RARE-EARTH ELEMENTS:

A brief overview including uses, worldwide resources, and known occurrences in Alaska

Information Circular 61

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COVER PHOTO CAPTIONS:

TOP: Sheeted REE-bearing veins, Dotson Trend, Bokan Mountain property, Alaska.
Photo from http://www.ucoreraremetals.com/docs/SME_2010_Keyser.pdf

BOTTOM: Rare-earth-element-bearing quartz vein exposed in granite, Bokan Mountain, Alaska.
Photo from http://www.ucoreraremetals.com/docs/SME_2010_Keyser.pdf

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DGGS Minerals Program

The Alaska Division of Geological & Geophysical Surveys (DGGS), part of the Department of Natural Resources, is charged by statute with determining the potential of Alaska's land for production of metals, minerals, fuels, and geothermal resources; the locations and supplies of groundwater and construction material; and the potential geologic hazards to buildings, roads, bridges, and other installations and structures. The Mineral Resources Section at DGGS collects, analyzes, and provides information on the geological and geophysical framework of Alaska as it pertains to the state's mineral resources. The results of these studies include reports and maps, which are used by scientists for various associated studies, by mining company geologists as a basis for their more focused exploration programs, and by state and federal agency personnel in resource and land-use management decisions.

This paper provides a brief overview of rare-earth elements, their uses, and current worldwide sources of their production. A summary of some Alaska occurrences of rare-earth elements and associated rocks is also included. This information circular is meant to be non-technical. A brief bibliography of geology papers describing Alaska rare-earth-element occurrences is included for those interested in more detailed geological information on rare-earth-element deposits in Alaska.

Introduction to Rare-Earth Elements

Rare-earth elements and the supply of and demand for these resources are currently significant news items. The global mining industry has ramped up exploration for mineral deposits containing rare-earth elements to meet the perceived future demand. High prices for rare-earth elements continue to drive exploration.

Rare-earth elements (REEs) are a group of chemical elements that occur together in the periodic table of the elements (fig. 1). The group consists of the 15 lanthanide elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Yttrium (Y) is generally included with the rare-earth elements because it

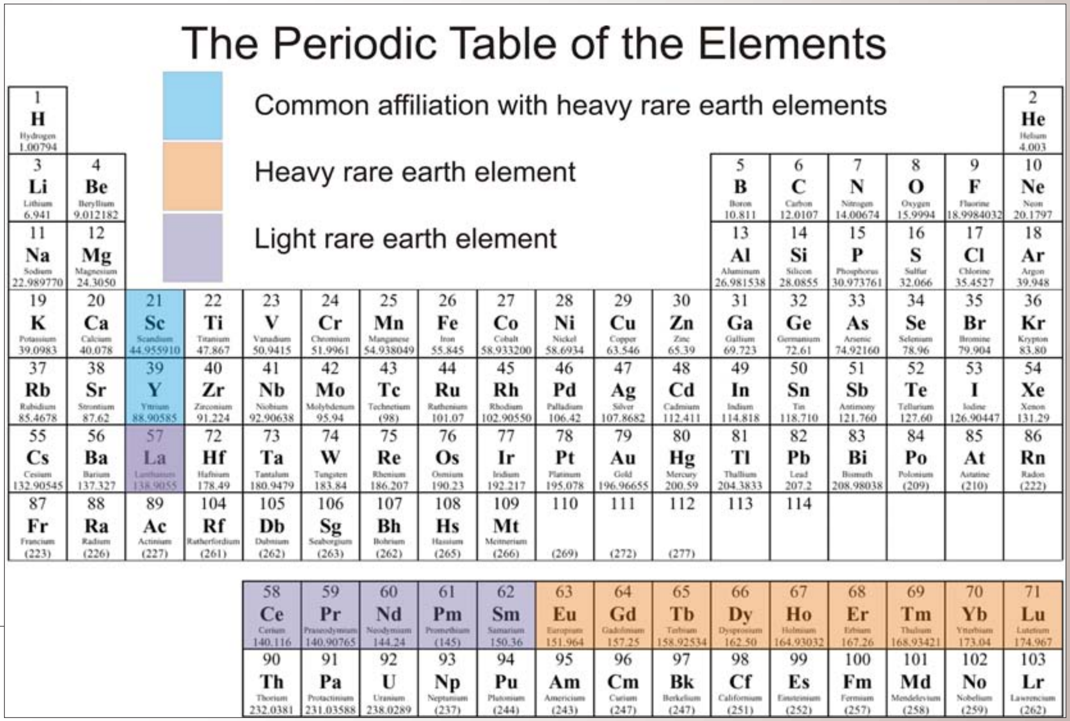

Figure 1. Periodic table of the elements with rare-earth elements highlighted. Most of the rare-earth elements are in the lanthanide series of elements. Base image from malaxos-chemistry.wikispaces.com.

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is chemically similar to the lanthanide elements and it is generally found in minerals that also contain rare-earth elements. Scandium (Sc) also occurs in most rare-earth-element deposits and is sometimes classified as a rare-earth element. The rare-earth elements are all metals and the group is often referred to as the "rare-earth metals." These metals have many similar properties, which often cause them to be found together in mineral deposits.

The rare-earth elements are often informally subdivided into "heavy rare earths" and "light rare earths" based on the atomic number of the element. Lanthanum, cerium, praseodymium, neodymium, promethium and samarium, with atomic numbers 57 through 62, are generally referred to as the "light rare earths." Yttrium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium, with atomic numbers 39 and 63 through 71, are generally considered the "heavy rare earths." Although yttrium, with an atomic number of 39, is lighter than the light rare-earth elements, it is included in the heavy rare-earth group because of its chemical and physical associations with heavy rare earths in natural deposits.

REEs form iron gray to silvery lustrous metals that are typically soft, malleable, and ductile, and usually reactive, especially at elevated temperatures or when finely divided (Cordier and Hedrick, 2010). Melting points for the REEs range from 798°C for cerium to 1,663°C for lutetium. The principal REE ores contain one or more of the following minerals or material: bastnäsite, loparite, monazite, and the lateritic ion-adsorption clays (Cordier and Hedrick, 2010).

