

Rare earth elements: Identification and economic considerations in the Oceanus Procellarum

by Lisa Haley

This article examines critical rare earth element (REE) data on Earth and the moon, including the geopolitics of developing national reserves from potential deposits versus developing such resources in the Oceanus Procellarum (Sea of Storms) region of our moon, which is at least two decades into the future.

Rare earths and 21st century technology

REEs have developed new importance, particularly in the last 20 years, because they are vital for their evolving functionality. The REEs have special properties used in a broad range of technical applications, hence they are extremely sought after. Once purified, REE are processed into oxides (cerium, Ce), phosphors (europium, Eu; terbium, Tb; yttrium, Y), metals, alloys, catalyzer magnets (Ce; lanthanum, La) and optical display screens that take advantage of these elements' unique magnetic, luminescent, or electrochemical properties.

Recycling REEs has just begun to take hold, but it is not yet profitable worldwide. Furthermore, rare earths are perceived to be a supply risk, as China controls more than 86 percent of mined and produced REEs on Earth as of 2020 (www.britannica.com).

Rare earth abundance

It is helpful to examine several indicators for REEs: (1) abundance in chlorine (Cl)-type carbonaceous chondrites (meteorites), a measurement of REE abundance in the solar system (Lodders, 2003), (2) crustal abundance on Earth and (3) abundance in bulk silicate Earth (BSE). Abundances for comparative non-REE elements, lithium (Li) and uranium (U), two commonly mined on Earth, are other instructive data points, as well as estimated abundance for the lunar Procellarum KREEP terrane (PKT).

Abundance in average CI carbonaceous chondrites, in parts per million (ppm), shows very low numbers for all REEs (under 1.0 ppm), except scandium at 5.83 and yttrium at 1.53. Comparatively, lithium is 1.46 and uranium is scarce at 0.01.

Crustal abundance measures the concentration of elements in the Earth's continental crust in milligrams per kilogram (mg/

kg) or ppm. Of all the 17 REEs, cerium is the most abundant in the Earth's crust at 66.5 ppm, followed by neodymium at 41.5 ppm, lanthanum at 39 ppm, yttrium at 33 ppm and scandium at 22 ppm. All were under 100 ppm, with the lowest abundances for lutetium at 0.80 ppm and thulium at 0.52 ppm. In comparison, the two non-REEs, lithium and uranium, are measured at approximately 50 ppm and 2.73 ppm.

The estimated average abundance of all REEs in the Earth's crust, which ranges from about 150 to 220 ppm, exceeds that of other metals mined on an industrial scale, such as copper at 55 ppm and zinc at 70 ppm. Unlike most commercially mined base and precious metals, however, REEs rarely concentrate into mineable ore deposits.

Another indicator of REE abundance is bulk silicate Earth, silicon (Si)/oxygen (O) mineralogy, also measured in ppm. BSE is the present-day mantle; Earth's mantle composition after subtracting the crust. For lanthanum, the concentration is 469 ppm; other REEs in the series have the highest abundances, such as cerium at 1,273.5 ppm and neodymium at 952.5 ppm. Gadolinium measured 425.8 ppm, samarium (Sm) 316.95 ppm, praseodymium 193.8 ppm and europium, lowest at 121 ppm. REEs are far more abundant in the BSE than the comparative non-REEs. For example, lithium measures 1.599 ppm, while uranium measures 14.57 ppm.

The asymmetrical moon

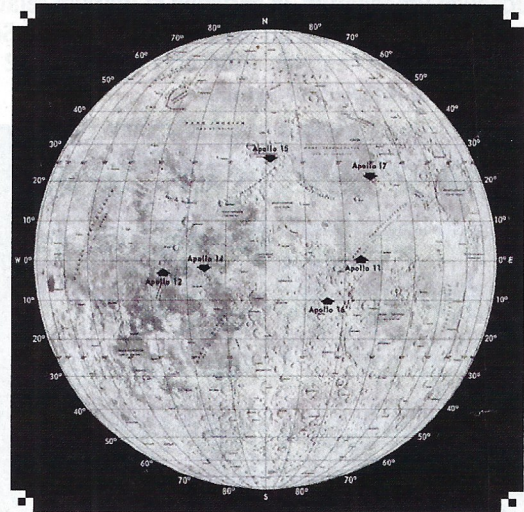
Earth's moon is a planetary body that underwent silicate-metal differentiation early during its 4.3 billion-year history. Starting with the Soviets' Luna spacecraft, which imaged the farside of the moon for the first time and provided evidence of an asymmetrical moon; the differences between nearside and farside images were striking in their contrasts.

