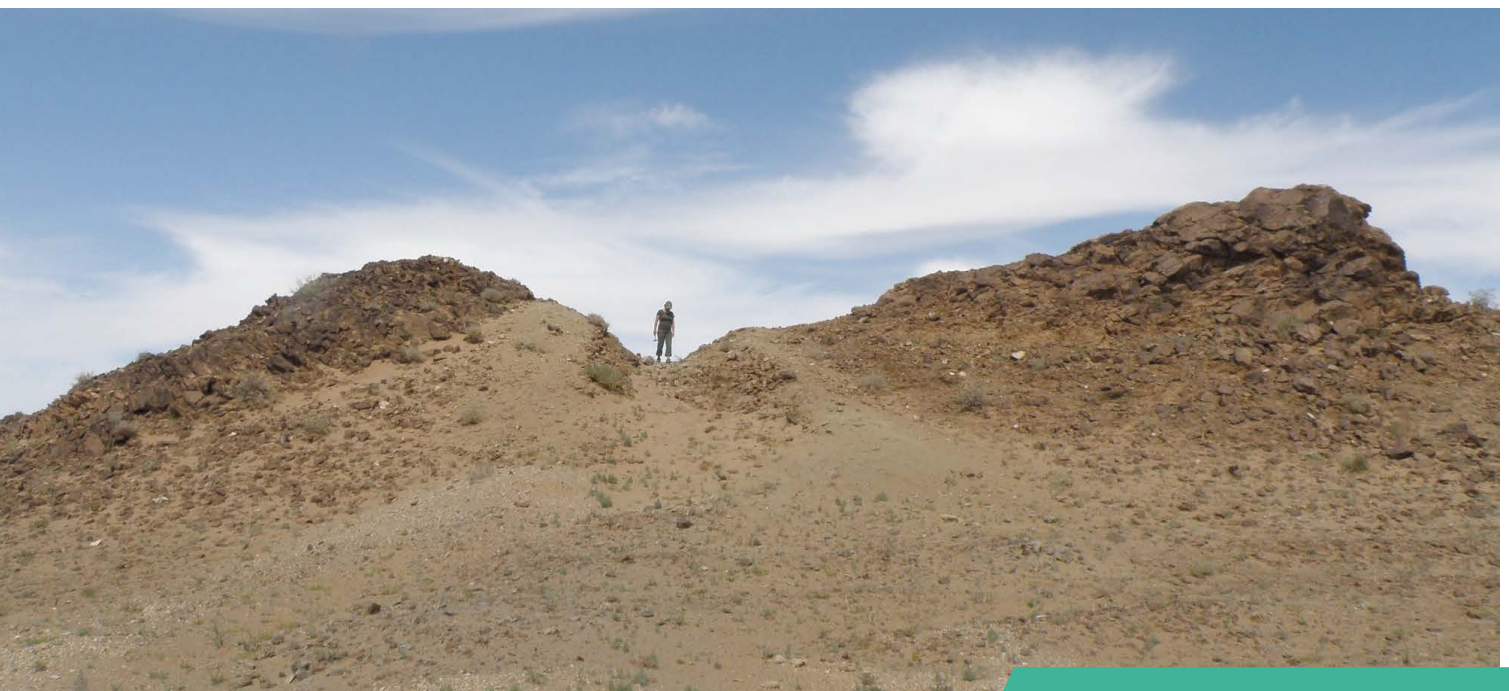


Rare Earths of Mongolia

Evaluation of Market Opportunities for the Principal Deposits of Mongolia

2nd Edition – Update 2023

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Titelbilder: Mushgai khudag main ore body (Camel hill)

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Glossary of terms

Basket price:

The theoretical price (usually in US\$/kg) that could be obtained for one kilogram of fully separated rare-earth oxides, containing rare-earth oxides in the same proportions as found in-situ within the deposit.

Concentrate:

A processing product containing the valuable ore mineral from which most of the waste material has been eliminated.

Cut-off grade (CoG):

The minimum mineral grade at which material can be economically mined and processed (used in the calculation of reserves).

Deposit:

According to the Mongolian Minerals Law, clause 4.1.9: Mineral deposit means mineral concentration that has been formed on the surface or in the subsoil as a result of geological evolutionary processes, where the quality and proven reserve makes it feasible to economically mine the natural resource.

Feasibility Study:

A comprehensive study of a deposit in which all geological, engineering, operating, economic and other relevant factors are considered in sufficient detail that it could reasonably serve as the basis for a final decision by a financial institution to finance the development of the deposit for mineral production.

Grade:

The amount of mineral in each ton of ore.

Leaching:

A method of extraction in which a solvent is passed through a mixture to remove some desired substance from it. Leaching is used to remove metals from their ores.

Mineral Reserve:

The economically mineable part of a Measured or Indicated Mineral Resource demonstrated by at least a pre-feasibility study. This study must include adequate information on mining, processing metallurgical, economic and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified. A Mineral Reserve includes allowances for dilution and losses that may occur when the material is mined.

Proved Mineral reserve:

An economically minable part of a Measured Mineral Resource that therefore holds the highest level of geological confidence. The deposit is also proved minable in terms of economic, mining, metallurgical, marketing, legal, social and governmental factors.

Probable Mineral Reserve:

The economically mineable part of an Indicated Mineral Resource and in some circumstances a Measured Mineral Resource demonstrated by at least a pre-feasibility study. The pre-feasibility study must include adequate information on mining, processing,

metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified.

Mineral Resource:

A concentration or occurrence of natural, solid, inorganic or fossilized organic material in or on the earth's crust in such form and quantity, and of such a grade or quality, that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge.

Measured Mineral Resource:

That part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of technical and economic parameters, and to support production planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough to confirm both geological and grade continuity.

Indicated Mineral Resources:

That part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics can be estimated with a level of confidence sufficient to allow the appropriate application of technical and economic parameters, and to support mine planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration and test information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough for geological and grade continuity to be reasonably assumed.

Inferred Mineral Resources:

That part of a Mineral Resource for which quantity and grade or quality can be estimated on the basis of geological evidence and limited sampling and reasonably assumed but not verified geological and grade continuity. The estimate is based on limited information and sampling gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes.

Mineral prospect (also: mineral occurrence):

A mineral prospect has the least level of confidence and refers to an occurrence of geological interest that does not yet have economic value.

Ore:

Metal or mineral, or a combination of these, of sufficient value in terms of quality and quantity to enable it to be mined and processed at a profit.

Ore body:

An ore body may correspond to an ore deposit, but more often the deposit includes several ore bodies.

Placer:

A surface mineral deposit with mineable concentrations of relatively heavy or hard minerals which have accumulated as a result of physical processes.

Pre-feasibility study:

A comprehensive study of the viability of a mineral project that has advanced to a stage where the mining method, in the case of underground mining, or the pit configuration, in the case of an open pit, has been established. It includes a financial analysis based on reasonable assumptions of technical, engineering, legal, operating, economic, social, and environmental factors, and the evaluation of other relevant factors which are sufficient for a Qualified Person, acting reasonably, to determine if all or part of the Mineral Resource may be classified as a Mineral Reserve.

Qualified Person:

Means an individual who (a) is an engineer or geoscientist with at least five years of experience in mineral exploration, mine development or operation or mineral project assessment, or any combination of these; (b) has experience relevant to the subject matter of the mineral project and the technical report related thereto; and (c) is a member in good standing of a professional association as defined by NI 43-101 (According to CIM – Canadian Institute for Mining, Metallurgy and Petroleum; other national definitions may vary).

Recovery:

A term used in process metallurgy to indicate the proportion of valuable material physically recovered in the processing of an ore. It is generally stated as a percentage of valuable metal in the ore that is recovered compared to the total valuable metal originally present in the ore.

Waste : ore ratio:

The tonnage or volume of waste material which must be removed to allow the mining of one tonne of ore in an open pit; expressed as tonnes of waste to tonnes of ore. Not to be confused with overburden: ore ratio, where the overburden is given as volume (cubic yard or cubic metres, and the ore as tonnes).

List of abbreviations

BGR

Bundesanstalt für Geowissenschaften und Rohstoffe – Federal Institute for Geosciences and Natural Resources

BMZ

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung – Federal Ministry of Economic Cooperation and Development (Germany)

CapEx

Capital expenditure

CRIRSCO

Committee for Mineral Reserves International Reporting Standards

JORC

Joint Ore Reserves Committee – Australian standard of disclosure for mineral projects

MMHI

Ministry for Mining and Heavy Industry

MPIGM

Mongolian Professional Institute of Geosciences and Mining

MRC

Mongolian Code for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves (The MRC Code)

MRPAM – prior MRAM

Mineral Resources and Petroleum Authority of Mongolia

MSPCMR

Mongolian State Professional Committee on Mineral Resources

MUST

Mongolian University of Science and Technology

NGS

National Geological Survey (of Mongolia)

NI 43-101

National Instrument 43-101 – Canadian standard of disclosure for mineral projects

OpEx

Operational expenditure

PEA

Preliminary Economic Assessments

RE – (L/H)REE – (T)REO

Rare earths – (light/heavy) rare earth elements – (total) rare earth oxides

Objective of the study

This report was initiated as part of the German-Mongolian cooperation project “Capacity development in mineral resources economics of the mining sector in Mongolia II”, which was funded by the German Federal Ministry of Economic Cooperation and Development (BMZ). It was prepared by the project partners BGR and MRPAM and is an update of the first version of the report from 2013 (MUFF AND TAMIRAA 2013).

The main objective of the study is to classify Mongolian rare earth (RE) deposits and occurrences in the global market and to compare the international RE projects and Mongolian occurrences based on relevant evaluation criteria. For this purpose, a comprehensive description of basic concepts and technical background, e.g., on the reporting of exploration results and ore mineral inventories, RE mining and processing and the global supply and demand situation is provided. Compared to the first version of the report, not all sections are entirely new, but in some cases only updated and directly adopted where information is still valid. The main innovation is the fully updated peer comparison table of selected RE projects in Appendix 1, which forms the basis for the assessment of RE resources in Mongolia. However, this study is not an evaluation of the global RE market and does not elaborate on the political and strategic importance of RE as reflected in various European and U.S. initiatives. For a further description of the geology in Mongolia linked to RE mineralization, the reader is advised to relevant literature (e.g., GEREL et al. 2021 ; DOSTAL and GEREL 2023).

Methodology

The authors thoroughly studied the technical reports and other information (web page, newsletter) made publicly available by companies as well as scientific literature for information on RE exploration projects worldwide. Additionally, commercially available information on the RE market by Roskill and S&P Global has been considered. Information on global reserves, resources, supply and demand is based on internal BGR statistics and publicly available sources (e.g. USGS 2023).

Information on RE deposits and occurrences in Mongolia was compiled exclusively by MRPAM from data submitted through the Mongolian State Professional Committee on Mineral Resources (MSPCMR) and from previous studies (e.g., ELSNER et al. 2011), publicly available information, field visits, and interviews.

The geological occurrence and morphology of ore deposits and the type of minerals that host REE have a strong influence on the economic viability of an RE deposit. Therefore, the basics of RE occurrences, their extraction and processing are briefly explained in the Chapter on "Basic concepts and technical background".

Mongolian RE deposits were evaluated through peer comparison, as no project is beyond pre-feasibility status and thus there is insufficient precise data for economic or technological evaluation methods.

In June 2012, MRAM (former name of MRPAM) and BGR staff conducted a week-long field trip to the South Gobi to collect on-site information on the RE prospects of Khotgor and Mushgai khudag. Selected samples were analyzed at BGR laboratories using SEM (scattered electron microscopy) to map the distribution of REE in the rock samples. Additional information on Mushgai khudag is based on resource data from Mongol gazar LLC, a national mining company, submitted to the MSPCMR.

Units in this study are in the metric system unless otherwise indicated. Prices and costs are in U.S. dollars (US\$) unless another currency unit is specified.

Basic concepts and technical background

Reporting of exploration results and ore mineral inventories

The mining cycle

A full mineral resources project cycle goes through the following stages, starting with the prospection & exploration phase:

- Conceptual planning (literature review)
- Reconnaissance and Prospection (analysing surface grab-samples, mapping and trenching, potential application of airborne geophysical exploration methods)
- General exploration (ground geophysics, first metallurgical studies, preparing technical reports as NI 43-101 or JORC)
- Detailed exploration (deposit modelling, metallurgical studies, test mining, economic evaluation for feasibility/bankable feasibility study)

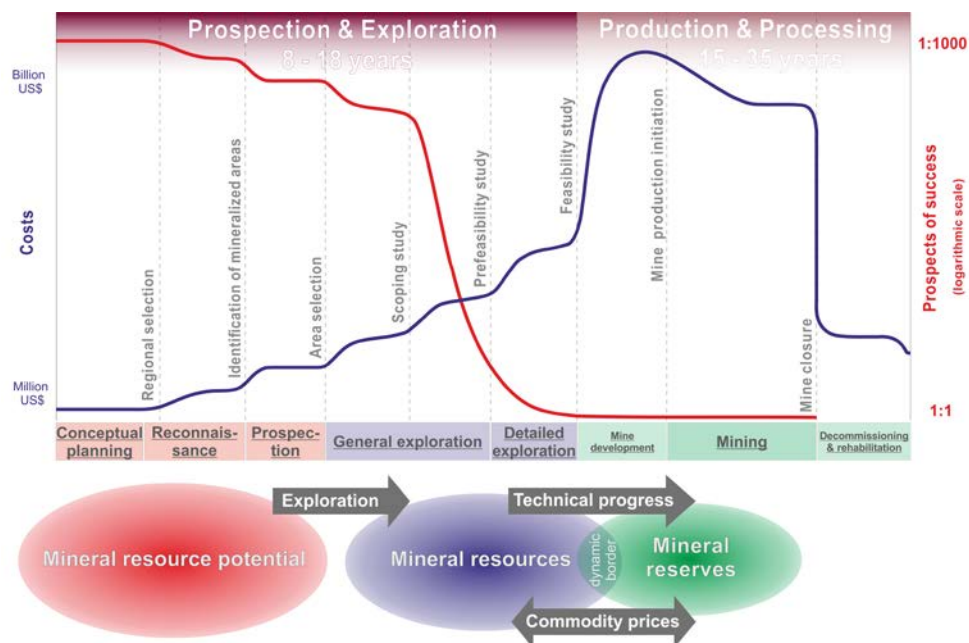


Figure 1: Schematic illustration of the mining cycle. The blue line indicates the increasing costs accompanied with each development step. Simultaneously, prospects of success that the deposit in fact goes into production increase with proceeding exploration activities and especially with the prefeasibility study (red line).

The exploration phase until a feasibility study is carried out is very time-consuming and takes at least eight, rather up to 18 years. At the same time, until a scoping study is conducted, the probability of the project going into production is relatively low. With further exploration progress, the prospects of success increase sharply, but this is also accompanied by rising costs (Figure 1). With a positive feasibility study, mineral reserves can be defined (see below) and, with sufficient funding, the production phase can begin with the following steps:

- Mine development (acquiring permits, securing finances, construction of mine infrastructure)
- Production (mining, processing, separation with a saleable product)
- Mine closure: Decommissioning and rehabilitation.

The concept of documenting mineral inventories

Within the first steps of exploration (conceptual planning, reconnaissance, prospection), the potential of mineral resources are inferred as sketched in Figure 1. With increasing exploration activities that include more detailed analytical methods, the mineral resources can be measured. Proved mineral reserves cannot be reported before a (bankable) feasibility study is completed that confirm an economic feasible extraction of the desired commodity. Reserves are the basis for production planning and their tonnage varies with the commodity price and available mining and metallurgical technology (see modifying factors, Figure 2). Reserve figures may be utilized to estimate the production time (not life time) of a mine. However, for estimating future supply security and strategic considerations, resource figures should be used.

Since the harmonization of mineral resource and mineral reserve definitions by UN-ECE (United Nations Economic Commission for Europe) and CRIRSCO (Committee for Mineral Reserves International Reporting Standards), the internationally accepted classification of mineral resources and reserves follows the pattern outlined in Figure 2.

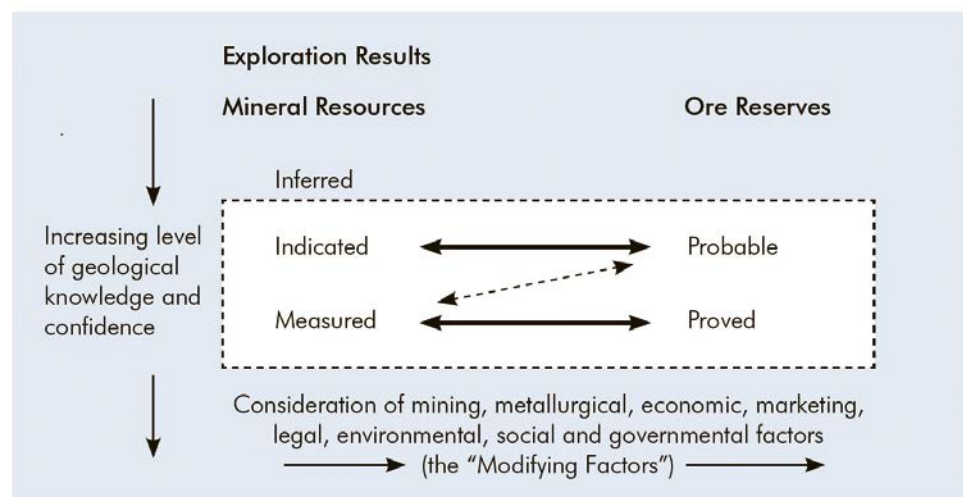


Figure 2: CRIRSCO reporting scheme for reporting mineral resources inventories (Exploration Results, Mineral Resources and Ore reserves) according to JORC and the NI 43-101.

The system outlined in Figure 2 is recognized by the internationally important organizations (JORC - Australasia, SAMREC - South Africa, NI 43-101 - Canada, SEC - USA, and the IMM - UK). The system follows the logic that the level and intensity of geological investiga-

tion (as illustrated in Figure 1) and "modifying factors" qualify and quantify mineralization. Modifying factors consider mining, metallurgical, economic, marketing, legal, environmental, social, and governmental conditions, which demonstrate at the time of reporting that economic extraction is justified.

In Mongolia, ore inventories are reported to the authorities and the Professional Reserve Committee applying the Mongolian Mineral Resources/Reserves Classification. This system closely resembles the system used in the Russian Federation that divides seven categories of mineral concentrations. These are assigned to three major groups, based on the level of exploration:

- fully explored reserves or resources (A, B, C1)
- evaluated reserves or resources (C2)
- prognostic resources (P1, P2, P3)

Reserves and resources that can be matched to the usual international categories from reporting codes as JORC and NI 43-101, are classified into five main classes designated by the symbols A, B, C1, C2 and P1 (Table 1). However, the international codes are only applied in Mongolia by those companies seeking for international investment.

