.677(9) x 2	– O(15)	2.581(8) x 2
– O(15)	2.754(8) x 2	– O(9)	2.789(12)
– O(22)	2.980(4) x 2	– O(24)	2.971(14)
– O(22)	3.075(15)	– O(21)	3.071(17)
< <i>A</i> (2) – O>	2.711	– O(5)	3.283(9) x 2
		< <i>A</i> (5) – O>	2.784
<i>A</i> (3) – O(5)	2.295(14)	<i>A</i> (6) – O(22)	2.419(15)
– O(14)	2.521(7) x 2	– O(12)	2.497(9) x 2
– O(2)	2.622(10)	– O(24)	2.533(16)
– O(16)	2.651(9) x 2	– O(18)	2.552(8) x 2
– O(18)	2.772(8) x 2	– O(10)	2.754(12)
– O(8)	2.967(3) x 2	– O(23)	2.955(16)
– O(20)	3.157(13)	– O(5)	3.267(18)
< <i>A</i> (3) – O>	2.718	– O(21)	3.381(9) x 2
		< <i>A</i> (6) – O>	2.799
<i>M</i> (1) – O(4)	1.908(8) x 2	<i>M</i> (3) – O(20)	1.958(14)
– O(17)	2.037(9) x 2	– O(4)	1.990(13)
– O(6)	2.040(8) x 2	– O(14)	2.173(8) x 2
< <i>M</i> (1) – O>	1.995	– O(6)	2.261(8) x 2
		< <i>M</i> (3) – O>	2.136
<i>M</i> (2) – O(13)	1.885(8)	<i>M</i> (4) – O(1)	1.879(7) x 2
– O(3)	1.887(8)	– O(15)	1.911(8) x 2
– O(2)	1.890(7)	– O(9)	1.965(8) x 2
– O(18)	1.906(9)	< <i>M</i> (4) – O>	1.918
– O(11)	1.947(7)		
– O(10)	1.958(9)	<i>Si</i> (1) – O(14)	1.636(8) x 2
< <i>M</i> (2) – O>	1.912	– O(11)	1.642(11)
		<i>Si</i> (5) – O(5)	1.593(15)



– O(17)	1.665(12)	– O(22)	1.596(16)
<Si(1) – O>	1.645	– O(15)	1.634(8) x 2
		<Si(5) – O>	1.614
Si(2) – O(21)	1.570(14)		
– O(8)	1.603(14)	Si(6) – O(12)	1.625(9) x 2
– O(18)	1.645(8) x 2	– O(23)	1.626(16)
<Si(2) – O>	1.616	– O(9)	1.680(12)
		<Si(6) – O>	1.639
Si(3) – O(20)	1.612(14)	Si(7) – O(19)	1.590(11)
– O(13)	1.633(8) x 2	– O(7)	1.612(13)
– O(7)	1.662(13)	– O(6)	1.641(8) x 2
<Si(3) – O>	1.635	<Si(7) – O>	1.621
Si(4) – O(16)	1.633(9) x 2		
– O(24)	1.642(16)	disilicate group angle	
– O(10)	1.678(13)	Si(7)–O(7)–Si(3)	149.6(9)
<Si(4) – O>	1.647		

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Table 7. Bond valences for zilbermintsite-(La).