Apollo orbital spacecraft, with remote sensing, displayed the first images of variations in composition that corresponded to West-East hemispheric asymmetry, but their instruments were limited to near-equatorial data. Clementine, a joint defense/NASA mission in the mid-1990s, gave scientists the first multispectral lunar map that clearly revealed the extent of the asymmetry and highlighted the uneven distribution of

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Figure 1

Apollo program landing sites. (Image courtesy of NASA)



nearside versus farside maria (“seas”) basalts — large, dark plains formed by ancient asteroid impacts on the farside that triggered volcanic activity on the opposite nearside.

Twenty-first century orbiter imaging further confirmed the stark geological differences between the near and farsides, and that of nearside highlands versus nearside mare terrain by stereo imaging, featured in NASA’s Lunar Reconnaissance Orbiter (LRO) cameras. The LRO’s wide-angle camera offers depth by comparing images of the same areas taken from different views. The LRO also has a narrow-angle camera that accesses high-resolution stereo by acquiring images from the same regions on successive orbits. This capability provides stereo images from across the entire lunar sphere.

Highlands, orange and red on topographical mapping, dominate the farside. Huge dark-blue areas show low-lying igneous basalt mare basins dominating the nearside. Nearside images also capture incredibly old mountains, craters and highlands of feldspar rock. Feldspar crystallized from magma features anorthosite, a plagioclase mineral consisting of aluminum silicates of sodium (Na) and/or calcium (Ca). These features are in conjunction with the mare basalts that are featured on the plains, especially the western regions that incorporate Oceanus Procellarum, Imbrium and several other nearside impact basins.

In 2019, the American Geophysical Union (AGU) announced new evidence about the moon’s crust, suggesting the nearside versus farside differences were caused by a wayward dwarf planet or asteroid colliding with the moon in the early history of the solar system (likely while on its own orbit around the sun). This impact caused the stark asymmetry between the moon’s heavily cratered farside and the lower-lying open basins of its nearside.

AGU’s team of researchers used NASA’s GRAIL (Gravity Recovery and Interior Laboratory) orbiting data from 2012 to design new measurements for computer simulations. They tested different early-moon impact scenarios and discovered that the structure of the farside is much thicker, due to its crust having an extra layer of deposit material.

Lunar KREEP

KREEP is an acronym built from the letters K (the atomic symbol for potassium), REE (rare earth elements) and P (phosphorus). It is a geochemical component of some lunar impact breccias, rock consisting of angular fragments cemented together, from nonmare regions and some basalts. One theory speculates that impact-induced emplacement of KREEP magma from

a primary mantle source was followed by transportation into the crust by rising columns.

According to the giant impact hypothesis, the lunar KREEP component, generated by the late-stage crystallization (99 percent solidification) of a primordial lunar magma ocean, represents the last about 0.5 percent of residual liquids, enriched in KREEP. In modeled scenarios by McSween (2019), both olivine and pyroxene, ferromagnesian minerals (iron (Fe) and magnesium (Mg)) sink while plagioclase floats. KREEP is the final gasp of melt, trapped between crust and mantle cumulates. Planetary differentiation to form cores, mantles and crusts is fundamental to KREEP concentration.

