Mineral spectra and chemistry of 32 rare-earth minerals and rare-earth oxides including niobium- and tantalum-oxide.

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1. License

2. Citation

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Koerting, F. et al., (2019) A Solar Optical Spectral Library of Rare Earth bearing minerals, RE Oxides, Copper bearing minerals and Apliki mine surface samples, Earth System Science Data Discussions https://doi.org/to be added

The spectral library presented here is part of a bigger collection of spectral libraries including samples from rare-earth minerals, rare-earth-oxides and field samples from a copper-gold-pyrite mine in the Republic of Cyprus (Koellner et al., 2019; Koerting et al., 2019a):

Koellner, N., Koerting, F., Horning, M., Mielke, C. and Altenberger, U. (2019) Mineral spectra and chemistry of 20 copper bearing minerals. GFZ Data Services. http://doi.org/10.5880/GFZ.1.4.2019.003

Koerting, F., Rogass, C., Koellner, N., Horning, M. and Altenberger, U. (2019a) Mineral spectra and chemistry of 37 copper bearing surface samples from Apliki copper-gold-pyrite mine in the Republic of Cyprus. GFZ Data Services, http://doi.org/10.5880/GFZ.1.4.2019.005

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4. Abstract

The data set contains mineral chemical analyses of 32 rare earth element (REE) -bearing minerals (REMin) and rare-earth oxides (REO) and their corresponding hyperspectral spectra. The hyperspectral data was acquired with the HySpex system in a range of 400 – 2500 nm and is presented in a spectral library. The two Rare Earth Element (REE) libraries consist of the spectra of 16 rare earth oxides powders (REO) and 14 REE-bearing minerals (REMin). In addition, it contains the spectra of niobium- and tantalum oxide, two elements technically not part of the REEs. The spectral library presented here is part of a bigger collection of spectral libraries including copper-bearing surface samples from Apliki copper-gold-pyrite mine (Koerting et al., 2019a, http://doi.org/10.5880/GFZ.1.4.2019.005) and copper-bearing minerals (Koellner et al., 2019, http://doi.org/10.5880/GFZ.1.4.2019.003). These libraries aim to give a spectral overview of important resources and ore mineralization.

5. Samples

The REE sample material comprises 16 REO powders and 14 REE bearing minerals (see table 1 for a list of the REE bearing minerals). The used REO powders belong to a series of rare earth metals and compounds (REacton®) and were received from Alfa Aesar. The REO powder names, product number and lot number can be found in Table 2. All REO powders contained at least 99.9% of the specified REE and were delivered together with concentration certificates, these geochemical certificates can be found in Table 4, below the geochemical measurement description. REO powders were obtained as high-purity materials with a grainsize of <63 µm. The REMin samples (ore minerals) were purchased from Gunnar Färber Minerals, an online trader of mineral_specimen. The mineral denotation is based on the sample name provided by Gunnar Färber Minerals. The X-Ray Fluorescence (XRF) data presented in the geochemistry data description should be consulted to validate the given mineral denotations by Färber Minerals. A sample list for the REMin can be found in A2, for the REO in A3 of the Appendix. All of the samples were measured in the course of the M.Sc. thesis of Sabrina Herrmann (Herrmann, 2019) and the Ph.D. thesis of Nina K. Boesche (Bösche, 2015).

Table 1: Mineral sample name, formula, size and provenance, modified after Bösche (2015) and Herrmann (2019).