	A(1)	A(2)	A(3)	A(4)	A(5)	A(6)	M(1)	M(2)	M(3)	M(4)	Si(1)	Si(2)	Si(3)	Si(4)	Si(5)	Si(6)	Si(7)	Σ	H-bonding	Σ
O(1)		0.24								0.56 ^{x2↓x2→}								1.36	-0.21(O24)	1.15
O(2)			0.27							0.54 ^{x2→}								1.35	-0.14(O4)	1.21
O(3)				0.22						0.54 ^{x2→}								1.30	-0.23(O23)	1.07
O(4)							0.59 ^{x2↓} x2→		0.48									1.66	+0.14(O2)	1.80
O(5)			0.63		0.05 ^{x2↓} x2→	0.05									1.08			1.86		1.86
O(6)	0.31 ^{x2↓}						0.43 ^{x2↓}		0.25 ^{x2↓}								0.96 ^{x2↓}	1.95		1.95
O(7)	0.05 ^{x2↓} x2→												0.91				1.03	2.04		2.04
O(8)			0.11 ^{x2↓} x2→	0.09	0.47							1.06						1.84		1.84
O(9)					0.18					0.44 ^{x2↓} x2→						0.87		1.93		1.93
O(10)						0.19		0.45 ^{x2→}									0.87	1.96		1.96
O(11)	0.09							0.46 ^{x2→}			0.95							1.96		1.96
O(12)		0.39 ^{x2↓} 0.24 ^{x2↓}					0.37 ^{x2↓}									1.00 x2↓		2.00		2.00
O(13)	0.32 ^{x2↓}			0.19 ^{x2↓}				0.54					0.98 ^{x2↓}					2.03		2.03
O(14)			0.35 ^{x2↓}	0.24 ^{x2↓}				0.35 ^{x2↓}			0.97 ^{x2↓}							1.91		1.91
O(15)		0.19 ^{x2↓}			0.30 ^{x2↓}					0.51 ^{x2↓}					0.97 ^{x2↓}			1.97		1.97
O(16)			0.25 ^{x2↓}	0.42 ^{x2↓}	0.32 ^{x2↓}									0.98 ^{x2↓}				1.97		1.97
O(17)	0.23						0.43 ^{x2↓} x2→				0.90							1.99		1.99
O(18)			0.18 ^{x2↓}			0.32 ^{x2↓}		0.51				0.95 ^{x2↓} ↓						1.96		1.96
O(19)	0.34			0.51													1.09	1.94		1.94



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O(20)			0.07	0.10 ^{x2↓} x2→					0.52				1.03					1.82		1.82
O(21)		0.61			0.09	0.04 x2↓ x2→						1.15						1.93		1.93
O(22)		0.11 ^{x2↓} x2→				0.46									1.07			1.83		1.83
O(23)					0.36	0.05 ^{x2↓} x2→									0.99			1.45	+0.23(O3)	1.68
O(24)					0.05 ^{x2↓} x2→	0.37							0.95					1.42	+0.21(O1)	1.63
Σ	2.02	2.79	2.75	2.72	2.54	2.63	2.90	3.04	2.20	3.02	3.79	4.11	3.90	3.78	4.09	3.86	4.04			

Note. Parameters from Gagné and Hawthorne (2015) and, for possible H-bonding from Ferraris and Ivaldi (1988). The values were calculated taking into account the refined occupancies for the *M*(1-4) and *A*(1) sites. For better clarity the split character of the O(23) and O(24) sites was not taken into account and this sites were considered as averaged with no splitting (the cations-O(23)/O(24) distances for bond-valence calculations including H-bonding were taken for non-split sites). Slightly low values of BVS for these sites are typical for the members of radekškodaite group. For Fe cations in *M*(3) site the bond-valence parameters of Fe²⁺ was used. The bond-valence parameters of Ce³⁺ were used for *A*(1-6) sites. The values of BVS for *A*(2-6) sites could be increased taking into account the presence of La³⁺ cations. Bond valences are calculated disregarding the minor occurrence of F.

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Table 8. *M1–M4* sites occupancies (s.o.) suggested for zilbermintsite-(La) based on the results of the crystal structure refinement.

Site	Refined s.o.	SSF _{exp}	Assigned s.o.	SSF _{calc}
<i>M1</i>	Fe _{0.55(2)} Al _{0.45(2)}	20.15(40)	Fe ³⁺ _{0.57} Al _{0.17} Mg _{0.26}	20.15
<i>M2</i>	Al _{0.936(16)} Fe _{0.064(16)}	13.83(22)	Al _{0.936} Fe ³⁺ _{0.064}	13.83
<i>M3</i>	Fe _{0.89(2)} Mg _{0.11(2)}	24.46(50)	Fe ²⁺ _{0.64} Mn ²⁺ _{0.15} Mg _{0.10} Fe ³⁺ _{0.11}	24.45
<i>M4</i>	Al _{0.91(2)} Fe _{0.09(2)}	14.17(28)	Al _{0.91} Fe ³⁺ _{0.09}	14.17

Note. SSF_{exp} and SSF_{calc} are the experimental and calculated site-scattering factors, respectively, normalized to unity.

