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Titanium

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Titanium is a lightweight metal that is virtually as strong as steel. As our technologies and industries have become increasingly sophisticated, demand for this relatively scarce, but highly desirable metal has increased rapidly. This information circular is written to acquaint the prospector and miner with titanium and its uses. A resume of typical geologic environments and production possibilities in Arizona is given.

Uses

The largest market for titanium is in the manufacture of pigments. Because of its high refractive index, titanium dioxide pigment imparts whiteness, opacity, and brightness to paints, varnishes, and lacquers. Titanium pigment is also used greatly in paper coatings and as paper fillers. Many plastic products such as polyethylene, polyvinyl chloride, and polystyrene incorporate titanium pigment because of its resistance to degradation by ultraviolet light and its chemical inertness.

Titanium dioxide pigment and other titanium compounds are used in many miscellaneous applications, including rubber tires, floor and wall coverings, glass fibers, ceramic capacitors, carbide cutting tools, and organotitanium catalysts. Titanium is classified as a strategic metal since much of it is consumed in the manufacture of high-performance jet aircraft, turbine engines, guided missile assemblies, spacecraft, nuclear power plants, and other ferroalloy products.

During the past decade domestic mine production of titanium minerals has been slightly less than 50 percent of primary demand. Imports from Australia, Canada, Norway, and the U.S.S.R. have generally met the balance of demand.

According to U.S. Bureau of Mines projections, primary mine production may fail to increase significantly as the anticipated demand for titanium rises into the 21st century. Indeed, the Bureau estimates that domestic production will range from a high of 42 percent to a low of 24 percent of U.S. primary demand in the year 2000. Coupled with the rise in domestic demand for titanium minerals is an accelerating foreign demand. Developing countries and even well developed countries with increasingly sophisticated needs will vie for a greater share of the world's supply of this unique metal.

Geology and Mineralogy

The most important titanium minerals are anatase (TiO_2), ilmenite ($FeTiO_3$), perovskite ($CaTiO_3$), rutile (TiO_2), sphene ($CaTiSiO_5$), and leucoxene. Leucoxene, a mineraloid, is an alteration product of ilmenite, from which a portion of the iron has been leached. Currently the minerals of commercial interest are ilmenite, leucoxene, and rutile. Production historically has come from three types of deposits: Beach and stream placers, massive deposits of titaniferous iron ore, and igneous complexes in which rutile occurs in association with anorthosite and similar, mafic crystalline rocks.

Beach and stream placers commonly contain both rutile and ilmenite, associated with other heavy minerals such as magnetite, monazite, zircon, garnet, staurolite, and sillimanite. Because of their hardness (5 to 6.5 on Mohs scale) and their resistance to chemical weathering, rutile and ilmenite tend to survive the various geologic processes, beginning with comminution of the source rock and ending with the sorting of the heavier minerals by moving water, and concentration in placer deposits.

In sand deposits ilmenite exhibits various degrees of alteration as a result of oxidation and preferential leaching of iron. Sand ilmenite concentrates may therefore vary widely in grade, ranging from about 48 percent TiO_2 for essentially unaltered South African ilmenites to 61 to 64 percent TiO_2 in Florida and New Jersey ilmenites. Ilmenites in the older beach lines at high elevations may run as high as 70 percent TiO_2. This alternation of ilmenite to progressively higher grade products appears to take place mainly above the water table. Appreciable amounts of still higher TiO_2 material, consisting almost entirely of leucoxene, can be concentrated from highly altered ilmenites by high-intensity magnetic separation.

Massive deposits of titaniferous iron ores are known in a number of countries. Their relative commercial value depends not only on the titanium content but on the liberation size of the titanium mineral. Presently ilmenite is being won from titaniferous iron ore deposits in New York, Canada, Finland, and Norway. In all cases the ore must be beneficiated before shipment.

Rutile and ilmenite occur in anorthosite in Virginia, and rutile is found with anorthosite in Canada and Mexico and in a mafic igneous complex in Arkansas. Although there has been production at some of these localities, the ore bodies are marginal.