Rare Earth Mineral	Formula	Mineral size	Collection Locality
Baropyrochlore. Fluorapatite	$(Ba, Sr)(Nb, Ti)_2(O,OH)_7$	0.5 x 0.2 cm	Mina Boa Vista. Catalao. Goias/Brazil
Bastnaesite (Ce)	$Ce[F\|CO_3]$	3 x 1.3 cm	Zagi Mountain. Warzal Dam. Pechawar. North-West Frontier Prov./Pakistan
Gadolinit (Y). Synchysite (Y). Fluorite	$Y_2Fe_2+Be_2O_2(SiO_4)_2$	1.1 x 0.7 cm	White Cloud Pegmatite. South Platte. Jefferson Co. Colorade/USA
Monazite (Sm) incl. Monazite (Nd)	$SmPO_4$. $(Nd,Ce, La)(P, Si)O_4$, $Ca(Ce, La)_2(CO_3)_3F_2$	0.2 x 0.2 cm	Svodovyi. Grubependity Lake. Maldynyrd Range. Prepolar Ural. Komi Republic. Russia
Parisite (Nd) incl. Parisite (Ce)	$Ca(Nd, Ce, La)_2(CO_3)_3F_2$	2.6 x 1.6 cm	Mountain Pass Mine. Ivanpah Mts. San Bernardino Co. California/USA
Polycrase (Y)	$(Y,Ca,Ce,U,Th)(Ti,Nb, Ta)_2O_6$	0.5 x 0.1 cm	Puoutevare Pegmatite. Tjalmejaure Lake. Jokkmokk Lappland/Northern Sweden
Synchysite (Y)	$CaY (CO_3)_2F$	1.5 x 2.5 cm	White Cloud Pegmatite. South Platte. Jefferson Co. Colorade/USA
Xenotime (Y) (a)	$Y PO_4$	0.7 x 0.3 cm	Novo Horizonte. Ibitiara. Bahia/Brazil
Xenotime (Y) (b)	$Y PO_4$	1.2 x 0.4 cm	Novo Horizonte. Ibitiara. Bahia/Brazil
Aegirine. "Acmite"	$NaFe^{3+}[Si_2O_6]$	4.5 x 2.5 cm	Rundemyr. Øvre Eiker. Buskerud. Norway/TYP
Fluorapatite. Albite	$Ca_5(PO_4)_3F$, $NaAlSi_3O_8$	1.2 x 0.5 cm	Golconda Mine. Governador Valadares. Doce Valley. Minas Gerais/Brazil
Fluorite	CaF_2	1 x 0.7 cm	Arbegona. Shashemanne.
Illmenite	Fe_2+TiO_3	2.5 x 1.5 cm	Mogok. Sagaing District. Mandalay/Myanmar
Zircon	$ZrSiO_4$	2 x 3 cm	Peixe alkaline complex. Monteirópolis. Jaú do Tocantins. Tocantis/Brazil

Table 2: Rare Earth Oxide Powders, Suppliers, Product Number and Lot Number. Certificates of purity are listed below in table 4 (Bösche, 2015; Herrmann, 2019).

Rare Earth Oxide Powder, Supplier	Product Number	Lot Number
Lanthanum (III) oxide, REacton	11272	B08X015
Cerium (IV) oxide, REacton	11372	L07S057
Neodymium (III) oxide, REacton	11250	C02W029
Samarium (III) oxide, REacton	11229	61200836
Europium (III) oxide. REacton	11299	A16Z001
Gadolinium (III) oxide, REacton	11290	A13W016
Terbium (III.IV) oxide, REacton	11208	J24Q019
Dysprosium (III) oxide, REacton	11319	61300733
Holmium (III) oxide, REacton	11280	J11X030
Erbium (III) oxide, REacton	11310	61000356
Thulium (III) oxide, REacton	11198	F25S060
Ytterbium (III) oxide, REacton	11191	61201069
Lutetium (III) oxide, REacton	11255	G14X082
Yttrium (III) oxide, Sigma-Aldrich	204927	MKBL2030V
Niobium (V) oxide, Alfa Aesar	11366	L18Y022
Tantalum (V) oxide, Alfa Aesar	14709	I14Y039

6. Hyperspectral measurements

The **HySpex VNIR-1600** and **SWIR-320m-e** (available at: https://www.hyspex.no/products/disc.php, 2019) are two line-scanning cameras. The two cameras are mounted in parallel. They cover the range of the visible to near infra-red light (VNIR, 400 – 1000 nm) and the short-wave infra-red (SWIR, 1000 – 2500 nm). They record an array-line of 1600 pixel (VNIR) and 320 pixel (SWIR) (push-broom scanning). Every pixel contains a spectrum with a total spectral sampling number of 408 bands.

In laboratory mode, the HySpex cameras are combined with a trigger pulse moving sleight (translation stage) of definable frame period (depending on the integration time of every array-line acquisition). The configuration of the translation stage framework, the cameras and the light source (45° illumination angle) are fixed, while the sleight and the samples are moving through the focal plane (Rogass et al., 2017). Detailed descriptions of the hyperspectral measurements and parameters can be found in Koerting et al. (2019).

7. Geochemical Measurements

Table 3 presents the sample type and corresponding concentration level determination. The REMins and REOs were analyzed differently, both of which are explained in this section. The laboratory certificates for the REOs are presented in Table 4.