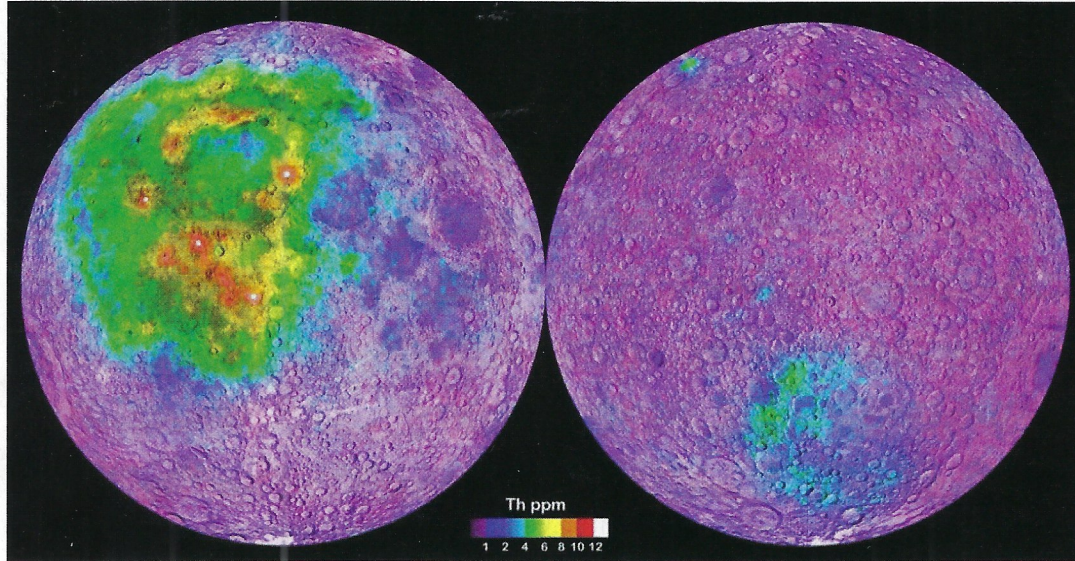
KREEP basalts have higher amounts of feldspar and silica minerals. Pyroxene, the most abundant dark mineral at the lunar surface, is found in samples from Apollos 14, 15 and 17 KREEP basalts. These KREEP basalts derive from the last dregs of liquid from the lunar magma ocean. KREEP basalts (present in impact melt clasts) are distinct from mare basalts because they have a lower Ca/Al ratio reflected in a scarcity of high-Ca pyroxene, the result of melting of the lunar interior.

In lunar rocks, sample evidence shows that REEs are concentrated in the very similar minerals merrillite and whitlockite, often accompanying other minerals. Rare earth metals, the lanthanides, along with scandium and yttrium, while not occurring as native element minerals on Earth, may occur in the lunar regolith. Along with merrillite, which carried more than 90 percent of an Apollo 11 ilmenite basalt rock’s total REE content, the sample showed high concentrations of yttrium plus REE metals.

Merrillite grains in a basaltic lunar meteorite contained highly enriched REEs at 5.5 percent by total weight, which is comparable REE content to LaPaz Icefield, Antarctica lunar meteorites. Two other lunar meteorites contain minor baddeleyite and the rare tranquillityite. The LaPaz samples may be silicic liquids enriched in potassium, zirconium (Zr), phosphorus and other incompatibles, such as

Figure 2

A thorium map of the moon. A map of the thorium content of the lunar surface, based on lunar prospector data, shows that a large area on the nearside of the moon, including the Imbrium Basin and Oceanus Procellarum, is enriched in thorium relative to the rest of the moon. There is also an area of enriched thorium (Th) on the farside, within the South Pole-Aitken basin, but it is less enriched than the area on the nearside. Note: only the Apollo 12 landing site (Fig. 1) came close to the PKT. (Images courtesy of NASA/Paul Spudis)



REEs, which were concentrated during the lengthy fractional crystallization of mafic (olivine and pyroxene) magmas.

The catastrophic impact from a Mars-size body that created the moon from Earth early in the solar system's history eventually endowed the moon with REEs. The subsequent collision by a dwarf impactor formed the asymmetry referenced above in recent AGU research.