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Table 9. Comparative data for minerals of the radekškodaite group.

Mineral	Zilbermintsite-(La)	Radekškodaite-(La)	Radekškodaite-(Ce)
Ideal formula	(CaLa ₅)(Fe ³⁺ Al ₃ Fe ²⁺)[Si ₂ O ₇] [SiO ₄] ₅ O(OH) ₃	(CaLa ₅)(Al ₄ Fe ²⁺)[Si ₂ O ₇] [SiO ₄] ₅ O(OH) ₃	(CaCe ₅)(Al ₄ Fe ²⁺)[Si ₂ O ₇] [SiO ₄] ₅ O(OH) ₃
E (epidote-type) block	Ferriallanite-(La)	Allanite-(La)	Allanite-(Ce)
Crystal system	Monoclinic	Monoclinic	Monoclinic
Space group	<i>P2₁/m</i>	<i>P2₁/m</i>	<i>P2₁/m</i>
<i>a</i> , Å	8.9605(5)	8.9604(3)	8.9702(4)
<i>b</i> , Å	5.7295(2)	5.7268(2)	5.7044(2)
<i>c</i> , Å	25.1033(13)	25.1128(10)	25.1642(13)
β , °	116.616(7)	116.627(5)	116.766(6)
<i>V</i> , Å ³	1152.21(12)	1151.98(7)	1149.68(11)
<i>Z</i>	2	2	2
Strongest lines of the powder X-ray diffraction pattern: <i>d</i> , Å – <i>I</i> , %	22.4 – 54 8.01 – 21 3.017 – 45 2.861 – 100 2.733 – 25 2.704 – 26 2.178 – 45	22.1 – 52 8.01 – 32 4.661 – 65 3.522 – 78 3.038 – 55 2.866 – 44 2.640 – 100	22.5 – 38 8.08 – 42 4.640 – 76 3.528 – 99 3.031 – 100 2.844 – 46 2.654 – 87
<i>D</i>_{calc} , g cm ⁻³	4.684	4.644	4.651
Optical data:			
Optical sign	Biaxial (+)	Biaxial (+)	Biaxial (+)
α	1.805(7)	1.790(7)	1.798(6)
β	1.812(7)	1.798(5)	1.806(6)



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γ $2V$ (meas.), ° Pleochroism	1.867(8) 40(15) Weak, in brown tones; $Z > Y > X$	1.825(8) 60(10) Weak, from marsh green to brown; $Z > Y > X$	1.833(8) 65(10) Weak, marsh green; $Z > Y > X$
Source	This paper	Kasatkin <i>et al.</i> , 2020b	Kasatkin <i>et al.</i> , 2020b

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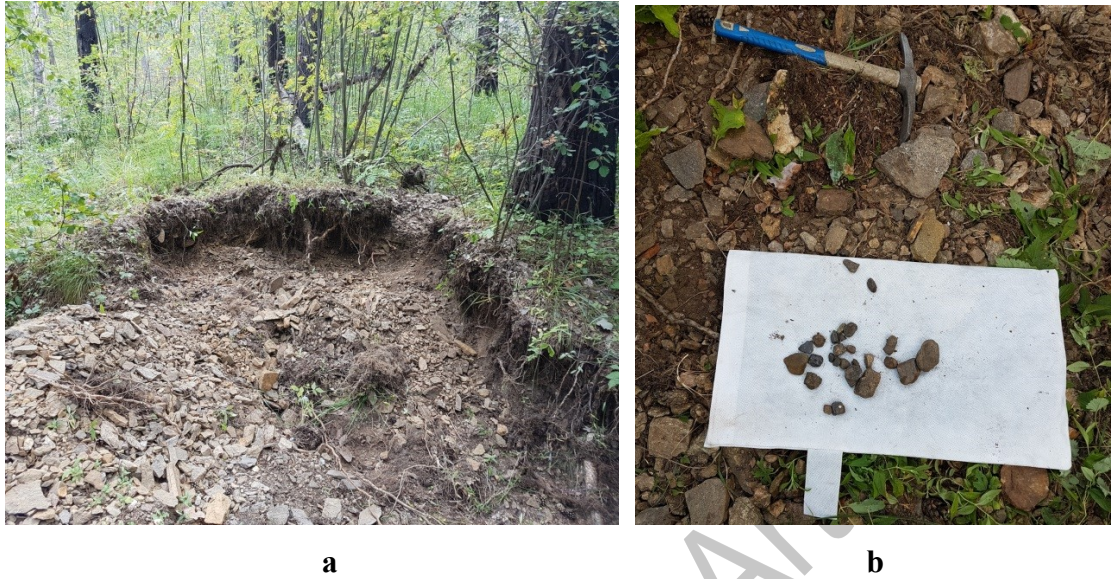


