Mine workings at Mountain Pass Rare Earth Mine. Clark Mountain in the background. Photo: Chris Higgins, CGS.

Figure 1. *List of minerals determined to be critical by the USGS in 2022. Note that rare earth elements include scandium, yttrium and the 14 lanthanides listed under Rare Earth Elements in the above image. The lanthanides are grouped into rare earth elements for this note.*

What are Critical Minerals?

Critical minerals are non-fuel minerals that are identified as essential to the economic and national security of the United States (U.S.). In most instances the U.S. is highly dependent on imports of these minerals through vulnerable supply chains (Fortier et al., 2018). In 2017, Executive Order 13817 directed the United States Geological Survey (USGS) to develop and maintain a list of non-fuel minerals and mineral materials determined to be critical to the U.S. In 2018, the USGS released a list of 35 critical minerals. Since mineral needs change with technological advances and societal demands, in 2022 the USGS updated this list to include 50 minerals.

Critical Mineral Occurrence

The list is actually made up of 50 elements (Figure 1), not minerals, most of which are metals, such as aluminum and tin, that occur on earth primarily in minerals and not as pure elements. Minerals are naturally occurring compounds that form through earth processes and constitute rocks. The rock that is mined to produce aluminum, for instance, is called bauxite. Bauxite is made up of multiple minerals including gibbsite, boehmite, and diaspore. These minerals are all composed of different proportions of aluminum, oxygen, and hydrogen. Additionally, the primary ore of tin is cassiterite, which is composed of tin and oxygen.

Critical Mineral Uses

Critical minerals are essential for modern society and are used in all sectors of the economy, including aerospace, national defense, healthcare, electronics, automotive, and home goods (Fortier et al., 2018), (Figure 2). A complete list of critical minerals and their uses is listed in Table 1.

Critical Minerals in a Cell Phone

Speaker:

Rare earth elements are used to make magnets in speakers and microphones.

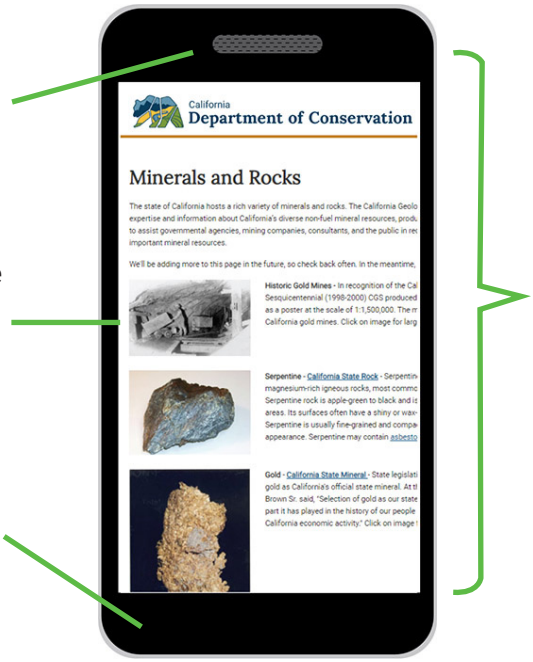
Screen and display:

Aluminum, gallium, and rare earth elements are used to make scratch-resistant screens and LEDs.

Indium and tin are used to make screens touch sensitive.

Battery:

Lithium, graphite, and germanium are used to make cell phone batteries.



Internal parts:

Arsenic is used to make radio frequency and power amplifiers.

Rare earth elements, tungsten, and germanium are used to make vibration motors.

Germanium, tin, tungsten, platinum, and palladium are used in circuitry.

Tantalum is used in capacitors to regulate voltage and improve audio quality in cell phones.

Figure 2. *Image of a smartphone with examples of critical minerals and their uses in the device (phone composition source: Jenness et al., 2016).*

Materials containing the critical minerals antimony, chromium, graphite, magnesium, and manganese were being actively mined in California before the 1900s.

