

Critical Mineral: Palladium

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Overview

Palladium (Pd) is a chemical element that is included on the United States Geological Survey's 2022 Final List of Critical Minerals. Pure Pd is an unreactive, dense, malleable, and silver-white precious (noble) metal. Pd is best known for its use in jewelry, but has societal importance for its use in chemical catalysts.

Pd is part of the platinum group elements (PGEs). The PGEs are Pd, platinum (Pt), rhodium (Rh), osmium (Os), ruthenium (Ru), and iridium (Ir). Pd and Pt are by far the most abundant of the six. These elements are found together in most natural deposits. They also have similar physical characteristics.



Figure 1. A ~1 gram (0.5 x 1 cm) sample of refined crystallized Pd metal. Photo by Hi-Res Images of Chemical Elements (CC-BY-3.0).

Supply

PGEs are typically reported as combined grades and masses of all six contained metals. South Africa has the largest PGE reserves at 63,000 t (metric tonnes). Russia (5,500 t), Zimbabwe (1,200 t), and the U.S. (820 t) round out the runners-up. In terms of production, Russia leads with 92 t Pd in 2023. Other significant Pd producers in 2023 were South Africa (71 t), Canada (16 t), Zimbabwe (15 t), and the U.S. (9.8 t). Recycling is an important secondary supply, with 42 t recovered domestically (mostly from older catalytic converters) in the same year. Other entities that refine and export Pd are the European Union and Switzerland. Compare the domestic mining (9.8 t) and recycling (42 t) production values with overall consumption in the same year: 64 t. Most domestic Pd mining and recycling occurs in Montana, with some byproduct Pd from the Eagle Mine in Michigan.

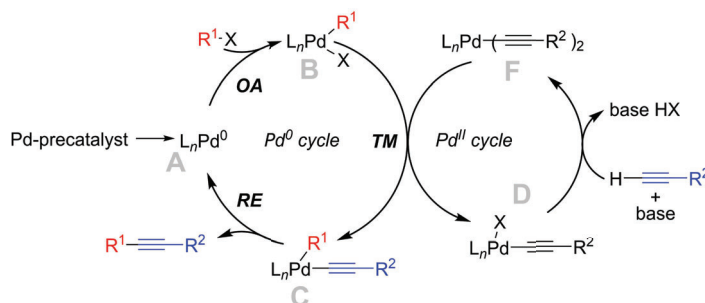


Figure 2. A diagram of the steps in a chemical reaction (Sonogashira reaction) that uses Pd as a catalyst to bond different organic compounds. This particular reaction is used to create certain pharmaceuticals, such as tazarotene. Catalysts are chemical reagents that speed up a reaction without being consumed. Image by Miha1391 (CC-BY-SA-4.0)

The average Pd value in 2023 was \$48,226,050/t.. Grades of Pd in deposits ranges from the byproduct level of ~0.4 g/t (grams Pd per tonne of ore) at the Eagle Mine to ~10.8 g/t in the Stillwater Complex of Montana.

Mineralogy

Pd can be found as natural alloys of PGEs in a native "nugget" state. It can also occur as sulfide, arsenide, antimonide, or telluride minerals such as braggite, vysotskite, mertieite, stibnopalladinite, or merenskyite. Aside from arsenic (As), antimony (Sb), tellurium (Te), and other PGEs, critical minerals that can be found with Pd are bismuth (Bi), chromium (Cr), cobalt (Co), nickel (Ni), titanium (Ti), and



Figure 3. Photograph of a sample of ore from the Johns-Manville (J-M) Reef taken from the Stillwater Mine in the Beartooth Mountains, Stillwater County. Here, reefs are layers in igneous intrusions that are rich in sulfide minerals. The brassy sulfide minerals contain PGEs (primarily Pd and Pt in the ratio 3:1 = Pd:Pt). The enclosed dark glassy minerals are olivine, pyroxene, and chromite. Field of view is ~9.5 cm wide. Photo by James St. John (CC-BY-2.0).