Analysis of lunar REE proves that familiar mineral names from Earth — monazite, thorite and yttrapatite — are present. In an Apollo 12 regolith sample, the mineral pyrochlore is associated with thorium (Th), uranium minerals, metallic iron and REE minerals such as whitlockite, perovskite, keiviite, tranquillityite and baddeleyite. In 2016, Lowe et al. detected REE-enriched phosphate (PO_4) in high-titanium (Ti) basalts from an Apollo 17 sample. All Apollo landing sites are identified in Fig. 1.

Chevkinite (cerium), another rare mineral, was identified in an Apollo 11 mare-basalt sample pocketed with other minerals and enriched in K, U, Th, REE (Y), P and other elements. The Procellarum KREEP Terrane is heavily associated with thorium, found as thorite. Figure 2 highlights a thorium map of the moon.

In some lunar rock samples, yttrium was observed in relatively high content in mineral form. An elusive REE, promethium (Pm), is almost exclusively produced in nuclear laboratories; however, if pitchblende ore, a uranium source, is discovered close to the lunar surface, promethium could be prioritized for off-

world nuclear energy in the decades ahead. Other REEs in the same location could also be used.

Uranium was detected in microgram/gram levels in all Apollo samples, along with other incompatible trace elements. In the commonly used space resources text, *Lunar Sourcebook: A User's Guide to the Moon*, Haskin and Warren show a clear correlation between thorium and uranium. Comprehensive, peer-reviewed research on Th, U and individual lunar REEs requires

new data from strategic lander and rover missions in the next decade to further knowledge of the identification and accessibility of these critical resources.

Procellarum KREEP

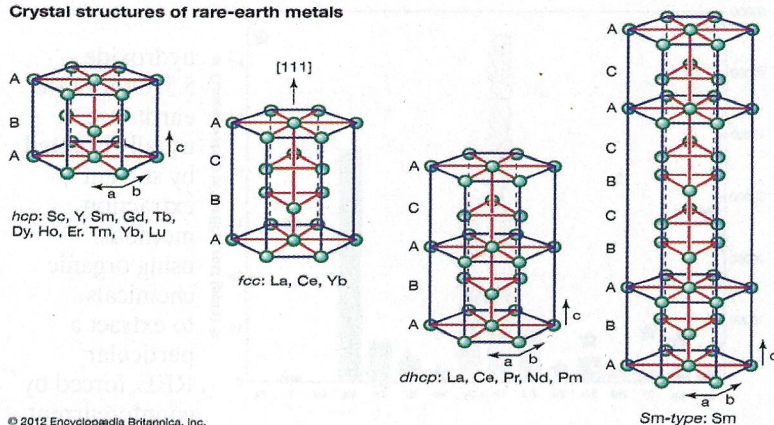
Particularly interesting for space resource scientists is the PKT in the northwest quadrant of the nearside of the moon in Oceanus Procellarum. NASA's lunar prospector employed a gamma-ray spectrometer to survey the entire moon, filtered for thorium detection, and provided a stunning, colorful map (Fig. 2). Analysis of the imaging data clearly highlights the PKT's chemical signature (bright yellow/orange), focused on Th in the region. Even though the PKT reservoir has not been sampled by "boots on the ground," the PKT on the lunar nearside is estimated to contain an astonishing volume of $2.2 \times 10^8 \text{ km}^3$ of KREEP-rich materials at depth. This terrane offers exciting prospective sites for future lunar REE exploration.

The moon features a variety of REE minerals found on Earth, with sample identification from the Apollo mission sites, as well as from orbiting sensing instruments like the Lunar Reconnaissance Orbiter Camera (LROC). Late-stage REE-rich magma pooled in the PKT of the lunar nearside's northwest quadrant.

The concentration of heat-producing elements in this region triggered mantle melting and overturn of cumulate piles, forming two suites of chemically distinct highland rocks, the

Figure 3**Illustrations of crystalline REE structures.**

Crystal structures of rare-earth metals



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magnesian and alkali (potassium oxide and sodium oxide) mineral suites. Low sodium concentrations in lunar rocks, along with the formation of merrillite in late-stage volcanic basalts, caused fine crystalline material to fill in the spaces between crystals. Figure 3 illustrates crystalline REE structures.