Table 3: Sample type and respective concentration level determination

ca	Concentration level determination
REO	Laboratory certificates
REMin	X-Ray Fluorencence (XRF), Electron microprobe analyser (EMPA) analyses

Table 4: Certificates of purity for REO powders, modified after (Bösche, 2015; Herrmann, 2019).

Lanthanum (III) oxide, REacton, Loss on ignition: - %	Product Number: 11272
La_2O_3: 99.9996 %	TREO: 99.24 %
CeO_2/TREO	0.32 ppm
Pr_6O_{11}/TREO	0.27 ppm
Nd_2O_3/TREO	0.44 ppm
Sm_2O_3/TREO	0.97 ppm
Y_2O_3/TREO	1 ppm
Fe_2O_3	2 ppm
CaO	< 10 ppm
SiO_2	22 ppm
CuO	< 2 ppm
NiO	1 ppm
PbO	1.1 ppm
Cl^-	33 ppm
D10	5.826 µm
D50	10.7811 µm
D90	18.802 µm

Cerium (IV) oxide, REacton, Loss on ignition: 0.73 %	Stock Number: 11327
CeO_2: 99.99 %	TREO: 99.26 %
La_2O_3/TREO	0.005%
Pr_6O_{11}/TREO	0.001%
Nd_2O_3/TREO	0.001%
Sm_2O_3/TREO	0.001%
Y_2O_3	0.001%
Fe_2O_3	0.001%
CaO	0.005%
SiO_2	0.002%
Cl^-	0.005%
Neodymium (III) oxide. REacton, Loss on ignition: - %	**Stock Number: 11250**
Nd_2O_3: 99.99 % min	TREO: - %
Na	1 ppm
Mg	2 ppm
Al	10 ppm
Si	20 ppm
K	1 ppm
Ca	4 ppm
Sc	<0.1 ppm
Ti	<0.1 ppm
V	<0.1 ppm
Cr	<0.1 ppm
Mn	0.3 ppm
Fe	4 ppm
Ni	0.2 ppm
Cu	<0.1 ppm
Zn	0.6 ppm
Y	2 ppm
La	4 ppm
Ce	4 ppm
Pr	5 ppm
Sm	2 ppm
Eu	<0.4 ppm
Gd	10 ppm
Tb	2 ppm
Dy	1 ppm
Ho	<0.2 ppm
Er	<0.2 ppm
Tm	<0.2 ppm
Yb	<0.2 ppm
Lu	<0.2 ppm
Pb	<0.2 ppm
Bi	<0.1 ppm
Th	<0.2 ppm
U	<0.1 ppm
Samarium (III) oxide. REacton, Loss on ignition: 1.35 %	**Product Number: 11229**
Sm_2O_3: > 99.98 %	TREO: >98.5 %
Remaining RE-Oxide total	0.02%
Fe_2O_3	13 ppm
NiO	< 1 ppm %
Co_3O_4	< 1 ppm
Cr_2O_3	< 1 ppm
Europium (III) oxide. REacton, Loss on ignition: 0.18 %	**Product Number: 11299**
Eu_2O_3: 99.99 %	TREO: 99.62 %
CeO_2	< 2 ppm
Pr_6O_{11}	< 2 ppm
Dy_2O_3	< 2 ppm
La_2O_3	< 2 ppm
Nd_2O_3	< 2 ppm
Sm_2O_3	< 2 ppm
Gd_2O_3	< 2 ppm
Tb_4O_7	< 2 ppm
Ho_2O_3	< 2 ppm

Table 4 (continued)