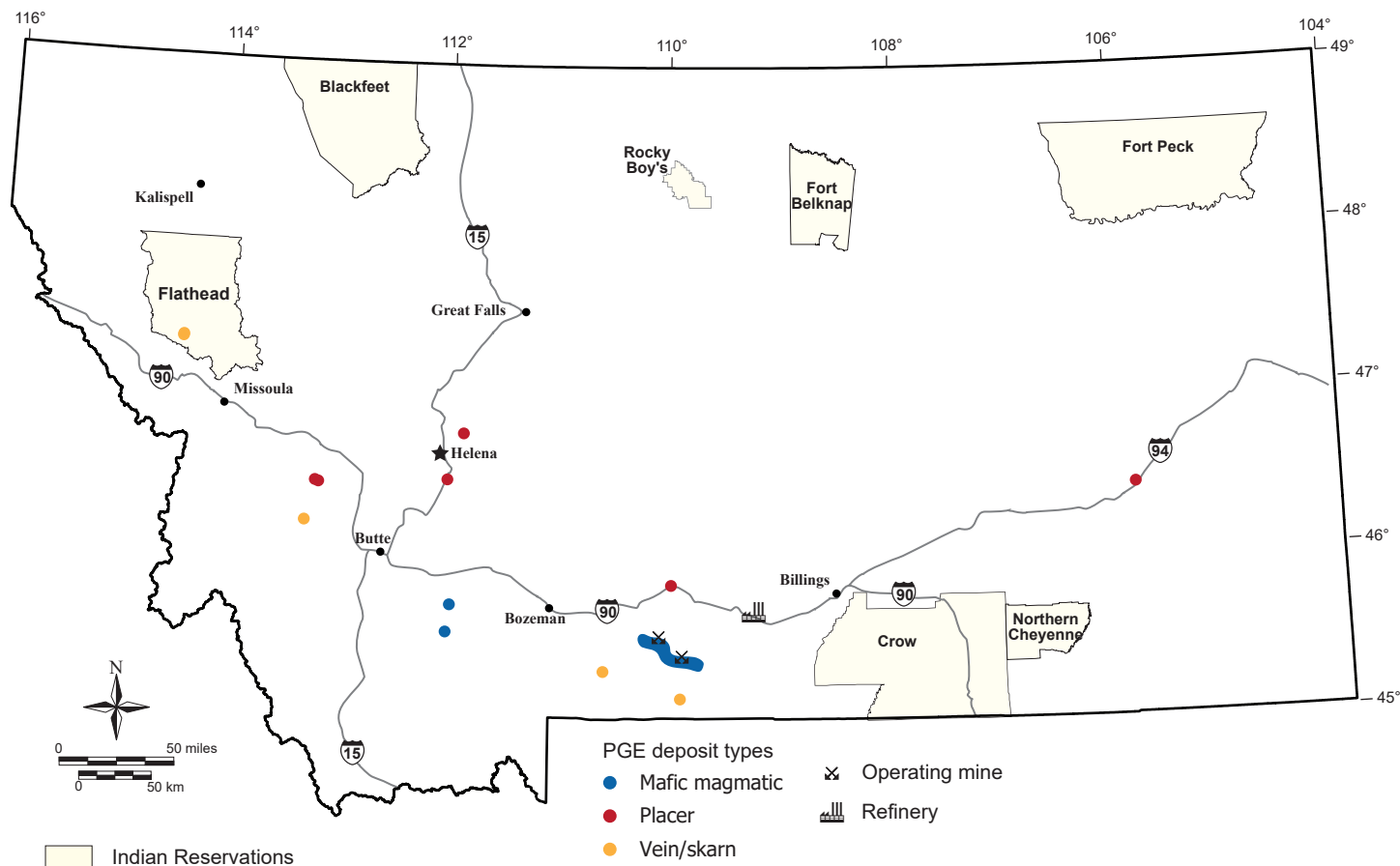


Figure 4. Map of western Montana displaying locations of prospective and known Pd mineralization.

vanadium (V). Other non-critical commodities commonly found with Pd are copper (Cu), gold (Au), silver (Ag), and iron (Fe).

The main hard rock deposit types for Pd are ultramafic-mafic intrusions. Byproduct Pd can also occur in other hydrothermal-magmatic deposits: skarn, massive sulfide, porphyry-type, and polymetallic sulfide vein. Weathering of these deposits can concentrate native Pd in placer deposits.

Deposits in Montana

The largest concentration of Pd mineralization in Montana is in the Stillwater Complex, a layered mafic intrusion (Stillwater, Sweet Grass, Park Counties). The Complex has geologic similarities to the Bushveld Complex in South Africa that hosts the bulk of the Pd in that country. There is also reported magmatic Pd in Madison County. Elevated Pd has been reported in some magmatic-hydrothermal vein and skarn deposits in Sanders (Flathead Reservation), Deer Lodge, and Park Counties. Placer Pd has been reported over a much wider area: Granite, Jefferson, Lewis and Clark, Sweet Grass, and even Custer Counties.

Outlook in Montana

Pd ore is produced from two mines within the Stillwater Complex: the Stillwater Mine in Stillwater County and the East Boulder Mine in Sweet Grass County. These have total resource estimates from 2023 of about 1213 t and 920 t of

Pd, respectively. The only other formal Pd resource reported in Montana is an inferred estimate of 64 t (at 0.25 g/t) in 2021 at the Stillwater West Project that is near these two mines. Mineral exploration at the Project is ongoing as of 2024.

There is also a major PGE refinery in Columbus, Montana, where ore from the two mines is processed. Also recycled here are PGE-bearing catalytic converters from older automobiles.

Research by the MBMG into mine waste sites in Montana is considering whether Pd could be a critical mineral recovered from these environmental liabilities.

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.