Table 1: Approximate correlation of terms used in the Mongolian Mineral Resources/Reserves Classification and the comparable Russian Resource/Reserve Classification with the terms of the Australian JORC and Canadian NI 43-101 reporting codes.

Mongolia		Russia (also applied in Kazakhstan, Uzbekistan, Ukraine, etc.)	Australia	Canada		
Mineral Resources/ Reserves Classification		Mineral Resources/ Reserves Classification	JORC	NI 43-101		
A´	A	A + B + C1	Demon- strated Reserve	Measured Resource	Proved Reserve	Measured Resource
B´	B	C2		Indicated Resource	Probable Reserve	Indicated Resource
C		C2 + P1	Inferred Resource		Inferred Resource	
P1		P1	Undiscovered		Prognosticated	
P2		P2			Speculative	
P3		P3				

The Mongolian stock exchange recommends mining companies to use the Mongolian Code for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves. The so-called MRC Code was prepared in 2014 by the Mongolian Mineral Resources and Reserves Committee (MRC) of the Mongolian Professional Institute of Geosciences and Mining (MPIGM) with participation of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) and the Mongolian State Professional Committee on Mineral Resources (MSPCMR). However, until now there is no practical implementation of the MRC Code. Thus, the MRC Code is not explained in detail here.

In 2015, the Ministry for Mining and Heavy Industry (MMHI) has made efforts and introduced a Mongolian reserve and resource classification to harmonize Mongolian and previously applied Russian reporting standards with recognized international standards. To this end, the School of Geology and Mining, which is part of the Mongolian University of Science and Technology (MUST), has developed most of the guidelines for the application of resource/reserve classification for a total of 30 minerals. To improve the conversion of old and new resource/reserve classifications and their inclusion in reserve calculation, MMHI, MRPAM and the National Geological Survey (NGS) intend to collaborate on a working group. That harmonization with international reporting standards is absolutely necessary is also evident with regard to the partially inconsistent and erroneous resource and deposit-related data of rare earth occurrences registered in the MSPCMR.

As illustrated in Figure 1, the prospection and exploration phase may last up to 18 years and the prospect of success is relatively low until at least a prefeasibility study is conducted. Afterwards, investment for the increasing costs associated with the extensive work during the detailed exploration is required in order to obtain a bankable feasibility study. Thus, despite a high number of rare earth exploration projects globally (cf. chapter Global supply and demand situation and resources of RE) only few projects will go into production. The main reasons for the delays or suspensions of (RE) mining projects are difficulties in raising the large amount of capital needed; but also, permitting problems caused by environmental issues (mainly the handling of hazardous wastes) cause delays because almost all RE mineralization is associated with radioactive minerals. Another reason for delays is the complicated elaboration of an efficient flow sheet for the concentration, chemical extraction and separation of the REE.

Definition of rare earths

Table 2: Rare earth elements divided in light and heavy rare earths. Shown is the element symbol with the atomic number (upper left) and the atomic weight (upper right) as well as the main technological use of the element.

Light rare earth elements (LREE)		Heavy rare earth elements (HREE)	
57 138,91 La Lanthanum	<ul style="list-style-type: none"> Petroleum refining High-index glass Flints Hydrogen storage Battery electrodes 	64 157,25 Gd Gadolinium	<ul style="list-style-type: none"> Magnets, high-index glass Lasers X-ray tubes Computer memory Neutron capture
58 140,12 Ce Cerium	<ul style="list-style-type: none"> Catalytic converters Oxidizing agents Polishing powders Yellow glass/ceramic Catalysts in self-cleaning ovens 	65 158,93 Tb Terbium	<ul style="list-style-type: none"> Green phosphors Lasers Fluorescent lamps
59 140,91 Pr Praseodymium	<ul style="list-style-type: none"> Magnets, lasers Green glass / ceramics Flints Pollution control 	66 162,50 Dy Dysprosium	<ul style="list-style-type: none"> Magnets Lasers
60 144,24 Nd Neodymium	<ul style="list-style-type: none"> Magnets Lasers Violet glass / ceramics Capacitors 	67 164,93 Ho Holmium	<ul style="list-style-type: none"> Lasers
61 146,92 Pm Promethium*	<ul style="list-style-type: none"> Nuclear batteries 	68 167,26 Er Erbium	<ul style="list-style-type: none"> Lasers (for communications) Vanadium steels
62 150,36 Sm Samarium	<ul style="list-style-type: none"> Magnets Lasers Neutron capture Masers 	69 168,96 Tm Thulium	<ul style="list-style-type: none"> Electron beam tubes Medical imaging systems (X-ray detection)
63 151,96 Eu Europium	<ul style="list-style-type: none"> Red/blue phosphors Lasers Fluorescent lamps Mercury vapour lamps 	70 173,04 Yb Ytterbium	<ul style="list-style-type: none"> Infrared lasers Electrical stress gauges Reducing agent
		71 174,97 Lu Lutetium	<ul style="list-style-type: none"> Scintillation counters
		39 88,91 Y Yttrium	<ul style="list-style-type: none"> Automotive use Microwave communications Lasers

The rare earth elements (REE) are a set of the 14 stable elements of the Lanthanides (excluding the radioactive promethium (Pm)) plus yttrium (Y), all of which are found in the 3rd secondary group of the Periodic Table of the Elements. Contrary to what their name suggests, most rare earth elements are not rare – the average enrichment in the earth's crust is similar to copper – but REE are less often concentrated in mineable deposits. The REE are divided into the more abundant light REE (LREE; La to Eu; see Table 2) and the less common heavy REE (HREE; Gd to Lu + Y; see Table 2)). LREE occur much more frequently in most deposits than HREE (> 90 %). However, the rare earths can only be mined together. The recoverable amount of individual rare earth oxides (REO) thus depends on the deposit composition. Increased demand from applications that require individual rare earths or rely on rarer REE can create an imbalance between mine production and demand. In particular, demand for Nd and Dy (for NdFeB magnets) is high compared to supply, while there is a significant oversupply for lanthanum and cerium.

In some definitions, Scandium (Sc) is also assigned to REE. However, while the Lanthanides and Y have very similar physical and chemical characteristics and commonly occurs in the same ore deposit due to its natural association, Sc differs in several properties and, thus, is not considered here. This classification follows the practice of the mining sector.

Although industrial demand for REE is relatively small in tonnage terms (131,500 t in 2020; ROSKILL 2021), they are essential for a diverse and expanding array of high-technology applications (Table 2). REE-containing magnets and lasers as well as metal alloys for batteries and lightweight structures are essential for many current and emerging alternative energy technologies, such as electric vehicles, autonomous systems, and wind power. Moreover, many other future technologies as lasers for autonomous vehicle (for a further elaboration see chapter Supply).

Classification of RE deposits and mining of RE ore

RE Minerals

A large number of complex RE-containing minerals (~245 silicates, oxides, carbonates and phosphates) are known. Economically important are currently mainly bastnaesite, monazite and xenotime. Most present day production comes from bastnaesite, followed to a much smaller extent by monazite in second place.

Bastnaesite is a fluorocarbonate mineral that carries mainly the LREE and a relatively low amount of thorium. Its chemical composition is $LREE(CO_3)F$. Bastnaesite contains from 70 – 74 % REO and it is the RE mineral of the carbonatite hosted REE deposits.

Monazite is a phosphate mineral with a composition of $LREE(PO_4)$. It contains about 35-60 % REO and may carry a high content of thorium. Depending on the most common rare earth element in monazite, the mineral is designated as "monazite-Ce", "monazite-La", and so forth. Primary monazite occurs as an accessory mineral in igneous rocks and is the RE mineral in alkaline igneous complexes. It is very resistant to weathering and abrasion, and therefore it accumulates in placer deposits and beach sands. Another phosphate mineral that can contain significant amounts of REE is apatite. It can be enriched with REE either during formation or during a later hydrothermal alteration (OWENS et al. 2019).

The RE minerals xenotime and loparite should also be mentioned although they are presently of minor economic importance in REE production. Xenotime is a phosphate mineral

(YPO_4 , where Y may be replaced by HREE) and contains 52 – 67 % REO, mostly of the heavy RE group. Xenotime is a heavy mineral with a high resistance to weathering and thus often accumulates in beach sands and placer deposits together with monazite. Loparite ((LREE, Na, Ca) (Ti, Nb) O_3) is basically a niobium ore mineral that may carry 32 – 34 % REO.

Many global exploration projects have recently focused on (per)alkaline deposits with alkaline igneous rocks (currently only one production site (Lovozerky, Russia), see below). In the future, (Zr-)silicate minerals such as eudialyte may gain importance due to their relatively high content of “magnet” REE (Nd, Dy) and their low radioactivity. However, processing of these minerals is very complicated and not yet economical.

Two more REE bearing carbonate minerals should be mentioned here because they are described in the studies on Mongolian RE deposits, although they are not yet of economic importance. These are:

1. Parisite with the chemical formula $Ca(Ce,La)_2(CO_3)_3F_2$. It contains about 27 % La_2O_3 and 34 % Ce_2O_3
2. Synchysite with the chemical formula $CaY(CO_3)_2F$. It may contain about 42 % Y_2O_3 .

RE Deposits

The minerals of RE occur in a variety of geological environments. They may be found in rocks related to magmatic activity. RE accumulations formed in this way are called “primary deposits”. The most significant RE deposits for current supply are carbonatite intrusions (e.g., Bayan Obo and Maoniuping in China, Mt. Weld in Australia, Mountain Pass in the U.S.) with the main value minerals bastnaesite and monazite.

Weathering and other surface processes may redistribute and concentrate the RE minerals occurring in primary deposits. Concentrations formed this way are called “secondary deposits”. Next to placer deposits, ionic clays are a major source for REE, mainly for HREE. They are a product of extensive weathering of RE bearing minerals and the REEs are adsorbed on the surface of the clays. As these ores only occur in tropical regions (predominantly in Southeast Asia), ionic clay deposits are not observed in Mongolia and, thus, not further considered in this study.

The mineral content, chemical composition, and style of mineralization of RE deposits is strongly influenced by the way the deposit formed. Therefore, the primary and secondary mineral deposit classes are commonly further subdivided (see USGS, BGS and many technical reports on REE deposits).

New extraction technologies makes it feasible to mine deposits in that rare earths are only one of many components within a bouquet of other value-elements. Additionally, projects have been considered that have been ignored in the past because of their low ore grade or complex mineralogy. For example, numerous known peralkaline deposits also have great potential, especially for HREE with relatively low radioactivity (e.g., in Sweden, Greenland, Canada, Australia; see Figure 7 in Global supply and demand situation and resources of RE). However, they cannot be extracted economically at present, especially because of the complex processing. The only active mining of peralkaline magmatites is currently taking place in Lovozerky, Russia. RE enrichments can also occur in phosphorites and hydrothermal vein deposits. One unusual project investigates

RE enrichments along a regional fault without evidence of magmatic origin (La Paz, USA; see Appendix 1).

Recently, mine tailings that contain significant amounts of RE but have not been mined in the past for technical and/or economic reasons have come into focus. Already in production is the extraction of monazite from the Eneabba tailings, which were created by mining heavy mineral sands from the associated placer deposit. Additionally, ore processing waste from uranium or coal mining is as an RE resource is part of basic research. These "technogenic deposits" may contain recoverable RE contents and the raw material is available without spending additional money on mining. In cases where improperly disposed waste from former uranium mining or abandoned uranium mines left a hazardous heritage, reprocessing of these waste piles and the proper disposal of the residue may even contribute to an environmental clean-up.

RE can thus be mined as main products or by-products. A main product bears all mining costs and production may be adapted to demand changes while production of by-products may not respond even when price increases are very strong. However, extraction of by-products is associated with only limited additional costs. Thus, the paired occurrence of RE with other products has important implications on the reaction to demand changes. Mines that produce REE as by-products may not react adequately to changes on the demand side. On the other hand, they are economically more robust in times of volatile RE prices because other minerals contribute more to the mine revenue than the RE.

The Mongolian RE deposits and occurrences investigated in this study are associated with carbonatite rocks (Mushgai khudag, Khotgor, Lugiin gol), hydrothermal-metasomatic alteration (Ulaan del) or located in an alkaline intrusive complex (Khalzan buregtei) and a monazite placer (Tsagaan chuluut), respectively.

Mining of RE Ore

The economic viability of an ore deposit is also dependent on the mining method applied to extract the ore. The selection of a mining method depends on many parameters. Proximity to the surface and a low waste: ore ratio are strong criteria for open pit mining. Other parameters for the selection of mining methods are morphology of the ore body (geometric outline and attitude), nature of the contact between ore and sterile host rock, internal distribution of ore grade within ore body (because of ore dilution) and geotechnical properties of ore and host rock.

Most RE deposits are mined in open pit operations. Open pit mining costs are approximately 1/3 of underground mining costs. However, underground mining is reasonable when access to the ore body is not possible via the surface (e.g., ore body under a lake), the cost of overburden removal is too high, the ore occurs in small, tabular bodies, or when underground mining facilitates the storage of hazardous waste by paste backfilling.

The cost for mining in the RE supply chain is relatively low compared to downstream processing. With an average intended ore throughput of about 1,000 to 5,000 tons per day at the RE projects considered (except for outliers, excluding placer deposits), the mass of material moved (waste and ore) is small compared to base metal mining. Mining costs are addressed in the chapter "The production chain of RE: from ore to metal oxide".

Waste streams and hazards of RE ore processing and refining

All waste streams from mining and processing rare earths can create radioactive hazards because RE minerals are naturally radioactive, mainly because of accessory uranium and thorium.

The disposal of radioactive substances and other mining waste is costly, prone to accidents. It has caused significant environmental damage and several permitting delays. Examples are :

- At Bukit Merah, Perak, Malaysia, the REE extraction from monazite- and xenotime-bearing by-products of the regional tin placer between 1975 and 1994 had generated large quantities of radioactive residues (2,250 t per year with 328 t ThO₂ and 13 t UO₂). It became one of the largest radioactive waste remediation cases in Southeast Asia due to inadequate waste management by the operator Asian Rare Earth, in which the Japanese company Mitsubishi Kasei was the major shareholder and is still engaged in an US\$ 100 million clean-up.
- The LAMP (Lynas Advanced Material Plant) in Kuantan, Malaysia was behind schedule because of permitting delays for the tailings and is still affected by the long-lasting social conflicts and protests related to the further processing of RE concentrates.
- Prior to closure in 2002, the Mountain Pass RE mine in California, USA, was discharging over 3,000 l/min of saline radioactive wastewater into inadequately sealed tailings ponds. Pollutants leaking from pipelines were the main reason for the (temporary) closure. Today, the Mountain Pass mine, with its largely closed water circuit, is one of the positive examples of RE mining.
- One of several reasons why China is strictly controlling the RE output is the environmental impacts caused by RE mining and processing. With the intention of lowering the ecological damage, China has strongly consolidated the national RE market and has closed illegal operations.
- The Kvanefjeld rare earth project in Greenland, one of the largest RE deposits out of China, is on hold because the new government recently passed a law setting the uranium threshold limit at 100 parts per million that cannot be met with the existing operation plan.

In Mongolia, the Minerals Law, the Environmental Law, and the Law on Nuclear Energy regulate environmental matters related to the mining and processing of rare earth elements.

The original exploration literature of the Russian geologists, and later exploration campaigns and field visits, show the presence of uranium and thorium. In fresh samples from Mushgai khudag, the occurrence of the RE mineral monazite, which is a carrier of thorium, has been shown by GRAUPNER (2012). The fact that Gamma-spectrometry is a common exploration tool in RE exploration, highlights the presence of radioactive minerals. For the Khalzan buregtei deposit in western Mongolia, it was found that the concentrations of thorium and uranium are correlated with the REE contents, that is, ore with higher grade contains higher levels of radioactive elements (see ELSNER et al. 2011).

Despite the lack of detailed investigations on the presence of radioactive elements in the Mongolian RE deposits, it is beyond speculation that radioactive substances will accumulate in the waste stream. Whether the amount of radionuclides will reach a level, which makes it necessary to separate the waste into "non-hazardous" and "hazardous" waste can be clarified once technological investigations are completed.

Traces of sulfide minerals have been described in the carbonate ores of Mushgai khudag, Khotgor and Lugiin gol, but acid mine drainage will not be a problem. The acid generation potential is extremely low due to the neutralizing properties of the carbonate minerals.

The Labor Safety Law and the Nuclear Energy Law clause 43 addresses the hazards related to the inhalation of dust containing radioactive isotopes of the uranium or thorium families.

The production chain of RE: from ore to metal oxide

Production steps

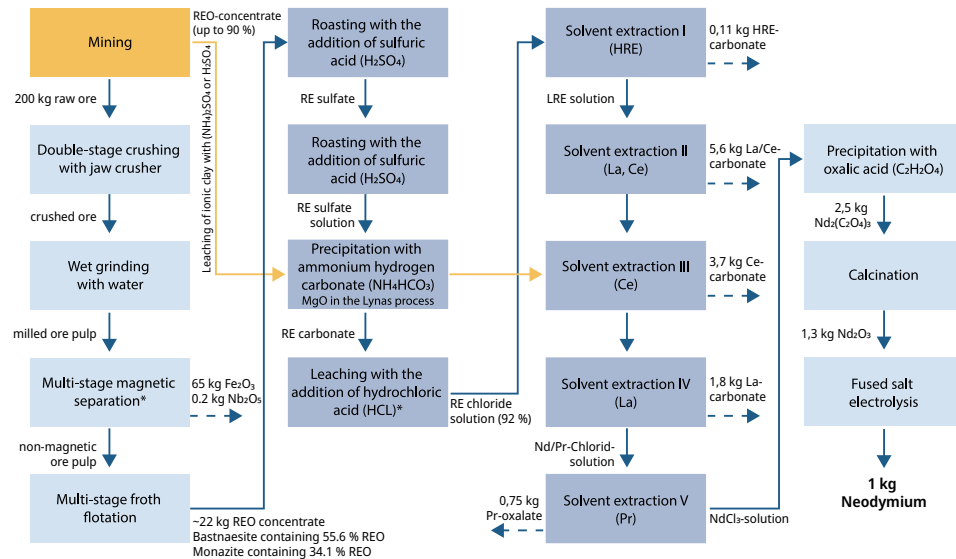


Figure 3: Simplified process chain for the production of 1 kg neodymium modified according to SCHREIBER et al. (2016) and MARX et al. (2018). The values (blue) refer to mining in Bayan Obo and further processing in Baotou (China; simplified mass balance based on literature data for ore grade and recovery rate). The Lynas production process in Mt. Weld (Australia) or Kuantan (Malaysia) follows the same principle (the process steps marked with * do not take place here). After leaching of ion adsorption clays (orange route), no further processing steps are necessary, and the basic steps of further processing are generally comparable (individual process steps may be modularly adapted).