Titanium minerals also occur in carbonatite deposits. Carbonatites are relatively rare igneous rocks that contain large amounts of carbonate. Appreciable quantities of anatase have been measured in carbonatites in Brazil, and a large resource of perovskite exists in a deposit near Montrose, Colorado. Most of these deposits, however, require the development of an economic processing method. Likewise, titanite (sphene) occurrences will probably not be developed for some time because of the relatively low TiO_2 content (40.8 percent) of the mineral and its difficult metallurgy.

Arizona Geological Possibilities

Outcrops of coarsely crystalline, mafic igneous rocks are uncommon in Arizona. Most known mafic rock occurrences are generally fine-grained basalts and scoria or diabase dikes of limited aerial extent. There are no known anorthosite bodies in the state.

Several instances of presumably coarse-grained, anorthosite-related rocks have been reported however. In the Eureka mining district of Yavapai County, in the area of Boulder Creek and Milholland Creek (SW 1/4, T15N, T9W), there is a gabbro mass up to 4,000 feet wide and 4 miles long. This mafic rock contains lenticular bodies of titaniferous magnetite ranging from up to 20 feet thick and several hundred feet long. The magnetite may contain some specularite and hematite as an intergrowth and is commonly associated with ilmenite, pyrite, apatite, and enstatite. These minerals frequently occur with leucoxene, hornblende, epidote, chlorite, zoisite, and uralite as accessory constituents in the gabbro.

Two samples of the best titaniferous magnetite contained 60.09 and 62.02 percent iron with 9.80 and 8.20 percent titania, respectively, and a trace of manganese. A trenching program during 1952 indicated that with depth some of the deposits increased in size and contained higher amounts of titania.

In the Mazatzal Mountains mining district, in the vicinity of Mt. Ord and Little Mt. Ord (SE1/4, T7N, R9E), there is a pyroxenite mass that straddles the boundary separating Gila County and Maricopa County. This mafic igneous rock outcrops over an area about 6 miles long and up to 1 1/4 miles wide. It trends northeasterly and is a member of Precambrian associates that comprise much of the outcrop in the Mazatzal Mountains, Tonto Basin, and the Sierra Ancha. Flanking the pyroxenite are metamorphosed sediments and volcanics and granite and related intrusive rocks.

Although there are no reports of titanium-bearing minerals in the pyroxenite, the rock may have gabbroic or anorthositic associates warranting further investigation. another pyroxenite occurrence, reportedly in a similar geologic environment, occurs approximately 20 miles west-northwest of the Mt. Ord location in the Magazine mining district of Maricopa County. The irregular outcrop is roughly equidimensional, comprising about 4 square miles. The coarsely crystalline rock occurs in the vicinity of Willow Spring Mountain and Humboldt Mountain, centered about the northeast corner of T7N, R5E.

Titaniferous iron minerals occur in a Precambrian, northeast-trending belt of rocks in the Sierra Ancha of Gila County. A taconitic iron formation occurs as lenticular masses and individual beds within the thick Yavapai Series of schist, quartzite, and arkosic sandstone. These highly ferruginous quartzites, reportedly crop out in an area over 6 miles long, extending from Del Shay Basin to Clover Creek Canyon. The area occurs, southeast of Sheep Basin Mountain, chiefly in the SE1/4, T8N, R11E and the S1/2, T8N, R12E.

Graduations between nearly pure titaniferous magnetite and hematite, titaniferous hematite, and ferruginous quartzite have been reported in the iron formation. Titania is present as ilmenite usually intergrown with hematite. The iron minerals specularite and limonite are also common.

Hematite grains generally range in size from 28- to 150- mesh, averaging 48- mesh. Some samples taken by the U.S. Bureau of Mines in 1961 contained as much as 9.8 percent TiO2. the calculated mineral content of one sample was 38 percent hematite and 14.5 percent ilmenite, and of another sample, 51 percent hematite and 16.5 percent ilmenite.