These residual melt pockets produced corresponding high REE concentrations, with KREEP rocks having more Na-rich compositions than mare basalts. Analysis of merrillite crystals using Apollo lunar samples, along with an Antarctic lunar meteorite, determined that lunar merrillite differs from terrestrial samples due to enriched Ca^{2+} , Na^+ , or $\text{Y}^+\text{REE}^{3+}$, and the lack of hydrogen (H^+).

Terrestrial industrial processes used to extract REEs from ore

Even though mischmetal, an oxide containing a mixture of REE with lanthanum and cerium dominating is available, most REEs are recovered as individual rare earth oxides (REOs).

Monazite and bastnasite ores go through the multiple steps of rare earth processing. In the 1950s, Frank Spedding and his co-workers at Iowa State University developed a technique of ion-exchange chromatography using solvents to dissolve a mixture and facilitated separation into components. From then on it was possible to separate REE in a reliable, efficient process yielding higher purity, although that method of separation has been surpassed by liquid-liquid exchange technology.

Most rare earths are used to make other REE chemicals, metals and alloys. For the purposes of this article, lanthanum processing will be examined, since La is representative of the extraction methods of most REEs, as they are often found in ores together. Lanthanum may be separated out by the historical method of fractional crystallization of lanthanum nitrate, $\text{La}(\text{NO}_3)_3 \cdot 2\text{NH}_4\text{NO}_3 \cdot 4\text{H}_2\text{O}$. Crystal structures of REE are represented in Fig. 3.

Fractional crystallization is a method of refining substances based on differences in the forming of crystals and solubility. If a mixture in solution crystallizes, for example, the temperature decreases, and the precipitate will contain more of the least soluble substance. This method is preferred by chemical engineers when they need to obtain extremely pure substances, or to recover marketable products from waste (Libretexts, 2021).

Ion exchange (+ or – electrically charged particles) is a liquid treatment method that isolates any undesirable ionic contaminants

from the liquid by exchange with another desirable, or less objectionable, ionic substance. Further separation by solvent extractions or ion-exchange chromatography produces a fraction that is La-enriched, followed by reduction with alkali or alkaline-earth metals in a vacuum or argon (Ar) atmosphere.

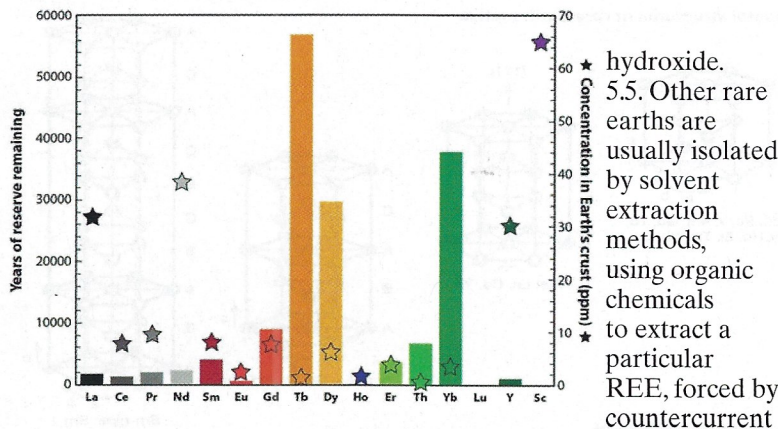
Multistep process for rare earth concentrates

In the summary below, multiple solvent extraction steps are listed because of low separation efficiencies. All steps described are courtesy of accessscience.com, Fractional crystallization (Chemistry Libretexts, 2021), unless otherwise noted.

