

Rare earth mining and consumption global trends and mining perspectives for the Mushugay Khudug deposit in southern Mongolia

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Abstract

In this work the 3 ore body drill core samples, 6 host rock samples from the main ore body of the Mushugay Khudug REE deposit in southern Mongolia were selected as most representative samples and studied by XRD and ICP-MS, LA-ICP-MS method to evaluate elemental and structural composition data of the deposit.

According to our determinations the main orebody of the Mushugay Khuduk deposit contain up to 130 kg/ton of REEs. Despite the moderate total mineable reserve the main ore body of the Mushugay Khuduk deposit might compete economically with world's biggest REE mining deposits such as Bayan-Obo (Inner Mongolia, China) or Mountain Pass (California, USA) if consider the deposit's higher REE grade and easier to mine local geological condition.

The important advantage of the Mushugay Khuduk deposit is that the relative contents of most valuable HREEs Eu, Tb, Dy, and Lu are significantly higher than that of Mountain Pass or Bayan-Obo. The relative net content of these four elements is 0.1% for Mountain Pass and 0.4% for Bayan-Obo, while the ore samples of the Mushugay Khuduk deposit has 0.75% according to our determinations.

Key words: Rare earth elements, Mushugay Khudug deposit in southern Mongolia.

I. CURRENT TRENDS IN GLOBAL RARE EARTH MINING AND CONSUMPTION

The group of rare earth elements (REEs) include fourteen lanthanide elements La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and geochemically similar to them two additional lighter elements Y and Sc. The 16 REEs are surprisingly not that rare as their group name says, they are relatively abundant in the Earth's crust. For example, the Cerium as the most abundant REE is actually more common in the Earth's crust than copper or lead. All other REEs contents in the Earth's crust are more than that of silver or mercury [1].

Even though REEs are relatively abundant in the Earth's crust, they are rarely concentrated into mineable ore deposits. According to the recent analysis on global rare earth resources and scenarios of future rare earth industry [2], the rare earth mineable reserves in Brazil rank the first with 37%, China is the second with 25%, the third is CIS (Commonwealth of Independent States) with

13%, and Vietnam ranks the forth with 10%, then goes Greenland (3.44%), Canada (2.9%), Australia (2.34%), India (2.18%), USA (1.06%), and tenth country is the South Africa (0.88%).

The major end uses for REEs include use in automotive catalytic converters, fluid cracking catalysts in petroleum refining, color phosphors in displays and fluorescent lamps, high power permanent magnets and rechargeable batteries for hybrid and electric vehicles, generators for wind turbines, lasers, glass coloring and polishing, and numerous other devices. There are important military applications, such as jet fighter engine turbine blades, missile guidance systems, antimissile defense, and satellites and communication systems.

Because of increasing consumption in a high tech industry, any new events on the REE market from deposit mining to global supply chain are becoming strategic important matter for most of developed countries. There are numbers of government official sources [3, 4, 5], company web sites [6, 7], scientific papers [2], top expert

analytical reports [8, 9, 10] that reveals current trends in global REE mining and consumption.

According to most recent US Congressional Research Service Report [10], world industrial demand for rare earth elements is estimated at 136,000 tons per year in 2010 and projected to rise to at least 185,000 tons annually by 2015. If the REE reserves are distributed much uniformly between continents, the mining, refinery, and global supply of REEs are concentrated historically in one country - China. The country meets more than 95 % of the continuously rising global REE demand during the last 5 years. On the other hand, the processing techniques are causing severe environmental damage forcing the Chinese government to restrict REE production since 2006. This restriction is causing a supply shortage which was already worrying developed countries, since they rely more and more on rare earths. Parallel to their production limit, China has imposed an export quota since 2006, to meet rising domestic consumption. By 2015, it has been forecast that China's demand will be 65% of world production vs. 54% in 2010, while rest of world demand, despite increasing, represents only 40% global demand in 2015 vs. 46% of global demand in 2010. In the future, it is even expected that some heavy rare earth oxides will not be exported at all from China. According to the report [10], because of tighter supply, prices for REE roses dramatically during last several years. For example the price for dysprosium metal rose from US\$250/kg in April 2010 to US\$2,840/kg by July 2011, while the price for neodymium metal rose from US\$42/kg to US\$334/kg in same period.