Figure 1: **a** – placer dump no. 2bis of the Mochalin Log REE deposit where the nodule with zilbermintsite-(La) was collected; **b** – freshly collected nodules with numerous REE-bearing minerals.

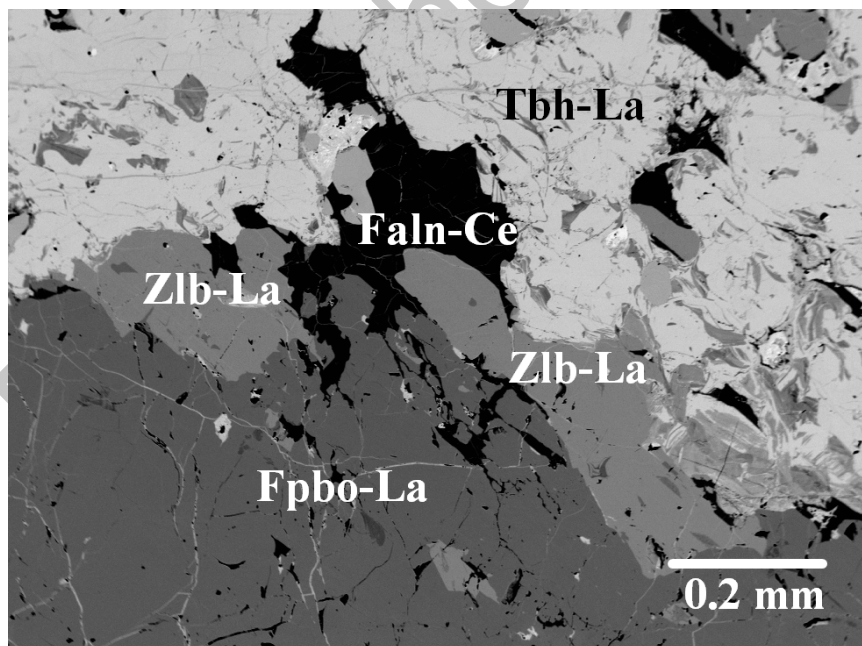


Figure 2. Zilbermintsite-(La) (Zlb-La) closely associated with ferriperbøeite-(La) (Fpbo-La), ferriallanite-(Ce) (Faln-Ce) and törnebohmite-(La) (Tbh-La). Polished section. SEM (BSE) image, specimen no. ML 196-2bis.



