



Critical Mineral: Graphite

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Overview

Graphite is a mineral that is included on the United States Geological Survey's 2022 Critical Minerals list. The mineral is hexagonally arranged carbon atoms as stacked sheets. It is a good conductor of both heat and electricity. Graphite is a very soft and lustrous mineral used in lubricants, refractories, brake linings, pencils, and electrodes. Demand for graphite is steadily increasing, as it is the most common material used for anodes in lithium-ion and other batteries.



Figure 1. A lithium-ion battery for a Samsung smartphone. Photo by Raymond Spekking (CC BY-SA 4.0).

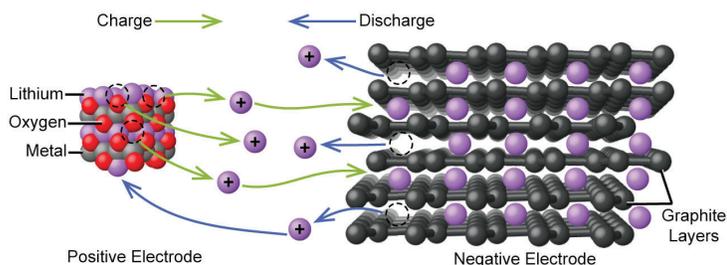


Figure 2. A schematic drawing of how the lithium-metal oxide cathode and the graphite anode work in a lithium-ion battery. The "metal" is usually cobalt, nickel, or manganese. Illustration from OpenStax, Rice University (CC BY-SA 4.0).

Supply

Graphite is sourced from hard-rock mines in metamorphic rocks. It can also be synthesized from coal in an energy-intensive process. The United States has produced no natural graphite for decades, and imported 82 kt (kilotonnes) of graphite in 2022. The dominant producer of graphite in 2022 was China, with 850 kt. The U.S. has no graphite reserves, but total resources (i.e., potential reserves) of >11,603 kt occur in seven states.

Not all graphite is equivalent. Different deposits will have different degrees of crystallinity and crystal size. The more crystalline the graphite, the more applications it has, and thus a higher value. After mining, graphite must then

be refined or milled according to its end use. For example, spherical graphite is desired for battery applications, whereas amorphous graphite is relegated to refractories. Refined spherical graphite pricing for 2023 ranged from \$2,000 to \$2,200 per tonne.

Mineralogy

Natural graphite most commonly occurs in metamorphic rocks, where carbon (e.g., organic matter in sedimentary rocks) is heated, compressed, and reduced to graphite. Host rocks for graphite are typically marble, quartzite, schist, or gneiss. Rarely, graphite deposits can be hosted in igneous rocks, such as the Albany graphite breccia in Ontario, Canada.

Graphite can occur as coarse, disseminated flakes in these rocks (flake graphite) or, more rarely, discrete veins or lenses inches thick of almost 100% graphite (vein graphite). Vein graphite is the most valuable type of graphite deposit. Amorphous graphite, where the crystals are poorly formed and small, is the least desirable.

Other commodities that occur with graphite include talc and other industrial minerals. Contrary to many other critical minerals, graphite contains only carbon and no deleterious components such as sulfur, heavy metals, or radionuclides. Thus, most graphite deposits pose few environmental threats from mining.



Figure 3. (Left) Box of HQ (6.35 mm diameter) core drilled from the Ruby Graphite Project, Beaverhead County. The crumbly portions are graphite rich. (Right) A grab sample of graphite ore from the old Crystal Mine waste piles on the site of the Ruby Graphite Project. Samples courtesy of Reflex Advanced Materials Corp. Photos by Adrian Van Rythoven, MBMG.