Import Reliance

Critical minerals occur all over the world; however, most production for each mineral occurs in one or two countries. In 2021, the U.S. was 100% dependent upon importation of 13 critical minerals and at least 50% dependent on importation of 39 of the 50 critical minerals (USGS, 2022a).

Although the U.S. imported critical minerals from over 20 countries in 2021, many of these mineral commodities come from a handful of countries, including China (12 critical minerals), Canada (10), South Africa (6), and Mexico (3). In 2021, the U.S. was at least 50 percent reliant on imports from these four countries for 26 critical minerals (USGS, 2022a).

Critical Minerals in California

California has a diverse assemblage of rock types and geologic settings that make it favorable for mining many types of minerals and metals. The discovery of gold in 1848 brought prospectors from all over the world to California with the hope of striking it rich. However, as early as the 1850s miners were searching for minerals besides gold (California Division of Mines

and Geology (CDMG), 1966; the CDMG's name was changed to the California Geological Survey in 2005). This search led miners to discover many other minerals, including some that are now considered critical. Minerals containing antimony, chromium, graphite, magnesium, and manganese, all of which are critical minerals, were being actively mined in California before the 1900s. In fact, some were being mined as early as the 1860s. By 1875, notably, California was the leading producer of chromium in the U.S. and maintained that status until 1940 (CDMG, 1966). In the 175 years since the California gold rush, prospectors have discovered all 50 of the critical minerals within the State (Figure 3). Of the 50 critical minerals found in California, 32 have been mined and produced. Since statehood in 1850, California has been one of the top yearly producers of tungsten, rare earth elements (REE), chromite, lithium, platinum, potash, strontium, and tin for at least one year.