- **Milling and beneficiation:** this step grinds the ore and produces a concentrate of REE minerals by gravity, magnetic and flotation techniques. The rock is ground down to a powder with a grain size smaller than the grain size of the ore minerals. The finer grained the ore, the more costly the milling process. The product of this step is a physical concentrate.
- The RE concentrate is dried, afterwards roasted with the addition of sulfuric acid and then digested with sulfuric acid. The dissolved RE are precipitated from the solution with ammonium hydrogen carbonate and subsequently washed and dried. In a new leaching step, the precipitates are transferred to a chloride solution with 92 % RE content via the addition of hydrochloric acid for subsequent separation by solvent extraction.
- **Solvent extraction (alternatively ion exchange):** The individual RE can then be selectively separated using organic solvents. At least twelve extraction steps must be carried out for each RE element (SPRECHER et al. 2014). Potential impurities such as Fe or Th require additional complex purification procedures.
- The RE chloride solution generated by solvent extraction is precipitated with oxalic acid followed by calcination resulting in separated REO with a purity of 99.99 %. For the production of a pure RE metal, e.g. Nd for magnet production, fused-salt electrolysis is used in the following. For the production of dysprosium, further process steps not specified here are necessary (mainly relevant for concentrates from ion adsorption clays).

RE production is much more complicated than the production of well known base and precious metals. This is because the individual rare earth elements, which are mined as a group, must be separated from each other. Years are spent on testing at a laboratory and pilot plant scale for the most efficient and economic method to recover the RE from the ore.

It is beyond the scope of this study to provide a detailed description of the RE metallurgy, and therefore only a generic process chain of RE ore from a carbonatite deposit, to which for example Mushgai khudag, Khotgor and Lugiin gol of Mongolia belong, is outlined in Figure 3. Further processing of RE concentrates from bastnaesite and monazite is comparable for most basic process steps. However, it can be assumed that the process steps differ significantly in detail, simply because of the different composition of the ores.

Production costs and prices of RE

Cost estimates

Operating and capital expenditures can be obtained from technical reports and Preliminary Economic Assessments (PEA) disclosed by many companies. The cost data used in this study have been collected from literature and technical reports. Cost estimates for the final production step, that is the metal refining stage, are not included.

Capital expenditures (CapEx)

The capital costs for RE mining and processing facilities are in the order of several hundred million to more than one billion US\$. Due to the relatively low tonnage mined per day, investments in the mining stage generally account for less than 15 % of total CapEx (including shipping and transport of the equipment to the site, plus initial stocks of spares).

Capital expenditures related to the processing of RE (concentrator plant, acid cracking plant, acid storage facilities) are above 1/3 of all the capital expenditures.

Investments in infrastructure depend strongly on available public transport infrastructure and the availability of electric power from a power grid. Because of the wide spread of capital expenditures published for construction, no numbers are quoted here for comparison.

The preparation and operation of waste disposal sites and tailings ponds, as well as mine closure and rehabilitation, also require high levels of investment. For a mine with a capacity of 4,000 t of ore per day and a life of 25 years, it seems reasonable to earmark 5 to 10 % of the total investment for waste management and mine closure.

Operating expenditures (OpEx)

Mining operating costs fluctuate throughout the life of the mine as total cycle time increases as the mine deepens. The data used are average life of mine assumptions, without considering inflation. Processing costs depend on the quality of the ore and the ore grade. Low-grades and fine-grained ores with complex intergrowths and mineral assemblages cause the highest operating costs. A superficial calculation of OpEx estimates in technical reports, still subject to uncertainty, indicates a cost for conventional ores (mainly carbonatite and peralkaline deposits in Australia and Canada) of about US\$ 100 to US\$ 400 per t ore processed (cf. Appendix 1).

By and large, the cost of projects in cold climates is higher than in more southern areas because of the need to build confined and thermally insulated workspaces and the limited efficiency of mechanical equipment.

A breakdown of the OpEx by production stages gives the following proportions:

- a) **Mining:** The mining phase accounts on average for 5 to 10 % of total operating costs (i.e. ~US\$ 5 to US\$ 40/t ore). Energy costs (e.g. diesel) and maintenance (including spare parts) are the main cost components of mining. Underground mining is about 3 to 5 times more expensive than open pit mining. Due to climatic conditions, open pit mining costs for Mongolia's RE deposits would be at the high end compared to other countries.
- b) **Processing:** In most published cost estimates, the operating costs for the milling and beneficiation stages, leaching and separation steps are cumulated and published as "processing costs". They cause up to 80 % of total OpEx (i.e. ~US\$ 80 to US\$ 320/t ore). Chemical reagents are the most costly consumable in this step. Some sources indicate that 1/3 of the processing costs are incurred in the milling and flotation unit, and 2/3 of the OpEx are incurred in the hydrometallurgy and precipitation facilities.
- c) **Sales, General & Administration (SG&A)** as product transport and tailings operation account for the remaining OpEx.

Not included in the OpEx are costs for mine closure and remediation and the exploration costs outside of the mining license area.

Capital and operating expenditures are strongly dependent on the performance of the processing plant, the recovery, and the consumption of reagents. For the Mongolian RE deposits, these processing tests have only been conducted on a laboratory scale (see Appendix 2: Mongolian RE deposit passports). Pilot scale processing tests are necessary before a reliable assessment of the economics of Mongolian RE deposits can be made.

RE price development

Prices of individual RE elements vary widely and ores containing a high proportion of high-priced REE have a clear economic advantage. The unit price of RE ore is expressed by a "basket price", which is the theoretical price that could be obtained for one kilogram of fully separated RE oxides, containing RE oxides in the same proportions as found in-situ within the deposit. In addition to RE, many by-products can contribute to mine revenues. Niobium, zirconium, uranium, tantalum are often by-products or co-products of RE deposits associated with alkaline intrusive complexes, while phosphate, fluorine, and iron can be recovered as by-products from carbonatite-type ore.

With regard to Mongolia, the results of systematic sampling of the entire ore bodies, determination of the REE basket price, the technological investigations on the recovery of REE and feasibility of by-products or co-products are not available, but are important for evaluating deposits and should be included in any assessment scheme. At least for the Lu-giin gol deposit a bulk sample (total 50 t oxidized and primary carbonatite ores) have been sampled from a representative ore body and tested in Poland for extraction of valuable concentrates of total (T)REO. Processing tests showed possible extraction of REO concentrate with >33 % TREO from carbonate ore by flotation.

Primarily due to the increasing influence of speculators and the artificial tightening of supply by Chinese manufacturers in 2010 and 2011, RE prices have risen dramatically, leading to an intensification of RE exploration. However, it was the demand side, which calmed the tense market situation by substitution and miniaturization of appliances. Thereafter, prices

for RE settled back to a relatively low level (Figure 4 top). With the recovery of the global economy after the first wave of the corona pandemic, there has been a sustained increase in the price of most rare earths, particularly Nd-Pr, which is important for high-powered permanent magnets. However, since early 2022, prices for Nd and Pr have begun to decline. Other LREE such as La remain permanently at a low level. (Figure 4). Thus, the economic viability of LREE deposits, such as those mainly found in Mongolia, is also dependent on the revenue from Nd-Pr.

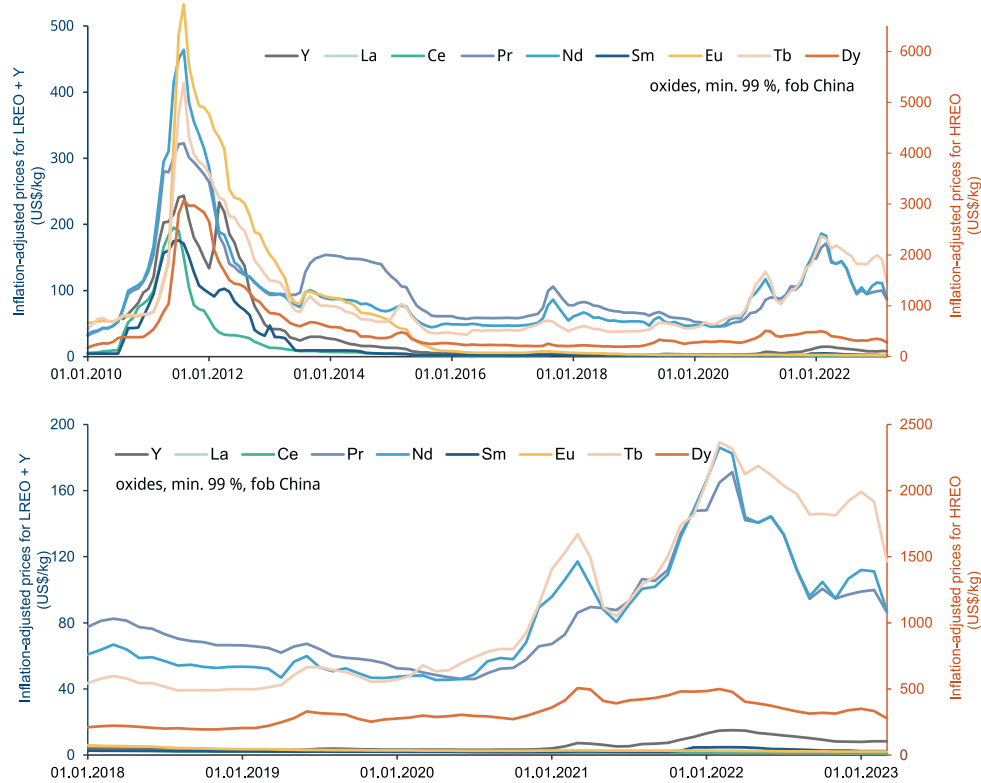


Figure 4: Inflation adjusted prices (US consumer price index (CPI), basis 2022) for LREO + Y (primary axis, blue/grey) and HREO (secondary axis, reddish) in US\$/kg from Jan 2010 to Mar 2023 (top) and in a close-up from Jan 2018 to Mar 2023 (bottom).

Global supply and demand situation and resources of RE

Supply

World mine production of REO in 2021 was 262,600 t, of which 64 % was extracted in China (according to the official production quota). Since 2013, a slight diversification of global rare earth mine production is observable with increasing production especially in the United States, in Myanmar and in Australia.

Next to general independence efforts, this is also related to the successfully curbed illegal production in China by consolidating the RE market and introducing strict production quotas (Figure 5). On the one hand, this has reduced pollution in China. On the other hand, it has greatly increased the market power of the state-owned RE companies. To date, two of the only four remaining RE companies in China that are in fact controlled by the government control more than 50 % of the global rare earth market. The supply gap created by the decline in illegal Chinese mine production has been partly filled by low-standard production of ionic clay in Myanmar. The RE concentrates from Myanmar and several other global mines are processed in China, resulting in a global share of 85 % (nearly 100 % for HREE).

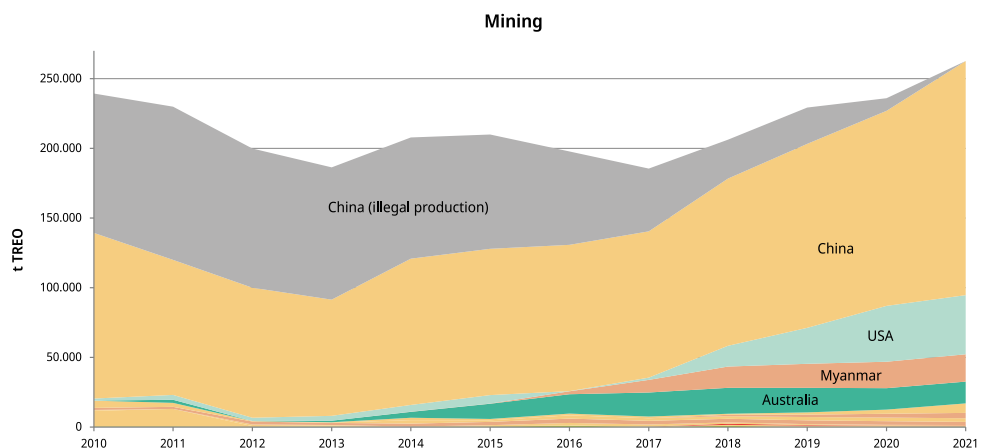


Figure 5: Mine production of rare earth oxides. The colours on the background indicate the governance rating of the respective countries, which were calculated using the mean value of the World Bank's Worldwide Governance Indicators (WGI; see Figure 7).

About 70 % of global REO production comes from carbonatites or its weathering products that are mainly exploited in industrial scaled open pit mines (LANGKAU & ERDMANN, 2020; Figure 6). With a global market share of about 25 % in 2021, the Bayan Obo carbonatite deposit (Inner Mongolia, China) is by far the largest RE mine. At Bayan Obo, extraction occurs as a by-product of (niobium-)iron ore production. In 2021, ores with 15,600 t REO content from the Australia based Mt. Weld mine (a strongly weathered carbonatite deposit) were processed in Malaysia. After multiple deferrals due to environmental compliance issues and financing problems, the Mt. Pass mine in the U.S. has been resume production of rare earth concentrates from bastnaesite hosted in a carbonatite body in 2018. The

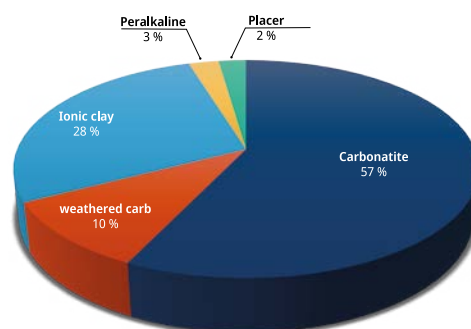


Figure 6: Estimated production share of the different deposit types in global RE mine production in 2021.

REO content of the concentrates was 42,400 t in 2021. In contrast to previous production, the rare earth concentrates are currently not processed into REO on site, but are exported to China for further processing. Following efforts by operator MP Minerals Ltd. and pressure from the U.S. government, downstream processing is expected to return to the U.S. by 2023 with lower costs and reduced environmental impact.

Ion adsorption clays in southern China and Myanmar account for about 16 % of global REO extraction (~42,000 t in 2021). In addition, prior to 2018, an estimated additional 40,000-150,000 t of REO per year were illegally/unofficially extracted from ion adsorption clays by approximately 200 small-scale mining sites in southern China (SCHÜLER-ZHOU 2018). Due to consolidation of the RE market in China and stricter implementation of controls, the illegal production could be almost curbed in 2021. Since 2017, large quantities of rare earth concentrates have been extracted in Myanmar on the border with China, mainly from ion adsorption clays, which have been brought to China for further processing (~20,000 t REO in 2021). Little is known about the exact origins and sustainability of extraction, and there are also reports of "laundering" of rare earths actually mined illegally in China, which is a possible explanation for why export figures are higher than actual production volumes (ROSKILL 2021).

Monazite extraction as by-product from placer deposits is currently occurring in a variety of countries (including USA, Australia, Vietnam, Thailand, Malaysia, Mozambique, South Africa, and Brazil). Largest producers of heavy minerals from placer deposits in 2021 were India and Madagascar. The specific production volume of rare earths from heavy mineral sands (HMS) is difficult to quantify because the monazite content in the extracted heavy mineral concentrates is often not reported.

Production and processing of monazite (and xenotime) mineral concentrates as by-product from HMS has increased significantly in recent years. The material is usually exported to China where it is processed as a by-product from titanium zircon mineral sand and the monazite is separated for subsequent rare earth processing. In China, the China Nuclear Group is the only company that holds a qualified licence to process monazite mineral concentrates. It co-operates with Shenghe Resources to source and import monazite concentrates for processing. This trend is expected to continue in the coming years.

There are a large number of heavy mineral sands operations globally. Greater integration at major HMS producers could provide an opportunity for further growth. However, the relatively high thorium and uranium content of monazite in most HMS continues to ham-

per project development. Radioactive material must be processed, stored and transported according to the Class 7 material guidelines.

The only active mining of peralkaline magmatites is currently taking place in Lovozersky, Russia, with an effective annual production of ~2,300 t REO. However, as indicated in Figure 7 and in Appendix 1, several peralkaline deposits are about to start (pre)production. On the one hand, these ores bear a complex mineralogy that complicated processing. On the other hand, with comparatively large amounts of HREE, their composition is ideal for the ratio of HREE/LREE demanded for magnets. Moreover, they contain only small amounts of thorium and their processing has a comparatively low environmental impact (WENG et al., 2016; LANGKAU & ERDMANN, 2020).

Worldwide resources situation

The resources of rare earths amount to more than a thousand times the current annual production and are thus significantly higher than for all other economically strategic metals (internal calculation of BGR). However, mining in countries with large resources, such as Brazil or Russia (21 million t REO content each; USGS 2023), currently takes place only to a very limited extent or not at all. Main reasons for this are on the one hand, the problematic economic viability of new rare earth projects, since the equipment required for further processing is very complex and therefore cost-intensive. On the other hand, low world market prices until 2020 and environmental concerns have prevented any of the numerous well-explored rare earth projects outside China (see Figure 7) from going into production.

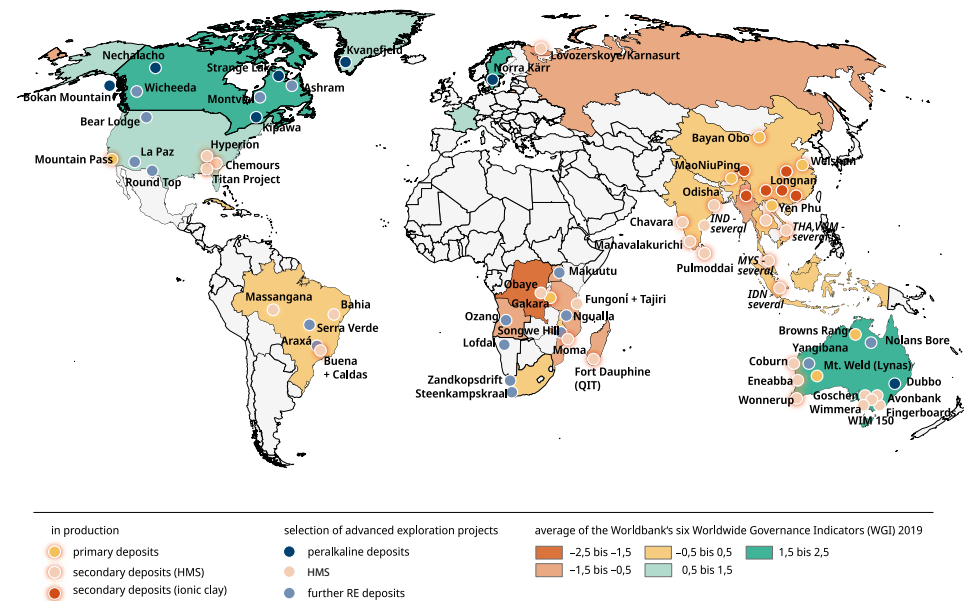


Figure 7: Producing rare earth mines and selected advanced exploration projects outside China. The colours on the background indicate the governance rating of the respective countries, which were calculated using the mean value of the World Bank's Worldwide Governance Indicators (WGI). Peralkaline deposits are listed separately due to their particular importance for potentially more environmentally friendly extraction. The numerous RE extraction sites from ion adsorption clays in China and Myanmar are shown here only as examples. For details on the single projects, see Appendix 1.