Uses of Rare-Earth Elements

Rare-earth elements, metals, and alloys that contain them are used in common consumer goods such as computer memory, DVDs, rechargeable batteries, cell phones, vehicle catalytic converters, magnets, fluorescent lighting, and much more. The demand for REEs used in these goods has surged over the past two decades. For example, 20 years ago cell phones were not available but the number in use today has grown exponentially to more than 5 billion units. Table 1 lists the major categories of REE usage in the United States.

Many rechargeable batteries are made with rare-earth compounds. Rechargeable lanthanum–nickel–hydride (La–Ni–H) batteries are gradually replacing nickel–cadmium (Ni–Cd) batteries in computer and communications applications and could eventually replace lead–acid batteries in automobiles (Haxel and others, 2005). Although more expensive, La–Ni–H batteries offer greater energy density, better charge–discharge characteristics, and fewer environmental problems upon disposal or recycling. Demand for small, long-lasting batteries is being driven by demand for portable electronic devices such as cell phones, readers, computers, and cameras.

Several pounds of rare-earth compounds are required for batteries that power electric vehicles and hybrid-electric vehicles. Rare-earth compounds are also used for powerful magnets in a wide range of products, from computer hard drives to wind turbines. As concerns for energy independence, climate change, and other issues impact the sale of electric vehicles and "green" energy systems like wind turbines and solar power panels, the demand for batteries made with rare-earth compounds is expected to increase dramatically.

Rare earths are used as catalysts, phosphors, and polishing compounds. These are used for air pollution control, illuminated screens on electronic devices, and optical-quality glass. Demand for all of these products is expected to rise.

Other substances can be substituted for rare-earth elements in their most important uses; however, these substitutes are usually far less effective and may have a higher cost.

Table 1. United States REE Usage[a]

Use	Percent
Chemical catalysts	22
Metallurgy and alloys	21
Petroleum refining	14
Catalytic converters	13
Glass polishing and ceramics	9
Phosphors for monitors, television, lighting	8
Permanent magnets	7
Electronics	3
Other	3

[a] 2009 data (USGS, 2011)

Critical Defense Uses of Rare-Earth Elements

Rare-earth elements play an essential role in modern national defense. Night-vision goggles, precision-guided weapons, and other defense technology rely on various rare-earth metals. Rare-earth metals are key ingredients for radar systems, avionics, and satellites. Substitutes can be used for rare-earth elements in some defense applications; however, those substitutes are not as effective. Several defense uses of rare-earth elements are summarized in table 2. There is also widespread use of commercial "off-the-shelf" products in defense systems, which include rare-earth metals, such as computer hard drives.

In 2010, the U.S. Government Accountability Office (GAO) assessed the likelihood of national security risks arising from the U.S.'s nearly 100 percent dependency on non-domestic sources for REEs. China, the primary source, cut its exports by 72 percent in 2010. The GAO report concluded U.S. defense systems will likely continue to depend heavily on REEs, on the basis of current technology and system designs utilizing REEs, and a lack of effective non-REE substitutes (U.S. Government Accountability Office, 2010). The lack of a domestic REE supply chain presents national security concerns for the U.S., and diminishes its ability to be a world-technology leader. For example, a 2009 National Stockpile configuration report identified lack of lanthanum, cerium, europium, and gadolinium as having caused some kind of weapon system production delay (U.S. Government Accountability Office, 2010).

Table 2. Department of Defense Uses of Rare-Earth Elements[a]

Element	Use
Lanthanum	Night-vision goggles
Neodymium	Laser range-finders, guidance systems, communications
Europium	Fluorescents and phosphors in lamps and monitors
Erbium	Amplifiers in fiberoptic data transmission
Samarium	Permanent magnets stable at high temperatures
Samarium	Precision-guided weapons
Samarium	"White noise" production in stealth technology

[a](U.S. Government Accountability Office, 2010)

Rare-Earth-Element Abundances

Rare-earth elements are not as "rare" as their name implies. Thulium and lutetium are the two least abundant rare-earth elements—but they each have an average crustal abundance that is nearly 200 times greater than the crustal abundance of gold (Haxel and others, 2005). Figure 2 shows the relative abundance of rare-earth elements in comparison to rock-forming, industrial, and precious-metal elements. The rare-earth elements have higher commodity prices than most of the other elements shown because REEs are not usually found in concentrations high enough for economical extraction.

The most abundant rare-earth elements are cerium, yttrium, lanthanum and neodymium. They have average crustal abundances that are similar to commonly used industrial metals such as chromium (Cr), nickel (Ni), zinc (Zn), molybdenum (Mo), tin (Sn), tungsten (W), and lead (Pb). However, these rare-earth elements are rarely found in extractable concentrations.

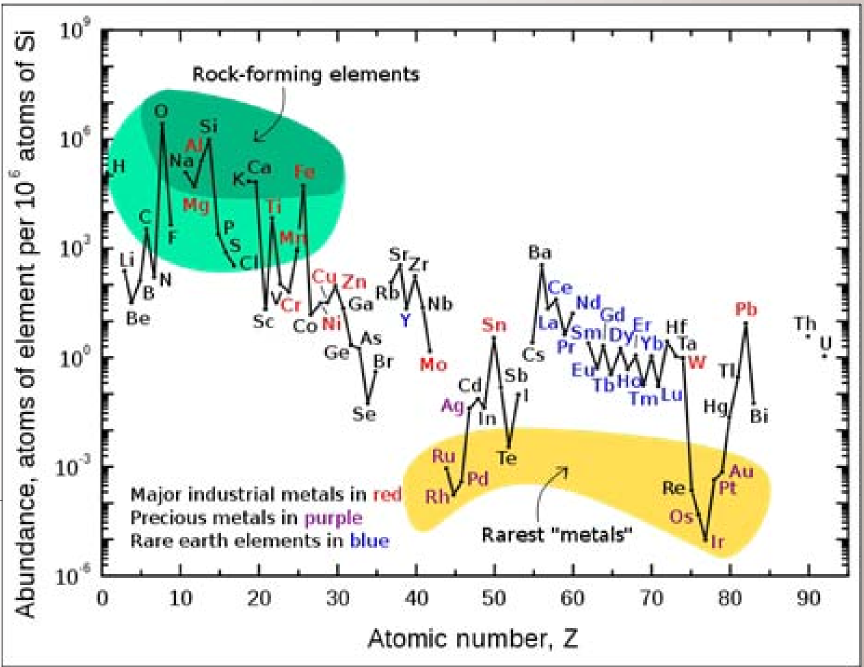


Figure 2. Abundance of elements in the earth's crust compared to one million silicon (Si) atoms (Haxel and others, 2005). Rock-forming elements are found in the green ovoid and the least-abundant (rarest) "metals" are highlighted in the golden area. The rare-earth elements have abundances in the midrange of all elements shown in this figure. Refer to figure 1 (periodic table) for an explanation of any chemical symbols not explained in text.