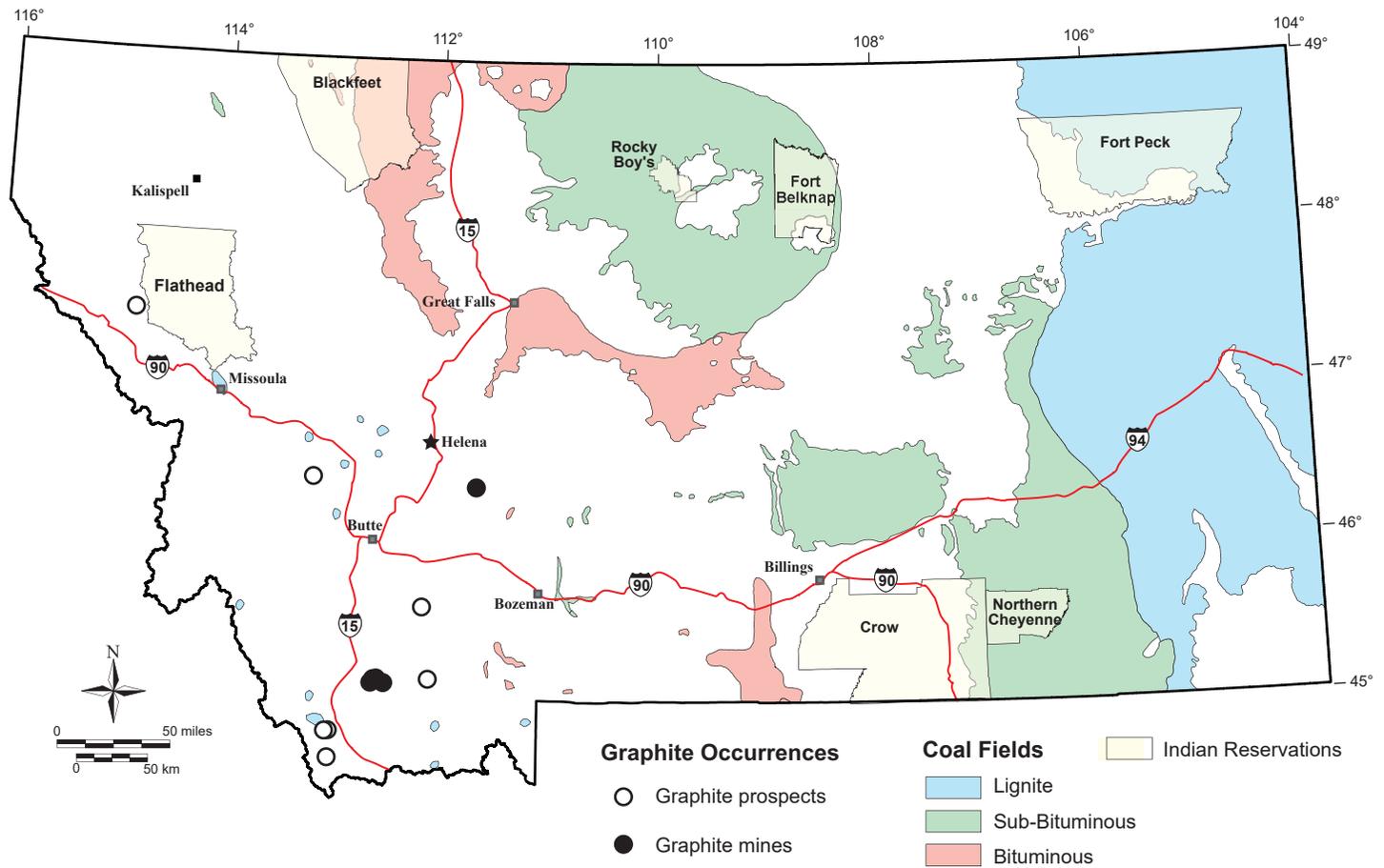


Figure 4. A map of Montana displaying known graphite prospects, graphite mines, and coal fields.

Deposits in Montana

Montana has a history of graphite mining. Of note are the Crystal, Birds Nest, and Crescent mines in Beaverhead County, where graphite was produced from vein and flake deposits in metamorphic rocks of the Ruby Range. A fourth mine, the Black Diamond in Broadwater County, produced amorphous graphite. Graphite mining ceased by the late 20th century. A few other graphite prospects are scattered throughout Beaverhead, Madison, Sanders, and Granite counties. In eastern Montana, the coal fields could provide abundant feedstock for synthetic graphite manufacture.

Outlook in Montana

With the increased demand for battery anode materials, the Ruby Graphite Project, near the Crystal and Birds Nest graphite mines, is a major venture to renew domestic graphite production in the U.S.A. Drilling on the project to delineate a resource body using modern methods began in August 2023.



Figure 5. A bituminous coal sample from Bearcreek, Montana (Carbon County). Field of view is 10 cm. Photo by Ryan Davison, MBMG.

About the MBMG

Established in 1919, the Montana Bureau of Mines and Geology (MBMG) continues to fulfill its mandate to collect and publish information on Montana's geology to promote orderly and responsible development of the energy, groundwater, and mineral resources of the State. A non-regulatory state agency, the MBMG provides extensive advisory, technical, and informational services on the State's geologic, mineral, energy, and water resources. The MBMG is increasingly involved in studies of the environmental impacts to land and water caused either by past practices in hard-rock mining or by current activities in agriculture and industry. The Montana Bureau of Mines and Geology is the principal source of Earth science information for the citizens of Montana. More information is available at mbmg.mtech.edu.