Demand

An important use of rare earths today, besides the use of mainly La and Ce as catalysts, in polishes and in metallurgy, is its use in neodymium-iron-boron (NdFeB) permanent magnets (Nd, Pr, Dy), which become heat-resistant thanks to the addition of ~8 % Dy (the average Nd/Pr content is 24 %). Especially for the energy transition, Nd and Dy play a crucial role in the generators of large offshore wind turbines and - most important in terms of quantity - in electric motors e.g. for the automotive industry. In particular, demand for these RE metals is expected to grow at an average annual rate of 6% through 2030, and total demand could increase from the current 131,000 t REO to 188,300 t REO (Figure 8; ROSKILL, 2021).

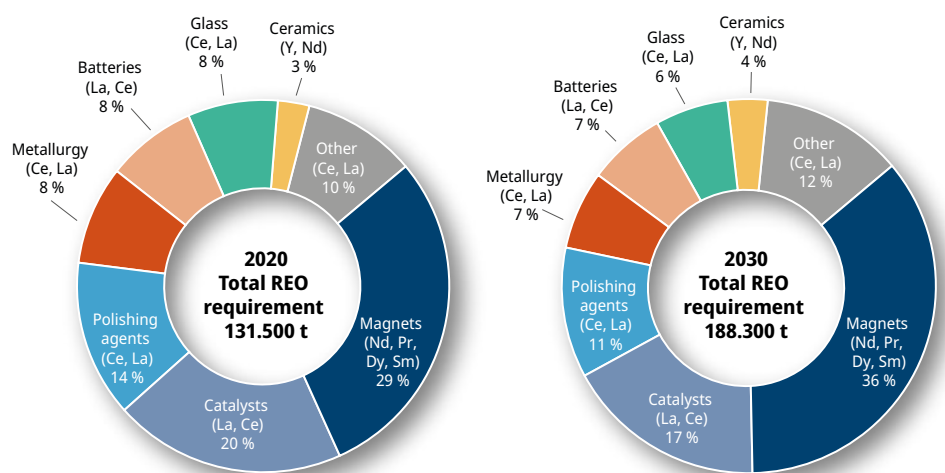


Figure 8: Total REO demand in 2020 and demand forecast for 2030, shown by use in %. The most important RE elements for each application are shown in brackets in descending order (BGR 2021; data/source ROSKILL 2021).

Valuation of principal RE deposits and occurrences in Mongolia

In Mongolia, the most promising RE deposits are associated with carbonatites (Southern Mongolia/Gobi desert) and alkaline felsic igneous systems (Western Mongolia; Figure 9). Compared to the assessment of Mongolia's principal rare earth deposits made in the first study published in 2013, little exploration effort has been made since then on the rare earth projects presented there. In addition to the three carbonate-bearing deposits Khotgor, Mushgai khudag and Lugiin gol the peralkaline deposit Khalzan buregtei presented in the earlier study and considered again here, two additional projects are newly considered: Ulaan del (peralkaline deposit) and the Tsagaan chuluut monazite placer in Eastern Mongolia (Figure 9).

While Lugiin gol, Ulaan del and Tsagaan chuluut are at an early exploration stage and can be considered occurrences rather than deposits, Khotgor, Mushgai khudag and Khalzan buregtei have recently been assessed as deposits of significant economic importance (DOSTAL and GEREL 2023). However, these deposits are also at a relatively early stage of exploration compared to the numerous rare earth projects around the world, and only a pre-feasibility study has been completed for Khotgor to date (according to NGS, a feasibility study for Khotgor is existent in their archives, but it is not publicly available). This section provides a brief description of the criteria useful evaluating the RE deposits in Mongolia with regard to the recent global market situation, including extensive diversification efforts.

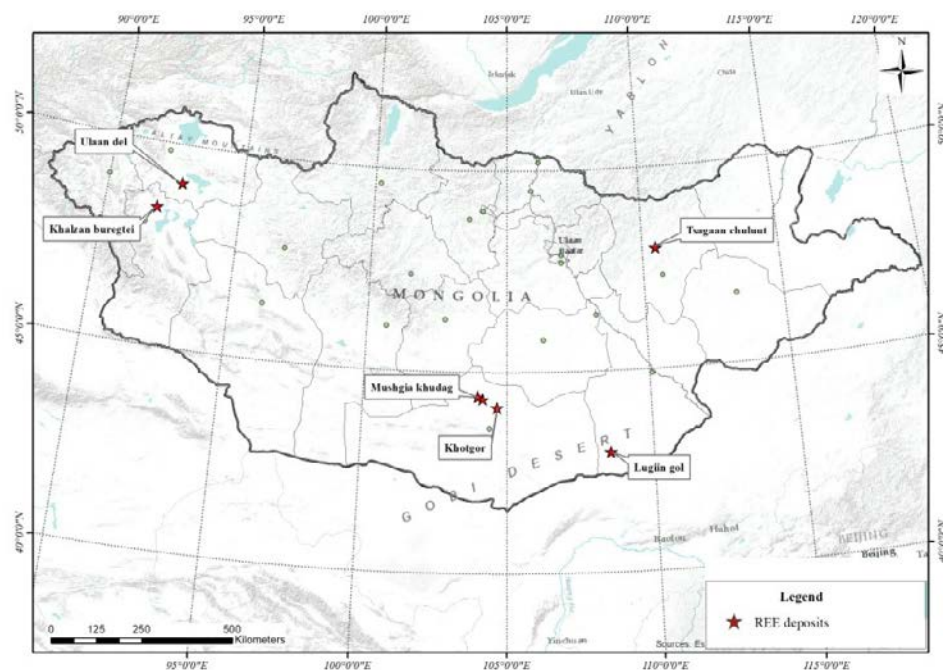


Figure 9: Location of the Mongolian RE deposits and occurrences considered in this report.

Peer group table

With the intention of finding out how to place the Mongolian RE deposits in a market entry scenario, a peer table of operating RE mine sites, selected RE exploration projects and the Mongolian RE deposits was compiled (Appendix 1). Information on the global projects have been compiled from available technical reports, scientific publications and public domain information sources. Information on Mongolian deposits has been summarized by expert knowledge of MRPAM derived, for example, from field trips. The resource date is based on the MSPCMR.

For an initial assessment of RE deposits, the following criteria were considered:

- geological factors (quality and quantity of ore body, morphology and dimension of ore body, distribution of valuable elements within the ore body)
- operational factors (production size / life of mine, mining methods required to extract the ore, dilution and losses of ore during mining, REE recovery during mining, efficiency of ore mineral concentration and REE extraction)
- economic factors (costs along the value chain from mine to saleable product, future demand/supply situation, product price, first-mover advantage)
- geographical factors (remoteness, availability of energy, transport, water supply)

These criteria were summarized in the peer table (Appendix 1) as far as possible. However, further important factors of host countries as political stability, ease of doing business, legal and regulatory governance as well as environmental and further sustainability criteria are not considered within this table.

Valuation criteria

The most important criterion for evaluating RE deposits for the purpose of this study is the quality of the ore deposit. For a meaningful comparison of the Mongolian deposits with the international ones, it is necessary to consider the different deposit types relevant for RE mining. Further evaluation criteria for the Mongolian RE occurrences such as economic including infrastructural conditions as well as selected sustainability aspects such as environmental and governance criteria are summarized in Table 6 below. These criteria should be considered at an early stage of deposit evaluation.

Quality of ore deposits

One of the most fundamental requirements for the economic development of a mine is that enough ore with a sufficient grade is present in the ground to ensure that the life of mine revenues are higher than the total costs, and that the quantity of extracted ore can sustainably feed the downstream processing plant. In addition to a high TREO content, the presence of a large quantity of ore is an advantageous criterion, as the high upfront investment for the construction of the processing plant requires a long life of mine, preferably of about 10 years or more.

Carbonatite-hosted group of RE prospects



Figure 10: Aerial view of the Khotgor deposit.



Figure 11: Mushgai khudag main ore body (Camel hill).

The peer table contains 19 carbonatite-hosted RE deposits summarized in Table 3. The selection of the international deposits is based on their significance, which is mainly determined by the development stage and the total TREO content. The resource sized of the 16 international carbonatite-hosted RE deposits comparable to the Mushgai khudag, Khotgor and Lugiin gol deposits of Mongolia range from 2.3 to 313.7 Mt with a mean value of 89.6 Mt (incl. the Mongolian deposits).

Ore grade ranges from 0.2 to 6.6 % TREO with a mean of 2.8 % TREO. The highest ore grade are reported by the mines, which are already in production (Bayan Obo, Mt. Weld, Mountain Pass).

Khotgor (Figure 10) contains 135.4 Mt of ore at an average grade of 1.3 % REO, corresponding to 1.7 Mt of TREO. Mushgai khudag (Figure 11) contains 25.2 Mt of ore at an average grade of 1.4 %, which relates to 0.4 Mt of TREO and Lugiin gol possesses 0.5 Mt of ore at a grade of 2.7 REO, which translates to 0.01 Mt of TREO. Regarding their TREO content, two of the three Mongolian deposits are much smaller than the group mean (2.4 Mt TREO), with the small underground deposit Lugiin gol being at the bottom of the scale. The TREO contained at Khotgor is higher than the median value (1.3 Mt), showing that Khotgor is in the upper half of the deposits of the peer group.

Table 3: Summary of selected carbonatite-hosted REE deposits ordered by decreasing TREO content.

Deposit	Country	Development stage	Reserves		Resources		TREO content (Mt)	Recovery rate (%)	Prod. capacity TREO (t/a)	LoM (a)
			Ore (Mt)	TREO (%)	Ore (Mt)	TREO (%)				
Bayan Obo	China	Operating			160.0	6.0	9.6	64.4	73,550	>50
Ngualla	Tanzania	BFS	18.5	4.8	214.4	2.2	5.5	36.8	10,000	25
Ashram Main	Canada	Pre-feasibility			249.1	1.9	4.7	83.6	16,852	25
Mt. Weld	Australia	Operating	19.5	8.5	55.2	5.4	4.6		26,500	>20
Longonjo	Angola	Feasibility			313.7	1.4	4.5		20,000	15
Montviel	Canada	PEA			266.6	1.5	3.9			
Mountain Pass	USA	Operating	21.0	7.0	34.8	6.6	3.8		39,000	>30
Khotgor	Mongolia	Pre-feasibility			135.4	1.3	1.7	84.7	4,500	23
Bear Lodge	USA	Pre-feasibility	14.2	2.8	46.9	2.8	1.7	79.0	6,800	45
Zandkops-drift	South Africa	Pre-feasibility	41.1	1.9	16.5	3.0	1.3	66.4	8,000	20
Araxá	Brazil	Suspended			28.3	4.2	1.2	92.0	1,000	40
MaoNiu Ping	China	Operating			20.0	4.1	0.8	63.3	19,750	
Songwe Hill	Malawi	Feasibility	8.5	1.6	48.5	1.4	0.8	48.4	2,841	18
Yangibana	Australia	Pre-production	12.2	1.1	20.8	1.1	0.4	77.3	8,500	15
Mushgai khudag	Mongolia	Exploration			25.2	1.4	0.4	60.0	14,000	11
Wicheeda	Canada	PEA			11.4	2.0	0.2	77.3		
Lofdal	Namibia	PEA			53.4	0.2	0.1		1,500	15
Weishan	China	Operating			2.3	3.7	0.1		6,000	
Lugiin gol	Mongolia	Exploration			0.5	2.7	0.0	70.0	377	26
Arithmetic mean			19.3	4.0	89.6	2.8	2.4	69.5	17,635	23
Min value			8.5	1.1	0.5	0.2	0.0	36.8	377	11
Max value			41.1	8.5	313.7	6.6	9.6	92.0	73,550	45
Median			18.5	2.8	46.9	2.2	1.3	70.0	9,250	22

Alkaline intrusive complex group of RE prospects

Peer Table 4 contains twelve RE prospects associated with alkaline complexes, of which the Khalzan buregtei and the Ulaan del deposits in western Mongolia are members. The mineral resources of the group range from 5.8 to 1033.0 Mt with a statistical mean of 344.0 Mt and a mean ore grade of 0.7 % TREO resulting in an average TREO content of 2.9 Mt. However, resources of the peer group vary considerably, which is reflected by the significantly lower median. In particular, the Kvanefjeld deposit in Greenland with a total REO content of 12.6 Mt is outstanding, while the Round Top deposit (USA) has a comparable ore content to Kvanefjeld but a significantly lower ore grade and thus an average TREO content.



Figure 12: Khalzan buregtei deposit. Photo from Mongolian National Rare Earth Corporation LLC (MNREC, 2021).

Compared to these values, Khalzan buregtei (49 Mt of ore with a mean ore grade of 0.6 % TREO according to ELSNER et al. 2011; Figure 12) is a low to medium-tonnage deposit with an ore grade comparable to the median of the peer group. The figures reported to the MSPCMR by Mongolian National Rare Earth Corp (MNREC) LLC, which wholly owns the Khalzan buregtei project and has intensified exploration work since 2021 are significantly higher (513 Mt of ore grading 0.46 %, equivalent to a TREO content of 2.0 Mt; see Appendix 2). However, since these data are not confirmed in any other source, both figures are given here. RE deposits hosted in alkaline intrusive complexes often contain additional rare metals as co-products or by-products and further exploration work is necessary to find out whether the tantalum, niobium and zirconium present in Khalzan buregtei can be economically recovered.

Table 4: Summary of selected (per)alkaline-hosted REE deposits ordered by decreasing TREO content.

Deposit	Country	Development stage	Reserves		Resources		TREO content (Mt)	Recovery rate (%)	Prod. capacity TREO (t/a)	LoM (a)
			Ore (Mt)	TREO (%)	Ore (Mt)	TREO (%)				
Kvanefjeld	Greenland	Pre-production	107.0	1.4	1010.0	1.1	12.6	72.2	7,900	
Lovozer-sky	Russia	Operating	18.0	0.9	593.0	1.1	6.8		3,600	40+
Nechalacho	Canada	Pre-production			342.9	1.4	4.8	92.7	9,286	23
Strange Lake	Canada	BFS			492.5	0.9	4.5	46.2 - 81.4	14,000	30+
Dubbo Zirkonia	Australia	Pre-production	18.9	0.8	75.2	0.8	0.7	72.3	3,250	40+
Round Top ¹	USA	BFS			1033.0	0.1	0.6	71.5	3,338	20
La Paz ²	USA	PEA			128.2	0.4	0.5			
Norra Kärr	Sweden	PEA	23.5	0.6	31.1	0.6	0.3	76.4	5,150	26
Khalzan buregtei	Mongolia	Exploration			49.0 (513.7) ⁵	0.6 (0.5) ⁵	0.3 (2.0) ⁵			
Kipawa	Canada	Feasibility			23.5	0.4	0.1	67.3	3,473	13
Bokan Mountain	USA	Pre-production			5.8	0.6	0.0	82.5	1,828	11
Ulaan del ³	Mongolia	Exploration			0.1	0.1	0.0	80.0		
Arithmetic mean ⁴			41.9	0.9	344.0	0.7	2.9	76.4	5,758	19
Min value			18.0	0.6	5.8	0.1	0.0	67.3	1,828	11
Max value			107.0	1.4	1033.0	1.4	12.6	92.7	14,000	26
Median			21.2	0.8	128.2	0.6	0.6	72.3	3,600	20

1 Rhyolite intrusion

2 Mineralized detachment fault

3 Hydrothermal-metasomatite alteration ore bodies

4 without Ulaan del, so as not to distort the average values

5 values in brackets reported to the MSPCMR (see text and Appendix 2)

The Zr-REE-bearing hydrothermal-metasomatically altered alkaline dikes of Ulaan del are a very low-tonnage, low TREO occurrence. Resources are reported for only 146 of the 300 mapped and sampled metasomatite dikes in the deposit area outside the ore fields.

Despite the relatively high amounts of valuable HREE such as Dy and the mostly lower environmental impact compared to other deposit types, only one peralkaline deposit is currently in operation (Lovozer-sky, Russia). This is mainly due to the complex mineralogy of oxide ores such as eudialyte, for which no established processing technology is available.

Placer deposit group of RE prospects

The production and processing of monazite (and xenotime) mineral concentrates as a by-product from existing or new HMS placer deposits has increased significantly in recent years and is occurring in a variety of countries (including USA, Australia, Vietnam, Thailand, Malaysia, Mozambique, South Africa, and Brazil). The largest active mines are located in

India and Madagascar. The specific production volume of rare earths from HMS is difficult to quantify because the monazite content in the extracted heavy mineral concentrates is often not reported. Peer Table 5 lists selected operating and advanced explored REE-bearing placer deposits in comparison to the Mongolian placer Tsagaan chuluut.

Table 5: Summary of selected REE-bearing placer deposits ordered by decreasing TREO content.

Deposit	Country	Development stage	Reserves		Resources		TREO content (Mt)	Prod. capacity TREO (t/a)	LoM (a)
			Ore (Mt)	TREO (%)	Ore (Mt)	TREO (%)			
OSCOM	India	Operating			3.06 ¹	50.00	1.53	6,000	
Donald	Australia	Feasibility	602.0	0.05	2427.0	0.06	1.46	3,550	
Manavalakurichi	India	Operating			2.46 ¹	50.00	1.23	3,000	
Chavara	India	Operating			1.84 ¹	50.00	0.92	2,250	
WIM 150	Australia	BFS	552.0	0.07	1650.0	0.05	0.90	5,000	
Fort Dauphine	Madagascar	Operating	358.0	0.04	1427.0	0.05	0.68	Ø 3,300	
Fingerboards	Australia	BFS	170.0	0.11	1190.0	0.03	0.36	12,000	15-20
Goschen	Australia	Pre-feasibility	199.0	0.09	629.0	0.05	0.34	3,780	20
Avonbank	Australia	BFS	312.0	0.07	490.0	0.06	0.29	10,000 ³	30
Titan Project	USA	PEA			431.0	0.05	0.20	4,389	
Eneabba	Australia	Operating	0.96 ²	10.35			0.10	12,000	9
Moma	Mozambique	Operating	820.0	0.01	6368.0		0.10	3,000	>100
Tsagaan chuluut	Mongolia	Exploration			0.6	0.07	0.0004 ⁵		2.5
Arithmetic mean ⁴			430.4	0.06	1826.5	0.05	0.68	5,689	35
Min value			170.0	0.01	431.0	0.03	0.10	2,250	9
Max value			820.0	0.11	6368.0	0.06	1.53	12,000	>100
Median ⁴			358.0	0.07	1308.5	0.05	0.52	4084.5	20

1 Monazite content with 50 % TREO

2 Monazite tailings

3 RE concentrate with xenotime (>33 % HREO) and monazite (>55 % LREO)

4 for reserves and resources without OSCOM, Manavalakurichi, Chavara, Eneabba and Tsagaan Chuluut, so as not to distort the average values

5 not considered for arithmetic mean and median

Tsagaan chuluut was first discovered in 1952 during geological mapping and prospecting work. The occurrence is a typical placer along shallow valleys in granites that has a continuous strip shape and is relatively stable in three spatial directions. The total resources of the occurrence were registered with the MSPCMR and indicated a monazite grade of only 275 t and a mine life of 2.5 years. Other sources indicate a monazite content of at least 758 t (BMW 2021). However, compared to the advanced explored deposits internationally or those in operation, with an average total REO content of 680,000 t, the Mongolian occurrence is far too small to be competitive (Table 5). In addition, the relatively high thorium and uranium content of monazite in most HMS (e.g. 7.4 % Th₂O₃ in Tsagaan chuluut) makes exploitation complicate. Radioactive material must be processed, stored, and transported in accordance with the guidelines for Class 7 material.