A possibly similar occurrence of titaniferous magnetite-hematite has been reported in Precambrian granite gneiss or quartz mica schist in the White Tank Mountains of Maricopa County. This occurrence is in the SW1/4, T3N, R3W, along the west flank of the mountains, about 12 miles north of Buckeye.

Intergrowths of ilmenite and some sphene occur with magnetite grains 65- mesh to about 1/2 inch in size and as segregations several inches in diameter. The iron mineralization trends northwesterly more than one mile. Three widely separated bulk samples taken by the U.S. Bureau of Mines in 1955 contained 5.6 percent iron and 0.76 to 1.18 percent titania.

Alluvial and placer deposits of ilmenite and titaniferous magnetite are scattered throughout Arizona. One of the largest alluvial deposits of this type comprises a desert plain, approximately 800 square miles, extending northwesterly from Red Rock, Oracle Junction, and Oracle to Casa Grande and Florence Junction, in Pinal County. Within this area titaniferous magnetite is intermingled and stratified with tan to buff colored sand, gravel, and silt derived from earlier erosion.

The heavy magnetite grains range in size from fine to coarse sand and are generally associated with ilmenite, sphene, apatite, zircon, monazite, and lighter minerals such as quartz, mica, and feldspar. Various localities within the alluvial plain contain magnetite concentrations ranging from 1 to 15 percent. Drilling in some areas indicates the presence of magnetite-rich sands to depths greater than 250 feet. A particularly good sample of the magnetite sand analyzed by the U.S. Bureau of Mines in 1959 contained 20.8 percent iron and 2.1 percent titania. Chemical analyses in 1956 of magnetic concentrates ranged from 62.8 to 63.2 percent iron and up to 2.8 percent TiO_2.

Similar deposits of low grade titaniferous magnetite occur in the central portion of T4N, R9W in the Big Horn mining district of northwestern Maricopa County and in the NE1/4, T4N, R14W in the northwest part of the Harquahala mining district of Yuma County (now La Paz County). In addition, ilmenite is reported to occur in ancient beach placers in Upper Cretaceous sandstone in the vicinity of the Black Mountain trading post, north of Cottonwood, Arizona, in Apache County. The grade of ilmenite is unknown.

Potentially significant rutile concentrations have been reported in some porphyry copper environments in the state. The tenor of rutile in copper ore from Bagdad, Yavapai County, is about 0.3 percent. the titania content, two- thirds of which is due to the presence of rutile, in the copper ore of the San Manuel deposit in Pinal County averages 0.75 percent. Recent beneficiation studies of the San Manuel mill tailings, by the U.S. Bureau of Mines, indicate that about 50 percent of the TiO_2 content could be recovered. Since many of these copper deposits range in size from 500 million to 1 billion short tons of ore, they could be a major source of titanium.

Other, perhaps more exotic, occurrences of titanium-bearing minerals have been reported in Arizona. Ilmenite, probably intergrown with magnetite or hematite, occurs with copper ore formed as a contact metamorphic deposit in Paleozoic limestone near a granitic intrusive at the Black Diamond mine in Cochise County. Rutile, associated with cupriferous pyrite and molybdenite, occurs as masses and veinlets in a pegmatite dike about 500 feet south of the Santo Nino mine in Santa Cruz County. Perovskite is reported with sphene in a pulaskite dike on Gunsight Mountain in the Sierrita Mountains of Pima County. Pulaskite is a coarse-grained igneous rock of intermediate composition similar to nepheline syenite but deficient in nepheline.

Suggestions for Prospecting

When prospecting for titanium it is important to keep in mind the types of geologic environment that traditionally supply most titaniferous ores. Geochemically, titanium generally accompanies iron during mineral formation in igneous or magmatic processes. Iron and titanium-bearing minerals tend to develop early, along with other ferromagnesian and high-calcium silicates, in the magmatic cycle and are therefore concentrated in mafic igneous complexes. Hence anorthositic or gabbroic terrains are looked to for possible ores of ilmenite or rutile.