Isolation of individual lanthanides:

1. Crushing, grinding and roasting of ores, followed by acidic and basic leaching, to produce a concentrate of lanthanides. Monazite, because of its magnetic properties, can be separated by a repeated electromagnetic process.
2. Treatment with hot concentrated sulfuric acid (H_2SO_4).
3. Drying and leaching in solution to produce a concentrate of REE. Lanthanum metal is acquired from its oxide by heating it with ammonium chloride (NH_4Cl) or fluoride (F^- anion) and hydrofluoric acid (HF) at 300 to 400 °C to produce the chloride or fluoride, leaving the early La ions in solution. Extraction of cerium from bastnasite uses hydrochloric acid (HCl) for purification, and to leach out Ce oxides.
4. The resulting REE-rich solution is processed through sequential steps to recover individual REEs. Cerium can be recovered by the addition of sodium hydroxide, (NaOH), which causes the Ce to drop out of the solution as an oxide or

Figure 4
Timeline of REE reserves (McLeod and Krekeler, 2017).



- to the REE-bearing leach solution.
- The individual REE target enters its organic phase and is separated from the leach solution.
- The resulting rare earth oxide is recovered by stripping with hot H_2SO_4 to produce water-soluble sulfates of the element.
- The acid filtrates are partly neutralized with NaOH to pH 3–4. Thorium precipitates out of the solution as hydroxide and is removed.
- Next, the solution is treated with ammonium oxalate, $(NH_4)_2C_2O_4$, to convert REE to their insoluble oxalates.
- The oxalates convert to oxides by annealing, a heat-treatment process used mostly to increase ductility and decrease the hardness of a material.

Ion exchange and solvent extraction mineral separation techniques, especially for the rare earths praseodymium, samarium, dysprosium, terbium (Tb), erbium (Er), holmium (Ho), thulium and ytterbium, have led to much easier isolation and fractional enrichment of REEs, and the cost has dropped greatly in the past few years (Eccles, 1994).

Praseodymium, dysprosium, terbium, thulium, lutetium, scandium and yttrium may also be prepared by other methods, such as by Ca reduction in a tantalum (Ta) crucible, under vacuum. The Los Alamos National Laboratory at the Department of Energy oversees this work in the United States. Calcium and tantalum impurities are removed by vacuum remelting.

Special cases

Promethium is produced in national nuclear energy laboratories, and the Pm-147 isotope is used in industrial applications. Metallic Pm is produced by heating Pm (III) fluoride (PmF₃) with lithium in a Ta crucible, or it can be obtained as Pm (III) hydroxide (Pm (OH)₃) from HCl acid. The extraction of europium (Eu)

from ore involves reduction with Zn electrolysis (Eu metal) or other methods converting the Eu (III) to Eu (II), which can react similarly to that of alkaline earth metals and precipitate as a carbonate or coprecipitate with barium (Ba) sulfate. Gadolinium (Gd) metal is obtained from its oxide or salts by heating it with Ca at 1,450 °C (2,640 °F) in an Ar atmosphere. Recently, electrochemical deposition has been successful in separating samarium (Sm) from other lanthanides. Samarium metal can also be produced by reducing the oxide with Ba sulfate. Holmium is extracted from ores processed to gain yttrium. Thulium (Tm) metal can be produced by oxide reduction with lanthanum. Scandium (Sc) can also be prepared by electrolyzing molten K, Li, and Sc chlorides, using electrodes of tungsten wire and molten zinc. Scandium is extracted from the red slime of alumina production by mineral acids.

Rare earth economics

The extraction of REEs depends on the concentration and mineralogy of the element in the host mineral or rock. The occurrence of a REE-enriched mineral does not necessarily correlate with the economic feasibility of mining that mineral deposit; mining companies must also look at the ore grade of the deposit to determine its profitability.

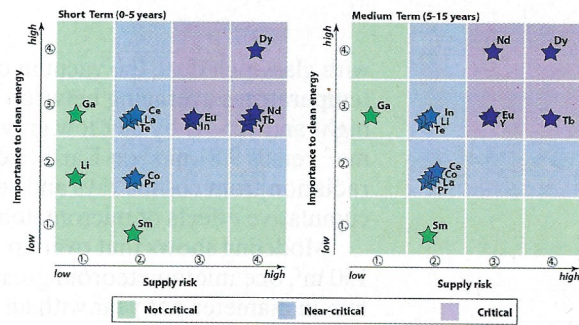
The complex metallurgy of REEs is difficult because no two REE ores are truly alike, so there is no standard process for extracting REE-bearing minerals and refining them into marketable and profitable REE compounds. To develop a new REE mine, the ores must be extensively evaluated by using a variety of known extraction methods, and a sequence of optimized processing steps, as previously noted. Compared with a new zinc mine, development for REE costs significantly more time and money.

