USGS
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USGS Mineral Resources Program

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Ti
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Titanium—Light, Strong, and White

As part of a broad mission to conduct research and provide information on nonfuel mineral resources, the U.S. Geological Survey (USGS) supports science to understand

- *How and where titanium resources form and concentrate in the Earth's crust*
- *How titanium resources interact with the environment to affect human and ecosystem health*
- *Trends in the supply of and demand for titanium in the domestic and international markets*
- *Where undiscovered sources of titanium might be found*

Why is this information important? Read on to learn about titanium and the important role it plays in the national economy, in national security, and in the lives of Americans every day.

Because of titanium's high strength-to-weight ratio, it is used for many spacecraft components. For example, the Hubble Space Telescope's primary mirror is made of titanium silicate glass. Photograph courtesy of NASA.

Titanium (Ti) is a strong silver-gray metal that is highly resistant to corrosion and is chemically inert. It is as strong as steel but 45 percent lighter, and it is twice as strong as aluminum but only 60 percent heavier. Titanium dioxide (TiO_2) has a very high refractive index, which means that it has high light-scattering ability. As a result, TiO_2 imparts whiteness, opacity, and brightness to many products.

Titanium was first discovered in 1791 by the British clergyman and amateur geologist William Gregor, who produced a white metallic oxide from black magnetic sands. In 1795, the German chemist Martin Klaproth named the oxide "titanium" after the Greek *Titans*, a mythical race of immortal giants with incredible strength and stamina. Pure titanium metal was first isolated in 1910 by chemist Matthew Hunter. Hunter's difficult isolation process made titanium metal mainly a laboratory curiosity until 1938 when William Kroll developed a method (known as the Kroll method) to produce titanium metal in commercial quantities. Because of the unique physical properties of titanium metal and the whiteness provided by TiO_2, titanium is now used widely in modern industrial societies.

How Do We Use Titanium?

Most titanium ore is refined into TiO_2 to impart a durable white color to paint, paper, rubber, wallboard, and plastic. The paint industry began using TiO_2 because of concerns about the environmental hazards related to the use of lead in paint. Because TiO_2 is relatively inert, it can also be used as coloring in such products as toothpaste, skim milk, candy, and sunscreen.

Only about 5 percent of the world's annual production of titanium minerals goes to make titanium metal. The high strength-to-weight ratio and corrosion resistance of titanium metal and its alloys make them particularly valuable to the aerospace industry. Because titanium metal is nonreactive in the human body, it is also used to make artificial hip joints, pins for setting bones, and other types of biological implants.

Most of the world's titanium output is refined into titanium dioxide (TiO_2), which is used to give a durable white color to many products, including paint, paper, rubber, wallboard, plastic, and toothpaste. Photograph ©2012 Tronox Ltd. All rights reserved.

Where Does Titanium Come From?

Titanium is the ninth most abundant element in the Earth's crust and can be found in nearly all rocks. The economic viability of a titanium deposit is determined by the grade and available tonnage, as well as the deposit type and titanium mineralogy. The most economically important titanium minerals are ilmenite (which is a titanium-iron oxide that crystallizes at high temperatures from magma) and two TiO_2 polymorphs, rutile and anatase (which have the same chemical composition but different crystal structures). Ninety percent of the world's titanium is accounted for by ilmenite, but because rutile has a very high index of refraction, it is the most desirable mineral for the pigment industry.

Economic high-grade magmatic ilmenite deposits are found in particular rock types. These deposits develop by crystallization of ilmenite from titanium- and iron-enriched magmas. Segregation and emplacement of these early ilmenite-laden liquids are likely related to dynamic magmatic processes accompanying the emplacement of anorthosite (a plagioclase-rich rock) and related mafic rocks. Magmatic ilmenite is currently being mined at the Lac Tio mine in Quebec, Canada, and at Tellnes, a large open pit mine in southern Norway.

Although magmatic ilmenite is an important source of titanium ore, much of the titanium mined today is from heavy mineral deposits. Heavy minerals (those with a specific gravity >2.85 grams per cubic centimeter, including ilmenite, rutile, and zircon) are concentrated in geologically young, unconsolidated shoreline sedimentary deposits and sand dunes and in equivalent geologically older deposits. These deposits develop when these relatively resistant minerals are eroded from magmatic or metamorphic parent rocks and subsequently transported, sorted, and finally deposited in shoreline and dune settings. The abundance and distribution of these heavy mineral deposits are related to geology, physiography, and coastal dynamics. Heavy mineral deposits are found along many continental margins, including the eastern coasts of North and South America, the southern coast of Africa, the coasts of India, and along the east and west coasts of Australia. Ilmenite and rutile in heavy mineral deposits provide more than one-half of the world's titanium production, and most of the remainder is supplied by the two large magmatic ilmenite deposits.