For most of US, UE, and Japanese REE end user companies an access to a reliable supply to meet current and projected demand of REE is becoming an issue of concern. In the coming decade, mines in the USA, Australia, Vietnam, and Brazil are expected to reopen or new open to cover the supply shortage. As shows predictions in [8], by 2015, the supply-demand imbalance will be compensated in general, but certain rare earths, including Neodymium, Europium, Terbium,

Dysprosium, and Erbium will still be in a supply deficit, while more abundant rare earths such as Lanthanum and Cerium will be in a surplus. It means that for new comers into global market who offer ores, concentrates, or oxides rich in heavy REEs (HREE), the demand will be much higher than to whom that will offer products with depleted HREEs.

II. A genesis, age and reserve of the Mushugay Khudug REE deposit in southern Mongolia

According to the Mineral Resources Authority of Mongolia [11], there are five known deposits, and hundreds of occurrences of rare earth minerals in Mongolia. Most promising, therefore, currently exploring four of them are the Khalzan Buregtei deposit in the Hovd province [11, 12, 13], the Mushugay Khudug [11, 14, 15, 22, 23] and Hotgor (Bayan Khoshuu) deposits [11, 23] in the Omnogov province, and the Lugin gol [16, 17, 23] deposit in the Dornogov province. All four deposits are located at west, west-south part of the country, along the so called Great lakes depression- to- central area of the Gobi desert as shown on the Google map (Figure 1).

Deposits are positioned along a straight line, at the south end of which is located biggest in the world iron ore - REE mining deposit Bayan Obo [18, 19, 20] in Inner Mongolia, China. Although locations of all five deposits sequenced toward water draining - running out direction of the prehistoric Paleo-Asian Ocean bank that was filled the present Gobi desert basin, there are no sufficient indications of common sedimentary or sedimentary -metamorphic origin of the deposits. Despite the particular dispute regarding to deposit forming mineralization history [18-20, 22, 23], the modern understanding is that the deposits were formed during Late Paleozoic - to - Late Mesozoic era continental tectonic rift processes as an alkaline-carbonatite volcanic-plutonic complexes in the Southern Mongolian alkaline province of the Central Asian Orogenic Belt.

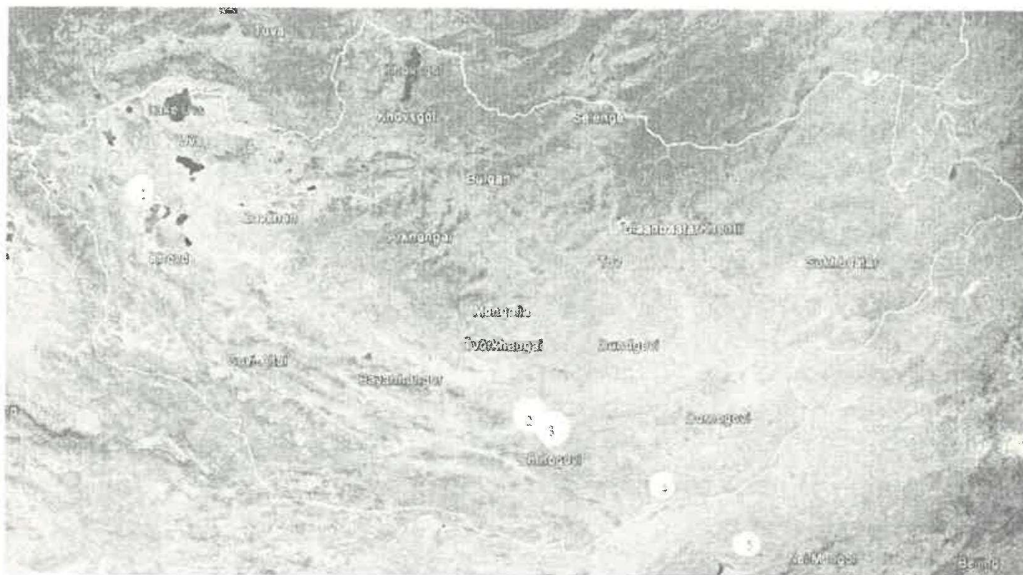


Figure 1. Locations of Mongolian biggest to date REE deposition sites are shown as numbered white circles: 1-Khalzan Buregtei, 2-Mushugay Khuduk, 3-Khotgor (Bayan Khoshuu), 4-Lugin Gol, 5- Bayan Obo (Inner Mongolia, China). Geological genesis, age, structure and petrological-geochemical composition of the sites are discussed in detail in references [12-20, 22, and 23].