The principal sources of rare-earth elements are the minerals bastnäsite, monazite, and loparite and the lateritic ion-adsorption clays. Despite their high relative abundance, rare-earth elements are more difficult to extract from their ore minerals than most other metals are from their ore minerals. The rare-earth elements are also difficult to separate from one another, due in part to their similar chemical properties. These factors add to the ultimate costs of producing rare-earth metals and make them relatively expensive compared to other metals. Their industrial use was very limited until efficient separation techniques were developed, such as ion exchange, fractional crystallization, and liquid-liquid extraction during the late 1950s and early 1960s.

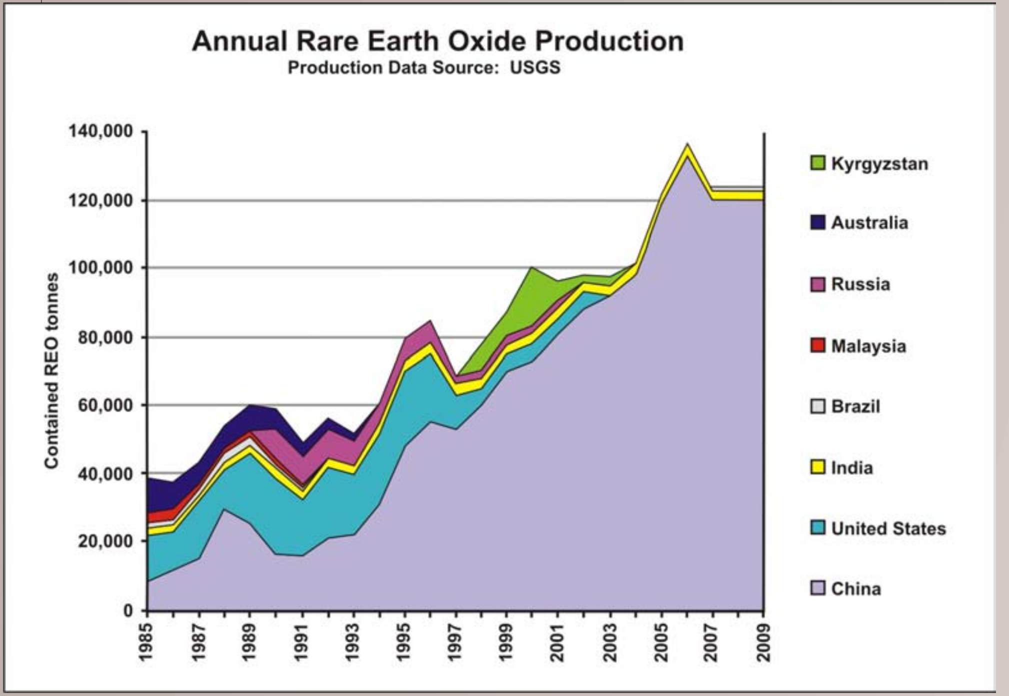
Research to create other possible extraction methods could ultimately lead to lower extraction costs of the rare-earth metals. Recycling of REEs from old equipment may add to the supply chain (Hurst, 2010). At high prices for REEs, reprocessing of tailing piles from former mining operations may also extract significant amounts of REEs (Hurst, 2010).

Rare-Earth Element Production

Only a few countries produce significant amounts of rare-earth elements. China is currently the dominant producer of rare-earth elements and is believed to be responsible for more than 95 percent of the world mine production on a rare-earth oxide equivalent basis (Haxel and others, 2005). Other countries with notable production in 2009 were: Brazil, India, Kyrgyzstan, and Malaysia; minor production may have occurred in Indonesia, Commonwealth of Independent States, Nigeria, North Korea, and Vietnam (USGS, 2011).

China became the world's dominant producer of rare-earth elements in the early 1990s, when production at the Mountain Pass Mine in California began to decline (fig. 3). China's dominance increased rapidly and in 2000 China accounted for about 90 percent of world rare-earth production. China sold rare earths at such low prices that the Mountain Pass Mine and others throughout the world were unable to compete.

Figure 3. Worldwide production of rare-earth oxides from 1987 to 2009 (USGS Minerals Yearbooks).



In 2009 China accounted for more than 97 percent of the world's rare-earth production (U.S. Government Accountability Office, 2010). China is also the dominant consumer of rare-earth elements, used mainly in manufacturing electronics products for domestic and export markets. Japan and the United States are the second- and third-largest consumers of rare-earth materials. The rare-earth separation plant at Mountain Pass resumed operation in 2007 and continued to operate throughout 2010 by processing previously mined rare-earth concentrates into lanthanum concentrate and didymium (75 percent neodymium, 25 percent praseodymium) products (USGS, 2011).

In 2010 China announced they would significantly restrict their rare-earth exports to ensure a supply for domestic manufacturing. This announcement triggered some panic buying and rare-earth prices shot up to record high levels. The 72 percent reduction of rare-earth exports from China in 2010 was followed by an announced 35 percent reduction in export for the first half of 2011 (Bloomberg News, 2010). The Chinese government allocated 15,919 tons of rare-earth exports for the first half of 2011, compared to exports of 24,555 tons in the first half of 2010 and 8,790 tons exported in the second half of 2010 (Bloomberg News, 2010).

China's future export policies are unpredictable, but most analysts expect the Chinese government to favor China's domestic interests, needs, and economic development. Additionally, the total expected production of REEs in China is expected to be insufficient for worldwide demand.