Further evaluation criteria for the Mongolian RE occurrences

Table 6 summarizes the ore deposit quality of the Mongolian RE occurrences as described in detail above and gives a qualitative overview with selected further criteria that should be considered at an early stage of deposit evaluation. Please note that the ranking is a subjective classification of the authors (partly adopted from the initial version of the study) and for a comprehensive evaluation of the occurrences, further aspects, especially with regard to ESG (environmental-social-governance) issues, have to be considered.

Table 6: Evaluation table for Mongolian RE occurrences with selected criteria

	Criteria	Khotgor	Mush-gai khudag	Lugjin gol	Khalzan buregtei	Ulaan del	Tsagaan chuluut
Ore deposit quality	Tonnage, grade	+	-	--	-	--	--
	Complexity of mineral composition	+	-	+	-		+
	Presence of high-price REE	-	-	-	+	-	
Economic criteria	Capital and operational expenditures	+/-	+/-	+/-	+/-		
	Procurement of chemicals	-	-	-	--	--	-
	Offtake agreements, financing	-	-	-	-	-	-
Infrastructural criteria	Proximity to public infrastructure	+/-	-	-	--	--	--
	Availability of consulting and construction services	+	+	+	+	+	+
Governance criteria	Administrative, political and business environment	--	--	--	--	--	--
	Technical and skill risk	-	-	-	--	--	-
Environmental criteria	Rehabilitation and mine closure costs and procedures	-	-	-	-	-	-
	Waste management	-	-	-	+	+	--

Rating compared to the respective peer group:
 ++ very advantageous; + advantageous; +/- neither advantageous nor disadvantageous; - disadvantageous;
 -- very disadvantageous; blank: no information for rating available

Economic criteria

In general, Mongolian RE occurrences have neither a decisive cost advantage nor a disadvantage compared to most members of their respective peer group. Procuring chemicals for processing requires importing large volumes, coupled with exchange rate risks and a dependence on reliable supply from Russia or China. Solid financing, e.g. via offtake agreements, is not available in the early phase of exploration.

Infrastructural criteria

Year-round operation of a RE mine and processing facility requires a well-developed transportation infrastructure, as a large amount of material, fuel and, chemicals must be transported. Most Mongolian RE occurrences will most likely encounter a transportation problem. However, transportation costs for RE projects in Africa, Australia, or parts of Canada will also be high, so transportation costs alone will not be a major disadvantage of Mongolian deposits. Rather, the geographic location as a landlocked country is likely to be important. Intermediate products can only be transported overland to/via China or Russia. Established consultants are generally available for mine planning, environmental and social impact assessments (ESIA), drilling programs, and other tasks.

Governance criteria

Mongolia has a history of fraudulent procedures for obtaining exploration and mining licences due to inefficient public sector institutions and cumbersome administration. The regulatory risk for receiving permits for storage and handling of radioactive waste is considered high, as many institutions at different levels of government are involved. Predictably, there are limited qualified engineers and technicians available on site.

Environmental criteria

In recent years, there have been some improvements in general environmental legislation that includes mining. For example, the principle of compensatory measures has been introduced and laws and regulations for reclamation and mine closure have been improved. However, there is usually a lack of long-term and practicable implementation concepts and measures that have a correspondingly visible impact. The core problem is the lack of, for example, reliable legal frameworks and practicable implementation options based on international standards and the development of long-term planning and utilization strategies. These are necessary for reclamation and subsequent, ecologically worthwhile use of former mining areas.

RE processing is inevitably associated with the accumulation of radionuclides in solid waste and effluents. It is expected that the Ministry of Environment and Tourism (MET) will strictly enforce the environmental law and make no concessions. The presence of radioactive elements such as uranium and thorium is particularly high in placer deposits (Tsagaan chuluut) and presumably lower in peralkaline deposits (Khalzan buregtei, Ulaan del).

Conclusion

Rare earth elements have come into focus in recent years, partly because of their chemical properties, which make them essential for low-carbon technologies, and partly because of Chinese market power, which raises concerns about security of supply. Thus, global diversification efforts, also supported by governmental subsidies, have increased dramatically. In view of this trend, Mongolian RE deposits are becoming more attractive on the one hand, while on the other hand, global competition is increasing and only the most promising deposits will go into production.

About 80 RE occurrences and more than 280 RE mineralizations are known on the territory of Mongolia (BMW 2021, internal communication). In this study, we have considered the three most prospective deposits and three additional occurrences to complete the picture with respect to the different deposit types. Although Khotgor, Mushgai khudag and Khalzan buregtei have recently been assessed as deposits of significant economic importance (DOSTAL AND GEREL 2023), Mongolia's major RE deposits are all at an early stage of exploration (only one pre-feasibility study has been conducted) and only Khotgor is in a competitive position relative to international peers in terms of TREO grade and content.

One disadvantage of Mongolia's RE deposits is their geographical location. All deposits are remote, which requires huge infrastructure investments. Moreover, since Mongolia is a landlocked country, the concentrates have to be transported to/via China or Russia or processed locally, which would require additional investments and know-how. In the latter case, a joint processing plant fed by the carbonatite-hosted RE deposits Khotgor, Mushgai khudag and Lugiin gol in the South Gobi, would be most promising.

In general, RE processing and refining is very important and the global bottleneck. If only concentrates were sold to China, there would be fierce competition with China's own mines and cheaper imports from Myanmar, which are higher quality in terms of high value HREE. On the other hand, RE imports are becoming more important for China, so this could be an option to become a RE producer.

In summary, however, no economic extraction of rare earths is expected in Mongolia in the short and medium term and further exploration efforts are required. The new joint centre on rare earth metals between Mongolia and South Korean announced in 2022 (ASIA NEWS NETWORK 2022) could be a first step to address the enormous challenges in commercializing the RE deposits. This must go hand in hand with an investment-friendly administrative, legal and policy environment.

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Appendix

Appendix 1: Peer comparison table of selected RE projects

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Angola	Longonjo (also Ozango), Huambo	313.7 Mt @ 1,43 % TREO	REE, mainly in monazite and bastnaesite	Feasibility started; Pensana Plc.	Open pit	Carbonatite	<ul style="list-style-type: none"> • Production capacity 20,000 t TREO/a • Processing in Pensana's Saltend rare earths separation facility in the UK (target capacity 12,500 t TREO/a) • CapEx US\$ 130 m • OpEx US\$ 36 / t mineral concentrate
Australia	Avonbank, Murray Basin in Victoria	488 Mt resources (incl. reserves) @ 4.0 % HM; 312 Mt reserves @ 4.3 % HM (0.086 % monazite, 0.026 % xenotime = 0.268 Mt monazite, 0.08 Mt xenotime)	Heavy minerals: zircon, monazite; REE in monazite and xenotime	Bankable Feasibility Study (BFS) and Approvals in progress; WIM resources Pty Ltd.	Open pit, WCP (wet concentrator plant); Shallow sedimentary ore body, approximately 8 km in strike length by 4 km cross strike	Placer, marine sands	<ul style="list-style-type: none"> • Life of Mine 30 years, >450 ktpa of heavy mineral concentrate (HMC) • Construction is expected to commence in 2024 • all the HM Concentrate will be exported to China for further processing • Existing infrastructure within project area - rail, roads, power & water. Located within 300km of several major ports
Australia	Browns Range, Western Australia	8.98 Mt resources @ 0.63 % TREO	REE; xenotime with very high HREE contents (e.g. 8.4 % Dy ₂ O ₃ of TREO)	Operating (pre-production in pilot scale facility); Northern Minerals	Mainly open pit, partly underground; Several near-surface orebodies within the dome structure	Skarn; Dome structure with hydrothermal xenotime bearing veins	<ul style="list-style-type: none"> • Life of Mine 15 years • Recovery Rate 80.4 % • Production capacity in pilot scale 590 t TREO/a, potential production 3860 t TREO/a) • Production of mixed RE carbonate • Relatively low Th and U contents

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Australia	Coburn, Western Australia	1,606 Mt resources @ 1.3 % total heavy minerals	REE; monazite	Operating (production start); Strandline Resources Ltd.	Open pit	Placer, heavy mineral sands	<ul style="list-style-type: none"> Capacity of 54,000 t/a zircon-titanium-monazite-concentrate
Australia	Donald, Victoria	Total Resource of 2,427 Mt @ 4.8 % TVHM (19 % Zircon, 8 % Rutile + Anatase, 32 % Ilmenite, 18 % Leucoxene, 2 % Monazite, 2,330 kt contained Monazite)	Heavy minerals; REE in monazite	Feasibility study in progress; Astron Ltd	Open pit	Placer	<ul style="list-style-type: none"> Combined the Jackson (formerly known as WIM 200) and Donald (formerly known as WIM 250) HM deposits. Astron is building an advanced materials manufacturing base in
Australia	Dubbo, New South Wales	18.9 Mt reserves & 75.20 Mt resources @ 0.75 % TREO	Titanium, zirconium, REE, niobium, hafnium; REE in eudialyte and bastnaesite	Preproduction; Australian Strategic Materials (ASM)	Open pit; Tabular ore body, sharp contacts; fairly regular distribution of value minerals within ore body	Peralkaline; Sub-volcanic trachyte horizontal intrusive body with fine-grained ore	<ul style="list-style-type: none"> Life of Mine 40+ years Recovery Rate 72.3 % Potential production 3,250 t TREO/a Very high CapEx US\$ 1 b OpEx US\$ 230 m/a, mainly for processing Processing initially in South Korea's Ziron Tech plant Low annual revenues from REE (~20 %)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Australia	Eneabba, Western Australia	0,96 Mt reserves @ 16% monazite (~50% REO)	Heavy minerals; REE in monazite	Operating (44.000 t of concentrate were shipped in 2020); Iluka Resources Ltd.	Open pit, WCP (wet concentrator plant); The stockpile physically presents as a body of fine-grained sand, approximately 300 m in length, 150 m wide, varying from 1 to 15 m thickness	Heavy mineral sand tailings stockpiled in a mining void in a placer deposit	<ul style="list-style-type: none"> • Extraction, processing and sale of a historical monazite-rich tailings stockpile at Eneabba. • Phase one: ~10.000 t/a monazite for 2 years • The finished mineral sands concentrate will be exported by ship from Geraldton (2020 44.000 t). • Potential asset life: ~13 years • Capex US\$ 10 m • Payback ~6 month of operation • Phase two: ~16.000 – 20.000 t/a monazite • Further upgrade • Potential asset life: ~11 years • Capex US\$ 20 - 40 m
Australia	Fingerboards Mineral Sands Project, Victoria	1,190 Mt resources @ 0.03% TREO (357 kt TREO); 170 Mt reserves @ 0.11% TREO (190 kt TREO)	REE in monazite and xenotime heavy minerals: zircon, ilmenite, rutile	Bankable feasibility study ongoing, Environmental Effect Statement (EES) and approvals process underway; Kalbar Resources Ltd	Open pit; Heavy mineral sands	Placer	<ul style="list-style-type: none"> • Start of mine operation planned in H₂ 2023 • Production 170 Mt ore/year • Life of Mine 15 - 20 years • Concentrate is to be processed in China (or Thailand) • Capital investment >200 million \$ • Operating costs 60 million \$/ year • Former Gippsland mineral sands project from Rio Tinto, ore body within the Glenaladale deposit

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Australia	Goschen, Victoria	199 MT reserves @ 3.7 % HM (0.13 % monazite = 0.26 Mt monazite) & 629 Mt resources @ 2.8 % HM (~ 0.08 % monazite = 0.51 Mt monazite);	REE in monazite, heavy minerals: zircon, rutile, monazite;	Pre-feasibility study; VHM Ltd	Open pit (truck and shovel), WCP (wet concentrator plant); Heavy mineral sands	Placer	<ul style="list-style-type: none"> Life of Mine 30 years Production 5 Mt ore/a increasing to 10 Mtpa Mine products are proposed to be transported via road or by rail for export overseas The Project will develop and export a combination of refined rare earth oxide products (about 3000 tpa), mixed heavy rare earth carbonate concentrates (about 14,000 tpa) and zircon and titanium minerals (up to 500,000 tpa). There are plans to develop also a rare earth minerals refinery at an established site in regional South Australia.
Australia	Mt. Weld, Western Australia	19.5 Mt reserves @ 8.50 % TREO & 55.2 Mt Resources @ 5.4 % TREO	REE, mainly in monazite Cut-off grade: 2.5 % TREO	Operating; Lynas Rare Earth Ltd.	Operating; Lynas Rare Earth Ltd. Open pit; supergene enrichment over primary ore, drilling and power-shovel	Strongly weathered carbonatite (almost laterite)	<ul style="list-style-type: none"> Life of Mine >20 years Effective production ~24,000 t TREO/a in 2020 Potential future production capacity 45,000 t TREO/a Waste : ore ratio 4.6 : 1 Along with the associated Gebeng plant in Malaysia, Lynas is the largest non-Chinese producer of refined rare earths Low thorium content (350 ppm) compared to other monazite projects due to strong weathering

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Australia	Nolans Bore, Northern Territory	29.5 Mt reserves @2.9% TREO & 55.9 Mt resources @ 2.6%	REE, phosphate, uranium; REE in (flour)apatite and allanite	Feasibility study completed (BFS from 2008); Arafura Resources Ltd.	Open pit; Steeply dipping veins	Hydrothermal veins; Structure related flour-apatite-veins	<ul style="list-style-type: none"> • Life of Mine 38 years • Recovery Rate 85.0% • Potential production 13,000 t TREO/a • high CapEx (US\$ >700 m) • OpEx US\$ ~160 m/a • NPV US\$ 1 b with an IRR of 18.1% • High amount of thorium (3.600 ppm ThO₂) • Life of Mine 38 years • Recovery Rate 85.0Y% • Potential production 13,000 t TREO/a • high CapEx (US\$ >700 m) • OpEx US\$ ~160 m/a • NPV US\$ 1 b with an IRR of 18.1% • High amount of thorium (3.600 ppm ThO₂) • Processing of HRE concentrates at USA Rare Earth LLC's Colorado pilot plant • offtake agreements with three Chinese magnet producers

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Australia	WIM 150, Victoria, Australia	1650 Mt resources (incl. reserves) @ 3.7 % HM (0,078 % monazite = 1.28 Mt and 0.014 % xenotime = 0.23 Mt) 552 Mt reserves @ 4.3 % HM (0.1 % monazite, 0.017 % xenotime)	Heavy minerals: zircon, Titanium dioxide, REE in monazite	Bankable feasibility study; Orient Zirconic Pty Ltd and Million Up Ltd	Open pit; Heavy mineral sand WIM-style fine grained sands characterised by sheet-like geometry	Placer, WIM-style fine grained sands	<ul style="list-style-type: none"> • Project is a Joint Venture between Orient Zirconic Pty Ltd and Million Up Ltd, a Hong Kong based investment fund. Murray Zircon Pty Ltd has been appointed to manage the project on behalf of the Joint Venture. • Strategic review of all historic work is being undertaken • Cut off 1 % THM • Within THM: 2.1 % monazite, 0.38 % xenotime
Australia	Wonnerup, Western Australia	~20,000 t resources @ 5-6 % monazite	REE in monazite	Operating; Tronox Holdings plc	Open pit; Heavy mineral sands	lacer	<ul style="list-style-type: none"> • Production of 1,000 t monazite / a as a monazite-bearing zircon-rutile mixture • Export to China
Australia	Yangibana, Western Australia	12.20 Mt reserves & 20.83 Mt resources @ 1.13 %TREO	REE, zirconium, potassium; REE in monazite	Feasibility study coompleted, pre-production; Hastings Technology Metals Ltd.	Open pit; Monazite veins	Carbonatite	<ul style="list-style-type: none"> • Life of Mine 15 years • Recovery Rate 77.3 % • Potential production 8,500 t TREO/a • CapEx US\$ 278 m • OpEx US\$ 99 m/a / US\$ 15.8 / kg REO • Mixed REO final product with a favorable Nd-Pr grade (38 % of TREO) • Veins strongly radioactive (>1.000 ppm ThO₂)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Brazil	Araxá, State of Minas Gerais	28.3 Mt @ 4.21 % TREO	REE by-product of niobium; REE in monazite, apatite	PEA from 2012, RE production suspended in 2018 due to low RE-prices; Companhia Brasileira de Metalurgica e Mineracao (CBMM)	Open pit; supergene enrichment; gradational contacts	Carbonatite	<ul style="list-style-type: none"> Life of Mine 40 years Recovery Rate 92.0 % Production capacity 1,000 t TREO/a CapEx US\$ 406 m (1st phase) + US\$ 214 m (later expansion)
Brazil	Bahia, State of Bahia		REE in monazite	Exploration, PEA scheduled for 2023; Energy Fuels		Placer	<ul style="list-style-type: none"> Potential production of 3,000 – 10,000 t monazite/a Feed for own processing facilities in the US
Brazil	Buena + Caldas, State of Minas Gerais		REE in monazite	Operating; INB - Indústrias Nucleares do Brasil S.A.		Tailings	<ul style="list-style-type: none"> Production of 800 t monazite in 2021 with a declining tendency
Brazil	Massangana, State of Rondônia		REE in monazite;	Development; Auxico Resources / Cooperativa Estanifera de Mineradores da Amazonia Legal Ltda (“CE-MAL”)		Tin tailings	<ul style="list-style-type: none"> Potential production of 37,500 t monazite
Brazil	Serra Verde, State of Goiás	911 Mt @ 0.12 % TREO	REE in monazite and xenotime	Suspended in during the financing and permitting phase after a BFC from 2018; Serra Verde Mineracao Ltd.	Open pit; vibrosieving, agitated leaching, filtering	Ionic clay; granitic saprolite	<ul style="list-style-type: none"> Potential production 5,000 – 7,000 t TREO/a Suspended in 2020 due to engineering difficulties that require additional investment (US\$ 100 – 150 m)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Burundi	Gakara, Bujumbura Rural	0.01 Mt @ 54.30 % TREO	REE; bastnaesite, monazite	Operating; Rainbow Rare Earths Ltd.	Open pit; Highly enriched REE-veins	Hydrothermal	<ul style="list-style-type: none"> • Life of Mine <10 years • Effective production 200 t TREO in 2020 after an initial production of 678 t TREO in 2018 • Generated RE mineral concentrates are entirely further processed in China
Canada	Ashram (Main), Quebec	249.1 Mt @ 1.88 % TREO	REE, tantalum, fluor spar, niobium; REE in monazite, minor bastnaesite and xenotime; Cut-off grade: 1.25 % TREO	Prefeasibility study ongoing; Commerce Resources Corp.	Open pit; hard ore, drilling and blasting; tabular ore body; irregular distribution of ore minerals within ore body	Carbonatite dykes, no super-genic enrichment	<ul style="list-style-type: none"> • Life of Mine 25 years • Recovery Rate 83.6 % • OpEx US\$ 7.91/kg REO • CapEx US\$ 770 m • Potential production 16,850 t TREO/a • Production of a high grade REE mineral concentrate of +40% REO • Partial refinery producing intermediate products • Located in remote area, own electric power supply • No radioactive or hazardous waste problems