The iron oxide - REE phosphate ore deposition site “Mushugay Khuduk” which is located at $44^{\circ}23'40''$ N; $104^{\circ}00'00''$ E in the Mandal-Ovoq sub province of the Umnugovi province, 500 km south-west of the capital city Ulaanbaatar (Figure 1) was discovered during 1974-1975 exploration campaign of the Mongolian-Soviet Union (former) joint geological survey expedition [14] and after was explored in more detail in 1983-1984, 1989-1994, and 2007-2009 years involving Mongolia - Poland, -Japan, and -Germany joint teams. Since 2000 the exploring license of the site is owned by the Remet LLC, a daughter company of the Mongol Gazar – the well-known in Mongolia fully domestic mining company [21]. The site is most explored REE deposition in Mongolia; about 100 drills were done with about 19000 meters of total lengths to distinguish at least 7 ore body.

According to the license owning company estimation, a commercially viable reserve of the main ore body of the deposit is around 4.8 million ton of REE ore or 64 thousand ton in REE oxides (REO). As shows series of preliminary study [14, 15, 22, 23], the Mushugay Khudag REE deposit is

composed of sheet-like magnetite-apatite ore bodies along the contact of the Jurassic syehite porphyry and the host Paleozoic sedimentary rocks. The ore bodies are locally accompanied by carbonatite dikes and veins of high-grade ores.

In this work the 3 ore body drill core samples, 6 host rock samples from the main ore body of the Mushugay Khuduk deposit were selected as most representative samples and studied by XRD, XRF, and ICP-MS method to evaluate elemental and structural composition data of the deposit.

III. The Mushugay Khuduk deposit sample analyses details

Approximately 10 kg of drill core section from the ore body (3 samples) and host rock (6 samples) were selected to cut by the Senior geologist of the license owner company Remet LLC (Mongolia) as a most representative key samples of the Mushugay Khuduk deposit for full chemical and structural analyses. The selected core sample pieces were hammer crushed to 5 cm size (Figure 1a) and then

crushed secondary to 5 mm with cylinder crusher (Siebtechnik) and finally 0.3 kg of fine grain of each sample were ball milled (Fritsch) to 63 μm size (Figure 1b, 1c) for ICP-MS

(Inductively Coupled Plasma- Mass Spectrometry), XRD (X-Ray Diffraction), and XRF (X-Ray Fluorescence) analysis.

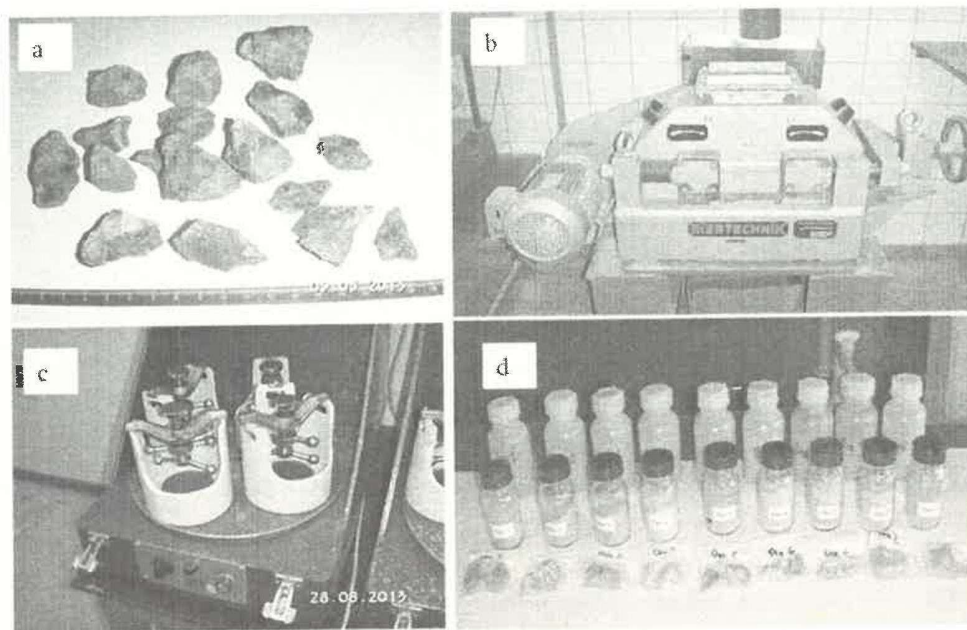


Figure 1. The hammer crushed drill core rocks from the REE ore deposition site Mushugay Khudug (a), the fine crusher to 5 mm size Siebtechnik (b), the fine miller to 63 μm grain powder Fritsch (c), and the hammer crushed (front row), fine milled (middle row), fine crushed (rear row) samples (d).