In 2010, U.S. House and Senate bills were introduced to encourage reestablishment of domestic REE industries. The Alaska Legislature passed House Resolution 16 in 2010 urging Congress to advance development of new REE reserves in the U.S., and continued exploration for REE deposits in Alaska.

World Rare-Earth Mineral Resources

Rare-earth elements are relatively abundant in the Earth's crust, but discovered mineable concentrations are less common than for most other ores. U.S. and world resources are contained primarily in bastnäsite and monazite. Figure 4 shows the location of some of the most important REE occurrences and deposits. Table 3 lists world mine reserves and 2010 mine production.

Bastnäsite deposits in China and the United States constitute the largest percentage of the world's rare-earth economic resources, while monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand, and the United States constitute the second-largest segment. Apatite, cheralite, eudialyte, loparite, phosphorites, rare-earth-bearing (ion adsorption) clays, secondary monazite, spent uranium solutions, and xenotime make up most of the remaining resources. Undiscovered resources are thought to be very large relative to expected demand (U.S. Geological Survey, 2011).

Mount Weld in Western Australia is probably the most promising mine development project with its higher-grade rare-earth ore and easier accessibility compared to the Canadian projects at Thor Lake in the Northwest Territories and Hoidas Lake in Saskatchewan (Hurst, 2010). Although construction and operations have begun for Mount Weld, there are still a number of hurdles to overcome. In addition, operations for Mount Weld will likely be costlier because the minerals will have to be transported to Malaysia, where they

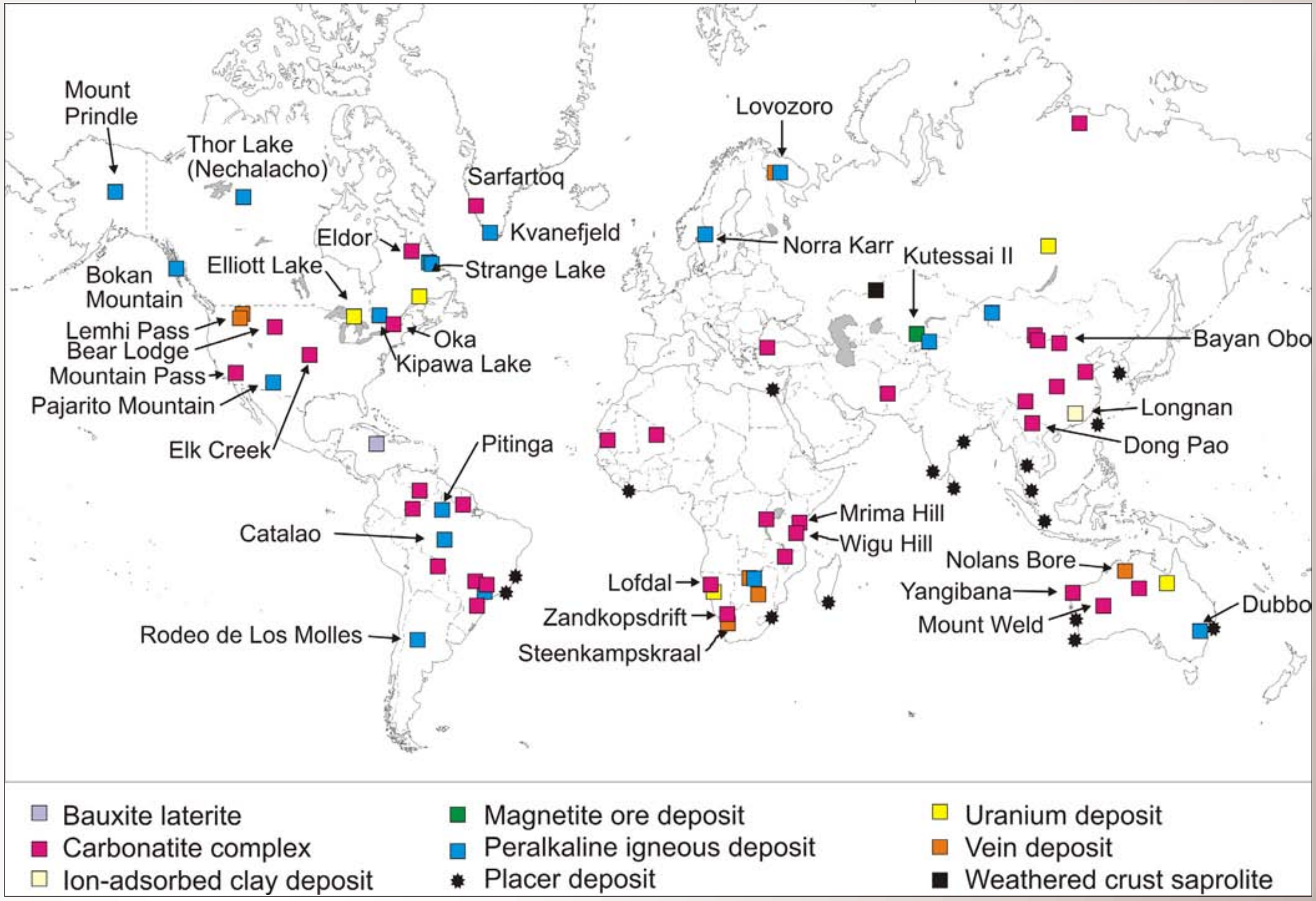


Figure 4. Global distribution of known rare-earth-element resources. Figure from Mariano and others, 2010, modified by Kaiser Research Online (http://www.kaiserbottomfish.com/s/Education.asp?ReportID=362761).

Table 3. World Mine Reserves and 2010 Mine Production

Country	Reserves[a] (tons of REE oxide)	Production (tons of REE oxide)
United States	14,300,000	0
Australia	180,000	0
Brazil	53,000	600
China	60,600,000	140,000
Commonwealth of Independent States (CIS)[b]	20,900,000	NA[c]
India	3,400,000	2,900
Malaysia	33,000	385
Other Countries	24,000,000	NA[c]
World Total (rounded)	**121,000,000**	**143,000**

Source: USGS Mineral Commodity Summaries, 2011

[a] As defined by the USGS, that part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative.