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Canada	Kipawa, Quebec	23.45 Mt @ 0.42 % TREO	REE, zirconium; REE predominantly in eudialyte, minor in mosandrite; Cut-off grade: 0.2 % TREO	Feasibility study ongoing; Vital Metals Ltd. (acquired a 68 % interest in Aug 2021 from former 100 %-owner Quebec Precious Metals Corp.)	Open pit; drilling and blasting, gently dipping tabular ore body	Peralkaline;	<ul style="list-style-type: none"> Life of Mine 13 years Recovery Rate 67.3 % Potential production 3,500 t TREO/a High HREE contents No sulfide minerals, therefore no acid drainage problem U and Th are contaminants in the main REE-Y-Zr mineralization Associated Zeus rare earth project was also acquired by Vital Metals
Canada	Montviel, Quebec	266.6 Mt @ 1.45 % TREO	REE, mainly in huanghoite/cebaite, Nb, Phosphate Cut-off grade: 1.0 % TREO	Preliminary economic assessment/ Scoping; GéoMégA Resources Inc.	Underground	Carbonatite	<ul style="list-style-type: none"> power and road infrastructure available Completion of a demo plant is planned for end of 2021. Full scale plant production target is 550 t "magnet" REE/a
Canada	Nechalacho, Northwest Territories	342,93 Mt @ 1,41 % TREO	REE, zirconium, niobium, tantalum; REE in monazite bastnaesite, allanite and fergusonite	Feasibility completed, start of mining operation; Vital Metals Ltd.'s develops the upper deposit while Avalon Advanced Materials Inc. who completed the feasibility study retain the rights for the larger deeper basal zone	Underground; layered series of rocks with increasing peralkaline characteristics at depth	Peralkaline intrusion; nepheline syenite	<ul style="list-style-type: none"> Life of Mine 23 years Recovery Rate 92.7 % Potential production 9,300 t TREO/a Very high CapEx (US\$ 1.38 bn), mainly for processing facilities OpEx US\$ ~300 m/a Rel. high HREE contents in fergusonite Vital Metals has signed a five-year agreement with REEtec AS (NOR) for the sale of REO products (1,000 t REO/a)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Canada	Strange Lake, Québec	492.5 Mt @ 0.92 % TREO	REE, niobium, beryllium, molybdenum; REE predominantly in allanite, minor in titanite and pyrochlore	Piloting, bankable feasibility study to be completed by 2022; Torngat Metals Ltd.	Open pit; hard rock, irregularly shaped ore body, pegmatite-hosted, variable grade distribution	Peralkaline granite complex	<ul style="list-style-type: none"> Life of Mine 30+ years Recovery Rate 46.2 – 81.4 % Potential production 14,000 t TREO/a Rel. high HREE-content OpEx US\$ 16.0/kg REO CapEx US\$ 615 m (including hydrometallurgical facility in Bécancour) Transport from remote area of deposit to Bécancour facility via hybrid airships
Canada	Wicheeda, British Columbia	11.37 Mt @ 1.96 % LREO	REE in monazite and synchysite/parasite-bastnaesite; Cut-off grade: 1.0 % LREE	PEA to be completed end of 2021; Defense Metals Corp.	Open pit; REE mineralization is preferentially hosted in dolomite carbonatite, xenolithic dolomite-carbonatite, strongly altered – brecciated mafic xenoliths and to a lesser degree, dolomite-calcite carbonatite and syenite.	Carbonatite; Intrusive carbonatite-syenite sill complex	<ul style="list-style-type: none"> Recovery Rate 77.3 %
China	Bayan Obo, Inner Mongolia	160.0 Mt @ 6.00 % (main & eastern part) @ <3.00 % TREO (western ore body)	REE and niobium are co-products of iron ore mining; REE in bastnaesite and monazite	Operating; China Northern Rare Earth Group	Open pit; hard ore; several ore bodies in pit	Carbonatite, hydro-thermal replacement	<ul style="list-style-type: none"> Recovery Rate 64.4 % Effective production 69,400 t TREO/a (mining quota 73,550 t TREO/a)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
China	Longnan, Jiangxi province	48.00 Mt @ 0.073-0.097 % TREO	REE	Operating; China Southern RE Group (joint venture between Ganzhou Rare Earth Group (60%), Jiangxi Copper (JCC; 35 %) and Jiangxi Tungsten Group (5 %)	Injection leaching of the relatively soft ion adsorption clay	Ionic clay	<ul style="list-style-type: none"> • Effective production 8,500 t TREO/a • Very high HREE contents
China	MaoNiuPing, Sichuan province	20.20 Mt @ 3.93 - 4.29 % TREO	RE (only LREE) in bastnaesite are the primary commodity, thus it is the largest primary RE deposit in China	Operating; China Southern RE Group (joint venture between Ganzhou Rare Earth Group (60%), Jiangxi Copper (JCC; 35 %) and Jiangxi Tungsten Group (5 %)		Carbonatite	<ul style="list-style-type: none"> • Recovery Rate 63.3 % • Effective production 19,750 t TREO in 2018 • Continuously capacity extension to 30,000 t TREO/a favored by a nationwide increased LREE mining quota in 2019 and 2020 that allows for expansion of the operation • Mineral concentrates from MaoNiuPing are treated in JCC subsidiary facilities Mianning Fangxing and Manshuiwan (capacity 16,000 t TREO/a)
China	Weishan, Shandong province	2.32 Mt @ 3.71 % TREO	REE in bastnaesite	Operating; Chinalco Rare Earths	Open pit	Carbonatite	<ul style="list-style-type: none"> • Effective production 6,000 t TREO/a • Smelting and separation quota of 1,700 t REO in 2020 • Rel. high OpEx compared to other Chinese deposits

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Congo, Democratic Republic	Obaye, old SOMINKI, Kooperative in North Kivu		REE in monazite	Operating; Auxico Resources Canada Inc. / Central America Nickel (CAN) (Kibara Minerals)	Open pit	Placer	<ul style="list-style-type: none"> • Production of monazite sand • Effective production 720 t monazite/a • Goal: 3,600 – 12,000 t monazite/a • Export to China
Greenland/Denmark	Kvanefjeld, Kommune Kujalleq	107.00 Mt reserves @ 1.43 % TREO & 1,010.00 Mt Resources @ 1.10 % TREO	REE, uranium, zinc, fluorspar; REE in steenstrupine	Preproduction/ Financing and permitting; Greenland Minerals Ltd.	Open pit; Hard ore	Peralkaline; Layered complex, steenstrupine as main REE mineral in apatitic nepheline syenite	<ul style="list-style-type: none"> • Recovery Rate 72.2 % • Production capacity 7,900 t TREO/a • Updated reduced CapEx of US\$ 505 m after initial CapEx of US\$ 1.3 billion • OpEx US\$ 8.5/kg REO • Mixed rare earth products are planned to be shipped to Shenghe Resources in China for separation and purification
India	Chavara, Kerala	1,84 Mt monazite @ 50 % TREO	Heavy minerals: Ilmenite, rutile, zircon, sillimanite, REE; REE in monazite	Operating; Indian Rare Earths Ltd. (IREL, state owned)	Dredging of the placer deposit	Placer	<ul style="list-style-type: none"> • Installed capacity 4500 t RE-chloride

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
India	OSCOM (Odisha sand complex), Odisha	3.06 Mt monazite @ 50 % TREO	Heavy minerals: Ilmenite, rutile, zircon, sillimanite, garnet, REE; REE in monazite	Operating; Indian Rare Earths Ltd. (IREL, state owned)	Dredging of the placer deposit	Placer	<ul style="list-style-type: none"> • Processing of mineral concentrate from IREL at Odisha plant by Toyota Tsusho Material with a production capacity of 2,000 t TREO/a (4 kt of monazite) • Mixed REO to be sold for further processing • The OSCOM plant capacity is undergoing a staged expansion, commencing with a new dredge and final name-plate capacities of 12 kt of monazite
India	Manavalakurichi, Tamil Nadu	2.46 Mt monazite @ 50 % TREO	Heavy minerals: ilmenite, rutile, zircon, sillimanite, garnet, monazite; REE in monazite	Operating; Indian Rare Earth Ltd. (IREL, state owned)	Dredging of the placer deposit	Placer	<ul style="list-style-type: none"> • Monazite concentrate is processed to RE separated oxides in the IREL Monazite Processing Plant (MoPP) • The Manavalakurichi plant has an production capacity of 6 kt of monazite
Madagascar	Fort Dauphine (QIT), Toliara	1,427 Mt resources @ 0,08 % monazite and 358 Mt reserves @ 0.07 % monazite	Ilmenite, Rutile, Zircon, Titanium, REE; REE in monazite	Operating; QIT Madagascar Minerals – QMM – of the Rio Tinto Group	Dredging of the placer deposit	Placer	<ul style="list-style-type: none"> • Effective production 3,300 t TREO/a • Processing of mineral concentrate • Monazite concentrate is shipped to China for further processing

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Malawi	Songwe Hill, Phalombe	8.48 Mt reserves @ 1.60 % & 48.50 Mt resources @ 1.37 % TREO	REE; REE primarily in synchysite (with minor parisite) and Apatite (with minor florencite); Cut-off grade: 1.0 % TREO	Definitive feasibility study completed; under development of Mkango Resources Ltd. Noble Group (Hong Kong) can acquire up to a 75 % interest	Open pit; hard ore, irregularly shaped, subvertical ore body, variable grade distribution	Carbonatite; vent, spatially associated with alkaline province	<ul style="list-style-type: none"> • Life of Mine 18 years • Recovery Rate 48.4 % • Potential production 2,840 t TREO/a • Processing plant planned in Poland by Mkango • CapEx US\$ 216.3 m • OpEx US\$ 84 m/a (US\$ 26.4/ kg REO)
Mongolia	Khalzan buregtei, Khovd province, Western Mongolia	49.0 Mt resources @ 0.6 % TREO (513.7 Mt resources @ 0.5% TREO according to data reported by the owners)	REE, Zr, Ta, Nb; elpidite, zircon, gittingsite, synchysite, bastnaesite, parizite, columbite, pyrochlore	Exploration stage; Mongolian National Rare earth corporation LLC and Mongolian Lanthanoid Corporation LLC	Open pit;	Peralkaline; metasomatic impregnation	<ul style="list-style-type: none"> • Life of Mine 71 years • Recovery Rate TREO 73.3 % • Potential production 2,000 t TREO/a • CapEx US\$ 2,225 m (as of 2014) • The presence of high levels of thorium and uranium will lead to the accumulation of solid hazardous waste, and possibly to hazardous effluents.

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Mongolia	Khotgor, Umnugovi Aimag, Southern Gobi Desert	135.4 Mt resources @ 1.26 % TREO	LREE; apatite hosted, bastnaesite, parasite, synchysite	Prefeasibility study completed; Parabellum Resources; Khotgor Minerals LLC	Open pit;	Carbonatite with metasomatic and hydrothermal activity.	<ul style="list-style-type: none"> • Life of Mine 23 years • Recovery Rate 84.7 % • Potential production 4,500 t TREO/a • CapEx US\$ 336 m (as of 2010) • Laboratory tests on mineral separation have been carried out • No pilot plant tests on ore dressing or REO separation have been conducted yet
Mongolia	Lugiin gol, Dornogovi province, Southern Gobi Desert	0,5 Mt resources @ 2.67 – 2.71 % TREO	LREE; synchysite, parasite, bastnaesite	Exploration stage; REO LLC and EKTU LLC	Underground; the ores occur predominantly as veins, ranging from a few centimetres to 2 meters wide and up to 1000 meters long	Carbonatite	<ul style="list-style-type: none"> • Life of Mine 26 years • Recovery Rate 70.0 % TREO • Potential production 20,000 t ore/a (<400 t TREO/a) • CapEx US\$ 8,941 m (as of 2009)
Mongolia	Mushgai khudag, Umnugovi province, Southern Gobi Desert	25.2 Mt resources @ 1.37 – 3.37 % TREO	Apatite hosted LREE, Sr, Ba; bastnaesite, parasite, synchysite	Exploration stage; REMET LLC, and Ji Es Bi Mining LLC	Open pit;	Carbonatite-hosted deposit associated with alkaline syenite-trachite volcanic-plutonic complex	<ul style="list-style-type: none"> • Life of Mine 11 years • Recovery Rate 60.0 % • Potential production 14,000 t TREO/a • CapEx US\$ 145.5

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Mongolia	Tsagaan chuluut, Khentii Aimag, Eastern Mongolia	0.6 Mt resources @ 0.07 % TREO	Ti, LREE; monazite	Early exploration stage; NABD LLC	Open pit;	Placer	<ul style="list-style-type: none"> • Life of Mine 2.5 years • Recovery Rate 89.7 % • Potential production 240,000 m³ ore/a • CapEx US\$ 345 m (as of 2018) • The low grade will give rise to large waste dumps and tailing ponds • Presence of radioactive minerals is an issue
Mongolia	Ulaan del, Uvs province, Western Mongolia	0.08 t resources @ 0.1 % TREO	Zr, REE, Nb	Early exploration stage; Geo-info LLC	Open pit;	Peralkaline; related to syenite-alkaline meta-somatites	<ul style="list-style-type: none"> • Life of Mine 30 years (as reported) • Recovery Rate 80 % • Potential production 130 t TREO /a • CapEx US\$ 9,324 m (as of 2018)
Mozambique	Moma, Nampula Province	820 Mt reserves @ 0.02 % monazite	Heavy minerals: zircon, titanium minerals; REE in monazite	Operating; Kenmare Resources	Dredging of the placer deposit	Placer	<ul style="list-style-type: none"> • 3,000 t monazite content per year • The monazite-rutile-zircon concentrate is shipped to China for separation and purification.

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Namibia	Lofdal, Kunene	53.40 Mt @ 0.17 % TREO	REE, mainly in xenotime with very high HREE contents (e.g. 8.1 % Dy ₂ O ₃ and 57.3 % Y ₂ O ₃ of TREO)	Preliminary economic assessment completed (since Oct 2014, update in 2022); Namibia Critical Metals Inc. (operator), Japan Oil, Gas and Metals National Corp. (51 % shareholder)	Open pit; Superficial dykes with hard ore	Carbonatite; rare earth mineralization is associated with large scale hydrothermal systems, carbonatite dykes, structural zones and plugs	<ul style="list-style-type: none"> • Life of Mine 16 years • Updated mineral resource estimate from May 2021 (former 6.16 Mt @ 0.29 %). Thus, LoM might be longer • Production capacity 2,000 t TREO/a (117 t DyO/a) • Separated REO desired end product • OpEx US\$ 50/kg REO • CapEx US\$ 163 m
Russia	Lovozerky (also Lovozero or Karnasurt), Murmansk Oblast	593.00 Mt @ 1.12 % TREO Reserves 18 Mt @ 0.85 % TREO	REE, magnesium titanium, tantalum, niobium; REE in loparite	Operating; Solikamsk Magnesium Works	Underground, open pit	Peralkaline; rare earth mineralization is hosted within nepheline-feldspar-aegirite pegmatite veins	<ul style="list-style-type: none"> • Life of Mine 40+ (up to 100) years • Production capacity 3,600 t TREO/a • Effective production ~2,700 t TREO/a • Significant amounts of thorium and uranium that raise environmental concern
South Africa	Steenkampskraal, Western Cape	0.61 Mt @ 14.35 % TREO	Thorium, REE; REE predominantly in monazite, also in Th-dominated apatite	Feasibility study completed; Steenkampskraal Thorium Ltd.	Underground; Steeply dipping veins with sharp contacts, 0.2 to 4.5 m wide	Vein hosted, associated with peralkaline magmatism	<ul style="list-style-type: none"> • Life of Mine 30 years • Recovery Rate 41.9 % • Potential production 2,700 t TREO/a • Low CapEx (US\$ 35 m) due to former monazite mining for thorium • OpEx US\$ 3 / kg mixes RE carbonate • High concentrations of thorium

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
South Africa	Zandkopsdrift, Northern Cape	41.12 Mt reserves @ 1.92 % TREO & 16.50 Mt resources @ 2.69 % TREO	REE in monazite and crandallite; Cut-off grade: 1.0 % TREO	Pre-feasibility study published in 2015 (no activities reported since that time); Frontier Rare Earths Ltd.	Open pit; superficial soft ore, irregularly shaped ore body, variable grade distribution	Carbonatite; supergene alteration of monazite-bearing carbonatite intrusion	<ul style="list-style-type: none"> • Life of Mine 20 years • Recovery Rate 66.4 % • Potential production 8,000 t TREO/a • CapEx US\$ 910 m • Own water (desalination) and electric power supply • Complex mineralogy requires more intense crushing and grinding to achieve economic liberation
Sri Lanka	Pulmoddai, Eastern Province		REE in monazite	Operating; Lanka Minerals Sands	Open pit	Placer	<ul style="list-style-type: none"> • Life of Mine 26 years • Recovery Rate 76.4 % • Potential production 5,150 t TREO/a • Mixed REO to be sold for further processing • CapEx US\$ 487 m • OpEx US\$ 110 m/a (US\$ 33/kg mixed REO) • PEA from 2021 with a 150 % higher NPV (US\$ 762 m, post-tax) than estimated in prefeasibility study • High amount of HREE • Low uranium and thorium contents
Tanzania	Fungoni, Dar es Salaam	21.8 Mt resources @ 2.8 % THM	REE in monazite	Definitive feasibility study from 2017, financing phase; Strandline Resources Ltd., (Nyati Mineral Sands Ltd)	Open pit; Heavy mineral sands	Placer	<ul style="list-style-type: none"> • Export to China (100 % offtake with Wenshend)