Garside reported in 2021 that the occurrence of REE-bearing minerals of economic interest that have reported deposits highlights the time and cost issues: 21 of the deposits report occurrences of greater than or equal to five REE minerals, 34 contain three to four REE minerals, and 44 of the deposits reported only one or two REE minerals.

The most significant problem in the accessibility of valuable REEs is that China controls close to 90 percent of them. Potential production locations tell a different story: worldwide there are multiple deposits in many countries. Mining them is complicated, as REEs are often found only with each other, and in minerals that require intensive extraction and processing to produce REE metal oxides or

Figure 5

REE supply risk (McLeod and Krekeler, 2017).



pure metal. It is currently not feasible at a justifiably commercial scale, nor necessary, for the space community — public or private — to strategically plan for mining lunar REE minerals.

Even though rare earths are abundant, their availability is limited, mainly because their abundance levels in many ores are quite low, less than 5 percent by weight. A potential economically viable source should contain more than 5 percent REEs, unless it is mined with another product such as zirconium, uranium or iron — which allows economic recovery of ore bodies with concentrations of as little as 0.5 percent by weight.

Commodities markets tell us part of the REE story. In 2019, scandium and yttrium metals were the world's 28th and 29th most traded products, with a total trade value of \$422 million (Global Rare-earth Metals Market, 2021-2026).

Demand and supply risk for REEs

Increasing demand for rare earths in renewable energy has become more critical across the globe. REEs like neodymium and praseodymium, which are important in clean-energy applications and in high-tech industries, are in the news as hybrid and electric vehicles gain popularity. Other factors, like the ongoing tensions between the United States and China, and the United States and Russia, are also putting the spotlight on REEs.

Since China is by far the world's largest producer of REEs, leading total global mine production in 2020, its monopoly has exacerbated an already troubled relationship between it and the United States (including concerns about China's business interests with Russia). Global politics are directing attention at supply-chain issues in the REE industry. The graph in Fig. 4 highlights one of the critical issues: the timeline of identified REE reserves, based on concentration (abundance).

Supply risk is another critical issue in the clean-energy sector, and along with national climate goals, is accentuating both the short- and long-term (5 to 15 years) criticality of REEs (Fig. 5).

Economics of lunar extraction

Extraction of REEs on Earth is complicated by the fact that in the ground, such elements are mixed with many other minerals in different concentrations. The raw ores go through a first round of processing to produce concentrates, which head to another facility, where high-purity REEs are isolated. Such facilities perform complex chemical processes usually involving liquid-liquid exchange technology, or solvent extraction methods (previously reviewed in

this article).

Solvent extraction, which involves hundreds of liquid containers that separate individual

REE, with steps that may have to be repeated thousands of times, is obviously not a likely extraction choice for moon minerals (Penn Today, 2022).

Clearly, REE mining and processing on Earth offer lessons for lunar resources utilization. The mass and cost of the technology, and the types of facilities required to process REE on the moon, would be prohibitive for decades to come. Our moon will offer the most valuable resource first: water-ice, a source for propellant (liquid O₂ and liquid H₂) and life support (O₂ and H₂O). The current state of geopolitics (the Russian war in Ukraine) may move the lunar REE timeline ahead due to national interests and rising global prices.

Space X has estimated that for returning to moon missions, its Starship space vehicle will cost customers approximately \$20,000 to \$30,000/km for delivering full-capacity payloads regularly to the lunar surface. Any mission goals to develop REEs on the moon will have to take these factors into consideration.