[b] Regional association of former Soviet republics.

[c] Not available

will be further processed into separate rare-earth elements (Hurst, 2010). Steenkampskraal is a former operating rare-earth mine in South Africa, which has been restarted. Production dates for some REE mines are projected to be: 2010—Steenkampskraal; 2011–2012—Mount Weld; 2012—Hoidas Lake; and 2013—Thor Lake (Hurst, 2010).

Exploration efforts to develop rare-earth-element projects surged in 2010, and investment and interest increased dramatically. Economic assessments continued in North America at Bokan Mountain in Alaska; Bear Lodge in Wyoming; Diamond Creek in Idaho; Elk Creek in Nebraska; Hoidas Lake in Saskatchewan, Canada; Lemhi Pass in Idaho–Montana; and Nechalacho (Thor Lake) in Northwest Territories, Canada. Other economic assessments took place in other locations around the world, including Dubbo Zirconia in New South Wales, Australia; Kangankunde in Malawi; Mount Weld in Western Australia, Australia; and Nolans Project in Northern Territory, Australia (U.S. Geological Survey, 2011).

Assessing Alaska's Rare-Earth-Element Potential

Mineral resources comprise a major part of Alaska's economic assets. Alaska is considered highly prospective with regard to strategic and critical minerals needed for domestic uses. Alaska's diverse geology hosts a wide range of mineral deposit types. Figure 5 shows a graph of mineral commodities imported into the United States as of 2009. Alaska currently produces some of these minerals, has produced some in the past, and has the potential to produce some quantity of most of these imported mineral commodities in the future. However, the location and magnitude of these resources are largely unknown. The State of Alaska cannot efficiently manage or develop assets that are unknown and not quantified. The benefits of a thorough mineral-resource information base include: (1) Enhancing community and local government economies and revenue opportunities; (2) Stimulating private-sector exploration and competitive development of Alaska's mineral resources; (3) Developing transportation corridors and infrastructures to known resources; and (4) Providing sound scientific information to support long-term decisions on management of state-interest lands.

The USGS compiled worldwide data on rare-earth-element mines, deposits, and occurrences from a variety of sources (Orris and Grauch, 2002). The report classifies the known occurrences by a number of geological criteria. The North American occurrences cited in Orris and Grauch (2002) and Long and others (2010) are summarized in table 4, including Alaska's Bokan Mountain property. Many of the occurrences have not been well studied and their economic potential is not really known (Orris and Gauch, 2002).

Evaluation of Alaska's REE potential is hindered by a lack of basic geologic data and compilation of existing data. Alaska has more than 70 known REE mineral occurrences (fig. 6, table 5) and millions of acres of selected or conveyed lands with the potential to contain REEs, but the mineral-resource potential of these occurrences and lands is poorly understood. The Bokan Mountain, Mount Prindle, and Tofty REE occurrences are briefly described below.

The Bokan Mountain property, located 37 miles southwest of Ketchikan on Prince of Wales Island, is Alaska's most significant REE prospect. Preliminary assessments suggest the area contains one of the larger REE deposits in North America, with significant enrichments in heavy REEs. The Bokan Mountain area contains 11 uranium–thorium occurrences, and the Ross–Adams pit is the site of Alaska's only past uranium–thorium mining (MacKevett, 1963; Thompson, 1997). The uranium, thorium, and rare-earth-element mineralization is hosted in the Jurassic Bokan Granite Complex, a crudely circular ring dike complex consisting of nine different phase of peralkaline granitic rocks (Thompson, 1997). Mineralization is found in irregular cylindrical "pipes," steep shear-zone-localized pods or lenses, and quartz veins. Exploration for uranium and rare-earth elements began a new phase when Ucore Uranium Inc. (subsequently Ucore Rare Metals Inc.) acquired 100 percent interest in the Bokan Mountain property in 2007, through staking federal mining claims and option agreements with claim holders. Ucore conducted extensive exploration, including geological mapping, geochemical sampling, geophysical surveys (airborne and ground), and drilling since acquiring the Bokan Mountain property. The exploration has identified additional mineralization on the property and changed the conceptual model for the formation of rare-earth-element mineralization in this area.