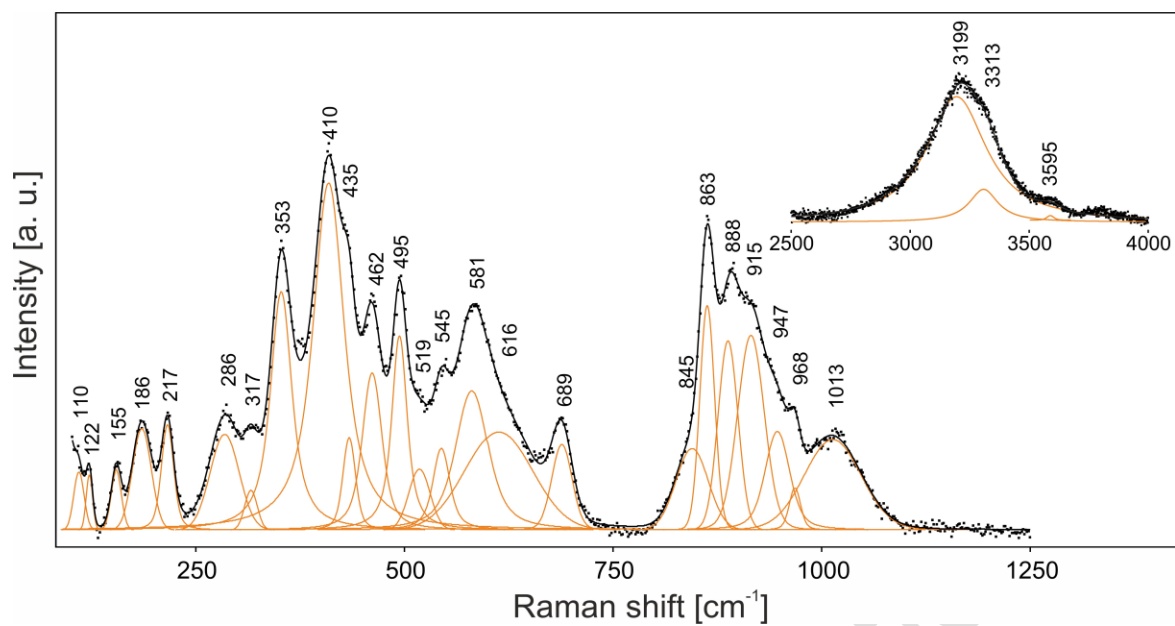


Figure 3. The Raman spectrum of zilvermintsite-(La) excited by 532 nm laser: in the 100–1500 cm^{-1} region and in the 2500–4000 cm^{-1} region (*inset in the upper right corner*). The measured spectrum is shown by dots. The curve matching to dots is a result of spectral fit as a sum of individual Voigt peaks shown below the curve.

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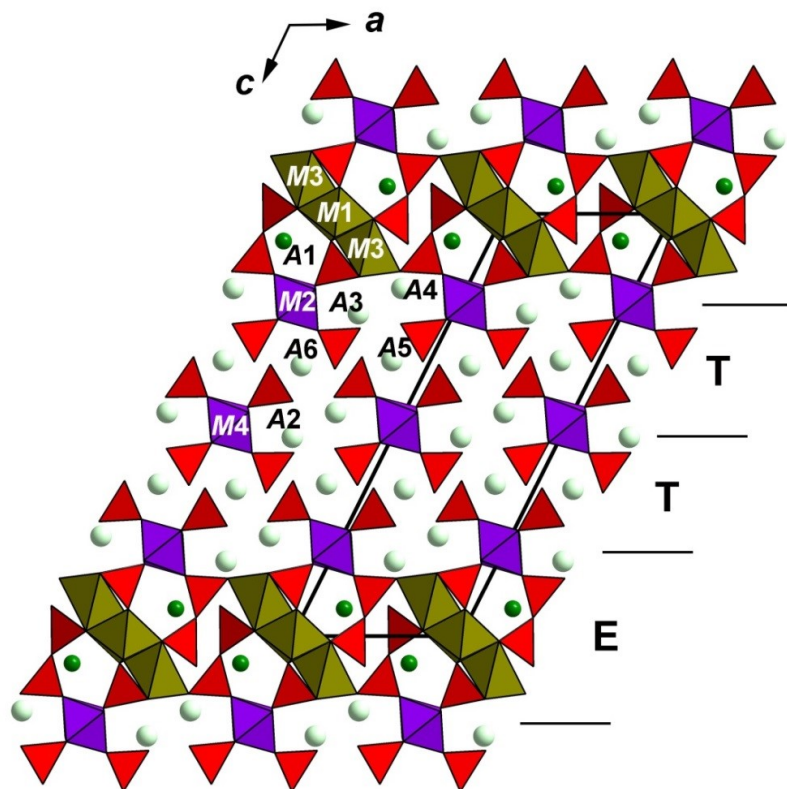


Figure 4. The crystal structure of zilvermintsite-(La). SiO₄ tetrahedra are red. Alternation of epidote-type slabs (E) and törnebohmitite-type slabs (T) is shown. The unit cell is outlined.

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