Er_2O_3	< 2 ppm
Tm_2O_3	< 2 ppm
Yb_2O_3	< 2 ppm
Lu_2O_3	< 2 ppm
Y_2O_3	< 2 ppm
Ca	5 ppm
CuO	< 1 ppm
NiO	< 1 ppm
PbO	< 1 ppm
Fe_2O_3	< 2 ppm
ZnO	< 5 ppm
SiO_2	23 ppm
Cl	< 77 ppm
Al_2O_3	< 10 ppm
D50	3.28 µm
Gadolinium (III) oxide. REacton, Loss on ignition: 0.40 wt%	Product Number: 11290
Gd_2O_3: > 99.97 wt%	TREO: > 99.52 wt%
Remaining RE-Oxide total	< 0.1 %
Eu_2O_3/TREO	0.0008%
Dy_2O_3/TREO	0.0004%
Y_2O_3/TREO	0.0003%
Tb_4O_7/TREO	0.0004%
Sm_2O_3/TREO	0.0003%
Fe_2O_3	0.0002%
Ca	0.0015%
NiO	0.0001%
CuO	0.0001%
SiO_2	0.0015%
MnO	0.0001%
CoO	0.0001%
Cr_2O_3	0.0001%
Terbium (III.IV) oxide. REacton, Loss on ignition: - %	Stock Number: 11208
Tb_4O_7: 99.99 % min	TREO: - %
Li	< 1 ppm
Na	2 ppm
Mg	< 1 ppm
Al	< 1 ppm
Si	20 ppm
P	< 1 ppm
S	5 ppm
K	< 1 ppm
Ca	10 ppm
Ti	< 1 ppm
V	< 1 ppm
Cr	< 1 ppm
Mn	< 1 ppm
Fe	3 ppm
Co	< 1 ppm
Ni	< 1 ppm
Zn	< 1 ppm
Y	2 ppm
Sr	< 1 ppm
Y	3 ppm
Ba	< 1 ppm
La	1 ppm
Ce	< 1 ppm
Pr	< 1 ppm
Nd	< 1 ppm
Sm	4 ppm
Eu	< 1 ppm
Gd	8 ppm
Dy	1 ppm
Er	2 ppm
Tm	<0.2 ppm
Tm	0.5 ppm
Yb	20 ppm
Lu	1 ppm
Hg	< 1 ppm
Pb	< 1 ppm
Bi	< 1 ppm
Th	< 0.2 ppm
U	< 0.3 ppm
Dysprosium (III) oxide. REacton, Loss on ignition: 0.49 %	Product Number: 11319
Dy_2O_3: 99.91 %	TREO: 99.5 %
Remaining RE-Oxide total	< 0.09 %
Fe_2O_3	41 ppm
Co_3O_4	< 1 ppm
NiO	< 1 ppm
CuO	< 1 ppm
Holmium (III) oxide. REacton, Loss on ignition: 1 %	Product Number: 11280
Ho_2O_3: > 99.9 %	TREO: > 99 %
Er_2O_3	0.01%
Dy_2O_3	< 0.001 %
Yb_2O_3	0.001%
Y_2O_3	0.002%
Fe_2O_3	0.001%
CaO	0.006%
SiO_2	0.003%

Table 4 (continued)

Erbium (III) oxide. REacton, Loss on ignition: 0.13 %	Product Number: 11310
Er_2O_3: >99.9 %	TREO: 99.8 %
Remaining RE-Oxide total	< 0.1 %
Fe_2O_3	< 5 ppm
V_2O_5	< 2 ppm
TiO_2	< 2 ppm
Co_3O_4	< 2 ppm
NiO	< 2 ppm
D 50	< 9.59 µm
Thulium (III) oxide. REacton, Loss on ignition: - %	**Stock Number: 11198**
Tm_2O_3: 99.99 % min	TREO: %
Si	20 ppm
Ca	< 5 ppm
Sc	< 1 ppm
Ti	< 5 ppm
V	< 5 ppm
Cr	< 5 ppm
Mn	< 5 ppm
Fe	< 10 ppm
Ni	< 5 ppm
Cu	< 5 ppm
Zn	< 2 ppm
Y	< 10 ppm
La	< 10 ppm
Ce	< 10 ppm
Pr	< 10 ppm
Nd	< 10 ppm
Sm	< 10 ppm
Eu	< 10 ppm
Gd	< 50 ppm
Tb	< 10 ppm
Dy	< 10 ppm
Ho	< 50 ppm
Er	< 200 ppm
Yb	< 100 ppm
Lu	< 100 ppm
Hg	< 1 ppm
Pb	< 1 ppm
Bi	< 1 ppm
Th	< 1 ppm
U	< 1 ppm
Ytterbium (III) oxide. REacton, Loss on ignition: 0.7 %	**Product Number: 11191**
Yb_2O_3: > 99.99 %	TREO: 99.2 %
Remaining RE-Oxide total	< 0.01 %
Fe_2O_3	< 2 ppm %
CaO	29 ppm
Co_3O_4	< 2 ppm
NiO	< 2 ppm
PSD (Microtrac Y100-SRA) d50	5.38 µm
Lutetium (III) oxide. REacton, Loss on ignition: 1 %	**Product Number: 11255**
Lu_2O_3: 99.97 % min	TREO: 99.00 % min
Fe_2O_3	0,0003%
SiO_2	0,0028%
CaO	0.01%
Er_2O_3	0.0040 % max
Tm_2O_3	0.0020 % max
Yb_2O_3	0.020 % max
Y_2O_3	0.0020 % max
Yttrium (III) oxide. Sigma-Aldrich	**Product Number: 204927**
Y_2O_3: 99.999 % min	
Trace REE	< 20 ppm
Na	5.5 ppm
Sc	0.1 ppm
Gd	0.6 ppm
Mg	1 ppm
Ca	1.6 ppm
Ba	0.1 ppm
Tb	0.6 ppm
Zn	5.4 ppm
La	10 ppm
Dy	0.5 ppm
Al	1.1 ppm
Ho	0.4 ppm
Pr	0.2 ppm
Mn	0.1 ppm
Nd	0.3 ppm
Fe	0.6 ppm
Sm	0.3 ppm
Eu	0.5 ppm
Niobium (V) oxide. Alfa Aesar	**Product Number: 11366**
Nb_2O_5: 99.9 % min	
Al	< 10 ppm
Cu	10 ppm
Mn	< 10 ppm
Ni	< 10 ppm