For the ICP-MS solution analysis the fine powdered samples were digested in acid mixture in three steps. In the first step an about 100 mg of rock powder was directly weighed accurately into a teflon digestion crucible. Then 2 ml of distilled HNO_3 was added and slowly heated to 30 $^\circ\text{C}$ during 1 hour and hold at 30 $^\circ\text{C}$ for 5 hours. The crucible temperature was raised further slowly (1 hour) to 50 $^\circ\text{C}$ and hold at this temperature for 5 hours. This pre-reaction heating in air step was aimed to oxidize and remove possible organic traces without loss of volatile inorganic elements such as As, Se, and Ge. Second step was pressurized digestion in Teflon crucibles: 3 ml of distilled HF, 3 ml of distilled HClO_4 were added and crucibles were tight closed and slowly heated in the high pressure digestion machine DAS 30 System (PicoTrace) for 1 hour to 50 $^\circ\text{C}$, hold at the 50 $^\circ\text{C}$ for 5 hour, slow heating to 150 $^\circ\text{C}$ for 1 hour, and hold at the 150 $^\circ\text{C}$ for 10 hour. Then the crucibles were cooled and opened. The solutions in crucibles were slowly heated in open air to 180 $^\circ\text{C}$

for 3 hour and hold for 12 hour at the 180 $^\circ\text{C}$ to complete volatile acids removing by fuming. In the last step, 1 ml of distilled and diluted (6N) HCl, 2 ml of distilled HNO_3 , and 5 ml of ultrapure H_2O were added to the dry salt residue and mixture were slowly heated to 150 $^\circ\text{C}$ (3 hours), holding at 150 $^\circ\text{C}$ for 1 hour to complete the digestion of all inorganic salts. Resulting clear solutions were carefully transferred into new PE bottles and ultrapure water was added to the 100 ml mark.

To record the mass spectra of elements from Li to U, the final liquid sample solutions were pumped at 1.0 mL/min rate into a mini-cyclonic spray chamber, which gives good sensitivity at low uptakes. The nebulized sample droplets-argon gas mixture was then introduced into ICP torch at the ion entrance of the quadrupole mass spectrometer ELAN DRC II (Perkin Elmer SCIEX). The ionization torch was operated at RF power of 1000 W and coolant argon flow of 10 L/min, auxiliary argon flow of 1.0 L/min, and nebulizer argon flow of 1.0 L/min.

The mass spectra of each sample was detected up to 60 seconds and acquired data was processed in the Iolite v2.31 software application environment [24], based on the Igor Pro 6.22 data processing program [25]. Final concentrations of elements were determined using Merck multi element solutions as internal standard. The recorded in same condition mass spectra of the NIST 600 standard solution was used as external reference.

The 2σ criteria average relative standard deviations (RSD) of element determinations were inversely depending on content of elements. The average RSD of the mostly rock forming high content elements Ca, Al, Mn, Pb, Sr, S, Mg, Fe, Sb, Na, Co, Si, Zn, Cu, P, Y, K, Cl, Ce, and La is less than 10%, the RSD of elements Ti, Cr, Sn, Ba, Zr, Rb lies between 10 and 20%, and the RSD of trace elements Gd, Nb, Sc, V, U, Pr, Ni, Ga, Eu, As, Th B, Mo, Cd, Li lies in interval from 20 to 50 %.

High resolution XRD spectra of ore body powder samples 1-3 were recorded with D 500

Table 1. Element contents in ppm in the selected samples of the Mushugay Khudug REE deposit, southern Mongolia, determined by the ICP-MS measurements. Most abundant light rare earths (LREE) are highlighted in gray color, while most valuable heavy rare earths (HREE) are highlighted in red color. Element content averages in the earth crust [1] are given in the last column.