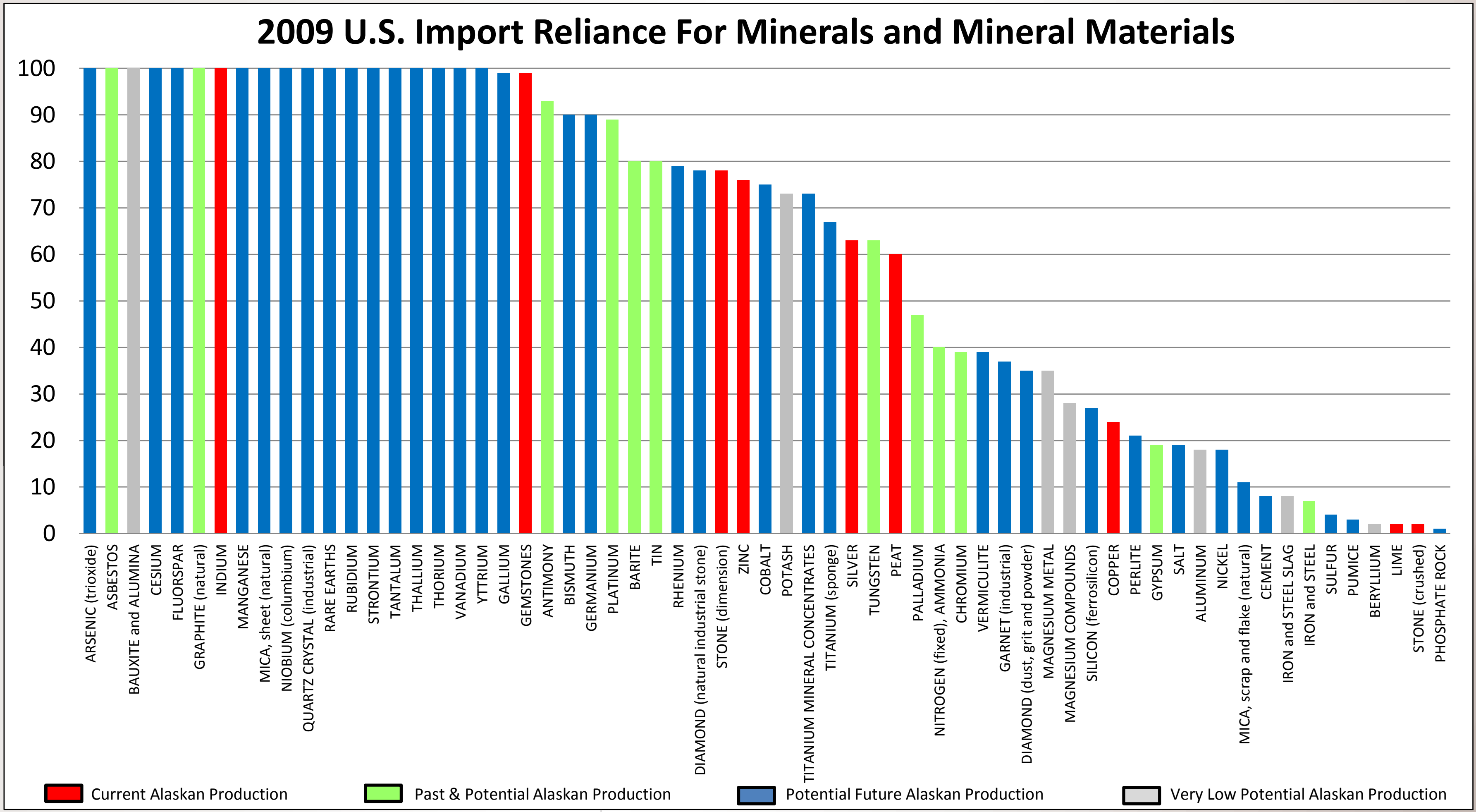


Figure 5. The United States relies on imports of critical minerals to satisfy current needs. Alaska has the potential to produce many of these minerals and materials. Alaska currently and historically has produced 21 of the 63 shown in this figure. Figure modified from U.S. Geological Survey, 2010.

Table 4. U.S. and Canada Rare-Earth-Element Deposit Reserves and Resources (excluding placer deposits)

Deposit Name	Location	Tonnage (tons)	Grade (percent total rare-earth oxides)	Contained total rare-earth oxides (tons)	Rank by tons of rare-earth oxides	Resource Type	Resource Reliability
Iron Hill	Colorado	2,671,248,000	0.40	10,684,992	1	Unclassified Resource	Low
Thor Lake (Lake Zone)	NW Territories	193,874,860	1.43	2,772,632	2	MI&I Resource[a]	Mod High[b]
Strange Lake	Labrador	151,678,178	0.97	1,471,170	3	MI&I Resource[a]	Mod High[b]
Mountain Pass	California	14,973,976	8.24	1,234,240	4	Proven and Probable reserve	High
Bear Lodge	Wyoming	11,767,156	3.60	423,168	5	Inferred Resource	Moderate
Oka	Quebec	231,420,000	0.13	294,234	6	Unclassified Resource	Low
Thor Lake (Lake Zone)	NW Territories	13,235,020	1.70	224,808	7	Proven and Probable reserve	High
Mineville	New York	9,918,000	0.90	88,160	8	Unclassified Resource	Low
Pea Ridge	Missouri	661,200	12.00	79,344	9	Unclassified Resource	Low
Diamond Creek	Idaho	6,391,600	1.22	78,022	10	Unclassified Resource	Low
Hick's Dome	Illinois	16,199,400	0.42	68,324	11	Unclassified Resource	Low
Wet Mountains	Colorado	15,380,614	0.42	65,018	12	Unclassified Resource	Low
Hoidas Lake	Saskatchewan	3,137,394	2.00	62,814	13	MI&I Resource[a]	Mod High[b]
Scrub Oaks	New Jersey	11,020,000	0.38	41,876	14	Unclassified Resource	Low
Bokan Mountain	Alaska	4,044,375	0.75	30,163	15	Inferred Resource[c]	Moderate
Bald Mountain	Wyoming	19,836,000	0.08	15,869	16	Unclassified Resource	Low
Thor Lake (North T)	NW Territories	1,251,872	0.71	8,816	17	MI&I Resource[a]	Mod High[b]
Music Valley	California	55,100	8.60	4,739	18	Unclassified Resource	Low
Zeus (Kipawa Lake)	Quebec	2,501,540	4.24	2,755	19	MI&I Resource[a]	Mod High[b]
Lemhi Pass	Idaho	551,000	0.33	1,818	20	Unclassified Resource	Low
Gallimas Mountains	New Mexico	50,692	2.95	1,543	21	Unclassified Resource	Low
Hall Mountain	Idaho	110,200	0.05	55	22	Unclassified Resource	Low
Pajarito	New Mexico	2,644,800	0.18	4.408	23	Unclassified Resource	Low
Elk Creek	Nebraska	43,418,800	unknown	unknown	24	Unclassified Resource	Low

[a] MI&I Resource = Measured, Indicated & Inferred Resource

[b] Mod High=Moderately High

[c] Resource type, tonnage, and rank for Bokan Mountain were updated from Long and others (2010) with figures from a March 7, 2011, Ucore Rare Metals Inc. press release.

Rare-earth-element prospects are known to occur along the length of Prince of Wales Island in alkaline complexes including peralkaline granite–syenite, carbonate, and pegmatites at Salmon Bay, Cholmondeley Sound, Dora Bay, Moira Sound, McLean Arm, and Stone Rock Bay (Thompson, 1997). Very little exploration has been conducted on these prospects.