Table 4 (continued)

Ta	300 ppm
W	30 ppm
Cr	< 10 ppm
Fe	20 ppm
Mo	< 20 ppm
Si	20 ppm
Ti	< 10 ppm
Tantalum (V) oxide. Alfa Aesar	Product Number: 14709
Ta_2O_5: 99 % min	
Na+K	<0.01 %
Mg	<0.01 %
Al	<0.01 %
Si	<0.01 %
Ca	<0.01 %
Ti	<0.01 %
V	<0.01 %
Cr	<0.01 %
Mn	<0.01 %
Fe	<0.01 %
Co	<0.01 %
Ni	<0.01 %
Cu	<0.01 %
Zn	<0.01 %
Nb	<0.01 %
Mo	<0.01 %
W	<0.01 %
Pb	<0.01 %

The geochemical measurements for the REMins where conducted using an X-Ray Fluorescence (XRF) instrument - Thermo Niton XL3t and an electron microprobe analyser (EMPA) from the University Potsdam (available at: https://www.thermofisher.com/content/dam/LifeTech/Documents/PDFs/china/Niton-XL3t-GOLDD-Spec-Sheet-2013Jan15.pdf (2019) and http://www.geo.uni-potsdam.de/electron-microprobe-analyser.html, 2019).

The XL3t is a light-weight, mobile XRF analyser. The measurement principle follows the principle of X-Ray fluorescence, where the sample inbound X-Rays excite electrons to a higher energy level in the sampled material. Energy in form of XRF radiation is released when these electrons return to their original state. The frequency of this radiation is characteristic for the measured chemical element and its intensity is correlated to the concentration level. The intensity of each element is detected as counts per second by the detector, a geometrically optimized large area drift detector (GOLDD). The maximum excitation voltage of the XL3t device is 50 kV, which means out of the full REE suite only four light REEs can be detected (Lanthanum, Cerium, Neodymium and Praseodymium).

Table 6 shows the measurement modes and filters used. In-depth description of the XL3t and the XL3t-results for each sample can be found in (Herrmann, 2019).

Table 6: Settings used for the Thermo Niton XL3t X-ray fluorescence device.

Thermo Niton XL3t Setting	
Measurement mode	Test all geo
Filter	Main, Low, High, Light
Filter measurement time	30 seconds each

Some of the REMin (xenotime, bastnaesite, fluorapatite, synchisite and ilmenite) were additionally analysed with a JEOL JXA-8200 electron microprobe (EMPA) at the University of Potsdam. The conditions used for the analysis were: 20kV acceleration voltage, 20nA beam current and a beam size of 2 µm. Counting times were between 10 s - 20 s on peak for major elements and 50 s for REE and other trace elements, respectively. The following spectral lines and mineral standards from Smithsonian and Astimex were used: fluorapatite (F Kα, P Kα, Ca Kα), albite (Na Kα), fayalite (Fe Kα, Mn Kα), wollastonite (Si Kα), omphacite (Al

Kα), $LaPO_4$ (La Lα), $PrPO_4$ (Pr Lβ), $CePO_4$ (Ce Lα), $NdPO_4$ (Nd Lβ), YPO_4 (Y Lα), $EuPO_4$ (Eu Lα), $SmPO_4$ (Sm Lβ), $LuPO_4$ (Lu Lα), $GdPO_4$ (Gd Lα), $ErPO_4$ (Er Lβ), $DyPO_4$ (Dy Lβ), $YbPO_4$ (Yb Lα), $HoPO_4$ (Ho Lβ), monazite (Th Mα, U Mβ, Tb Lα), uranothorite (U Mβ), crocoite (Pb Mβ). The EMPA data were reduced using the PRZ-XXP correction routine. A detailed description can be found in Koerting et al. (2019).