Elements	Ore_1	Ore_2	Ore_3	Host rock_4	Host rock_5	Host rock_6	Host rock_7	Host rock_8	Host rock_9	Earth crust (Wedepohl 1995) [1]
Li	42.30	64.70	30.30	32.30	44.50	44.60	47.50	73.70	38.50	18
Na	7,620	4,150	4,850	29,200	21,800	61,000	9,740	26,300	21,300	23739
Mg	6,890	8,270	3,230	10,800	18,100	7,900	6,190	5,980	8,060	22312
Al	18,800	10,800	11,700	88,500	88,300	121,000	35,600	76,200	43,000	79915
P	51,300	44,400	67,700	5,860	5,720	2,380	52,200	11,900	54,600	1800
K	12,800	7,620	8,060	76,700	12,900	56,200	24,400	60,700	30,100	19924
Ca	57,500	61,200	70,900	28,700	37,400	3,990	56,800	33,400	50,600	39308
Sc	5.72	6.13	3.02	15.80	28.60	20.10	5.05	13.90	9.25	16
Ti	2,480	2,800	3,150	4,290	4,680	6,500	3,390	6,250	3,220	4077
V	509.00	514.00	757.00	582.00	844.00	679.00	641.00	663.00	606.00	98
Cr	51.80	38.60	44.30	109.00	113.00	154.00	62.10	97.60	78.20	126
Mn	2,770	2,560	2,800	2,980	2,740	492	1,310	1,320	1,300	774
Fe	36,900	38,900	50,300	33,500	54,700	34,300	46,100	61,400	49,400	43925
Co	8.99	6.92	9.41	10.30	25.20	6.72	10.90	15.60	19.00	24
Ni	13.60	10.80	21.80	22.70	30.60	13.20	13.50	31.10	15.70	56
Cu	6.58	6.50	14.20	18.20	80.40	30.90	19.60	38.90	72.00	25
Zn	225.00	203.00	292.00	205.00	255.00	139.00	261.00	207.00	224.00	65
Ga	1,380	1,380	1,370	124.00	107.00	133.00	1,090.00	204.00	994.00	15
Ge	420.00	416.00	418.00	12.10	12.80	4.88	322.00	33.30	302.00	1.4
As	224.00	223.00	244.00	34.90	54.70	60.20	203.00	69.40	193.00	1.7
Se	440.00	412.00	419.00	99.10	88.70	133.00	342.00	94.40	335.00	
Y	2,380	2,470	2,310	71.40	71.40	32.40	1,660.00	148.00	1,460	24
Zr	247.00	365.00	270.00	208.00	70.10	241.00	250.00	284.00	132.00	203
Nb	10.20	16.90	12.70	16.60	16.90	15.50	15.10	32.80	11.60	19
Mo	65.60	56.70	54.40	7.13	22.30	42.50	41.50	22.50	21.80	1.1
Cd	0.54	0.63	0.61	0.32	0.45	0.20	0.50	0.45	0.54	0.1
Sn	2.16	2.48	2.07	2.51	1.66	2.55	2.43	3.31	2.25	2.3
Sb	5.31	6.42	6.14	1.59	1.56	2.19	6.66	4.00	3.66	0.3
Te	0.23	0.34	0.33	0.13	0.13	0.30	0.22	0.32	0.27	0.005
Rb	54.50	44.30	30.70	173.00	50.00	138.00	82.10	180.00	76.80	78
Sr	4,950	4,410	5,430	3,730	23,200	812	4,630	1,780	3,590	333
Cs	9.07	13.60	5.83	8.90	36.70	14.60	14.20	15.30	6.86	3.4
Ba	763.00	869.00	740.00	1,350	748.00	1,070	894.00	1,400	1,180	584

La	34,500	36,900	33,500	566	542	140	25,300	2,470	18,800	30
Ce	62,800	67,000	61,800	986	1,020	180	45,200	3,940	35,300	60
Pr	5,950	6,360	5,910	125.00	133.00	21.40	4,360	347	3,430	6.7
Nd	17,300	18,400	17,100	365.00	401.00	66.60	12,700	1,150	10,400	27
Sm	1,710	1,800	1,690	39.00	43.00	9.60	1,230	102.00	1,060	5.3
Eu	296.00	314.00	300.00	7.94	8.25	1.92	278.00	18.60	222.00	1.3
Gd	1,660	1,780	1,670	36.90	40.20	8.79	1,250	116.00	1,040	4.0
Tb	140.00	146.00	140.00	3.32	3.54	1.21	122.00	8.55	105.00	0.65
Dy	480.00	478.00	547.00	12.50	12.70	6.43	399.00	25.20	356.00	3.8
Ho	97.10	103.00	98.40	2.28	2.29	1.26	71.30	4.63	63.00	0.8
Er	318.00	339.00	315.00	7.31	7.42	3.79	233.00	16.40	203.00	2.1
Tm	34.10	37.10	33.90	0.85	0.83	0.57	24.50	1.85	21.90	0.3
Yb	226.00	244.00	225.00	6.18	5.77	4.07	164.00	14.50	143.00	2
Lu	27.60	30.70	28.30	0.89	0.80	0.57	20.30	2.22	17.80	0.35
Hf	5.29	7.61	4.96	5.52	1.73	6.35	4.93	6.12	2.97	4.9
Ta	0.75	1.01	0.77	0.83	0.40	0.98	0.71	1.39	0.56	1.1
W	11.00	15.70	15.40	7.45	12.80	12.30	17.30	19.30	10.70	1.0
Ir	0.017	0.025	0.015	0.018	0.005	0.018	0.015	0.020	0.009	
Pt	0.043	0.060	0.033	0.053	0.013	0.052	0.037	0.052	0.021	
Tl	0.69	0.56	0.44	1.52	1.43	2.77	1.05	1.91	0.79	0.52
Pb	140.00	274.00	198.00	76.20	55.90	78.90	330.00	186.00	125.00	14.8
Bi	25.20	28.40	24.20	0.87	1.64	0.60	19.20	1.52	14.90	0.09
Th	1,580	1,620	1,030	33.00	25.20	14.50	575.00	83.80	809.00	8.5
U	1,020	1,190	1,020	27.70	39.80	29.60	715.00	76.90	742.00	1.7