U.S. Department of the Interior
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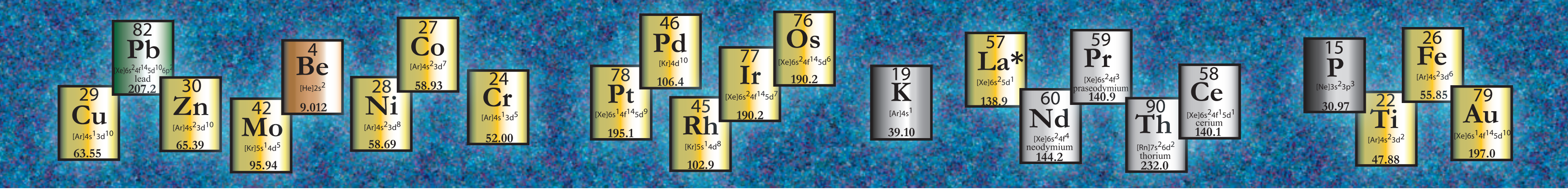


Worldwide Supply of and Demand for Titanium

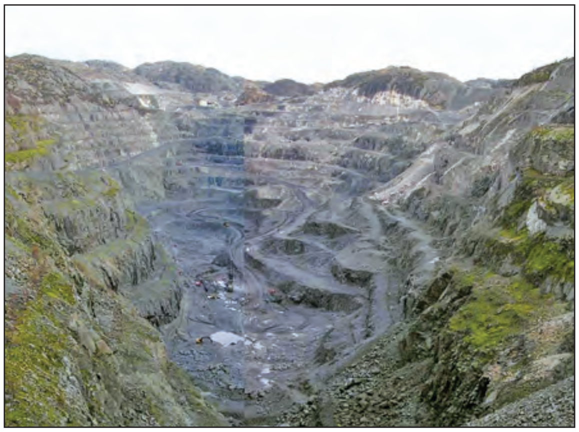
Titanium is supplied to world markets as ilmenite concentrate, rutile concentrate, synthetic rutile (derived by the removal of iron from ilmenite), and titanium slag (derived from smelting ilmenite). The United States is heavily dependent on imports of titanium mineral concentrates to meet domestic needs; the source countries for U.S. imports of titanium mineral concentrates in 2012 included Australia, Canada, Mozambique, Sierra Leone, and South Africa. In the United States, Florida and Virginia are currently producing titanium mineral concentrates from heavy-mineral sand deposits. Their combined production is only about 4 percent of total world production, and U.S. reliance on imports is likely to increase, as these mines are expected to be depleted by 2020. In 2012, about 39 percent of the world's production of titanium mineral concentrates came from Australia and 35 percent came from South Africa. Other countries producing ilmenite and rutile included Brazil, Canada, India, Madagascar, Mozambique, Norway, Sierra Leone, Sri Lanka, Ukraine, and Vietnam. Global demand for titanium is driven largely by demand for TiO_2 pigment. Demand for titanium metal is largely driven by construction of new aircraft. Improving global economic conditions will likely increase worldwide demand for titanium metal and TiO_2.

Ilmenite ore. Photograph courtesy of Brigham Young University/Andrew Silver (from U.S. Geological Survey Photographic Library, Denver).

Did you know... ***Images from NASA's Lunar Reconnaissance Orbiter suggest that basalts on the Moon may have titanium concentrations 10 times higher than basalts on Earth***

How Do We Ensure Adequate Supplies of Titanium for the Future?

The United States hosts large identified titanium resources. Coastal heavy-mineral sand deposits in the southeastern United States contain large resources of ilmenite and rutile. Anorthositic rocks in the Eastern and Western United States have potential for significant titanium resources but have not been fully explored. In Minnesota, mafic rocks containing ilmenite and titanomagnetite (an iron-titanium oxide) in the Duluth Complex, which is a group of mafic intrusions about 1.1 billion years old, may represent the largest known titanium resource in North America. The Iron Hill alkalic complex in Colorado is estimated to contain about 350 million metric tons of titanium reserves averaging about 11.5 percent TiO_2 in the mineral perovskite (a calcium-titanium silicate). Unconventional deposits containing abundant titanomagnetite, such as the Duluth Complex, or perovskite, such as the Iron Hill deposit, will require development of new cost-effective methods for the extraction of titanium from these minerals. Unless new mines can be developed from conventional and (or) unconventional deposits, the reliance of the United States on imports of titanium mineral concentrates is likely to increase.



Ilmenite open pit mine at Tellnes, Sokndal, Norway. Photograph courtesy of Mike Norton/CC-BY-SA-3.

The U.S. Government is funding research on low-cost extraction of titanium metal from oxide ores. Private industry is working to develop new metallurgical methods for titanium deposits that currently have unfavorable mineralogy or trace element concentrations. To predict where future domestic titanium resources might be located, scientists from the U.S. Geological Survey (USGS) are updating models that describe how and where titanium minerals are concentrated into potentially economic deposits and developing new resource assessment methods to support the stewardship of Federal lands. The USGS also compiles up-to-date statistics and information on the worldwide supply of, demand for, and flow of titanium mineral concentrates. These data are used to provide information for domestic and international policymakers and decisionmakers in the public and private sectors.

Did you know... ***Living bone will fuse to titanium metal (osseointegration), making titanium invaluable for human biological implants***

For More Information

- On production and consumption of titanium: http://minerals.usgs.gov/minerals/pubs/commodity/titanium/

The USGS Mineral Resources Program is the principal Federal provider of research and information on titanium and other nonfuel mineral resources.

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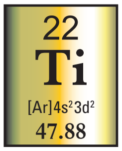

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