8. File description

8.1. <u>REE-spectral-library.zip</u> and <u>REO-spectral library.zip</u>: Spectra: Envi Spectral Library File and ASCII

The spectra for each mineral are presented in an Envi Spectral Library file format "GFZ_HySpex_REMin" and "GFZ_HySpex_REMin.hdr" and a text file format "GFZ_HySpex_REMin.txt". The spectral library can be visualized in Envi as seen in Figure 1. Figure 2 shows the text file. It presents the wavelength in column 1 and the reflectance values of the samples from column 2 – 15.

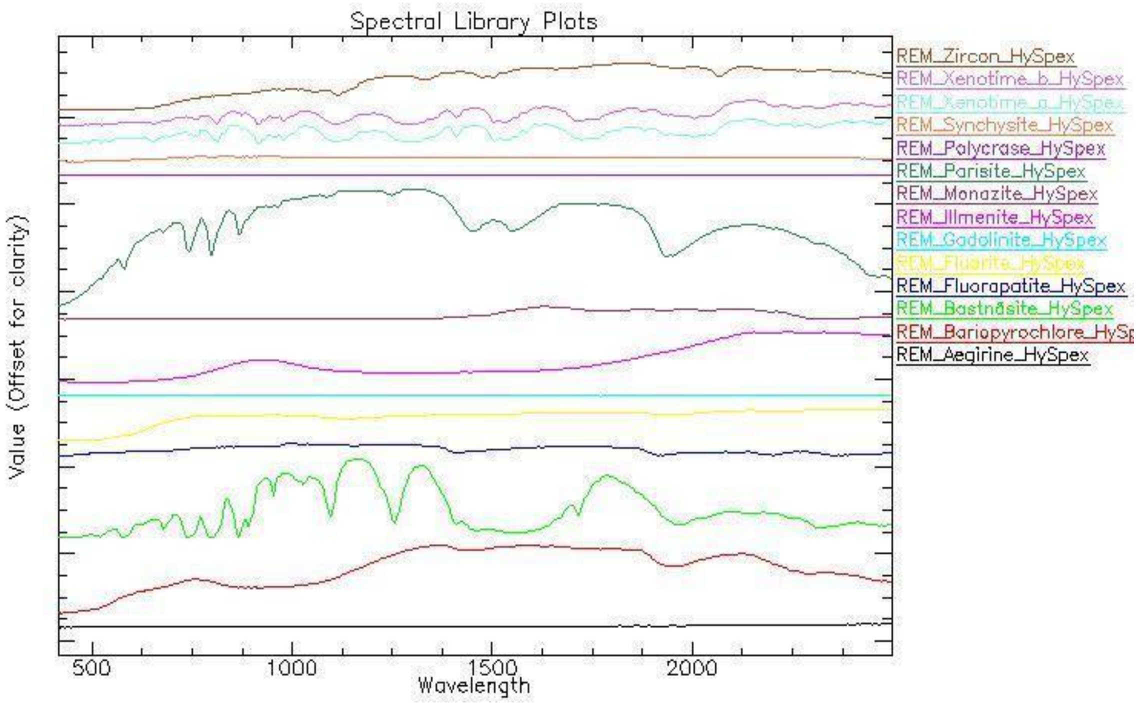


Figure 1: Spectral library plot of the different rare-earth minerals.

```
ENVI ASCII Plot File [Thu Sep 05 16:02:21 2019]
Column 1: Wavelength
Column 2: REM_Aegirine_HySpex~~1
Column 3: REM_Bariopyrochlore_HySpex~~2
Column 4: REM_Bastnaesite_HySpex~~3
Column 5: REM_Fluorapatite_HySpex~~4
Column 6: REM_Fluorite_HySpex~~5
Column 7: REM_Gadolinite_HySpex~~6
Column 8: REM_Illmenite_HySpex~~7
Column 9: REM_Monazite_HySpex~~8
Column 10: REM_Parisite_HySpex~~9
Column 11: REM_Polycrase_HySpex~~10
Column 12: REM_Synchysite_HySpex~~11
Column 13: REM_Xenotime_a_HySpex~~12
Column 14: REM_Xenotime_b_HySpex~~13
Column 15: REM_Zircon_HySpex~~14
   414.802917   434.000000   545.000000   395.000000   525.000000   260.000000
94.000000   797.000000   205.000000   877.000000    90.000000   239.000000   346.000000
347.500000   136.000000
   418.439636   392.000000   556.000000   379.000000   528.000000   254.000000
68.000000   793.000000   252.000000   912.000000    63.000000   159.000000   356.000000
328.500000   110.000000
```

Fig 2: Text file of the spectral library.

8.2. <u>XRF_REMin.xlsx</u> Geochemical Analyses

The analysis of the REOs is presented in the Table 5 above.

The XRF geochemical analysis of the rare-earth minerals is presented in in an excel file named "**XRF_REMin.xlsx**", the header of the excel file is described in table 6.

Table 6: Description of the header of the X-Ray Fluorescence data from excel file

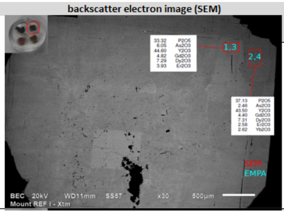
Header of Excel file	Explanation
Reading No/ Name	Mineral sample name