During weathering and sedimentation processes, titaniferous magnetite, ilmenite, and rutile tend to remain intact as individual minerals. Therefore as highlands containing these minerals are eroded, nearby basins may accumulate alluvial deposits or placers rich with titanium carriers. Natural sorting of these minerals in water further concentrates them with other heavy minerals such as garnet, monazite, and zircon.

In looking for lode occurrences of titanium in Arizona one of the most favorable areas would be the northwest-trending belt of Precambrian rocks that crop out from the southeast corner of the state to Lake Mead. Within this broad stretch of ground the area between Globe and Bagdad appears particularly interesting in light of reported occurrences of diorite, gabbro, and titaniferous iron formations. In addition to the localities mentioned in a previous section of this report, there are suspected occurrences of coarse- grained mafic igneous rocks southeast and west of Prescott and in the vicinity of Bagdad.

Since titanium minerals are frequent associates of magnetite, a portable magnetometer is a useful prospecting tool. Reconnaissance magnetic surveying and field checking may help the prospector define target areas of titaniferous iron concentrations either as lode or placer occurrences.

The mineral ilmenite is characterized by an iron-black color, submetallic luster, and conchoidal fracture. It has a hardness of 5 - 6 and a specific gravity of 4.5 - 5. It is opaque and has a black to brownish red streak. Ilmenite is not strongly magnetic, as in magnetite, and its streak is significantly less red than hematite.

Rutile commonly occurs as prismatic crystals that are vertically striated or furrowed. The mineral is usually reddish brown in color, although it may be red, yellowish, or even black, and it has a sub-adamantine luster and a subconchoidal or uneven fracture. It has a hardness of 6 - 6.5 and a specific gravity of 4.18 - 4.25. It is transparent to opaque and has a pale brown streak. The specific gravity of rutile is substantially lower than that of cassiterite (6.5) with which it may be confused.

To test these suspected minerals by wet chemical means for their titanium content, they must first be pulverized, heated, and dissolved in hydrochloric acid. Although rutile is insoluble in most acids it may be made soluble by fusing it with soda (anhydrous sodium carbonate). The acid solution is filtered and then heated with metallic tin. As the liquid is concentrated by evaporation it will turn blue or violet if titanium is present.

For a bead test prepare a bead of salt of phosphorus on a platinum wire and dip the hot bead into the powdered mineral. Using a blowpipe, the bead is then held in the reducing flame. The bead will probably assume a brownish yellow or red color due to the presence of some iron. Then treating this bead with tin on charcoal will produce the violet-red color diagnostic of titanium.

Production Possibilities

There has been no production of titanium in Arizona although titaniferous iron ores and black sands containing titaniferous magnetite, ilmenite, and rutile have been mined locally for their iron content. Currently the known occurrences of titanium-bearing minerals are sub economic. Grades of 9.8 percent TiO_2 reported in the titaniferous magnetite that occurs in the gabbro of the Eureka mining district and in the iron formations of the Sierra Ancha are comparable to the low grade (9.5 - 13.4 percent TiO_2) category of ore mined from the Sanford Lake deposits of New York. The Sanford Lake ores contain locally, however, zones that grade more than 17 percent TiO_2.

Conclusions

Titanium is truly a metal for this age. In this time of quickening scientific and technological advancement, the strong, lightweight metal will be utilized increasingly in many applications. World demand will tend to accelerate as developing nations acquire more sophisticated needs.

As domestic demand increases and as the western U.S. becomes more industrialized with increased manufacturing capability, opportunities will arise that will enable Arizona to continue in its role as a leading supplier of mineral wealth. As markets expand and as resources in the eastern U.S. are depleted, further exploration and development of Arizona's titanium resources will be pursued.

The Department of Mines and Mineral Resources will continue to actively support development of new mines. It will continue to encourage prospectors and miners to search for and produce strategic metals such as titanium. Copious information in the Department files and library is available to the public, and field engineers are always available to advise the interested person on geologic and engineering matters.