Another significant REE occurrence is found in an igneous complex near Roy Creek, about 18 miles west of Mount Prindle in interior Alaska. The property is approximately 16 miles north of Mile 44 of the Steese Highway and is currently within the White Mountain National Recreation Area; the area is closed to mining. The Mount Prindle syenite complex was originally staked for uranium in 1978 by MAPCO Inc. MAPCO sampled and drilled the Roy Creek property and identified several small deposits that are extremely high in thorium and rare-earth elements (Armbrustmacher, 1989). Mineralization occurs as fissure veins containing allanite, bastnäsite, monazite, thorianite, thorite, uraninite, and xenotime with fluorite in a Cretaceous-age granitic igneous complex with five types of granitic-type igneous rocks dominated by syenite (Freeman and Schaefer, 1998). Rock samples contain up to 0.1 percent uranium oxide and 15 percent rare-earth elements (Freeman and Schaefer, 1998). Samples of a mineralized fracture zone from a drill core sample at the Roy Creek prospect contained more than 0.2 percent thorium, the upper limit of determination by emission spectrography, and a concentrate sample from sediment in Roy Creek contained thorite, allanite, cassiterite, scheelite, and sapphire corundum (Weber and others, 1988).

A slightly different type of rare-earth-element occurrence is found near Manley Hot Springs in interior Alaska in a Triassic carbonatite sill with a strike length of at least 6 miles (Reifenstuhl and others, 1998). The Tofty Ridge prospect has been explored since 1978, including approximately 5,300 feet of core drilling by the U.S. Bureau of Mines and industry (Szumigala and others, 2004). Best known results from the exploration are 30 feet of trench rock sampling that average more than one percent REE (as cerium and lanthanum) and 0.15 percent niobium. Portions of the core were geochemically anomalous for niobium, REE, and yttrium (Szumigala and others, 2004). Nearby creeks may have placer REE resources.

Additional geological, geochemical, and geophysical studies are required to understand Alaska's REE occurrences and to determine the size and grade of these deposits. Additional exploration and study may lead to additional mineral discoveries.

Table 5. Alaska rare-earth-element occurrences and anomalies.

Map No.	ARDF No.	Historical site name(s)	Elements (minor elements)
1	DP003	Aichilik River	Y, Yb, REE
2	ML015	Okpilak River	Mo, U (F, possibly REE)
3	ML013	Fire Creek	P (REE)
4	CO027	Unnamed	Pb, REE
5	EA037	Unnamed (on Slate Creek)	REE, Th
6	EA039	Ruby Creek	REE, Th
7	CI027	Hot Springs Creek	U?, REE, Th?, W
8	CI078	Unnamed (near head of Hope Creek)	F (Cu, Mo, Pb, REE?, Sb, W, Zn)
9	CI051	Roy Creek; Little Champion Creek	U (REE)
10	BT018	Unnamed (southeast of Sithylemenkat Lake)	Sn (As, Bi, Cs, Cu, Nb, Pb, Rb, REE, Ta, W)
11	TN009	Unnamed (Spooky Valley)	Ag, Pb, Zn (Bi, La, Mo, Sn, U, W)
12	TN083	Unnamed (upper Idaho Gulch)	Ce, Nb (Ag, REE, U)
13	TN099	Tofty Ridge	Ce, Nb, Y (Ag, REE, U)
14	TN115	Karshner Creek	REE
15	HU008	Boston Ridge	REE, Th, U
16	HU011	Unnamed (northeast ridge of Caribou Mountain)	REE, Th, U
17	HU016	Unnamed (in Zane Hills, south of upper Caribou Creek)	REE, Th, U
18	SH010	Unnamed (northeast of Solsmunket Lake)	W (REE, Th, U)
19	MD003	Unnamed	Th, U (REE)
20	MD002	Unnamed	Th, U (Ce, REE)
21	MD004	Unnamed	Nb, Th, U (Ce, REE, W)
22	MD005	Unnamed	Th, U (Ce, Rb)
23	MD012	Unnamed	Zn (Ce, Rb)
24	BN094	Windy Creek	Mo, Pb, Zn (Ag, Ba, La, Sn)
25	TE042	Unnamed (on Tin Creek, tributary to Lost River)	Be, Sn, F
26	SO044	Unnamed (on Rock Creek)	REE, U
27	SO043	Unnamed (tributary to Vulcan Creek)	REE, U
28	SO042	Unnamed (tributary to Clear Creek)	REE, U
29	SO040	Unnamed (tributary to Clear Creek)	REE, U
30	SO041	Unnamed (tributary to Clear Creek)	REE, U
31	SO039	Unnamed (tributary to Clear Creek)	REE, U
32	SO038	Unnamed (tributary to Clear Creek)	REE, Sn, U, W
33	SO037	Clear Creek	REE, U
34	SO036	Kwiniuk River	Cu, REE, W
35	SO159	Unnamed (east of Eagle Creek)	REE, Th, U
36	SO003	Golovnin Bay	REE, U, W
37	SO001	Cape Darby	REE, U, W
38	RM020	Unnamed (southern Russian Mountains)	Sb (Nd, Ta, U)
39	SM005	Unnamed (northeast of head of Getmuna Creek)	Ce, Hg, Nb, Zn (Au, Cr, Cu)
40	MG036	Eudialyte	REE, Zr (Th, U)
41	SM037	Unnamed (northeast of lower Sue Creek)	Ce, La, Sm, Th, U, W, Zr (Au, Cu, Hg, Pb)
42	LH006	Unnamed (near Swift River)	REE
43	LH007	Unnamed (near Swift River)	REE
44	MF026	Monarch No. 1 and No. 2	Au (Ag, Pb, REE)
45	JU060	William Henry	Cu, Pb, REE, Zn (Au)
46	JU057	Lucky Six Creek; William Henry	Cu, Pb, REE, Th, U, Zn
47	JU254	Unnamed (near Salmon River)	REE (Y, Zr, Nb, Th, La, Ce, Pr, Nd)
48	PE001	Unnamed (near mouth of Port Camden)	Th, U (Ce, La)
49	PE021	Unnamed (near Totem Bay)	Th, U (Ce, La, Nd)
50	PE056	Unnamed (near Salmon Bay)	REE, Th, U (Mo)
51	PE055	Paystreak Vein; Marker Vein	U, Th, REE (Mo)
52	PE060	Unnamed (along Snow Passage)	F (Au, Ba, Ce, La)
53	BC004	Unnamed (near Cone Mountain)	U? (Ce, La, Mo, Nd, Th)
54	BC090	Unnamed (near Black Crag)	Ag, Au, Cu, Mo, Zn (Ce, La, Nd, Sm, Th, U)
55	CR172	Unnamed (at head of Dora Bay)	Nb, REE, Y
56	DE042	Unnamed (near Mallard Bay)	Au, Ce, Cu, La, U (Y, Zr)
57	DE043	Unnamed (north shore, Stone Rock Bay)	Au, Ce, Cu, La, U (Y, Zr)
		BOKAN MOUNTAIN PROPERTY (named sites listed below)	
58	DE020	Little Jim; Little Joe No. 1, Little Joe No. 2	(Nb, REE, Th, Ti, U, Zr)
59	DE030	Shore	Be, Nb, REE, Th, Ti, U, Y, Zn, Zr
60	DE028	Upper Cheri	Be, Nb, REE, Th, U, Y, Zr
61	DE029	Cheri; Cheri No. 1	Be, Nb, REE, Th, U, Y, Zr
62	DE031	Geoduck	Be, Nb, REE, Th, U, Y, Zr
63	DE015	Geiger	Nb, REE, Ta, Th, U, Y, Zr (F, Ge, Pb, Zn)
64	DE019	Wennie (Lazo Group); I and L No. 1 and 2	Nb, REE, Th, U
65	DE017	Sunday Lake	Nb, REE, Th, U, Y, Zr
66	DE027	Carol Ann; Carol Ann No. 1; Carol Ann No. 2; Carol Ann No 3; Dotson	Nb, REE, Th, U, Y
67	DE021	I,L, and M; ILM; I, L, and M Nos. 1-3	Nb, REE, Th, Y, U, Zr
68	DE022	Irene-D	Nb, REE, U, Y, Zr
69	DE023	I and L; I and L Nos. 3-5	Nb, Th, U (Ce, Dy, Er, F, Gd, Ho, La, Nd, Pb, Y, Yb, Zn, Zr)
70	DE016	Boots	REE, Th, U
71	DE025	Historic Ross–Adams Mine	U (REE, Th)