Conclusion

Is it wise to plan on rare earth mineral mining in the PKT? It is extremely unlikely that REE extraction will happen in the near future — a projected timeline could involve decades. Since transportation of materials payloads to the moon from Earth would cost \$20,000 to \$30,000/kg, REE resource mining would only be economically beneficial if extraction and utilization occurred on the moon, for the lunar technology and energy required to go beyond an outpost in Oceanus Procellarum to a functioning base.

Bringing REEs back to Earth is not a viable option while there are still so many untapped potential deposits worldwide. Increasing demand for REE-dependent technology, supply risk criticality and geopolitics will continue to raise REE prices until scarcity is replaced by economically productive new reserves and efficient global REE recycling.

Mining operations on the moon would certainly be far riskier than on Earth. Extremely difficult technology challenges include energy-intensive approaches, robotic labor, heavy-equipment damage, a lunar environment filled

with glass-rich dust, the vacuum of space, temperatures averaging between -170°C at night and 125°C by day, low gravity at 1.6 m/s^2 versus 9.81 m/s^2 on Earth, exposure to radiation from cosmic rays and solar flux, and the cumulative effects of micrometeoroid hits.

Modeling shows that over an area of about 150 m^2 , one micrometeoroid greater than 0.5 mm in diameter per year with an impact velocity of about 13 km/s would excavate a crater about 1.8 mm in diameter at a depth greater than 1 mm . The problems of such dangerous operating conditions on the lunar surface must be solved before any mining can begin.

These significant hazards to lunar structures, base supports, processing plants and instruments pose daunting problems for REE mining. The risks should be assessed, quantified and mitigated. Only ground-truth sampling via landers and rovers can give space resource scientists the additional data required to accelerate REE use in the PKT. Similarly, it is imperative that extraction of lunar rare earth elements in situ be used in situ. ■

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Biden administration announces steps to secure rare earth supply chain

THE BIDEN administration announced that it will implement recommendations from the Department of Commerce to secure the rare earth element (REE) supply chain. These efforts include bolstering domestic production throughout the supply chain, promoting demand for magnets produced in the United States, engaging with allies and partners on supply-chain resilience, supporting the development of a skilled workforce and encouraging research to mitigate supply-chain vulnerabilities.

The administration decided against restricting imports of neodymium magnets that come primarily from China, the White House said.

Politico reported that the decision to not restrict imports likely avoids a trade fight with China and others that export the magnets. The decision could also ease the concerns of U.S.

automakers who rely on imports of magnets for finished products.

Biden's decision is based on the results of a 270-day Commerce Department investigation which found that U.S. reliance on imports of the powerful magnets are a threat to U.S. national security, and recommended a number of steps to increase domestic production.

Commerce's suggestions included making investments in key segments of the magnet supply chain; incentivizing domestic production; working with allies and partners on supply-chain resilience; supporting the development of a skilled workforce to produce neodymium magnets in the United States; and supporting ongoing research to mitigate supply-chain vulnerabilities, the administration said.

"Today's report affirms the single-point-of-failure risk we face, and the importance of MP Materials'

mission to restore the full rare earth supply chain to American shores. At Mountain Pass, our team is working urgently to create a sustainable supply base for all rare earth materials needed to produce magnets. And, in Fort Worth, we are expeditiously building a state-of-the-art facility to transform these materials into alloys and finished magnets. While it will take years to reinvigorate America's industrial leadership, we are making steady and unwavering progress each day," MP Materials said in a statement.

The Biden administration already has used the Defense Production Act and other authorities to invest nearly \$200 million in three companies — MP Materials, Lynas Rare Earths, and Noveon Magnetics — to increase U.S. capacity to process REEs, such as neodymium, and to boost U.S. production of neodymium magnets from current negligible levels. ■

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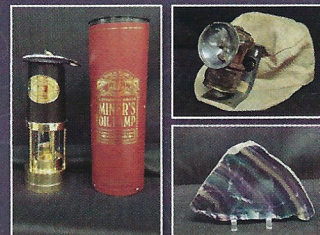
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