Duration	Duration time of measurement
Units	ppm
Element	The elements listed below each other are: Nd, Pr, Ce, La, Ba, Sb, Sn, Cd, Pd, Ag, Bal, Mo, Nb, Zr, Y, Sr, Rb, Bi, U, Th, As, W, Re, Ta, Hf, Ni, Co, Fe, Mn, Cr, V, Tl, Ca, K, Cl, S, P, Si, Al, Mg
Element error	Element standard deviation

8.3. <u>REMin_SEM_EMPA.xlsx:</u> Mineral chemical Analyses

The excel file "REMin_SEM_EMPA.xlsx" includes the backscatter electron images of the analyzed samples, the results of EMPA analyses and measurement conditions. The excel file header is described in Table 7. Figure 3 shows a screenshot of the EMPA/SEM data found in the excel file.

Sample | backscatter electron image (SEM)

Xenotime (Y) (b)



EMPA analysis (measurement conditions: 20kV, 20nA, dia 2, PRZ-XXP data reduction method) [wt.%]

No.	SiO_2	FeO	CaO	P_2O_5	As_2O_5	Y_2O_3	La_2O_3	Ce_2O_3	Nd_2O_3	Sm_2O_3	Eu_2O_3	Gd_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Yb_2O_3	Lu_2O_3	F	Total	Comment
1	0,00	0,00	0,02	28,58	4,99	40,02	0,00	0,00	0,32	0,72	0,13	2,20	6,86	1,33	3,58	1,39	0,63	0,06	93,68	REF1_1_Xtm_light
2	0,00	0,00	0,01	32,19	1,42	41,57	0,00	0,00	0,26	0,41	0,10	1,86	6,73	1,47	3,78	1,90	0,79	0,10	94,95	REF1_1_Xtm_dark
3	0,09	0,00	0,00	22,90	9,41	38,33	0,08	0,07	0,45	0,89	0,12	2,12	6,23	1,37	3,69	1,79	0,67	0,12	91,09	REF1_1_Xtm_light 2
4	0,06	0,00	0,02	31,14	2,85	39,65	0,00	0,14	0,28	0,77	0,14	2,17	6,99	1,39	3,90	1,86	0,63	0,09	94,94	REF1_1_Xtm_dark2

Figure 3: Exemplary sample chemistry from the Excel file "REMin_SEM_EMPA.xlxs", explanation below in Table7.

Table 7 Explanation of excel file header of the SEM/EMPA measurements

Header of Excel file	Explanation
Sample	Sample name
backscatter electron image (SEM)	Showing backscatter electron image, the results of SEM analyses and the location on the sample for EMPA analysis
EMPA analysis	measurement conditions of EMPA analysis and elements reported as oxides in wt.%
[wt.%]	unit of element oxides
No.	Point of measurement
SiO2	Silicon dioxide
…..	various oxides listed
F	Fluorine
Total	total in wt.%
Comment	Sample name - measurement point (No)

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