Sources: Modified from http://ardf.wr.usgs.gov/; NURE sediment data from http://pubs.usgs.gov/of/1997/ofr-97-0492/state/nure_ak.htm

ALASKA'S RARE-EARTH-ELEMENT POTENTIAL

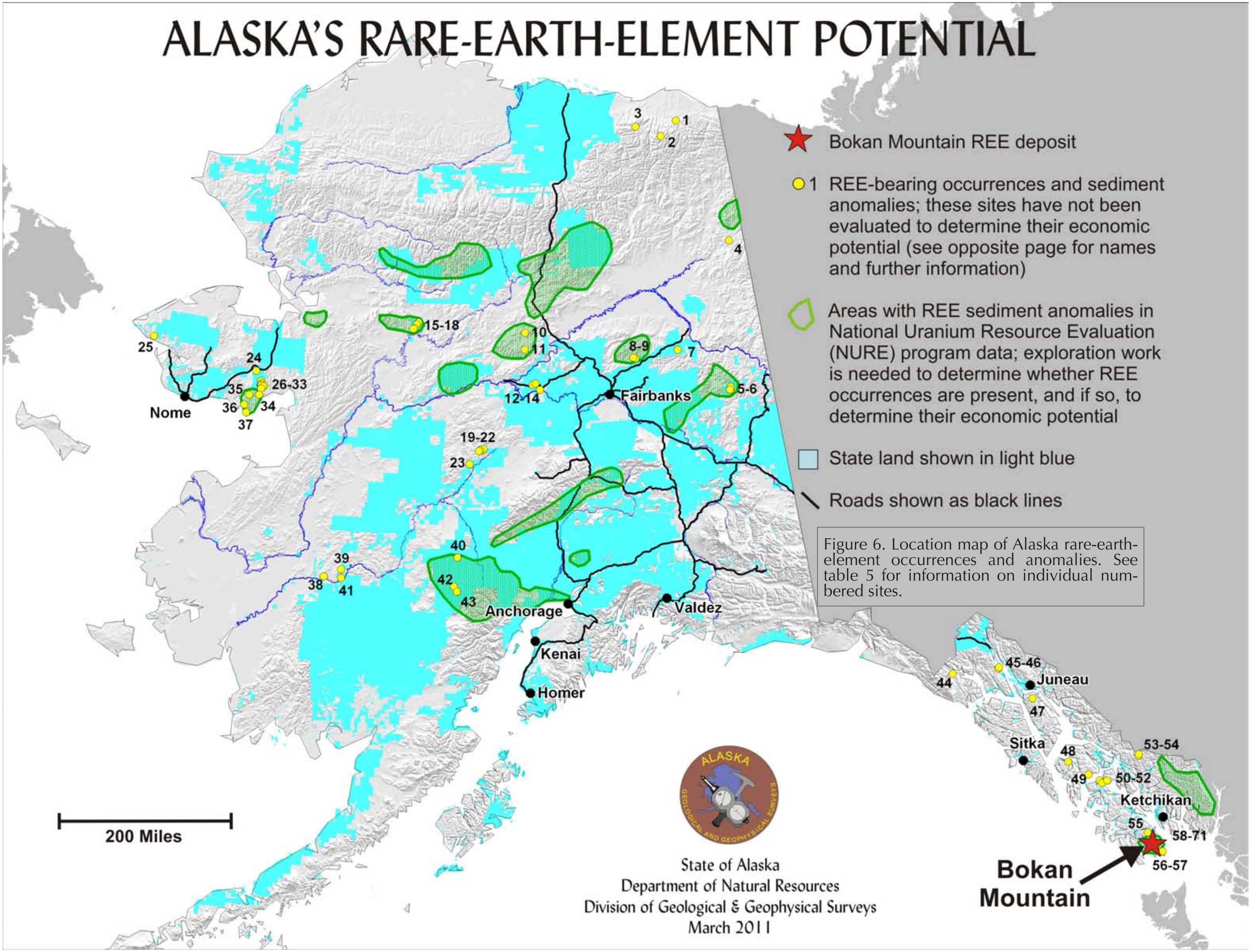


Figure 6. Location map of Alaska rare-earth-element occurrences and anomalies. See table 5 for information on individual numbered sites.

State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys
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