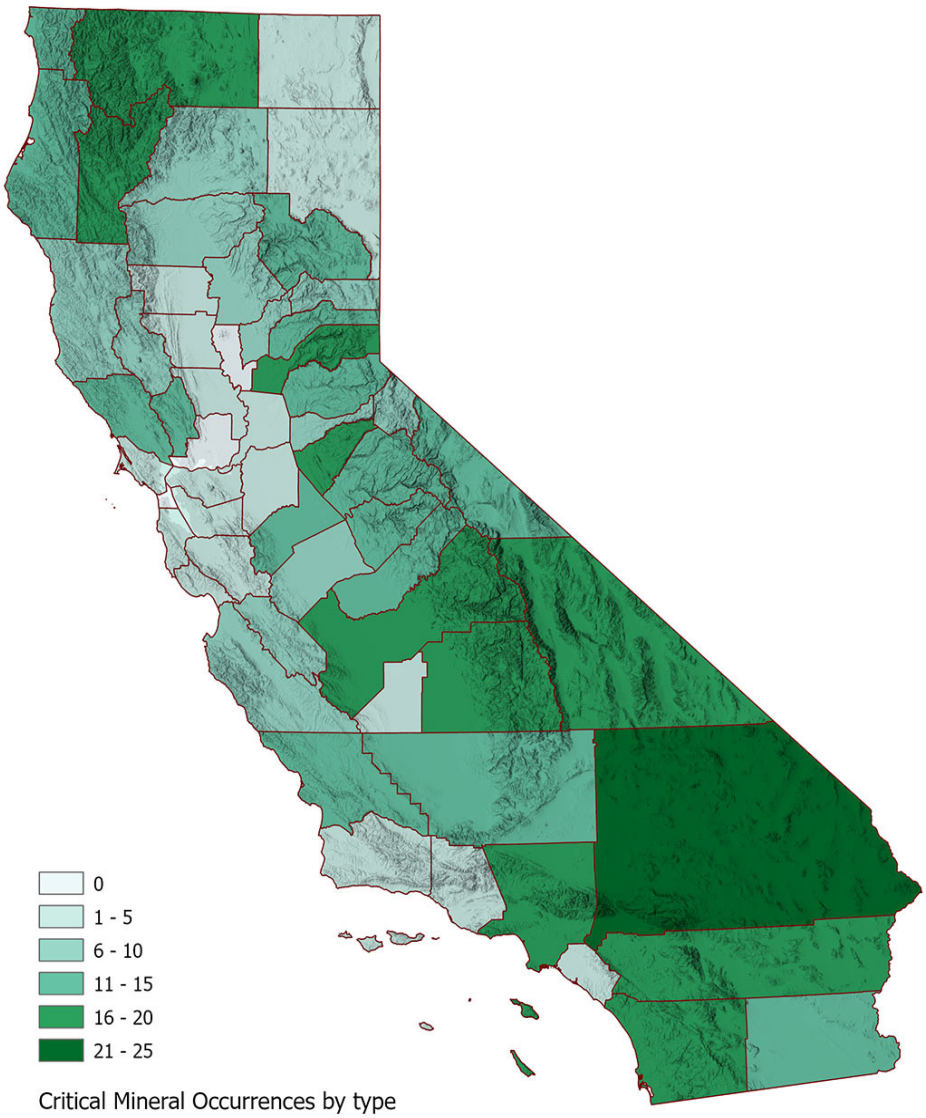


Figure 3. *Map of California counties showing the number of critical mineral occurrences by type. Due to USGS reporting methods all lanthanide REE minerals are grouped into a single occurrence. Mineral occurrences determined using USGS Mineral Resource Data System (USGS, 2005).*

By 1875, notably, California was the leading producer of chromium in the U.S. and maintained that status until 1940 (CDMG, 1966).

Right: *Sample of beryl (blue) on quartz (white) from the California Blue Mine near the town of Yucca Valley in San Bernardino County. Beryl is mined to produce beryllium. Photo: Sara Gallagher, CGS.*

Left: *Sample of vanadinite. Vanadinite can be mined to produce vanadium. Photo: Catt Wesoloski, CGS.*

In the time since California became a state, prospectors have discovered all 50 of the critical minerals within the State.

Current Production of Critical Minerals in California

As of 2023, only two operations within California are actively producing critical minerals. An industrial plant that produces magnesium compounds by processing sea water and the Mountain Pass REE mine. Although Mountain Pass produces REE, until recently it was unable to refine the ore to a useable product. The ore was pulverized at the Mountain Pass facility and shipped to China for further processing. Because the supply chain relied on China for processing, the U.S. was 100% reliant on China for their imports. Recently Mountain Pass constructed a facility to process the ore into REE oxides, including neodymium-praseodymium oxides which are used in the production of magnets. Once fully operational, the Mountain Pass processing facility will decrease the U.S. reliance on foreign countries for REE.

Sample of lepidolite (pink) on microcline (white) collected from the Little Three Mine near Ramona in San Diego County. Lepidolite is mined to produce lithium. Photo: David Reioux, CGS.

Table 1. *Table listing the 50 critical minerals, their associated ore mineral(s), the percentage of the mineral products imported based on total consumption in the U.S. in 2021, and the top countries from which the U.S. imports. The table also includes common uses and the occurrence/production history in California.*