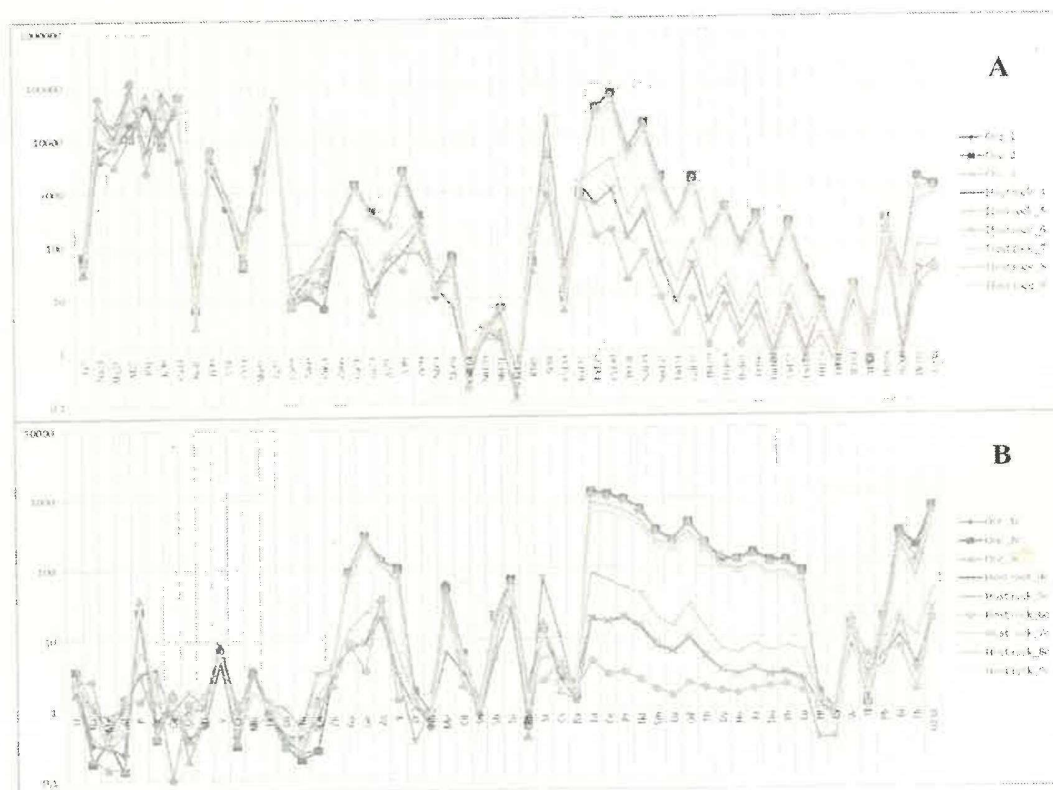


Figure 2. Graphical representation of data in the Table 1. The upper graph A shows detected contents in ppm, while the lower graph B represent element contents normalized to their corresponding average earth crust contents [1]. The number behind each element symbol on the bottom of the graph A is the mass number of isotope that represents the desired to detect element.

As shows the Figure 2A, contents of REEs plots series of similar to each other zig-zag lines. The zig-zag behavior reflect the Oddo-Harkins general rule that in any natural mineral containing REEs, the content of any odd numbered REE is tends to be less than content of his two even numbered close neighbors because of less stability

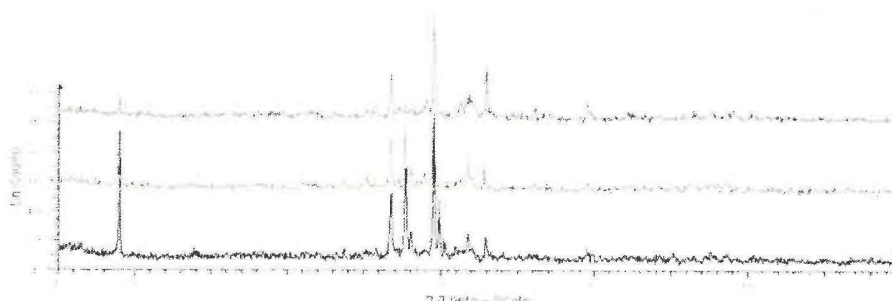
of odd numbered nuclei. The REEs content zig-zag behavior is observable not only within minerals, rocks containing REEs, such the behavior is exists in the average content of REEs in the earth crust. As a consequence, the zig -zag line on the Figure 2A transforms into nearly monotonous line on the earth crust normalized line on the Figure 2B.