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Tanzania	Ngualla, Mbeya	18.5 Mt reserves @ 4.8 % & 214.4 Mt resources @ 2.15 %	REE in bastnaesite; Cut-off grade: 1.0 % TREO	Feasibility study completed (BFS update until Feb 2022); Peak Resources Ltd.	Open pit; Variable grade distribution	Carbonatite; Carbonatite pipe and colluvial gravel	<ul style="list-style-type: none"> Life of Mine 25 years Recovery Rate 36.8 % Potential production 10,000 t TREO/a Rel. low CapEx (US\$ 330 m) OpEx US\$ ~100 m/a Low uranium and thorium contents low overburden:ore ratio Separation and refining in Tees Valley Refinery (GBR)
Tanzania	Tajiri, Dar es Salaam	286.0 Mt resources @ 3.3 % THM	REE in monazite	Scoping study; Strandline Resources Ltd., (Nyati Mineral Sands Ltd)	Open pit; Heavy mineral sands	Placer	<ul style="list-style-type: none"> Capacity of 60,000 t of zircon-rich concentrate containing monazite + garnet
Uganda	Makuutu, Iganga	78.6 Mt @ 0.084 % TREO	REE; Cut-off grade: 300 ppm TREO-Ce ₂ O ₃	Scoping study completed, feasibility study ongoing; Ionic Rare Earths Ltd. (51 %-owner), Rwenzori Metals Ltd. (shareholder)	Open pit; heap leaching of the shallow, near surface orebody, with clay layer averaging 11.9 m thick under cover approximately 3 m deep using ammonium sulfate	Ionic clay	<ul style="list-style-type: none"> MoU with China Rare Metals and Rare Earth (Jiangsu) (CHINALCO) in relation to the development of the project
USA	Bear Lodge, Wyoming	14.2 Mt reserves & 46.9 Mt resources @ 2.78 % TREO	REE; REE in bastnaesite and monazite; Cut-off grade: 1.5 % TREO	Prefeasibility study from 2016, pilot plant study completed in 2020; Rare Element Resources Ltd.	Open pit; Drilling and blasting; gradational contacts; irregular distribution of RE within ore body	Carbonatite; veins and dikes within alkaline complex	<ul style="list-style-type: none"> Life of Mine 45 years Recovery Rate 79.0 % Potential production 6,800 t TREO/a Life-of-Mine CapEx US\$450 m (initially US\$ 290 m) OpEx US\$ 52.4 m/a Own separation plant aspired

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
USA	Energy fuels, Utah The Chemours Company, Georgia	Monazite sand is purchased from deposits in Georgia and Tennessee, USA It is planned to purchase, monazite from north America, Madagascar, New Zealand, South America	Uranium, REE; REE in monazite	Operating (since 2021); Energy Fuels	Open pit; Heavy mineral sands	Placer	<ul style="list-style-type: none"> • Energy fuels purchases monazite sand being mined and produced at HMS operations from Chemours Co, Georgia and Hyperion, Tennessee • Processes monazite to produce RE carbonate at its White Mesa Mill in Utah • Potential production 720,000 t ore/a • Currently Processing 2,500 t/a monazite • Goal to process ~15,000 – 30,000 t/a monazite • Further processing initially in Neo Performance's Silmet plant in Estonia • Fully integrated REE production in USA is planned 2023/2024
USA	La Paz, Arizona	128.20 Mt @ 0.04 % TREO	REE; Main RE-minerals are allanite and monazite	Preliminary economic assessment to be completed in 2021; American Rare Earths Ltd.	Open pit; Hard ore, gradational contacts	Mineralized detachment fault	<ul style="list-style-type: none"> • OpEx US\$ 8.5/kg REO • Uncomplicated mineralogy, lack of uranium and thorium • Favourable preliminary metallurgical work

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
USA	Mountain Pass, California	21 Mt reserves @ 7.00 % TREO & 34.78 Mt Resources @ 6,57 % TREO	REE, mainly in bastnaesite; Cut-off grade: 3.0 % TREO	Operating; MP Materials Corp. (65 %) with Shenghe Resources as a 10 %-venturer	Open pit; tabular ore body with intermediate inclination, variable grade distribution within mineralized zone	Carbonatite body associated with alkaline intrusion	<ul style="list-style-type: none"> Life of Mine >30 years (permission until 2042) Effective production 39.000 t (est.) TREO/a in 2020 High waste : ore ratio (8 : 1) Own production of separated NdPr is expected to start in 2023; currently RE concentrates are shipped to China for further processing by shareholder Shenghe resources
USA	Round Top, Texas	1,033 Mt @ 0.06 % TREO	REE, beryllium, uranium; REE in disseminated microcrystals of fluorite (yttrifluorite and yttrocerite); Cut-off grade: 428 ppm yttrium	PEA and BFS ongoing, potential production in 2023; USA Rare Earth LLC (80 %), Texas Mineral Resources Corp. (205)	Open pit; hard ore, tabular ore body, shallow dip, constant grade distribution within pit model	Near-surface rhyolite intrusion	<ul style="list-style-type: none"> Life of Mine 20 years Recovery Rate 71.5 % Potential production 3,325 t TREO/a CapEx US\$ 600 m (initially US\$ 350 m) Rel. low OpEx US\$ 48/kg TREO) High HREE- (29 % of TREO) and very high Y-content (45 % of TREO) MoU with Lynas Corp. Ltd. to build a rare earth separation facility in Texas
USA	Titan Project, Tennessee USA	431 Mt @ 2.2 % THM (2.1 % TRE in THM)	Heavy minerals: zircon, rutile, monazite; REE in monazite + xenotime Cut-off grade: 0.4 % THM	Scoping study expected Q1 2022; Hyperion Metals	Scoping study expected Q1 2022; Hyperion Metals	Placer	<ul style="list-style-type: none"> 9.5 Mt HM, 201 kt monazite + xenotime, Hyperion has an MoU with Energy fuels to evaluate supply of monazite

Country	Project, Location	Mineral resources & ore reserves	Value elements; REE minerals	Development stage; (Main) Owner	Mining method and ore deposit morphology	Deposit type	Remarks (infrastructure; environmental liabilities; economic metrics)
Vietnam	Yen Phu, Northeast Vietnam	1.90 Mt @ 1.24 % TREO	REE, Nb, Th; REE in monazite, bastnaesite and xenotime	Operating; Thaiduong Group	Open pit	Hydrothermal	<ul style="list-style-type: none"> • Effective production 1,000 t TREO/a • Ores are processed to mixed and separated rare earth products in Vietnam • High thorium content (0.17 %)

Appendix 2: Mongolian RE deposit passports

The information on the deposits has been compiled by Tamiraa A. from data submitted to MRPAM, publicly available information, field visits and interviews. Company-owned data were not included.

Name of property	Khotgor
Value elements or minerals	apatite, magnetite, light REE-minerals
Location	Umnugovi Aimag, Southern Gobi Desert; Southern Gobi; the deposit lies 68 km north-east of Dalanzadgad town in Umnugovi province; The deposit lies 68 km north-east of Dalanzadgad town in Umnugovi aimag, located at the edge of Khanhongor and Tsogt-ovoo soums.: 44° 07' 47" N; 104° 40' 19" E.
Access, infrastructure	No public infrastructure present; access by gravel road; no access to electric power grid; no surface water available. Nearest small airport at Dalanzadgad.
Exploration history	The Khotgor rare earths deposit was discovered in 1979 – 1982 during a Soviet-Mongolia joint mapping project; Between 2005 and 2009, QGX LLC., a Canadian listed company, carried out detailed exploration activity including core drilling; The Hotgor rare earths deposit was discovered in 1979-1982, during Soviet-Mongolia joint mapping and later QGX LLC Canadian 100 % wholly owned company did detailed exploration activity during 2005 and 2009. Pre-feasibility study had completed and submitted to the Mineral Reserves Council of Mongolia in 2011. In the summer of 2012, further core drilling was carried out by QGX LLC. In 2022, after reviewing the results of previous research works at the Khotgor research area, trench excavation for the purpose of obtaining oxidized ore samples and also column drilling for the sampling of enrichment technology the work was carried out with relevant experiments. The total number of channels excavated in the central part of the deposit. The average length is 226 m. Drilling was 2000 m.
Development status	Exploration stage, pre-feasibility study completed Laboratory tests on mineral separation have been carried out; but no pilot plant tests on ore dressing or REO separation have been conducted yet.
Deposit type	Carbonatite with metasomatic and hydrothermal activity. Subvolcanic, small pluton-related metasomatic-hydrothermal system.
Deposit geology	The deposit is in a volcanic-breccia pipe with apatite-magnetite-phlogopite mineralization associated with nepheline syenite. Tubular, steeply dipping ore bodies (breccia pipe, veins). The width of individual ore bodies ranges from 1 – 30 meters, and they extend lengthwise from 10 – 150 metres along strike.
Petrography of host rocks	Carbonatitic breccias and veins. Nephelinitic syenites have a tube-like form and are composed of nepheline and some phlogopite, magnetite, hematite, fluorite, apatite and celestite.
Ore types and ore mineralogy	There are two main types of ore: <ul style="list-style-type: none"> • Veins bearing REE minerals • Breccia with REE mineralization cements Ore mineralogy is very complex e.g. apatite-fluorite, magnetite-apatite, fluorite-celestite-magnetite-apatite, brecciated rocks with carbonate cement material and some eruptive breccia as different content. The main RE minerals are bastnaesite, apatite, parisite, and synchysite. Khotgor RE deposit is formed in volcanic-breccia pipe type mineralization with apatite-magnetite-phlogopite.

Resource situation	The total resources of the deposit were registered with the MSPCMR: 135,357,200 t of ore, grading 1.26 % TREO, (categories B + C), containing TREO 1,213,700 t;
Ore processing	100 kg sample has been submitted for testing to Nagrom LLC laboratory in Hong-Kong; Flotation recovery 70 % of metal, with a grade of 25 %.
Environmental considerations	The low grade will give rise to large waste dumps and tailing ponds. No reliable information on presence of radioactive minerals.
Relevant literature, data sources	Report 3676; 1:200 000 geological mapping; 6101 QGX LLC exploration report; 6403 feasibility study.

Name of property	Mushgai khudag
Value elements or minerals	Apatite hosted LREE, Sr, Ba, bastnaesite, parasite, synchysite
Location	Administratively the deposit belongs to Mandal-ovoo soum of Umnugovi province; 120 km north-west from Dalanzadgad town. 600 km from Ulaanbaatar. Coordinates of Khuren Khad (Apatite hill), which is a prominent hill approximately in the centre of the license area: 44° 23' 04" N; 104° 00' 40" E.
Access, infrastructure	Access by all-season dirt road; no adequate transport infrastructure in place; no access to surface water; high voltage power line approximately 260 km to NW. Olon Ovoot open pit gold mine is located approximately 17 km to the NE and is connected by dirt road. Nearest settlements are Mandal Ovoo village (32 km) and Bulgan village (55 km). Nearest small airport at Dalanzadgad, about 100 km to the South.
Exploration history	The Mushgai khudag rare earths deposit was reported in early 1973's, prospected in 1983 – 1984 by the Russian-Mongolian joint academic expedition, and explored in more detail between 1989 and 1994 by private companies. The most recent exploration campaign took place between 2007 and 2012 by the Mongol Gazar Company. Rare earth-metal-hosting alkaline magmatic rocks were discovered in early 1970's by a Soviet-Mongolian scientific expedition. Scientific researches have continued until mid of 1980's. An investigation as preliminary exploration have been carried out in 1990 – 1991's, with drillings. Starting from mid of 1990's private companies were obtained exploration licences and active exploration programs are ongoing.
Development status	Exploration stage; laboratory level tests on mineral separation have been carried out; no pilot plant tests on ore dressing or REO separation have been conducted. Semi-detailed exploration included trenching and drilling have been completed.
Deposit type	Carbonatite-hosted deposit associated with alkaline syenite-trachyte volcanic-plutonic complex. Mineralized breccias zones, ore pipes (apatite and magnetite), carbonate vein zones, eruptive breccias pipes etc. Most of REE hosted in fluoro-apatite mineralization with LREE-P-Nb-F.
Deposit geology	Carbonatite-hosted deposits are associated with an alkaline syenite-trachyte volcanic-plutonic complex forming a ring structure of about 27 km diameter. Primary carbonatite is overlain by regolith.
Petrography of host rocks	Main plutonic host rocks are nepheline syenite, granosyenite, and shonkinite porphyry. Trachyte and latite are the dominant volcanic rock types. Apatite-magnetite and carbonatite diatremes or dikes cut these rocks. Carbonatites are composed of calcite-fluorite. Host rocks are mainly alkaline plutonics such as nephelinitic syenites, shonkinite, trachite, latite, trachitic-basalts, andesitic-basalts etc. Trachitic volcanic are in dominant. Complex carbonatite, apatite, apatite-bastnaesite, carbonatite, quartz-carbonatite-fluorite ore Forms a ring structure of 27 km in diameter and consists of Late Jurassic alkaline intrusive and subvolcanic rocks, nepheline syenites. At least 17 different ore bodies, spaced from 100 – 1200 m apart, of various shapes, structures and composition were revealed. Seven ore bodies were found out to be most mineralised and studied in more detail. Apatite-bastnaesite carbonatite and apatite are the most important ores, as they are most enriched in rare earths.

<p>Ore types and ore mineralogy</p>	<p>Mushgai khudag presently hosts six ore zones (Tumurtei, Khuren Khad, Main ore, High Grade ore, Monazite, and Jonshit) have been discovered with tens of different ore bodies, which may be steeply dipping tabular or lenticular, breccia, stockworks, and veins or subhorizontal volcanic sheets.</p> <p>Four styles of mineralization have been reported: carbonate cemented mineralized breccia; mineralized carbonatite. (mainly "apatite-bastnaesite ore"); magnetite-apatite ore, and apatite ore (mainly "phosphatic ore").</p> <p>Regarding the composition, apatite-bastnaesite carbonatite ores and apatite ores are the most important ones, and each of them has been subdivided into several specific types.</p> <p>Main REE minerals are: bastnaesite, apatite, perrierite, parisite, synchysite; minor ore minerals are iron minerals, phosphate minerals, and monazite.</p> <p>Apatite-bastnaesite carbonatite ore: calcite, dolomite, celestite, barite, fluorite, apatite, bastnaesite, other REE minerals (REO up to 3.5 %, average 1.5 %).</p> <p>Apatite ore types: magnetite-apatite, fluorite-celestite-magnetite-apatite, apatite, phlogopite-apatite, feldspar-apatite, syenite with schlieren of apatite (REO average 2.6 %),</p> <p>Quartz-carbonatite-fluorite ore: fluorite, calcite, quartz, celestite, apatite, monazite, barite (REO up to 4.6 %)</p> <ul style="list-style-type: none"> • Apatite, apatite-magnetite-phlogopite ores form pipe-like bodies. Massive, partly flow textures are characteristic. • Mineralised breccias zone (body 1) has long up to 1000 m extension and variable width with highly mixture of different rocks. • Fluorite-celestite-carbonate ores form eruptive explosion-like local bodies at the south of the area • Individual carbonatite, dolomite and mixed ores form mainly small veins (up to 1 m wide) with relatively low in REE (less than 1 – 20 % RE₂O₃)
<p>Resource situation</p>	<p>The total resources of the deposit were registered with the MSPCMR: 25,235,505 t of ore, grading 1.37 – 3.37 % TREO (categories B + C), that is 365,102 t net TREO</p>
<p>Ore processing</p>	<p>Processing would be difficult because of the presence of several different ore types and REE minerals; elevated radioactivity (U, Th). Ore dressing, processing and economic mineral extraction testing have been experimented at laboratory level. No pilot plant tests have been carried out.</p>
<p>Environmental considerations</p>	<p>The low grade will give rise to large waste dumps and tailing ponds. Radioactivity associated with the ore may require precautions in the production steps carried out in confined spaces and deposition of waste stream products. Permits for hazardous waste may be required. The deposit area is rocky desert and semi-desert territory and does not belong to a special protective area or province. There are no land use and development plans yet.</p>
<p>Relevant literature, data sources</p>	<p>4385 hydrogeological study; 4516 geophysical study; 4680 1:50 000 geological mapping; 4714 prospecting-evaluation; 4795 1:10 000 prospecting; 3875 pre-evaluation; 4173 scientific work; 6319 REMET exploration report; 6710 Mushgai Khudag exploration report.</p>

Name of property	Lugiin gol
Value elements or minerals	LREE, synchysite, parasite
Location	The Lugiin gol deposit is located 50 km south of Khatanbulag soum, Dornogovi province, and 100 km east of the Khanbogd alkaline pluton. Coordinates of summit within property: 42° 57' 00" N, 108° 34' 00" E
Access, infrastructure	750 km of Ulaanbaatar, about 300 km from nearest railway station Sain-Shand town, 70 km to south from large copper-porphyric deposit Tsagaan-Suvarga, Tavan-Tolgoi, 200 km from world's largest rare earth mine Bayan Obo, Inner Mongolia, China, 150 km east of large copper-gold deposit Oyu-Tolgoi.
Exploration history	<p>In early 1970-s Soviet-Mongolian joint Research Expedition on Geological survey (named as "Joint Geological Expedition of Academy of Science of the USSR and MPR") first determined presence of alkaline plutonic rock distribution with recognisable rare metals mineralization. Following, in 1983 Mongolian-Polish Joint geoscientists group have visited the sites and started an active exploration project at present site named as "Lugiin gol REE" target. Project completed during 1984-1990 and included detailed gravimetric survey 1:5000, detailed topogeodetic survey 1:5000, detailed magnitometric survey 1:5000, detailed geological mapping 1:5000 and petrographic description.</p> <p>Generally, there were fixed and detailed explored up to 22 carbonatite vein dyke bodies and explored with trenching, shafting, drillings and other methods, including radiometric detail surveyings.</p> <p>Productive (possible) representative bulk sample (total 50 t oxidized and primary carbonatite ores) have been sampled from representative ore body and tested in Poland for extraction of valuable concentrates of TREO (report is available in Polish and Russian languages at Geological Archive). Pilot plant processing tests showed possible extraction of REO concentrate with >33 % TREO from carbonate ore due to flotation and hydrometallurgical testing and following processing up to oxide determination.</p> <p>2005-2009 A-jet limited Co.Ltd local company did detailed exploration in 6,7,8 ore bodies, in 2013 EKTU Co.Ltd Mongolian-Polish national company was conducting detailed exploration in western part of the Lugiin gol.</p>
Development status	Detailed exploration
Deposit type	Vein type, carbonatite rocks with F-carbonates as synchysite, bastneazite etc. Ore minerals (synchysite mainly contains 50 – 60 % of TREO) itself grades up to 30 % of rock mass.
Deposit geology	Nephelinic syenite related metasomatic (only total occurrence in the region). Theoretically Late Mesozoic rift-geneous huge belt of South Mongolia. (Soviet sources). Actual age of nephelinic syenites is Triassic.
Petrography of host rocks	<p>The Lugiin gol pluton itself has stock-like intrusion (3 km in diameter) of nephelinic basic to intermediate magmatic rocks, intruded into late Paleozoic metasediments. The pluton has circle structure on the plane and composed of (early to later):</p> <ul style="list-style-type: none"> • ijolite or Fe-Mg alkali rocks • malifinite or alkali gabbroids • foiyte (nepheline rich syenite) main intrusion • altered Na-syenite(ore producing phase) or libenevitised Na-syenites • host hornfelse rim (early intrusion hosted mudstones and sandstones) • phoenites (fenits) kind of contact metamorphic rocks probably formed after arcogenic-metasediments <p>Mineralization is related to peralkaline granitic and alkaline syenite bodies.</p>