Critical Mineral[1]	California Production[2]	Associated Ore/ Mineral(s)[3]	Import Reliance[4]	Top Import Sources	Common Uses[5]
Aluminum	Limited to none	Bauxite	44%	Canada	Cans, foil, doors, airplanes, trucks, cars, boats, appliances, and cookware
Antimony	Previously produced	Stibnite	84%	China	Hardener in lead, alloying agent, and fire retardant
Arsenic	By-product from other mineral production	Arsenopyrite	100%	China, Morocco	Pressure treated lumber, pesticides, and semi-conductors
Barite	Previously produced	Barite	>75%	China	Cement and drilling fluids
Beryllium	Previously produced	Beryl, bertrandite	16%	Kazakhstan	Satellite communication, alloying agent in aerospace and defense industries
Bismuth	Previously produced	Bismuthinite, bismite, by-product of lead processing	90%	China	Alloying agent, medications, atomic research, and nontoxic substitute for lead
Cesium	Limited to none	Pollucite	100%	No Data	Drilling fluids, fireworks, and research and development
Chromium	Previously produced	Chromite	80%	South Africa	Stainless steel and other alloys
Cobalt	Limited to none	Cobaltite, by-product of copper and nickel processing	76%	Norway, Canada	Rechargeable batteries, superalloys, airbags, paints, varnishes, inks, and dyes
Fluorspar	Previously produced	Fluorspar	100%	Mexico	Manufacture of aluminum, gasoline, and uranium fuel
Gallium	By-product from other mineral production	By-product of bauxite and zinc processing	100%	China	Integrated circuits, optical devices, lasers, and LEDs
Germanium	By-product from other mineral production	By-product of zinc processing	>50%	China	Fiber optics and night vision
Graphite	Previously produced	Graphite	100%	China, Mexico	Lubricants, batteries, and fuel cells
Hafnium	Limited to none	Zircon	No Data	Germany, France	Nuclear control rods, alloys, and high-temperature ceramics
Indium	By-product from other mineral production	By-product of zinc processing	100%	China, Canada	Liquid crystal displays
Iridium	By-product from other mineral production	Platinum group alloy	No Data	No Data	Hardening agent, electrochemical anode coating, and chemical catalyst
Lithium	Previously produced	Petalite, lepidolite, spodumene, brines	>25%	Argentina, Chile	Batteries, ceramics, glass, metallurgy, and pharmaceuticals

Critical Mineral[1]	California Production[2]	Associated Ore/ Mineral(s)[3]	Import Reliance[4]	Top Import Sources	Common Uses[5]
Magnesium	Compounds currently produced from sea water	Dolomite, magnesite, brucite, carnallite, olivine, sea water	<50% metal	Canada, Israel	Alloying with aluminum, reducing metals
Manganese	Previously produced	Pyrolusite, rhodonite, rhodochrosite	100%	Gabon, South Africa	Steelmaking, dry cell batteries, and fertilizers
Nickel	Previously produced	Laterite, pentlandite	48%	Canada, Mexico	Stainless steel, superalloys for the aerospace industry, rechargeable batteries
Niobium	Limited to none	Pyrochlore, columbite	100%	Brazil, Canada	Alloying agent and super alloys for jet engine and rocket components
Palladium	Limited to none	Cooperite, platinum group alloys	37%	Russia, South Africa	Catalytic converters, medical and dental devices, and chemical production
Platinum	Limited to none	Sperrylite, cooperite, platinum group alloys	70%	South Africa, Germany	Catalytic converters for cars, fertilizer production, oil refining, and jewelry
Rare earth elements	Currently produced in California.	Bastnasite, monazite, loparite	>90%	China	Batteries, magnets, and electronics
Rhodium	By-product from other mineral production	Platinum group alloy	No Data	No Data	Catalytic converters for cars, electrical components, and as a catalyst
Rubidium	Limited to none	By-product of cesium and lithium processing	100%	No Data	Medication, electronics, quantum computers, specialty glass, night vison
Ruthenium	By-product from other mineral production	Platinum group alloy	No Data	No Data	Catalysts, electrical contacts and chip resistors, chlorine production
Scandium	Limited to none	Thortveitite, by-product of uranium processing	100%	No Data	Alloys, fuel cells, ceramics, electronics, lasers, lights, and radioactive isotopes
Tantalum	Previously produced	Tantalite, by-product of lithium processing	100%	China	Capacitors and alloying agent
Tellurium	By-product from other mineral production	By-product of copper processing	>95%	Canada	Steelmaking and solar cells
Tin	Previously produced	Cassiterite	78%	Canada, Indonesia	Protective coatings, alloys for steel, and solder
Titanium	Previously produced	Ilmenite, leucoxene, rutile	90%	South Africa	White pigment (paint, paper, and plastics), and alloying agent
Tungsten	Previously produced	Scheelite, wolframite	>50%	China	Wear-resistant metals, heavy metals, alloying agent, and cemented carbides