Crystal structure of the yellowish brown ore rock (Figure 2a) powdered samples (ore-1, -2, -3) were examined with XRD method using Siemens D 500 spectrometer. XRD data was collected with Cu anode at room temperature from 5° to 60° for Bragg 2θ angle with 0.02 step size. Qualitative phase analysis was made with PDF-2 database to determine crystal phases. Typical XRD

spectra of the samples are shown on the Figure 3. Most of lines not belonging to rock forming basic minerals in the XRD spectra were identified as lines of bastnaesite CeCO_3F , several weak lines might be identified belonging to monazite (GdPO_4 , SmPO_4), and synchysite $\text{CaCe}(\text{CO}_3)_2\text{F}$.

Figure 3. XRD spectra of the ore rock powder samples: ore_1 (blue), ore_2 (red), and ore_3 (black).

Attempts to determine age of ore rock by age dating [26, 27, 28]. For these purpose the 25



measuring of $^{238}\text{U} / ^{232}\text{Th}$ isotope ratio in monazite crystallites were done with the Laser Ablation-ICP-MS (LA-ICP-MS) method which is widely uses in geochemical trace element analysis of rocks, rock

pieces of shiny faced 1-5 mm size yellow, yellow-brown and black color crystal species were selected with tweezers from the crushed to middle size ore samples 1, 2, and 3 (Figure 4).

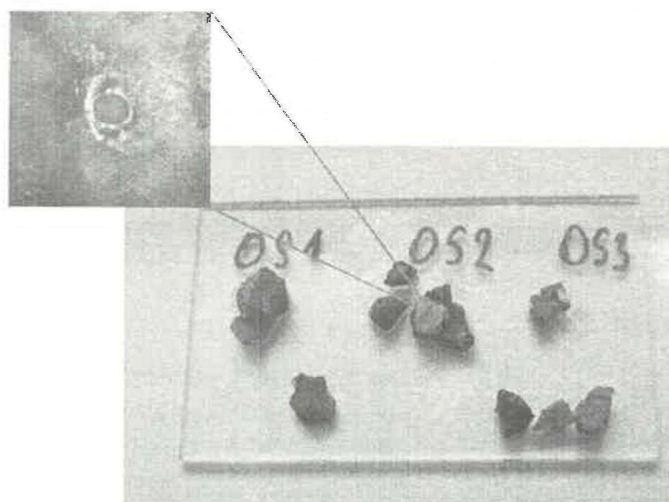


Figure 4. The 1-5 mm size yellow, yellow-brown and black color crystal species from ore sample 1 (OS1), ore sample 2 (OS2), and ore sample 3 (OS3) selected for LA-ICP-MS analysis. The upper left inset shows optical microscope magnified image of the laser ablated 120 μm diameter sampling hole on the surface of one of OS2 crystallite specimen.

The selected crystal species were ablated by 193 nm UV pulsed laser beam with repetition rate 5Hz coming from ArF excimer laser Compex (LambdaPhysik, Germany), coupled to the mass spectrometer ELAN DRC II (Perkin Elmer SCIEX). Single laser pulse energy density

delivered onto the 120 μm diameter size sample surface area was around 5 J cm^{-2} , and was spatially well homogenized to ablate flat-bottom crater. Ablated from the sample nano-size fine dust material was transported through tubing by argon flow and feed ICP torch at the ion entrance of the

mass spectrometer. Final concentrations of elements in crystallites were calculated using Ca as internal standard element. The recorded in same condition mass spectra of the NIST610 glassy standard material was used as external reference.

Surprisingly the LA-ICP-MS readouts of these crystals were shown the Ca-to- P content ratio that might be recognized as apatite instead of monazite. Therefore a monazite species in rocks of main orebody of the Mushugay Khuduk deposit might occur mainly in sub millimeter size grains.

For the three key ore samples, the average and net content of nine LREE and eight HREE are given grouped in the Table 2. As shows the Table 2, the LREE plus HREE net mass content reaches 13 % or 130 kg/ton. According to the US

Geological Survey 2010 report [4], the largest known and most economic to mine REE deposit Mountain Pass in USA has REO grade 8.9%. The largest and most profitable reserve in the world Bayan-Obo in Inner Mongolia (China) has REO average grade 4.5% [3]. Despite the moderate total reserve (64 thousand ton in REO) the main ore body of the Mushugay Khuduk deposit might compete economically with Mountain Pass or Bayan-Obo if consider the deposit's higher REE grade and easier to mine local geological condition [11].