<p>Ore types and ore mineralogy</p>	<p>Ore type may belong to soviet (calcite dominated) type carbonatite of mid-thermed hydrothermal origine. Carbonatites form veins and dykes up to 1 m wide and 1 km long bodies mainly related (genetic and space) to altered syenites. Major minerals: Calcite, plus dolomite, quartz, synchysite, fluorite, hudnthorite (Mn-rich calcite) strontianite etc. Darks are pyrite, sphalerite, galena, boulengerite, rutile and mainly fluorite and partly apatite. Oxidation zones not exceed 15 m depth and mainly represented as Fe-hydrooxide and Mn-enriched calcites. Main REE mineral is synchysite (D.BATBOLD etc, 1997, Japan) with minor parasite, bastneasite and some reentenite. These minerals may contain certain amount of ThO₂ which was clearly identified by radiometric measurements.</p> <p>The Lugiin gol pluton is 3 km in diameter forming a ring structure. Radial dikes in the internal contact of pluton are represented by syenite-porphry, microsyenite, pseudoleucite, syenite-porphry, and tinguaitite. Lugiin gol complex is built out of hundreds of mineralised veins and dikes, of which 21 have been found ore to be of potential economic use. However, their average thickness is just 35 cm. Main ore minerals are synchysite, parasite, and accessory: pyrite, galena, goethite, and limonite.</p>
<p>Resource situation</p>	<p>The total resources of the deposit were registered with the MSPCMR: 541,317 t of ore, grading from 2.67 – 2.71 % TREO, (categories B + C), containing TREO 14,519 t;</p>
<p>Ore processing</p>	<p>Lab experiments at ICCT (MAS (gravitation, flotation)). Laboratory research on hydrometallurgical processing of lanthanide raw material in Kowary, Hydromet sp. Polish, 2013</p>
<p>Environmental considerations</p>	<p>The low grade will give rise to large waste dumps and tailing ponds.</p>
<p>Relevant literature, data sources</p>	<p>4407 pre-exploration study, 4584 feasibility study (1989), 4191 Lugiin gol prospecting-exploration, 4394 Hydrogeological study.Report 5384 1:200 000 geological mapping; 6060 REO LLC exploration report; 7162 ECTU LLC exploration report.</p>

Name of property	Khalzan buregtei
Value elements or minerals	REE, Zr, Ta, Nb, elpidite, zircon, gittingsite, synchysite, bastnaesite, parizite, columbite, pyrochlore.
Location	Khovd province, Myangad subprovince, Western Mongolia
Access, infrastructure	Road connection to Khovd (~50 km; 40 km paved road); 110 kV-power grid a few km's away (WES –Russian supplier); two rivers near by; airport at Khovd; no railway connection available. Khovd river is running 15 km west of the area.
Exploration history	<p>Exploration history started, when the complex was explored for uranium.</p> <p>1983: Discovered by Russian-Mongolian Academic expeditions.</p> <p>1989: Prospecting by Soviet geologists.</p> <p>1990: Trenching, drilling, sampling resulted in preliminary assessment of potential resources by Soviet geologists.</p> <p>2011: Prospectivity report and recommendation on further exploration by Micromine.</p> <p>2011-2013: Extensive exploration activities were done by private national company Mongolian Lantanoide Corporation in 30 % of the deposit. Extended core drilling program by Mongolian National Rare Earth Corporation LLC (MNREC), under supervision of Micromine;</p> <p>2016-2019: In the focus of an Mongolian-German research project funded by the German Federal Ministry of Education and Research</p> <p>2022-2023: MNREC LLC started exploration activity with its own funds within the scope of the MV-012335 mining license including extensive exploration drilling.</p>
Development status	Detailed exploration
Deposit type	<p>Rare metal and RE deposit associated with alkaline igneous complex. Light and heavy REE-Nb-Ta-Zr-Be-and Y-bearing alkaline intrusive rocks (syenite)</p> <p>The mineralization are related to per-alkaline granitic and alkaline syenite bodies. Generally speaking rare earth mineralization is related to:</p> <ul style="list-style-type: none"> • Dyke-like pegmatitic and ekerite rocks. • Metasomatic impregnation mineralization of zircon, pyrochlore etc.
Deposit geology	The area is characterized by extensive but low-grade mineralization of rare earths and rare metals in the central part of the mountain range. Within this low-grade mineralization, high-grade ore occurs as gently dipping dikes, as stockworks in K-spar granite and dissemination within alkalic granites and syenites.
Petrography of host rocks	<p>The project area consists of volcano-sedimentary rocks, nordmarkite, pantellerites, alkali granites and pegmatite's. The REE mineralization is hosted by alkali granites which have a steeply dipping contact which in the south is occupied by a pegmatite and in the east and north is a tectonic contact.</p> <p>Major host rocks of alkali plutons are Cambrian-Silurian aged metabasalts and meta-volcanics which were metamorphosed as green schists. Ore mineralization host rocks are alkali plutonic rocks such as per-alkaline granites, nordmarkites and dyke rocks as pantellerite, comendite, pegmatites etc.</p>

<p>Ore types and ore mineralogy</p>	<p>Metasomatic impregnation mineralization of zircon, pyrochlore etc. Light and heavy REE, Nb, Ta, Zr, Be, and Y Major ore minerals are: pyrochlore, columbite, elpidite-armstrongite, bastnaesite, zircon, amorphous REE minerals, zircon, zirconium silicates and hydro-silicates. Pyrochlore and columbite carry tantalum and niobium. The REE occur in many minerals, mainly in bastnaesite, monazite, synchysite, xenotime, and perhaps in fluorite and apatite. Mineralization is represented by elpidite (up to 17%), gittingsite, pyrochlore, polilithionite, REE fluorcarbonates, monazite, zircon, amorphous zircon-Nb-REE silicates, and fluorite.</p> <p>Ore description(mineralogy, texture, type, presence of other valuable or detrimental minerals): The granites and nordmarkites are cut by basaltic and pegmatitic dikes. All the rocks are highly fractured. There is an extensive low-grade but large mineralization of rare earths and rare metals in the central part of the mountain range. Main minerals of Ta and Nb are pyrochlore and columbite. Columbite occurs as small pseudomorph phenocrysts in pyrochlore and does not represent any productive importance. Pyrochlore is characterised by octahedric and xenomorph grains, 0.01 – 2-3 mm (average size is 0.1 – 0.15 mm). Zircon the main mineral of zirconium and hafnium, forming fine porphyric grain size <1.0 mm. In addition, at elevation 1900-1950 m monazite in 1800 – 1950 m bastnaesite occur. Although fluorite is observed in fine porphyries along the fractures and stringers in whole outcrop. Mineralization is located within following spaces: 3 major quartz-albite metasomatic linear bodies, vertical shear zones, cataclazided zones with pegmatoid dykes. Metasomatised zones are in 50 – 150 m width. Other mineralized zones are 20 – 150 m long and 5-30 cm up to 3-4 m wide. Ore mineralization has massive and brecciated texture with fine grains. Mineral composition is complicated. Alkaline microcline-albite granite has slightly porphyry-like texture. This type of ore contains rare metal minerals up to 25 % of rock volume, within that 17 % of elpidite-armstrongite minerals, uncommonly Columbite was formed as pseudomorphous inclusions in pyrochlore along contacts of pegmatite dykes and along endo-contact of alkaline granite stock. Pyrochlore forms intergrowth with other ore minerals. Zircon forms small inclusion crystals up to 1mm in size. Zircon replaces elpidite. Elpidite is widely distributed and forms 1-3mm platy crystals. Monazite, bastnaesite and fluorite were formed irregular fine impregnations. Major ore: Pyrochlore, Columbite, Elpidite-Armstrongite, Bastnaesite, Zircon, Amorphous REE-Zr silicates and hydro-silicates. Secondary ore: Polilithionite, Monazite, Thorite, Orthite, Xenoteme, Synchysite, Hematite, Hoetite, Limonite Rare: Abukumalite, Milarite</p>
<p>Resource situation</p>	<p>The total resources of the deposit were registered with the MSPCMR: 513,702,430 t @ TREO 0.46 % (Dy 0.01 %, Ta 0.01 %, Nb 0.1 %, Zr 0.30 %) Metal content (t): TREO 2,014,934 t (lower values in the other literature; see Table 4)</p>

Ore processing	<p>Very complex (first experiments at the VIMS-Moscow; before 1991)</p> <ol style="list-style-type: none"> 1. magnetic processing and flotation with low recovery 2. chemical-metallurgical processing <p>In cooperation with Central Geological Laboratory in Mongolia Experimental work of the Mineral Concentration Laboratory for Technological Experimental Research was carried out at the Outokumpu (Geological Research Center) in Finland. Gravitation-flotation has been suggested as the best method for ore dressing.</p> <p>Recovery Rate TREO 73.32% with a grade 3.32 %, Zr 43.42 % with a grade 14401 g/t, Nb 65.31 % 2269 g/t</p> <p>Intertek Laboratory (Beijing, China) and ALS laboratory (Vancouver, Canada) were used as the analytical laboratories for the project. Three separate rounds of mineralogy and metallurgy studies were carried out by the following organizations and laboratories:</p> <ul style="list-style-type: none"> • Australian Nuclear Science and Technology Organization (ANSTO); • Central Geological Laboratory (Ulaanbaatar, Mongolia); • Rheinisch-Westfälische Technische Hochschule at Aachen University in Germany (RWTH). <p>These studies have shown that Khalzan buregtei's REE- and Nb-bearing minerals are the same as those encountered in other REE Nb deposits that are currently being successfully mined. This bodes well for the development of a process that can segregate and extract the individual REEs and purify them to rare-earth oxides that are the form in which the rare earth elements are usually marketed. Studies on methods for concentrating the rare earths have shown that it is possible to concentrate a high percentage of the REEs in a small percentage of the original run-of-mine tonnage.</p> <p>The single most valuable metal at Khalzan buregtei is dysprosium (Dy), followed by neodymium (Nd). Although the four of the rare earths account for more than half of the recoverable value, niobium (Nb) and tantalum (Ta) also have significant value. Some REE deposits also have significant Nb and Ta grades and use processes that recover these as by-products. Khalzan buregtei is categorized as a peralkaline granite REE deposit. Although there are several other REE deposit of this type around the world, there is only one operating rare-earth mine in a peralkaline granite, Lovozero in Russia.</p>
Environmental considerations	<p>The presence of high levels of thorium and uranium will lead to the accumulation of solid hazardous waste, and possibly to hazardous effluents.</p> <p>The presence of high concentrations of sulphide minerals which could cause acid mine drainage has not been reported</p>
Relevant literature, data sources	<p>Report 4505 geological mapping at scale 1:50 000. 7795 Mongolian National Rare Earth Corporation LLC exploration report; 7524 Mongolian Lantanoide Corporation LLC exploration report.</p>

Name of property	Ulaan del
Value elements or minerals	Zr- REE (Zircon-Rare earth elements)
Location	The Ulaan del deposit is located geographically in the territory of Zavhan sub-province, Uvs province, Western Mongolia and is in the south-west of Khyargas Lake within the Lake Island arc terrane (Lake Zone) of the Northern Mongolian domain (Fig. 1). Central geographical position of the deposit is 49° 03' 19"N and 92° 45' 07"E on M-46-102 sheet of 1:100 000 scale nomenclature map of Mongolia.
Access, infrastructure	Access to the site could either be by airway from Ulaanbaatar to Ulaangom- Uvs province center or drive by highway from Ulaanbaatar (1100 km W) to the site. The Ulaan Del Zr-REE project area is 120 km S from Ulaangom town- province center and 40km NNW from Zavhan sub-province center.
Exploration history	Russian geologist Gavrillov and other geophysicists first identified a number of Ta-Nb-Zr mineralization in the prospecting area in 1987 using a 1: 50,000 scale aerial geophysical mapping. In 1988-1989, prospecting assessment was resumed in the mineralized area. In the northern part of the study area, by aerogeophysical activity revealed an occurrence called Shar Tolgoi. During an airborne geophysical survey on the scale of 1:50000 and explored Shar Tolgoi occurrence with a few drilling and trenching. From the exploration, the geological probable reserves assessed at REE bearing ore of 19,900 tonnes of Ta ₂ O ₅ , 19,000 tonnes of Nb ₂ O ₅ and 1.4 Mt of ZrO ₂ (MININ et al., 1991). Since 2007, Geo-info LLC has been carrying out an extensive exploration and drilling activity.
Development status	Exploration stage
Deposit type	Hydrothermal-metasomatite alteration ore bodies
Deposit geology	The Project is characterised by Zr-bearing mineralization identified in rhyolitic, trachy-rhyolitic and syenite dike complex of Middle-Late Devonian known as Halzan that is hosted in the granitic complex of Middle-Late Cambrian age. Dikes are represented by andesite, andesine-basalt, diabase, granite, granite-aplite, syenite, microsyenite, rhyolite, trachyrhyolite, trachyte with brecciated, porphyric, tuff-lavas structure and likely related to tectonic and hydrothermal/ hydrothermal-metasomatoses events associating with the fault zones.
Petrography of host rocks	Zr-REE bearing dikes are reddish, to pinkish brick reddish, pale reddish brown, brown in color. Dense, porphyric, brecciated, sometimes form autobreccia, within the dikes, porous and intersect with carbonatic veinlets Zr-REE bearing. Strongly enriched with hydrous iron oxides, abundance with black to grey-black phenocryst/crystals and fluorine minerals.
Ore types and ore mineralogy	Hydrothermal-metasomatoses altered alkaline dikes (quartz-albite metasomatites). The mineralization is hosted in quartz-albite-metasomatite dikes in Cambrian peralkaline granitic rocks. The density of dikes 8 – 20 per 100sq km, 20 and more in the southern half of studied area. Dikes are stockworking, crossing each other and striking mostly from SE to NW and W-E can be observed too. Dipping angle of dikes varied from 60-75° and 80 – 90°. The thickness of dikes varies from 0.3 m to 2 – 3 m stretching along strike up to 700 m on the surface. Thickness can often reach up to 3m and more in drill holes. Common ore minerals are zircon, synchysite, xenotime, monazite, fluorite, REE-bearing dark minerals.

Resource situation	The total resources of the deposit were registered with the MSPCMR: 82,130.4 t of ore, grading from 0.1 % TREO, (category C), containing TREO 124,786.9 kg, 0.240 % ZrO ₂ (238,931.4 kg), 0.036 % Nb ₂ O ₅ (34,834.7 kg); prognosticated resources in a depth 50 m (P1) 308,892.5 t of ore RE ₂ O ₃ 306,002.3 kg, ZrO ₂ 792,540.8 kg, Nb ₂ O ₅ 113,561.6 kg.
Ore processing	Technological ore enrichment test has not done yet, but mineral liberation analyses done at GTK laboratory in Finland, 2013. The results of the analyses showed that mineral composition of the ore and REE minerals and their relationships. Xenotime (Y) and zircon (Zr) are mineralogically and spatially closely associated, almost both minerals presented in the same clasts edging each other and liberated almost at the same level. The XBSE method was used to analyse the liberation, particle size and mineral contents. XBSE is the extended liberation analysis method, where each BSE image is collected and segmented to delineate mineral grain boundaries in each particle and each mineral grain is analysed with one X-ray, i.e. with the area X-ray analysis.
Environmental considerations	Potential direct and indirect environmental impacts may cause from project (mining) activities: 7 impacts are low, 5-medium and 9 are strong (destroy of soil cover and pollution, geological environment destruction, livestock pastures, ground water pollution and etc.).
Relevant literature, data sources	1:200 000 geological mapping; 8551 Geo-info LLC exploration report.

Name of property	Tsagaan chuluut
Value elements or minerals	Monazite, magnetite, ilmenite, light REE's Ce, Th, U
Location	Khentii Aimag, Kherlen, Binder and Umnudelger Soums, 45 km on paved road NE of Umnudelger soum. Coordinates of summit within property: 47° 58' 34" N, 110° 30' 50" E, elevation 1962 metres. The area is composed of low to mid hilly topography. Located between to large river system. Onon and Herlen river valleys. Average elevation is around 1400 m above sea level (Baltic). Permafrost zones are rare and fixed maximum 2 – 3 m thick but irregularly located.
Access, infrastructure	The deposit is located in the Khentii Aimag, 45 km northeast of Umnudelger Soum, 385 km from Ulaanbaatar, 85 km south runs the Ulaanbaatar-Choibalsan highway. The gravel road is passable at any time of the year except during heavy snowfall.
Exploration history	The placer deposit was first discovered in 1952 in the frame of geological mapping and prospecting works at a scale 1:50 000 and in 1953 as a result of pre-exploration activities. During 1952 – 1957, Russian Dornod's geological expedition did mapping at a scale 1:50000, and conducted exploration of tin mineralization in the Modot district, estimating the reserves of other parts of the monazite placer deposit, such as Tsagaan chuluut and Khar Burgastai. 2011 – 2016 – Mongolian national company NADB co. Ltd recalculated resources.
Development status	Exploration
Deposit type	Monazite placer deposit. Placer sandy sediments composed of mostly grains of quartz, feldspars, biotite and amphiboles or pyroxenes. Determined are: garnet, ilmenite, hematite, tourmaline, fluorite, zirkon, apatite, rutile, sphene, monazite, xenotime, cassiterite etc. Garnets are common.
Deposit geology	The area belongs to the periphery of the Hercynian old Undurkhaan granite massif. The main ore mineral, monazite, is an accessory to granite, and monazite placer has accumulated in river valleys such as Tsagaan chuluut and Baruun Burgastai, which wash granite massifs. The accumulation of monazite includes alluvial-proluvial sandy and sandy-fractured sediments of modern origin. Undurkhaan granite massif and quaternary sediments. Small and medium grained biotite granites, coarse grained and pegmatite granites and porphyric granites.
Petrography of host rocks	Host rocks are Hercynic aged granites. Granites are several types as mid to fine grained biotitic granites; coarse-grained and pegmatitoidic granites, porphyric granites.
Ore types and ore mineralogy	The deposit has a continuous strip shape and is relatively stable in three spatial directions. Typical placer deposition along shallow valleys within granites.
Resource situation	The total resources of the deposit were registered with the MSPCMR: 596,701.0 m ³ tn of ore, 460 g/ m ³ of monazite, U-0.46 %, Th ₂ O ₃ 7.4 %, Ce ₂ O ₃ - 27.2%(categories B + C), containing 274.55tn of monazite; U-1.24 tn; Th ₂ O ₃ -20.27 tn; Ce ₂ O ₃ -74.62 tn.
Ore processing	No technological testing.
Environmental considerations	The low grade will give rise to large waste dumps and tailing ponds. Presence of radioactive minerals is a big problem.
Relevant literature, data sources	Report 812; 1:50 000 geological mapping; 8549 NADB LLC exploration report

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