Critical Mineral[1]	California Production[2]	Associated Ore/ Mineral(s)[3]	Import Reliance[4]	Top Import Sources	Common Uses[5]
Vanadium	Previously produced	By-product of iron ore and uraniferous sandstone processing, coal and petroleum residues	100%	Canada	Alloying agent with titanium for jet engines and high-speed airframes
Yttrium	Currently produced in California	Bastnasite, monazite	100%	China	Catalysts, ceramics, electronics, lasers, metallurgy, and phosphors
Zinc	Previously produced	Sphalerite, smithsonite	76%	Canada	Metallurgy to produce galvanized steel, alloying agent
Zirconium	Limited to none	Zircon	<25%	South Africa, Senegal	High-temperature ceramics

Footnotes:

[1] Critical mineral list from the United States Department of the Interior published Final List of Critical Minerals USGS 2022b

[2] California Production determined from USGS 2022a Mineral Commodity Summaries, CDMG Bulletin 191, and the USGS 2005 Mineral Resources Data System (MRDS)

[3] Associated Ore/Mineral(s) determined from USGS 2022a Mineral Commodity Summaries, CDMG Bulletin 191

[4] Import Reliance and Import Sources data from USGS 2022a Mineral Commodity Summaries

[5] Common Uses compiled from USGS 2022a Mineral Commodity Summaries, Final List of Critical Minerals USGS 2022b, CDMG Bulletin 191, USGS OFR 2018-1021

References

1. California Division of Mines and Geology, 1966. Mineral Resources of California, Bulletin 191, 450p.
2. Fortier, S.M., Nassar, N.T., Lederer, G.W., Brainard, J., Gambogi, J., and McCullough, E.A., 2018. Draft critical mineral list—Summary of methodology and background information—U.S. Geological Survey technical input document in response to Secretarial Order No. 3359, U.S. Geological Survey Open-File Report 2018–1021, 15 p., https://doi.org/10.3133/ofr20181021.
3. Jenness, J.E., Ober, J.A., Wilkins, A.M., and Gambogi, J., 2016. A world of minerals in your mobile device, U.S. Geological Survey General Information Product 167, 2 p., http://dx.doi.org/10.3133/gip167.
4. United States Geological Survey, 2005, Mineral Resources Data System, Mineral Resources Online Spatial Data, website accessed on 10 October 2022, https://mrdata.usgs.gov/mrds/.
5. United States Geological Survey, 2022a. Mineral commodity summaries 2022, U.S. Geological Survey, 202 p., https://doi.org/10.3133/mcs2022.
6. United States Geological Survey, 2022b. 2022 Final List of Critical Minerals, 87 Federal Register 10381 (February 24, 2022)., https://www.federalregister.gov/documents/2022/02/24/2022-04027/2022-final-list-of-critical-minerals.

To download this Note with Authorship Documentation attached, visit conservation.ca.gov/cgs/publications/cgs-notes

Visit us on on the world wide web and social media:

www.conservation.ca.gov/cgs twitter: cageosurvey instagram: cageosurvey

cgs-note-58-critical-minerals-Final_Version 08-08-23 16:19 mfonseca

AUTHORSHIP DOCUMENTATION AND PRODUCT LIMITATIONS

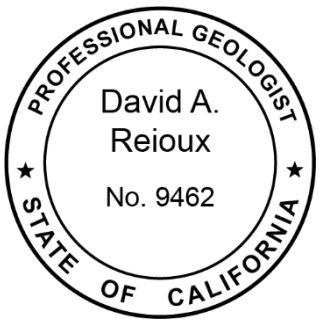
PUBLICATION TITLE: CGS NOTE 58 Critical Minerals

LIMITATIONS: The California Department of Conservation makes no warranties as to the suitability of this product for any given purpose. This note should not be considered as an authoritative or comprehensive source for critical mineral data. For more information on critical minerals, please visit the California Geological Survey Mineral web page at: https://www.conservation.ca.gov/cgs/minerals

Author – David Reioux PG 9462

David Reioux

Date: 27 July 2023



This authorship document accompanies CGS Note 58 with the following citation:

Reioux, D., 2023, Critical Minerals: California Geological Survey Note 58, 7 p.