Table 2. REE, As, Th, and U contents of the three selected samples of main ore body of the Mushugay Khuduk deposit are given in ppm. Averaged relative content of each REE are given in percents.

REEs and other important elements	Ore_1, ppm	Ore_2, ppm	Ore_3, ppm	Average content, ppm	Average content in percents	Earth crust, ppm [1]	Earth crust, in percents
Sc	5.7	6.1	3.0	5.0	0.004	16.0	8.68
La	34,500.0	36,900.0	33,500.0	34,966.7	26.897	30.0	16.28
Ce	62,800.0	67,000.0	61,800.0	63,866.7	49.128	60.0	32.56
Pr	5,950.0	6,360.0	5,910.0	6,073.3	4.672	6.7	3.64
Nd	17,300.0	18,400.0	17,100.0	17,600.0	13.538	27.0	14.65
Sm	1,710.0	1,800.0	1,690.0	1,733.3	1.333	5.3	2.88
Eu	296.0	314.0	300.0	303.3	0.233	1.3	0.71
Gd	1,660.0	1,780.0	1,670.0	1,703.3	1.310	4.0	2.17
LREE Sum				126,251.6	97.116	150.3	81.55
Tb	140.0	146.0	140.0	142.0	0.109	0.7	0.35
Dy	480.0	478.0	547.0	501.7	0.386	3.8	2.06
Ho	97.1	103.0	98.4	99.5	0.077	0.8	0.43
Er	318.0	339.0	315.0	324.0	0.249	2.1	1.14
Tm	34.1	37.1	33.9	35.0	0.027	0.3	0.16
Yb	226.0	244.0	225.0	231.7	0.178	2.0	1.09
Lu	27.6	30.7	28.3	28.9	0.022	0.4	0.19
Y	2,380.0	2,470.0	2,310.0	2,386.7	1.836	24.0	13.02
HREE Sum				3,749.4	2.884	34.0	18.45
As	224.0	223.0	244.0	230.3		1.7	
Th	1,580.0	1,620.0	1,030.0	1,410.0		8.5	
U	1,020.0	1,190.0	1,020.0	1,076.7		1.7	

The next advantage of the Mushugay Khuduk deposit is that the relative contents of most valuable HREEs Eu, Tb, Dy, and Lu are higher than that of Mountain Pass or Bayan-Obo. According to [2], relative net content of these four elements is 0.1% for Mountain Pass and 0.4% for Bayan-Obo, while the Mushugay Khuduk has 0.75% according to the Table 2. High contents of iron and phosphorus in both orebody and host rock (Table 1) samples are suggestive sign of these two essential mining elements as byproduct of the deposit.

The principal deleterious impurities in REE-bearing ores are thorium and uranium, which imparts an unwanted radioactivity to the ores. As shows the Table 2, average content of thorium-232 is 1410 ppm and uranium-238 is 1077 ppm. These elevated levels of radioactive thorium and uranium must be subject of concern for further ore mining and refining into marketable rare earth compounds. Special disposal methods must be used to bury radioactive waste of further ore processing. Attention must be paid also to the 230 ppm considerable amount of arsenic, which is well known carcinogenic element to humans.

V. Summary

According to our determinations the main orebody of the Mushugay Khuduk deposit contain up to 130 kg/ton of REEs. Despite the moderate total mineable reserve the main ore body of the Mushugay Khuduk deposit might compete economically with world's leading REE mining deposits such as Bayan-Obo or Mountain Pass if consider the deposit's higher REE grade and easier to mine local geological condition.

The important advantage of the Mushugay Khuduk deposit is that the relative contents of most valuable HREEs Eu, Tb, Dy, and Lu are significantly higher than that of Mountain Pass or Bayan-Obo. The relative net content of these four elements is 0.1% for Mountain Pass and 0.4% for Bayan-Obo, while the Mushugay Khuduk has 0.75% according to our determinations.

The average content of thorium-232 is found 1410 ppm and uranium-238 is found 1077 ppm in main orebody. These elevated levels of radioactive thorium and uranium must be subject of

concern for further ore mining and refining into marketable rare earth compounds. Special disposal methods must be used to bury radioactive waste of further ore processing. Attention must be paid also to the 230 ppm considerable amount of arsenic, which is well known carcinogenic element to humans.

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